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Subject: Revised *Site Observational Work Plan for the Naturita, Colorado, UMTRA Project Site*

Dear Mr. Gillen:

Enclosed is a copy of the revised *Site Observational Work Plan (SOWP) for the Naturita, Colorado, UMTRA Project Site*. The document contains information to support the compliance strategy of natural flushing for arsenic and no remediation and application of alternate concentration limits (ACLs) for uranium and vanadium.

The document contains information to support the compliance strategy of natural flushing for arsenic and no remediation and application of alternate concentration limits for uranium and vanadium. The compliance strategy for vanadium and uranium was revised based on NRC's review of the draft SOWP. The NRC review letter (February 25, 2002) requested additional information and questioned DOE's basis for "moving past the ACL option" associated with the PEIS decision framework diagram. The DOE has taken this comment into full consideration and revised the draft SOWP based on the NRC review.

We would appreciate your comments by July 5, 2002. Let me know if this is a problem.

If you have questions or require additional copies, please contact me at 970/248-7612 or Dick Dayvault at 970/248-6375.

Sincerely,

Donald R. Metzler
Program Manager

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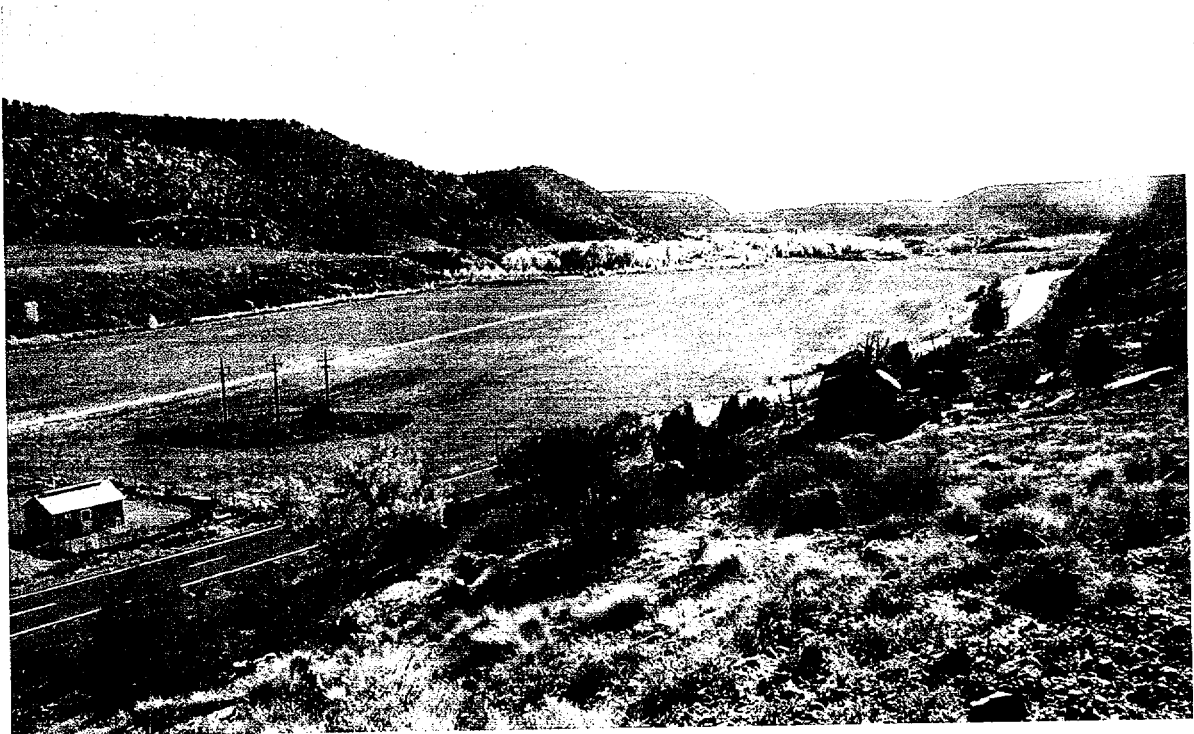
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UMTRA

Ground Water Project

Site Observational Work Plan for the Naturita, Colorado, UMTRA Project Site



May 2002

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



UMTRA Ground Water Project

**Site Observational Work Plan
for the Naturita, Colorado,
UMTRA Project Site**

May 2002

Prepared by
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Grand Junction Office
Grand Junction, Colorado

Work Performed Under DOE Contract No. DE-AC13-96GJ87335

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Appendix C	Surface Water Analytical Results (Included on CD)
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Appendix G	Data Set Used in Pattern Recognition Modeling

Plate

Plate 1

Acronyms and Abbreviations

ACL	alternate concentration limit
AEC	U.S. Atomic Energy Commission
ASTM	American Society for Testing and Materials
AWQC	ambient water quality criteria
BAF	bioaccumulation factors
BCF	bioconcentration factor
BLRA	Baseline Risk Assessment
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	chlorofluorocarbons
CFR	Code of Federal Regulations
cfs	cubic feet per second
COPC	contaminant of potential concern
cm ³	cubic centimeter(s)
DOE	U.S. Department of Energy
EC	electrical conductivity
E-COPC	ecological constituent of potential concern
EHPA	ethylhexyl phosphoric acid
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ESL	Environmental Sciences Laboratory
FONSI	finding of no significant impact
FR	Federal Register
ft	foot (feet)
ft/day	foot (feet) per day
ft ² /day	square feet per day
g	grams
gal	gallon(s)
gal/day	gallons per day
GCAP	Ground Water Compliance Action Plan
GJO	Grand Junction Office
GMWL	Global Meteoric Water Line
gpm	gallons per minute
HCA	hierarchical cluster analysis
HCl	hydrochloric acid
HI	hazard index
HQ	hazard quotient
IC	institutional control
ICP-MS	inductively coupled plasma–mass spectrometry
i.d.	inside diameter
IRIS	Integrated Risk Information System
K	hydraulic conductivity
K _d	distribution coefficient
kg	kilogram(s)
KPA	kinetic phosphorescence analysis
kW-hr	kilowatt-hour
L	liter

L/s	liter(s) per second
LOAEL	lowest-observed-adverse-effect levels
lb	pounds
LTMP	Long-Term Management Plan
LTSP	Long-Term Surveillance Plan
m	meter(s)
MAP	Management Action Process
MCL	maximum concentration limit
µg/L	micrograms per liter
µm	micrometer(s)
µS/cm	microsiemens per centimeter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mL	milliliter
mL/g	milliliters per gram
mL/min	milliliters per minute
mm	millimeter(s)
mV	millivolts
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect levels
NRC	U.S. Nuclear Regulatory Commission
NWQL	National Water Quality Lab
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
ORP	oxidation-reduction potential
PC	principal component
PCA	principal component analysis
pCi/g	picocuries per gram
pCi/L	picocuries per liter
PEIS	Programmatic Environmental Impact Statement
PeRT	Permeable Reactive Treatment
PVC	polyvinyl chloride
RAP	Remedial Action Plan
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act
Rd	distribution ratio
RO	reverse osmosis
ROD	Record of Decision
rpm	revolutions per minute
RRM	residual radioactive material
SDWA	Safe Drinking Water Act
SEE	Site Environmental Evaluation (database)
SOWP	Site Observational Work Plan
SV	similarity value
TAGR	Technical Approach to Ground Water Restoration
TDS	total dissolved solids
TEL	threshold effect levels
U(VI)	mobile uranium-valence plus 6

UCL ₉₅	95 percent upper confidence limit
UMTRA	Uranium Mill Tailings Remedial Action (Project)
UMTRCA	Uranium Mill Tailings Radiation Control Act
USC	United States Code
USGS	U.S. Geological Survey
ZVI	zero valent iron

Executive Summary

This document is the Site Observational Work Plan (SOWP) for the Naturita, Colorado, Uranium Mill Tailings Remedial Action (UMTRA) Project site. The purpose of this report is to document characterization of the site using the observational approach and the proposed strategies for achieving ground water compliance with requirements established in the Uranium Mill Tailings Radiation Control Act (42 *United States Code* 7901 *et seq.*) and the United States Environmental Protection Agency's (EPA's) Health and Environmental Protections Standards for Uranium and Thorium Mill Tailings (Title 40, *Code of Federal Regulations*, Part 192).

The Naturita mill, located about 2 miles north of the town of Naturita along the west side of the San Miguel River, began operation in 1939 for vanadium production. It was converted to include the production of uranium during the Manhattan Project of the early 1940s, and continued to co-produce uranium and vanadium until it closed in 1958. During its life, the mill processed 704,000 tons of ore from the Uravan Mineral Belt. Most of the tailings were purchased by Ranchers Exploration and hauled several miles to another site for heap leaching in the late 1970s. From 1993 to 1998, the UMTRA surface cleanup removed another 771,400 cubic yards of residual radioactive material (RRM) to the Upper Burbank engineered disposal site at Uravan, about 15 miles to the northwest. RRM was left at a number of locations under the application of supplemental standards, especially near Highway 141, along the San Miguel River, and in an adjoining and downgradient vicinity property. Currently, no mill buildings remain, and the site meets the UMTRA surface standards.

The U.S. Department of Energy (DOE) began collecting data about the ground water contamination during the surface program and published a Baseline Risk Assessment in 1995. Section 6 of this SOWP updates that risk assessment. DOE has worked with the U.S. Geological Survey to collect and analyze data from an additional 26 monitoring wells and 16 surface locations during 2000 and 2002. Results indicate that three contaminants of potential concern—arsenic, uranium, and vanadium—pose a potential risk to human health, and vanadium poses a potential risk to ecological receptors.

Hydrologic tests, water age determinations, and chloride analysis of the uppermost aquifer, the alluvial aquifer, indicate that the system receives most of its recharge from the San Miguel River south of the site and transmits water from south to north. Other sources of recharge are the intermittent streams from uplands to the west and from rainfall. Subsurface flow is slower along the western side of the site away from the San Miguel River. Water containing uranium contamination also exists on the east side of the San Miguel River, across the river from the adjoining downgradient vicinity property. Additionally, these analyses suggest that water is being lost to evaporation from the ground water system due to excavations down to the ground water surface in an adjoining gravel pit operation on the upgradient side of the site. If this continues, and the operation is expected to expand, the volume of ground water entering the site may diminish and the estimated flushing rates may also diminish. Therefore, the rates of flushing in the ground water model may not be conservative. The bedrock below the alluvial aquifer consists of mudstones, siltstones to sandstones, and shales of the Brushy Basin Member of the Morrison Formation. Hydrologic tests indicate that the Brushy Basin sediments create an effective aquitard for downward migration of surface contamination and also limit upward migration of water from sandstone units below it. Therefore, only the alluvial aquifer is contaminated at Naturita.

Ground water flow and transport modeling indicates that arsenic will flush to the UMTRA maximum concentration limit (MCL) of 0.05 mg/L within 10 years. Only two wells had arsenic levels slightly above the MCL and both show a trend of decreasing concentrations; and the area containing these elevated values is small. However, uranium and vanadium have higher concentrations, are more widespread, and do not flush within the 100-year regulatory timeframe. Modeling predicts 135 years will be required for uranium to flush to 0.044 mg/L (the UMTRA MCL) and more than 1,000 years will be required for vanadium to flush to 0.33 mg/L (a health-based risk concentration).

Two compliance strategies are proposed for the site: (1) natural flushing with institutional controls (ICs) and continued monitoring for arsenic, and (2) no remedial action with the application of alternate concentration limits (ACLs) for uranium and vanadium, and with ICs and continued monitoring as a best management practice. U.S. Nuclear Regulatory Commission's guidance for ACL applications was prepared for Title II UMTRA sites, but this guidance can also be followed for Title I sites if modifications are made to accommodate the differences between Title I and Title II sites.

Natural flushing for arsenic is expected to require 10 years or less. The most recent sampling round showed concentrations of arsenic slightly below the 0.05 mg/L in the two wells that had previous hits slightly above this MCL. If this trend continues for three sampling rounds, arsenic will be removed from the list of potential contaminants.

ACLs for uranium and vanadium are proposed because modeling has shown that neither contaminant will naturally flush to acceptable concentrations within the 100 years permitted for natural flushing. Uranium is expected to require 135 years to attenuate to the UMTRA standard of 0.044 mg/L and vanadium could require more than 1,000 years to attenuate to 0.33 mg/L, a human-health based standard.

ACL, point of compliance (POC) values, are 3 mg/L for uranium and 6 mg/L for vanadium. These points apply to any location within the IC boundary and are action levels. If monitoring shows that these levels are exceeded in the future, appropriate corrective action will be investigated and enacted. These values were selected because human health and environmental risks were shown to be acceptable for these concentrations, which are slightly more than current maximum concentrations for these constituents anywhere inside this IC area. The current maximum concentrations are located within the footprint of the former millsite.

Points of Exposure (POEs) are any points located along the San Miguel River where the river contacts the former millsite and any point downgradient of the millsite along the river for approximately 3,750 feet, as shown by the IC boundary. A dilution calculation was performed for the San Miguel River using the maximum concentrations of uranium and vanadium ever recorded at the site, which are greater than the proposed ACL values, and using a 20-year low flow for the river. The calculation shows that the river dilutes uranium and vanadium seepage of ground water into the river system by 3,000 to 5,000 times. This demonstrated a sufficient dilution of vanadium to be protective of aquatic life in the river if ACLs are maintained at the POCs. ICs will be established to protect humans from ingesting ground water.

As part of the ACL application, a corrective action assessment was performed. The assessment addressed practicable corrective actions, technical feasibility of corrective actions, corrective action costs and benefits, and selection of a practicable action that would achieve hazardous

constituent concentrations that are as low as reasonably achievable. Section 8 of this SOWP presents details of this assessment. Because no one or no ecological system is currently being harmed by the contamination, the assessment showed that remedial action would cause more potential environmental harm and be potentially more dangerous to workers than leaving it in place and implementing ICs. Costs would also be unreasonably high for the benefits gained.

An IC boundary is proposed for the site that includes an area from the upgradient end of the former millsite to a point on both sides of the San Miguel River 3,750 feet downgradient. This area includes all possible portions of the alluvial aquifer that are currently contaminated or might be contaminated by plume migration due to milling related activities. Because the site is wholly in private ownership, DOE would seek an IC to prevent anyone from drinking contaminated water from within this IC boundary. The IC will be in the form of an environmental covenant for perpetuity between the Colorado Department of Public Health and Environment and the three affected landowners. DOE will be a third party beneficiary to this agreement. In addition to excluding anyone from drinking contaminated water inside the IC boundary, the covenant would also require radon mitigation of future dwellings; compliance with state uranium mill tailings regulations for any excavation or construction activities in surface program supplemental standards areas; continued allowance of monitoring wells on their properties; and access to their properties with prior notification for inspection purposes.

No one is currently drinking ground water from the site, and no one is anticipated to be using it for drinking water. One family is living downgradient in the contaminant plume and inside the IC boundary. They currently haul drinking water from another source. DOE plans to drill a water well into a sandstone aquifer below their property that contains potable water and provide drinking water to their cistern. The well will be cased off to prevent any possible cross contamination from overlying water-bearing intervals.

Future samples will be collected from river and monitor well locations upgradient, onsite, and downgradient of the former millsite to ensure that humans and the environment will remain safe and until the levels of contamination fall below MCLs or risk-based levels. Samples will be analyzed for arsenic, uranium, and vanadium annually for the first 5 years after the Ground Water Compliance Action Plan is accepted and every 3 years thereafter for the next 30 years, or until contamination falls below MCLs or risk based levels for three consecutive samplings. The monitoring plan will be reevaluated periodically to determine if changes are required.

End of current text

1.0 Introduction

1.1 Purpose and Scope

The Naturita UMTRA Project site is a former uranium and vanadium ore processing facility located about 2 miles northwest of the town of Naturita, Colorado, along Colorado State Highway 141 (Figure 1-1). The Naturita site is bounded by the San Miguel River on the east and the highway on the west. Private property borders the northern, downgradient edge of the site and the southern, upgradient portion of the site. The City of Naturita owns the central portion of the site; Chemetall Foote Corp, a German company, owns the northern and southern parts of the site.

The former tailings pile at the site was removed to a heap-leach reprocessing plant along State Highway 90, about 3 miles southeast of the intersection of Highways 90 and 1241 at Coke Oven during 1977 to 1979. After being reprocessed, the tailings were stabilized at that location with 2 to 10 feet (ft) of cover. The DOE completed surface remediation in 1997. A significant amount of residual contaminated soils and other materials that remained at the Naturita site were removed and transported to the disposal cell at Uravan; however, some contaminated materials were left in place through the application of supplemental standards. After the remedial action, the site was backfilled with clean fill material and recontoured. The land was seeded, but vegetation remains somewhat sparse.

DOE's goal is to implement a cost-effective compliance strategy that is protective of human health and the environment at the Naturita site. The proposed compliance strategies to clean up the alluvial ground water at the site are (1) no ground water remediation of constituents with concentrations that do not pose a potential risk and do not exceed EPA standards, and (2) natural flushing of ground water in combination with the application of supplemental standards for constituents with concentrations that pose a potential risk or exceed EPA standards. Institutional controls will prohibit some ground water uses during the natural flushing period, and DOE will conduct ground water monitoring to observe progress of remediation.

This SOWP documents the strategy that will allow DOE to comply with EPA ground water standards at the Naturita site and provides a mechanism for stakeholder participation and review. Site-specific data are presented that support the proposed strategy.

Compliance requirements for meeting the regulatory standards at the Naturita site are presented in Section 2.0. Site background information, including an overview and history of the former milling operation and current water and land use, are reviewed in Section 3.0. Results of the field investigations conducted at the site from 1998 through 2001 are presented in Section 4.0. Site-specific characterization of the geology, hydrology, geochemistry, and ecology are synthesized in the site conceptual model in Section 5.0. Potential human health and ecological risks associated with ground water contamination are summarized in Section 6.0, and the proposed compliance strategy to clean up the ground water and a brief analysis of alternatives are presented in Section 7.0 and Section 8.0, respectively.

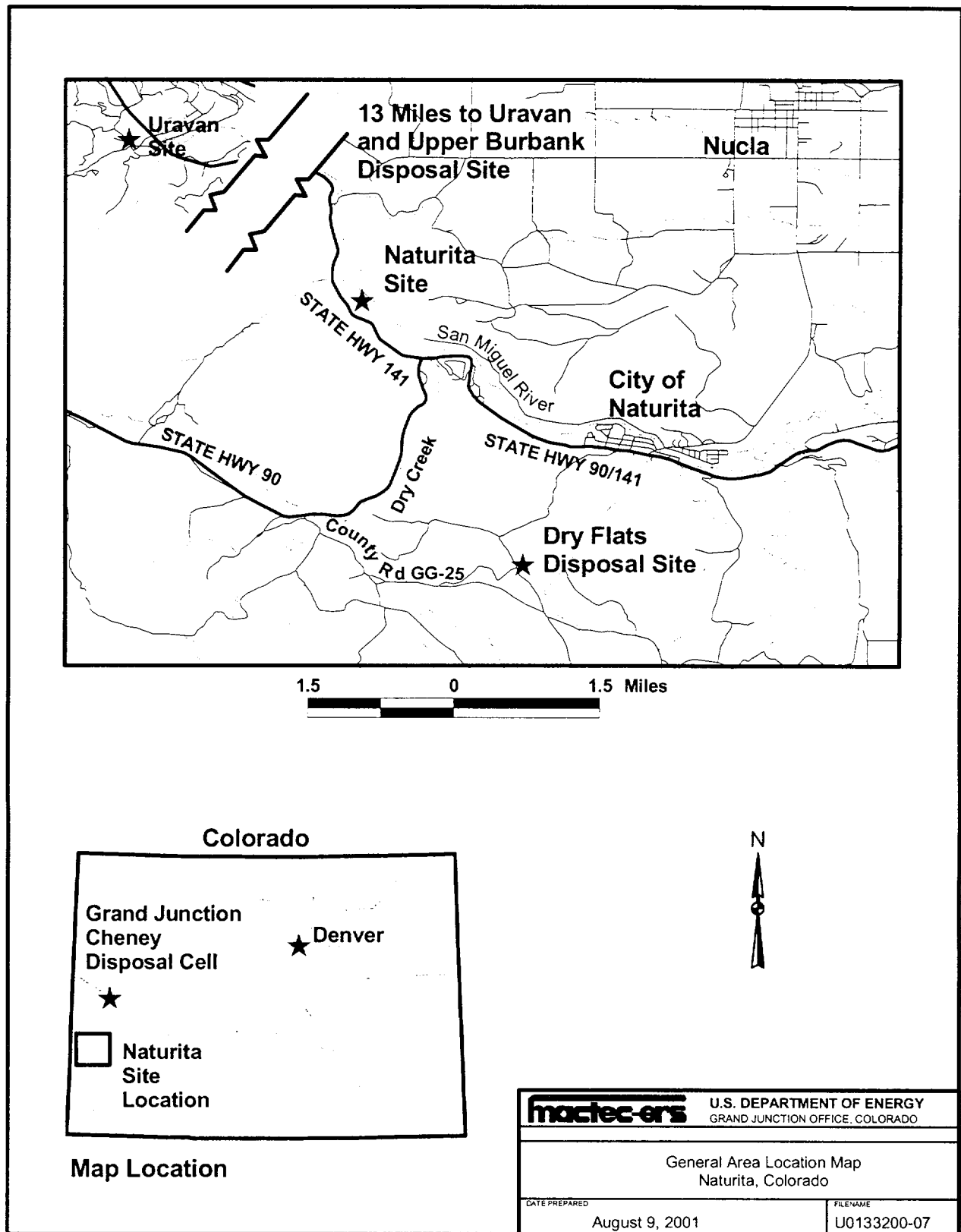


Figure 1-1. Site Location Map

1.2 UMTRA Ground Water Project Programmatic Documents

Programmatic documents that guide the SOWP include the *UMTRA Ground Water Project Management Action Process (MAP) Document* (DOE 2001), the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project* (PEIS) (DOE 1996), and the *Technical Approach to Groundwater 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-making framework for conducting the UMTRA Ground Water Project. DOE will follow PEIS guidelines to assess the potential programmatic impacts of the UMTRA 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 1998a) provides some site characterization information regarding the geology and ground water hydrology. This information was supplemented in developing the SOWP to strengthen the site conceptual model. After a ground water compliance strategy is selected for this site, a Ground Water Compliance Action Plan (GCAP) will be prepared to document the remediation decision. The GCAP will serve as a stand-alone modification of the RAP.

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

After a 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 or environmental assessment) will be prepared, if required by the NEPA process, to determine the potential effects, if any, of implementing the proposed compliance strategy.

End of current text

2.0 Regulatory Framework

A ground water compliance strategy is proposed for the Naturita site (see Section 7.0) to achieve compliance with EPA ground water standards applicable to Title I UMTRA Project sites. This section identifies the requirements of the Uranium Mill Tailings Radiation Control Act (UMTRCA), the EPA ground water protection standards promulgated in Title 40 Code of Federal Regulations (CFR) Part 192 Subpart B, NEPA, and other regulations that are applicable to the UMTRA Ground Water Project.

2.1 UMTRCA

The United States Congress passed the UMTRCA (42 USC 7901 *et seq.*) in 1978 in response to public concerns about potential health hazards from long-term exposure to uranium mill tailings. UMTRCA authorized DOE to stabilize, dispose of, and control uranium mill tailings and other contaminated materials at inactive 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 the U.S. Nuclear Regulatory Commission (NRC) in consultation with affected 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 USC 7922 *et seq.*), authorizing DOE to extend without limitation the time needed to complete ground water remediation activities at the processing sites.

2.2 EPA Ground Water Protection Standards

UMTRCA requires EPA to promulgate standards for protecting public health and the environment from radiological and nonradiological hazards associated with uranium-ore processing and the resulting residual radioactive materials (RRM). On January 5, 1983, EPA published standards (40 CFR Part 192) for RRM disposal and cleanup. The standards were revised and a final rule was published January 11, 1995 (60 FR 2854). This rule states that the standards established under Title I provide protection that is consistent, to the maximum extent practicable, with the requirements of the Resource Conservation and Recovery Act (RCRA).

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, "Summary of Human Health and Ecological Risk", of this document, complies with these requirements and identifies the constituents of concern at the Naturita site.

2.2.1 Subpart B: Standards for Cleanup of Land and Buildings

The regulations allow the option of complying with four general standards. Three are numerical standards and are set forth in 40 CFR 192.02 (c)(3) as follows:

- **Background level**—Concentrations of constituents in the uppermost aquifer in an area that were not affected by ore-processing activities.
- **Maximum Concentration Limit (MCL)**—EPA defined maximum concentrations for certain hazardous constituents in ground water; these limits 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, 40 CFR 192.04 and are presented in Table 2–1 of this document.
- **Alternate Concentration Limit (ACL)**—An ACL 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.

Table 2–1. Maximum Concentration Limits of Inorganic Constituents in Ground Water at UMTRA Project Sites

Constituent	Maximum Concentration Limit ^a
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	.002
Molybdenum	0.1
Nitrate (as N)	10.0 ^b
Selenium	0.01
Silver	0.05
Combined radium-226 and radium-228	5 pCi/L
Combined uranium-234 and uranium-238	30 pCi/L ^c
Gross alpha-particle activity (excluding radon and uranium)	15 pCi/L

^aConcentrations reported in milligrams per liter (mg/L) unless otherwise noted.

^bEquivalent to 44 mg/L nitrate as NO₃.

^cEquivalent to 0.044 mg/L, assuming secular equilibrium of uranium-234 and uranium-238.

pCi/L = picocuries per liter.

Reference: 60 FR 2854.

2.3 Natural Flushing Standards

Subpart B also allows the use of natural flushing to meet EPA standards. Natural flushing allows natural ground water processes to reduce the contamination in ground water to acceptable standards (background levels, MCLs, or ACLs). Natural flushing must allow the standards to be met within 100 years. In addition, institutional controls and an adequate monitoring program must be established and maintained to protect human health during the period of natural flushing. Institutional controls would prohibit inappropriate uses of the contaminated ground water. The

ground water also must not be a current or projected source of drinking water for a public water system during the period of natural flushing, and beneficial uses of ground water must be protected.

2.3.1 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 of Subpart B are met on a site-specific basis using information gathered during site characterization and monitoring. The plan to meet the standards of Subpart B must be stated in a site-specific GCAP. The plan must contain a compliance strategy and a monitoring program, if necessary.

2.4 Supplemental Standards

Under certain conditions, DOE may apply supplemental standards to contaminated ground water in lieu of background levels, MCLs, or ACLs (40 CFR Part 192). Supplemental standards may be applied if any of the following conditions are met:

- Remedial action necessary to implement Subpart A or B would pose a significant risk to workers or the public.
- Remedial action to meet the standards would directly produce health and environmental harm that is clearly excessive compared to the health and environmental benefits of remediation now or in the future.
- The estimated cost of remedial action is unreasonably high relative to the long-term benefits, and the RRM does not pose a clear present or future hazard.
- There is no known remedial action.
- The restoration of ground water quality at any processing site is technically impracticable from an engineering standpoint. Guidance for what is deemed technically impracticable is provided by EPA (1993b, 1996b, 2000b).
- The ground water is classified as limited-use ground water. Subpart B of 40 CFR 192 defines limited-use ground water as ground water that is not a current or potential source of drinking water because the concentration of total dissolved solids (TDS) exceeds 10,000 milligrams per liter (mg/L); there is widespread ambient contamination that cannot be cleaned up using treatment methods reasonably employed in public water systems; or the quantity of water available to a well is less than 150 gallons (gal) per day. When limited-use ground water applies, supplemental standards ensure that current and reasonably projected uses of the ground water are preserved (40 CFR Part 192).
- Radiation from radionuclides other than radium-226 and its decay products is present in sufficient quantity and concentration to constitute a significant radiation 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 (i.e., 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, "Site Conceptual Model," presents a summary of the geology, hydrology, and geochemistry 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 strategies and includes a justification for selecting a natural flushing to MCL remediation strategy for arsenic, supplemental standards for vanadium and uranium, and monitoring and institutional controls (ICs) for all three constituents.

2.5 Cooperative Agreements

UMTRCA requires that compliance with the ground water standards be accomplished with the full participation of states that are paying part of the costs, and in consultation with Indian tribes on whose lands uranium mill tailings are located. UMTRCA also directs DOE to enter into cooperative agreements with the states and Indian tribes. DOE entered into a ground water cooperative agreement with the Colorado Department of Public Health and Environment (CDPHE) in March 1998.

2.6 National Environmental Policy Act

UMTRCA is a major federal action that is subject to the requirements of NEPA (42 USC 4321 *et seq.*). Regulations of the Council on Environmental Quality (to implement NEPA) are codified in 40 CFR Part 1500; these regulations require each federal agency to develop its own implementing procedures (40 CFR 1507.3). DOE-related NEPA regulations are in 10 CFR Part 1021, "National Environmental Policy Act Implementing Procedures". DOE guidance is provided in *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements* (DOE 1993b).

Pursuant to NEPA, in 1994 DOE drafted a PEIS for the UMTRA Ground Water Project. The PEIS document was made final in October 1996. The purpose of the PEIS was to analyze the potential impacts of implementing four programmatic alternatives for ground water compliance at the designated processing sites. The preferred alternative for the UMTRA Ground Water Project was published in a Record of Decision in 1997. All subsequent action on the UMTRA Ground Water Project will comply with the Record of Decision.

2.7 Other Regulations

In addition to UMTRCA, EPA ground water standards, and NEPA, DOE must also comply with other federal regulations and executive orders that may be relevant to the UMTRA Project sites. Examples include regulations that require protection of wetlands and floodplains, threatened or endangered species, and cultural resources. Other regulations, for which the state may be delegated authority, include requirements for water discharge and waste management. Executive orders include those related to pollution prevention and environmental justice.

2.8 State Regulations

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

2.9 DOE Orders

Several 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 are in DOE Order 5400.1 series, partially superseded by DOE Order 231.1. DOE Order 5400.5 requires protection of the public from radiation hazards. DOE guidance pertaining to NEPA is contained 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).

End of current text

3.0 Site Background

The Naturita UMTRA Project site is in western Colorado, Montrose County, approximately 2 miles north of the city of Naturita (Figure 1-1). It is situated on an elongate north-south section of floodplain between Colorado State Highway 141 on the west and the San Miguel River on the east. The site is the location of a former vanadium and uranium mill that operated intermittently from 1939 until 1958. The historical site area, a boundary used during the surface remedial action, enclosed 53 acres. The current site area is expanded to include property owned by the City of Naturita and Chemetall-Foote and now consists of 79 acres (Plate 1). This section presents an overview of the site's physical setting and climate, a history of the former milling operation and remedial actions, a summary of previous investigations, and the City of Naturita's current land use plan.

3.1 Physical Setting and Climate

The former millsite is located in the northeastern part of the Colorado Plateau Physiographic Province at the eastern edge of canyonlands country. Incised streams and large structural warps producing ridges and intervening basins characterize the area. Major physiographic features near the site include the valley occupied by the San Miguel River at an elevation of 5,355 ft and Sawtooth Ridge to the west and southwest that is slightly over 6,000 ft high.

The region has an arid to semiarid climate with high evaporation, low precipitation, low humidity, and large temperature variations. The average annual rainfall is about 13 inches per year (DOE 1995). Rainfall occurs during the summer and fall in high-intensity, short-duration, late afternoon thunderstorms that are conducive to runoff. Precipitation occurs in the winter as snowfall. Temperatures show considerable diurnal and seasonal variations. Winters are cold; average monthly temperatures are typically below freezing in December and January. Summers are warm; average monthly temperatures are in the 70s °F from June to August.

3.2 Site History

3.2.1 Milling History

Rare Metals Company built the Naturita vanadium mill about 1930 with a loan of \$427,000 from the Vanadium Corporation of America (VCA). As collateral for the loan, VCA held the mortgage to the mill, and when Rare Metals failed in the mid-1930s, VCA foreclosed, performed improvements, and finally reopened the mill in 1939 (Shumway 1970). A salt-roast water-leaching process was used initially, but this was altered in 1942 to include recovery of uranium for the Manhattan Engineering District project. The ore was salt roasted and quenched in a carbonate solution, followed by carbonate leaching. Residues from this process were acidified with sulfuric acid to extract extra metals. These solutions were neutralized with excess sodium carbonate, and sludges were recirculated to reclaim additional uranium and vanadium. The carbonate leach liquor, containing uranium and vanadium, was treated with sulfuric acid and boiled to expel carbon dioxide. A filtrate containing the metals was fused with a reducing mixture of salt, soda ash, and either sawdust or fuel oil. After fusion, the ash was water-leached, dissolving vanadium and leaving the uranium. Additional steps concentrated vanadium as "red cake" (Merritt 1971).

The mill was originally designed to operate at about 150 tons per day capacity but was increased in 1954 to 350 tons per day. An overhead aerial photograph of the millsite taken in 1954 shows the mill and a large area of tailings located along the San Miguel River (Figure 3-1). The ore storage area on the west side of Colorado Highway 141 was already in use. The river shows a prominent distributary channel meandering across the vicinity property (Maupin Property) to the north. Tailings may have eroded off the millsite and may have been deposited in and along this channel. The mill closed in 1958 when the contract with the Atomic Energy Commission (AEC) expired. During the life of the mill, approximately 704,000 tons of ore was processed (Ford, Bacon, & Davis Utah 1981).

Ores for the mill were mined predominantly from the Salt Wash Member of the Morrison Formation from the Uravan Mineral Belt. Uranium and vanadium minerals were predominantly carnotite and tyuyamunite. About 51 percent of the ores came from contractor-controlled properties; the remaining 49 percent came from independent producers (Albrethsen and McGinley 1982). From 1961 to 1963, VCA operated an upgrader plant at the site, and concentrates were sent to their operations at Durango, Colorado, for further treatment. From 1963 to 1978, the millsite was used as a general headquarters for the downsizing VCA. They brought mining and milling equipment from all over the Colorado Plateau to the Naturita site and sold it to other mining interests (DOI 1994). Figure 3-2 is an overhead aerial photograph of the millsite in 1966 showing the maximum areal extent of the tailings pile. The distributary channel meandering across the vicinity property to the north is still apparent.

In the fall of 1969, Foote Mineral and the Colorado Department of Health tried to stabilize the tailings that were next to the San Miguel River by covering them with topsoil and seeding, fertilizing, and watering the surface to allow the grass to root. This was done in part because tailings were eroding from the site during flood periods of the San Miguel River (DOI 1994). This stabilization apparently met with only limited success, because a 1974 overhead aerial view of the site shows barren tailings (Figure 3-3). The photograph was taken during spring or summer (trees are green), so any vegetation on the tailings should be visible. Buildings along Highway 141 are being used (a car is in front), and the tailings pile shows lineations, probably from the reclamation efforts. At the time approximately 704,000 tons of tailings are located on the site (Ford, Bacon, & Davis Utah 1981). A road or dike or both appear along the eastern side of the tailings pile where it contacts the San Miguel River. The distributary channel in the vicinity property has been modified and now cuts across the property farther north. The oval feature on the vicinity property was a local racetrack (named "Little Indy Speed Way") constructed by a family member of the property owner. The distributary channel has apparently deposited sediments and water in the eastern interior of the racetrack and could have deposited tailings on the vicinity property during this time.

By the 1970s, the price of uranium was attractive again, and in 1975, Foote Mineral leased a part of the millsite to the Nuclear Division of General Electric as a buying station for uranium ore. This continued into the 1980s. In 1976, Ranchers Exploration and Development Corporation bought 24 acres of tailings located on the site and removed an estimated 360,000 tons of tailings to a new location 4 miles to the south up Dry Creek. From 1977 to 1979, Ranchers heap-leached the tailings and recovered an additional 380,000 pounds of uranium and 1,840,000 pounds of vanadium (DOI 1994). In 1978 VCA merged with Foote Mineral, and the downsizing of all former VCA operations accelerated.

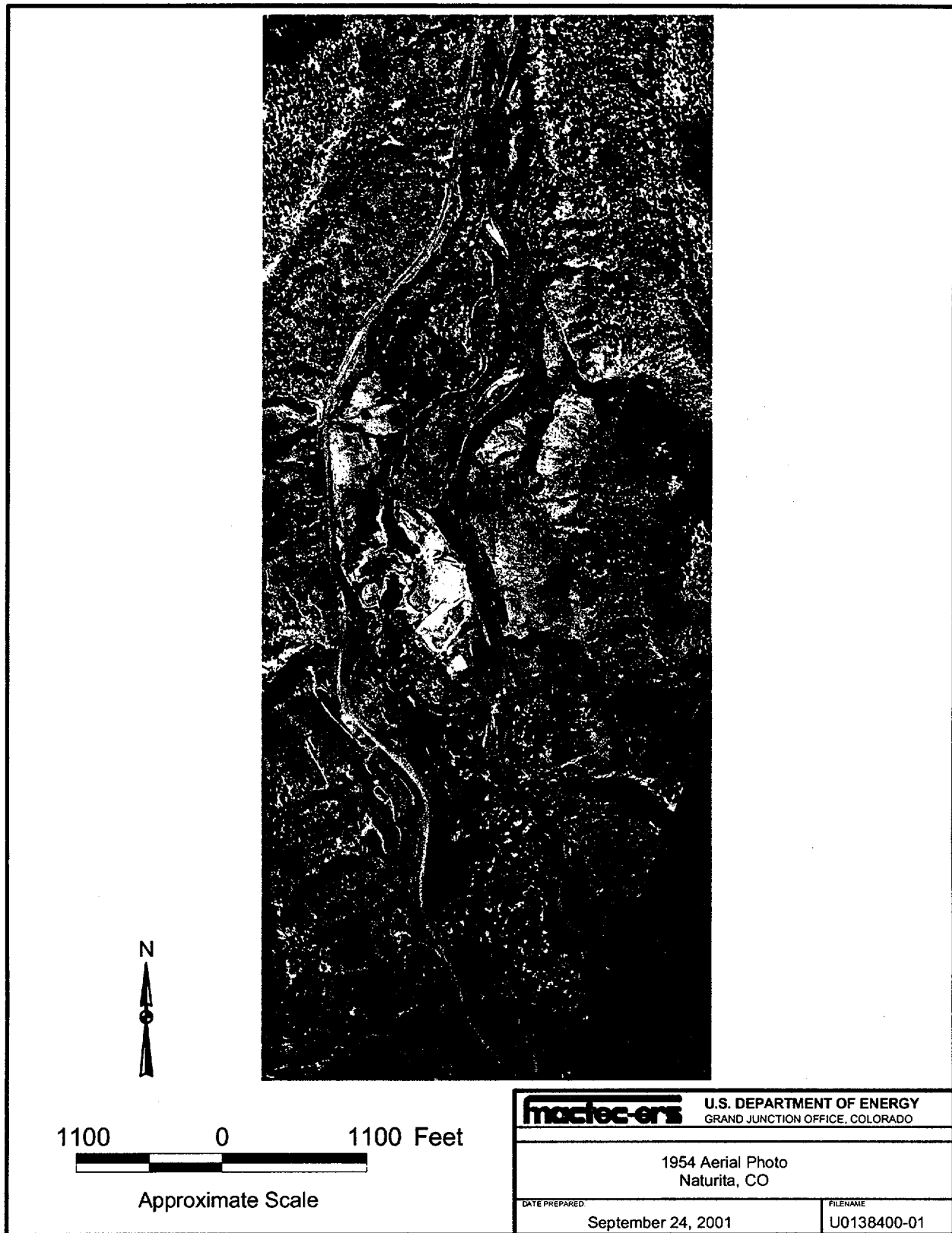


Figure 3-1. Overhead Aerial Photograph Taken in 1954

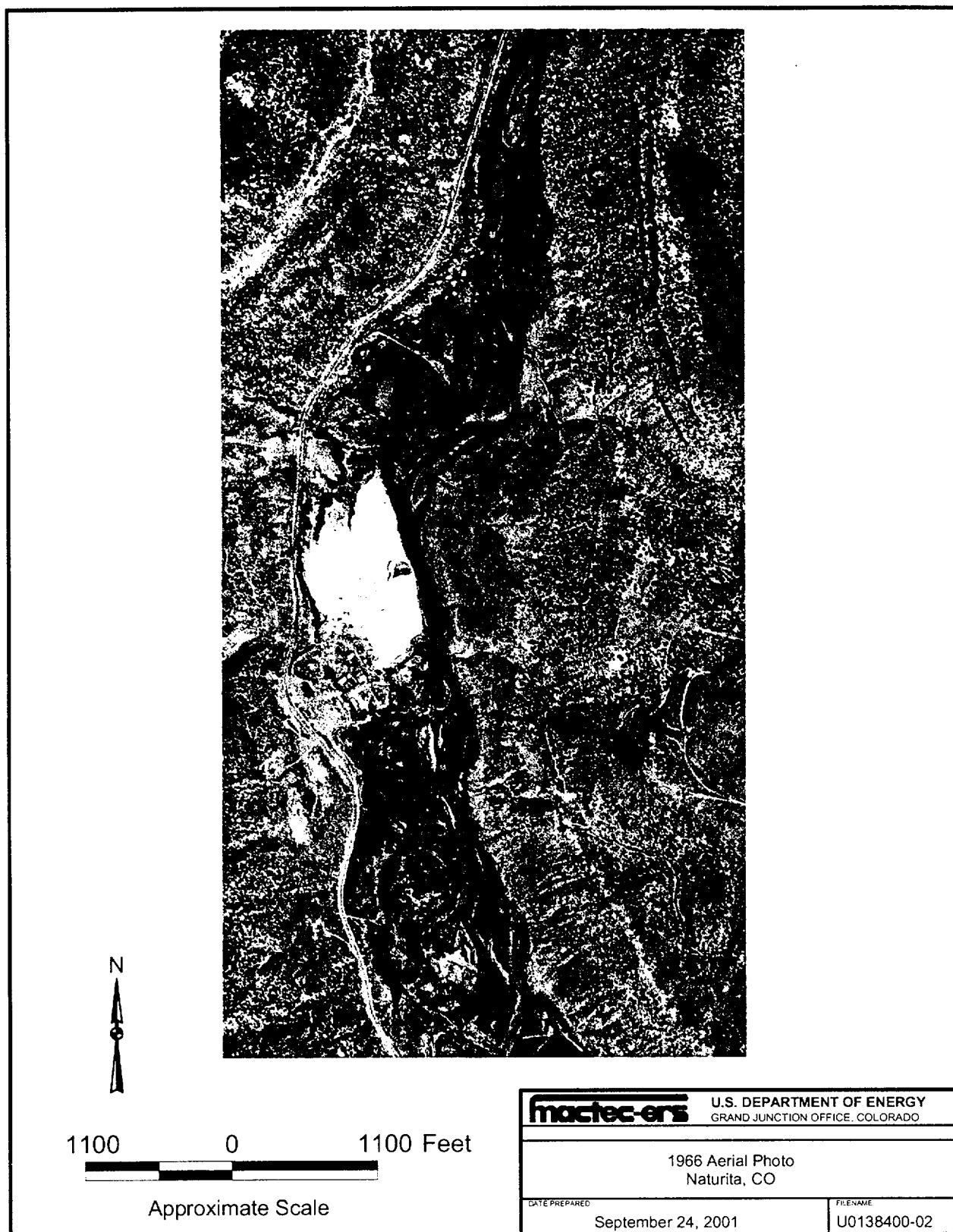


Figure 3-2. Overhead Aerial Photograph Taken in 1966



Figure 3-3. Overhead Aerial Photograph taken in 1974

3.2.2 Remedial Action History

Ford, Bacon, and Davis Utah performed an engineering assessment of the site for DOE in 1981 and proposed remedial actions with associated cost estimates. In 1984 and 1985, DOE again evaluated the radiological contamination at the site and supplied information to be used in the proposed remedial action that started in 1994. Figure 3-4 is an overhead aerial photograph of the millsite from 1986 that shows the former tailings pile with considerable vegetative cover. The San Miguel River has established its present course and no longer has a distributary channel crossing the vicinity property to the north and displays the unusual 90-degree turn from east to north in this area. A sand bar east of the former racetrack began to form and became vegetated with small willow saplings in the next decade. The former river channel scarp is the source for surface location 0538 (sometimes referred to as a spring).

During this time, the ownership of the mill changed several times. Foote Minerals was purchased by Cyprus Mining, who merged with Amax mining company to form Cyprus-Amax Minerals Corporation, who owned the site in 1994. Cyprus-Amax later became Cyprus-Foote, which was purchased by the German company, Chemetall, who formed the new company and became the current landowner, Chemetall Foote Corporation. Another previous landowner, Hecla Mining, who bought Ranchers Exploration in 1984, sold their property to the City of Naturita for one dollar (personal communication with Greg Hall, Naturita mayor, March 2001). Plate 1 shows the current land status for the site; Chemetall Foote owns north and south parcels and the City of Naturita owns the central portion.

The UMTRA Project surface remedial action at the site occurred between January 1993 and September 1998 (DOE 1998a). During this time, 771,400 cubic yards (yd³) of RRM were removed from the site. The approximate breakdown is 315,520 yd³ from the former mill yard, 10,340 yd³ from the former ore storage area, 209,880 yd³ from windblown areas, 225,490 yd³ from the former tailings area, and 10,170 yd³ from stockpiled demolition debris. In addition, a contiguous vicinity property to the north (NT-065, the Maupin property) underwent remedial action, and 93,602 yd³ of material was removed (DOE 1998b). All material was hauled by truck to the Upper Burbank disposal cell about 15 miles to the northwest near the townsite of Uravan, Colorado. Figure 3-5 is an oblique aerial photograph from July 1994 of the mill yard before buildings were razed. It shows the former office buildings, the semicircular concrete pad used during the ore-buying era, and new trailers and equipment moved to the site to begin demolition. Figure 3-6 is an oblique aerial photograph from July 1996 of the mill yard showing the demolition of all buildings, construction of the retention pond for the decontamination pad, and an associated retention dike along the lower side of the site. Figure 3-7 is an overhead aerial photograph from May 1998 showing the final grade for the site. The RRM has been removed from the entire site, and considerable material has been removed from the vicinity property to the north, including the area of the old racetrack. Large cottonwood trees around the river bend were left at the owner's request. Figure 3-8 is an oblique aerial photograph showing the site in March 2001. Reseeding efforts have met with limited success, and another attempt will be made to address this in the fall of 2001.

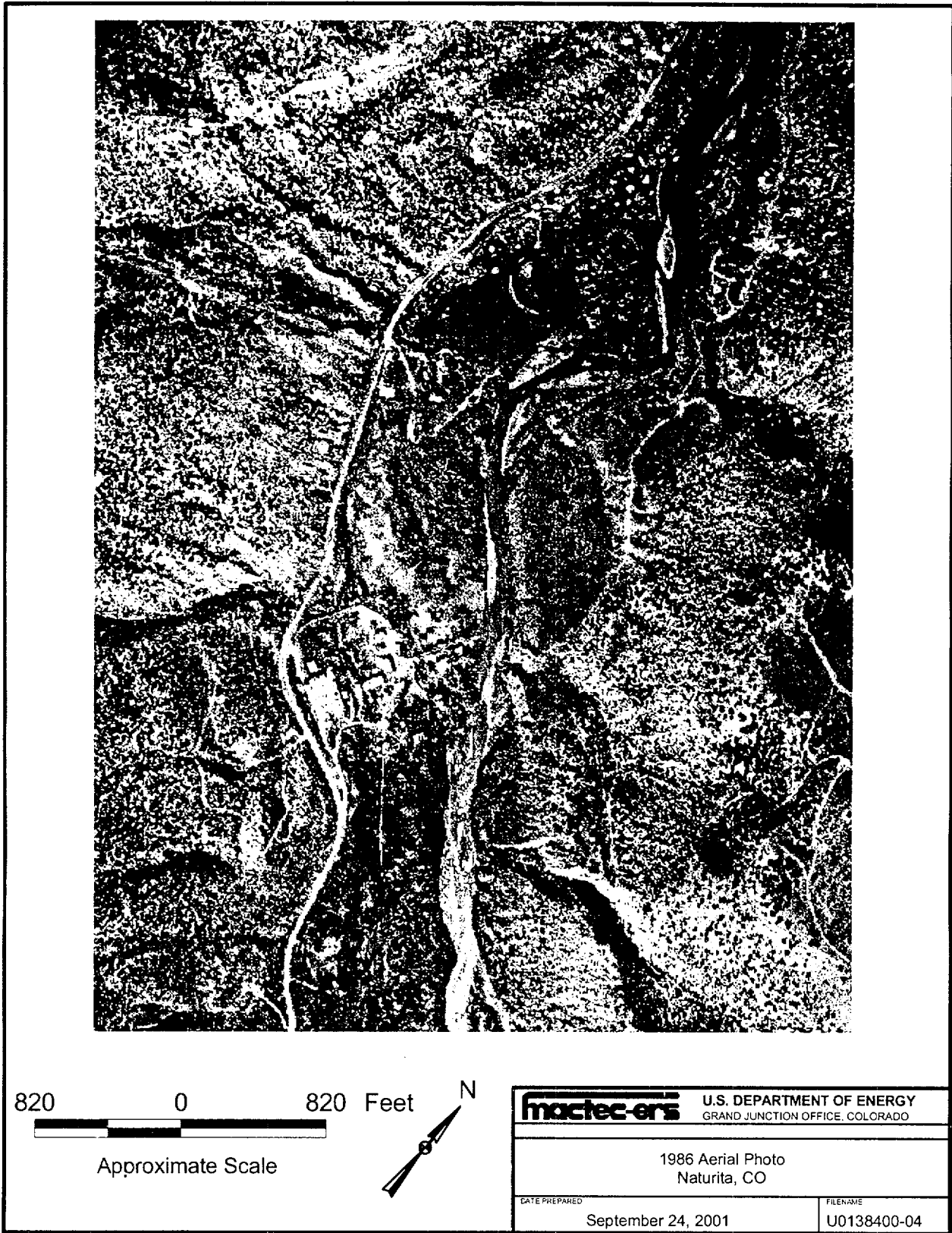


Figure 3-4. Overhead Aerial Photograph taken in 1986

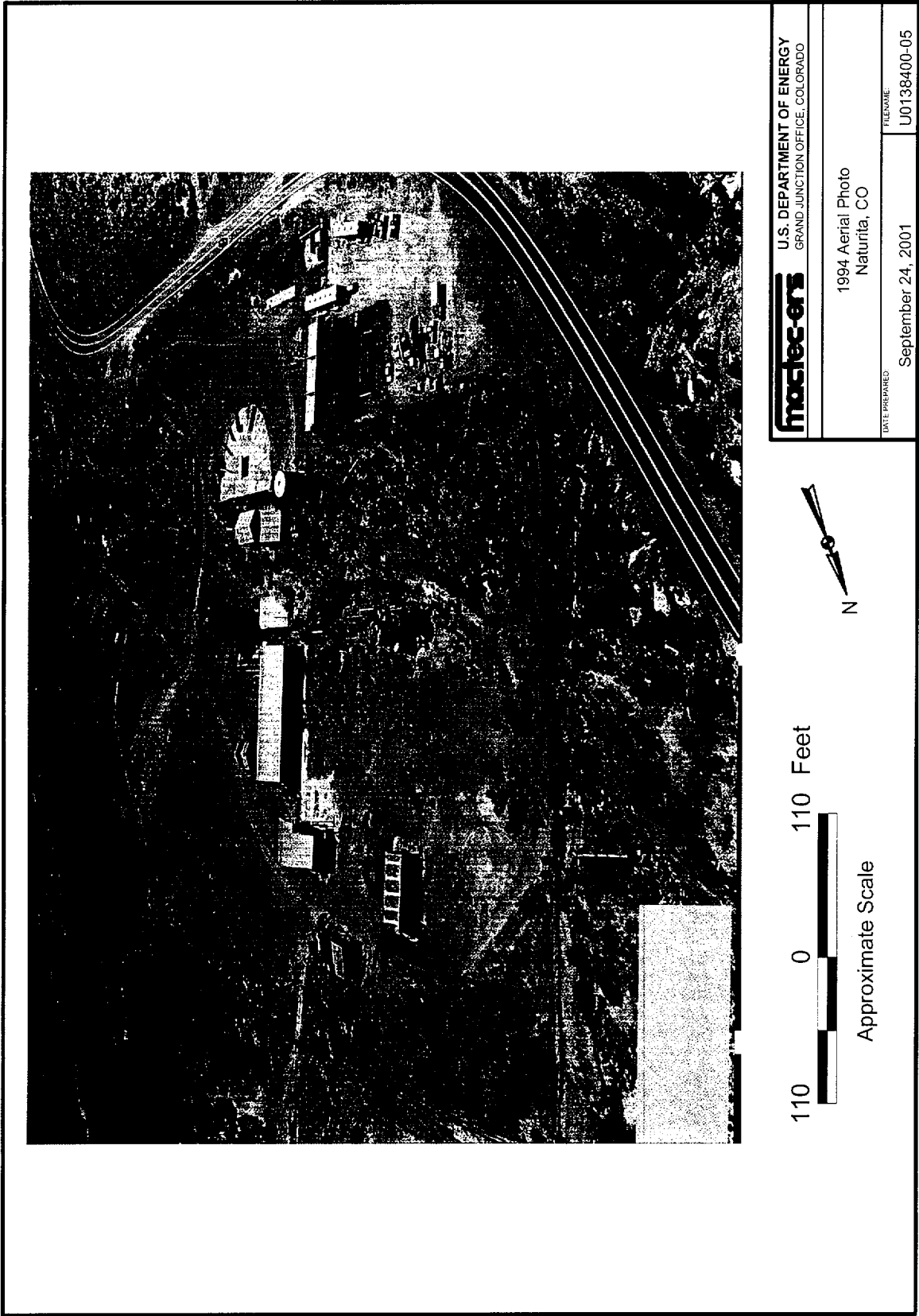


Figure 3-5. Oblique Aerial Photograph taken in 1994

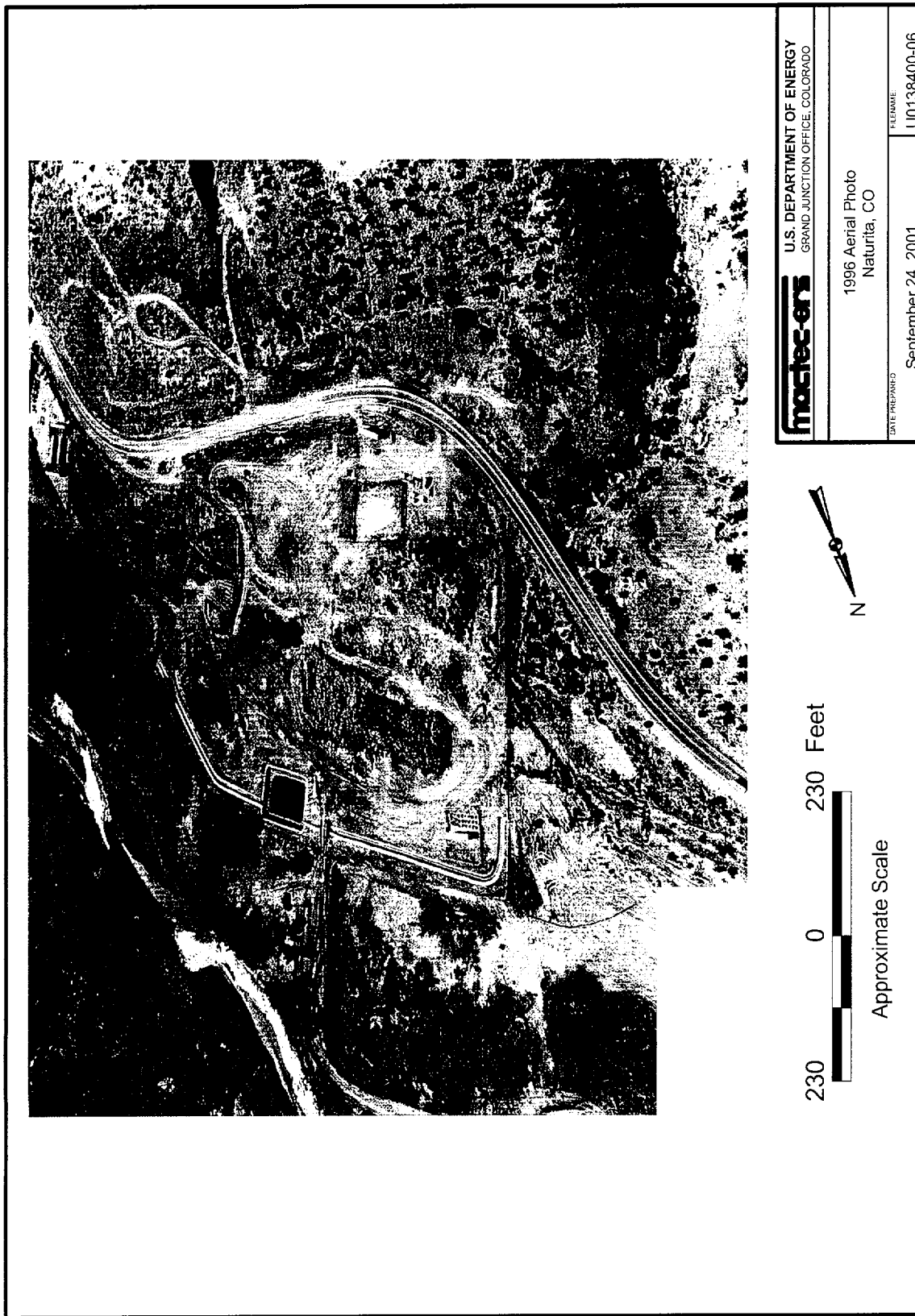


Figure 3-6. Oblique Aerial Photograph taken in 1996

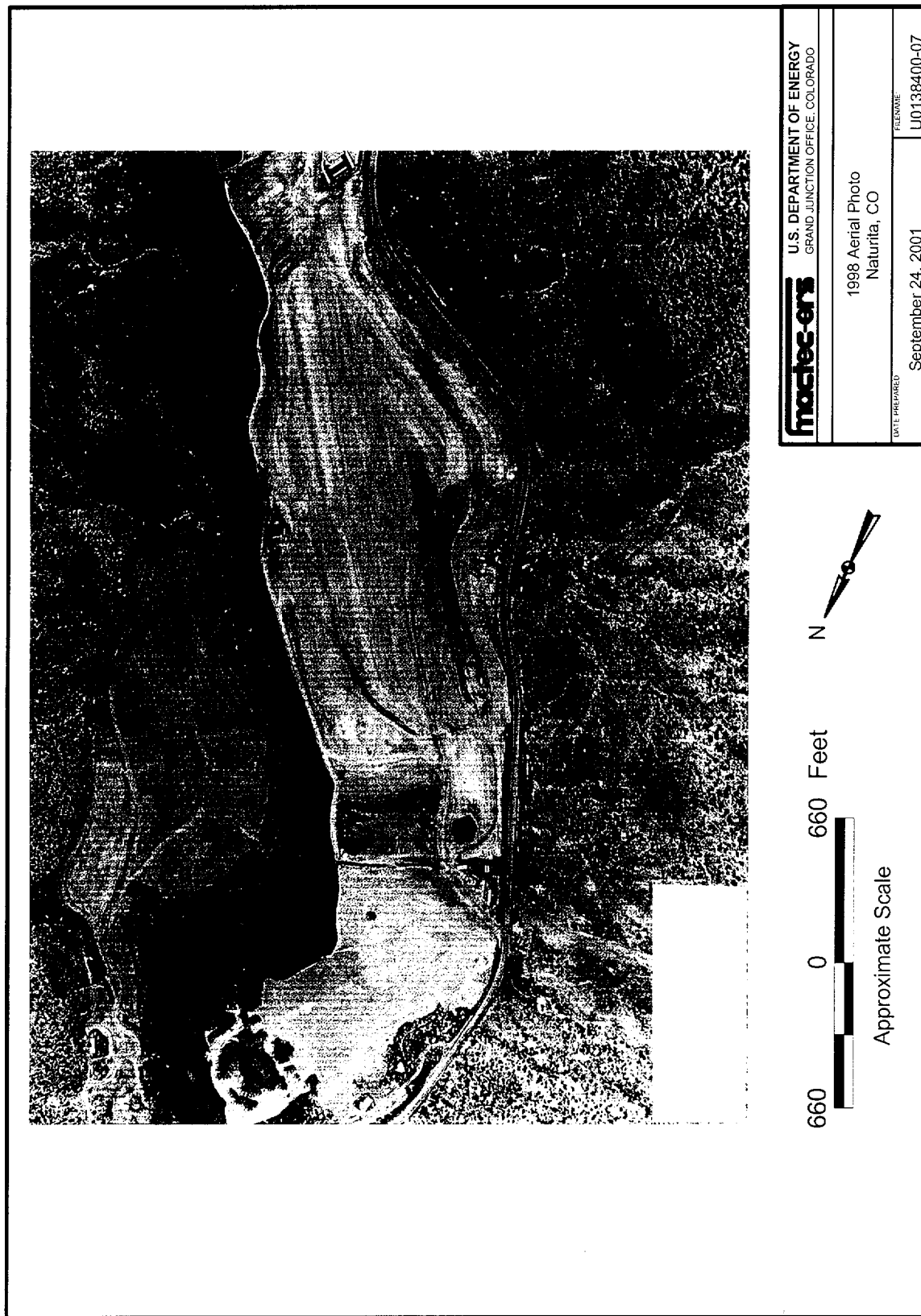


Figure 3-7. Aerial Photograph taken in 1998

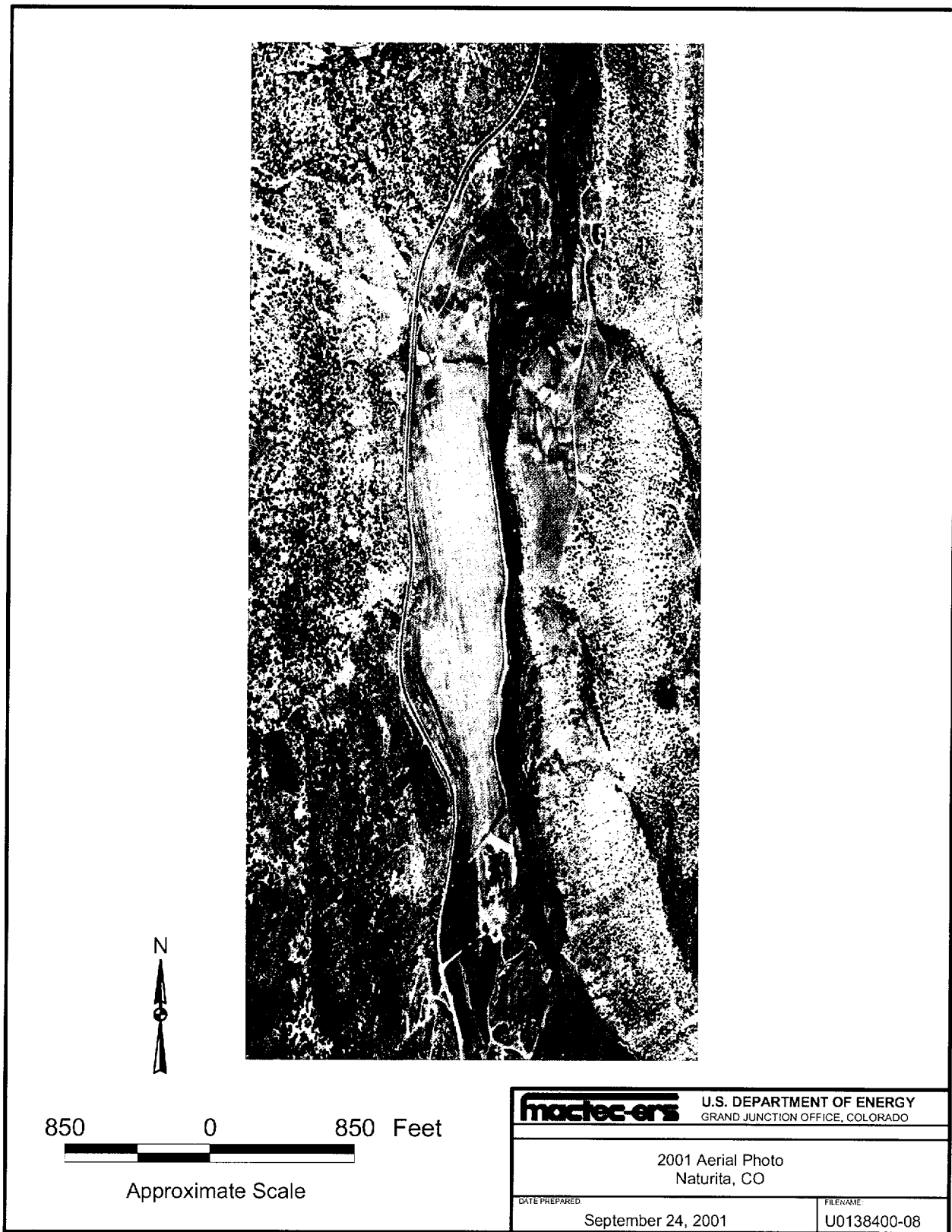


Figure 3-8. Oblique Aerial Photograph taken in March 2001

3.2.2.1 Supplemental Standards Areas

The Naturita site is unusual because of the large amount of supplemental standards areas left during the surface cleanup (DOE 1998a). Five areas of supplemental standards, totaling 11 acres (14 percent of the total site area), were left on the site and large areas of supplemental standards, also totaling 11 acres (36 percent of the total vicinity property area), were included in the vicinity property downgradient of the site (see Figure 8-3). Just over one acre on the millsite was left because the radium-226 standard was not met after excavating to 1 ft below the water table. Other supplemental standards areas on the millsite were left because removing the RRM would produce excessive environmental harm and increased risk to workers who would have to remove it compared to the low radiological hazard. These areas were along the steep slopes of U.S. Highway 141, near high-voltage power poles, and in wetland areas adjacent to the San Miguel River.

Contamination on approximately 5 of the 11 acres on the downgradient vicinity property was left on the floodplain near the San Miguel River because the property owner did not want the area disturbed, and the harm to the environment outweighed the benefit of removing it. The area is a riparian corridor with mature cottonwoods and other habitat suitable for indigenous species. The other 6 acres on the vicinity property, where RRM is probably windblown contamination, was left along State Highway 141 because of low radioactivity and potential danger to workers who would have to work along the steep banks.

3.2.3 Previous Investigations

Merritt (1971) provides detailed descriptions of the uranium concentration process, mill by-products, and process waste streams. Albrethsen and McGinley (1982) summarize the history of the domestic uranium procurement policies and practices under the AEC. McWilliams and Schoch-Roberts (1994) discuss the VCA mill as an important historical activity in the country's nuclear energy saga and provide detailed discussions about the processing and milling history.

Coffin (1921) discusses the early radium, uranium, and vanadium mines in southwestern Colorado. Fischer and Hilpert (1952) discuss the geology of the Uravan Mineral Belt. Chenoweth (1981) reviews uranium and vanadium deposits in the Uravan Mineral Belt. Weir and others (1984) discuss the regional hydrology.

Site-specific hydrogeologic and geochemical investigations and remedial actions are described in an engineering assessment (Ford, Bacon & Davis Utah 1981), an environmental assessment (DOE 1994), a BLRA (DOE 1995), a report by Groffman and Erskine (1996), a final RAP (DOE 1998a), a completion report (DOE 1998b), and a vicinity property completion report (DOE 1999a).

Table 3-1 is an update to Table 3.2 in the BLRA. This table shows the history of wells sampled at the site from 1998 to 2001. Only wells 0547 and 0548 remain from the surface program. Wells listed in Table 3-1 are currently being sampled.

Table 3-1. Current Monitor Well Information

Well ID	Location	Years Sampled	Times Sampled	Interval Screened (ft)
0548	Northwest of former tailings pile	1986, 1987, 1989, 1992, 1994, 1998-2001	20	16.0-21.0
0547	Southeast of former mill yard	1986, 1987, 1989, 1992, 1994, 1998-2001	20	10.0-20.0
MAU01	Maupin property, S border	1998-2001	9	9.2-14.2
MAU02	Maupin property, S border	1998-2001	9	15.8-16.8 triple completion
MAU03	Maupin property, NE	1998-2001	9	2.2-9.2 triple completion
MAU04	Maupin property, NE	1998-2001	9	3.2-10.2
MAU05	Maupin property, S border	1998-2001	9	8.2-8.7
MAU06	Maupin property, center eastern	1999-2001	8	3.5-8.5
MAU07	Maupin property, farthest N	1999-2001	8	2.9-7.9
MAU08	Maupin property, SW border	1999-2001	8	6.2-11.2
NAT01	N boundary former tailings pile	1998-2001	9	17.0-17.5 double completion
NAT02	Former tailings pile	1998-2001	8	6.4-11.4
NAT03	Former tailings pile	1998-2001	9	6.3-11.3
NAT04	Former tailings pile	1998-2001	9	12.0-12.5 triple completion
NAT05	Former tailings pile	1998-2001	9	8.7-13.7
NAT06	Former tailings pile	1998-2001	9	11.6-12.2 triple completion
NAT07	Former tailings pile	1998-2001	9	11.8-12.3 triple completion
NAT08	Former tailings pile	1998-2001	9	6.3-11.3
NAT09	Former tailings pile	1998-2001	9	5.7-10.7
NAT10	Former tailings pile	1998-2001	9	6.8-11.8
NAT11	Former tailings pile	1998-2001	9	8.7-13.7
NAT12	Former tailings pile	1998-2001	9	13.9-14.4 double completion
NAT13	Former tailings pile	1999-2001	8	11.8-12.3 triple completion
NAT14	Former tailings pile	1999-2001	8	11.0-11.5 triple completion
NAT15	Former tailings pile	1999-2001	8	13.8-14.3 triple completion
NAT16	Former tailings pile	1999-2001	8	11.7-12.2 triple completion
NAT17	Former mill yard	1999-2001	8	10.7-11.2 triple completion
NAT18	Former mill yard	1999-2001	8	10.7-11.2 triple completion
NAT19	Former mill yard	1999-2001	8	6.0-11.0
NAT20	S site boundary	1999-2001	8	5.2-10.2
NAT21	S site boundary	1999-2001	8	9.3-9.8 triple completion
NAT22	S site boundary	1999-2001	8	9.3-9.8 triple completion
NAT23	Northern site	1999-2001	8	4.7-9.7
NAT24	Northern site	1999-2001	8	4.7-9.2
NAT25	Northern site	1999-2001	8	10.2-15.2
NAT26	NW site	1999-2001	8	10.7-15.7
NAT27	Former tailings pile	1999-2001	8	6.7-7.2 triple completion
NAT28	Former tailings pile	1999-2001	8	6.7-7.2 triple completion
NAT29	Former tailings pile	1999-2001	8	1.4-6.4
NAT30	Southern site	1999-2001	8	7.8-8.3 triple completion
DM1	Background, gravel pit	1999-2001	8	2.7-7.7

3.3 Land and Water Uses

The population of Naturita is approximately 700. The town was a center for mining radium, vanadium, and uranium for 80 years and still supports coal mining and an associated power plant. A gravel pit operated by Southwest Redimix abuts the site on the south (upgradient) side. The pit intersects the water table and may influence migration of alluvial ground water across the site. Ranching and farming are the main occupations in the valley around the millsite.

One ranch residence is adjacent to the site on the downgradient side. The residents haul drinking water for domestic use and do not have a well.

The Blessing Ditch crosses the site from south to north on the west side. This irrigation ditch was last operational in 1972. The grade for a potential ditch was established on the site during remedial action.

Land including and surrounding the former millsite is zoned agricultural. The City of Naturita identifies the land within the former millsite as having possible uses as a western park or golf course. A portion of the site is currently deeded to the town, and the remainder belongs to Chemetall Foote. Plans to transfer the Chemetall Foote property to the City are under consideration.

Currently, there are no uses for ground water at the site. The ground water in the alluvial aquifer is of lesser quality than water from the San Miguel River flowing adjacent to the site. Livestock drink from the river. No domestic wells exist in the contaminated portion of the aquifer.

End of current text

4.0 1998 to 2001 Field Investigations

4.1 Introduction

The U.S. Geological Survey (USGS) has been conducting research sponsored by NRC at the Naturita site since 1997. NRC is interested in sorptive interactions between uranium and substrate, and more efficient and effective methods of measuring them. DOE teamed with the USGS to use their knowledge and sampling expertise to produce this SOWP. Therefore, most of the sampling from 1998 to 2001 was conducted by USGS and supplemented to a limited extent by DOE. Most surface and ground water analyses and soil/sediment analyses were also performed by USGS at their labs in Menlo Park, California, and Denver, Colorado. Other analyses were performed at the DOE Grand Junction Office.

4.2 Ground Water Monitoring Well Installations

The ground water monitor wells were installed by USGS with funding from NRC for a field demonstration of a uranium(VI) surface complexation model. Specifically, the wells were installed to (1) obtain an understanding of the direction and velocity of ground water flow; (2) characterize the ground water chemistry at the site, including the extent of uranium contamination; (3) investigate the role of U(VI) sorption in host sediments and rock; and (4) conduct small-scale tracer tests and aquifer tests to investigate U(VI) transport. Installation procedures, construction details, and locations for the wells are described in this section. Figure 4-1 shows monitoring well locations.

4.2.1 Wells Installed in 1998 and 1999

A total of 39 ground water monitoring wells were installed during October 1998 and June 1999. Two types of wells were installed: (1) 2-inch-diameter, single completion wells screened over a 5-ft interval at the bottom of the alluvial aquifer, and (2) 0.5-inch-diameter, multiple completion wells with two to three wells in the same borehole, each screened over a 6-inch vertical interval at different depths. All wells were drilled using the USGS drilling rig with hollow stem augers. Wells installed in June 1999 were drilled using a casing-advance method. Twenty wells were completed with 2-inch inside diameter (i.d.), flush joint, inside threaded, polyvinyl chloride (PVC) casing with size 20 slotted screen. One well was constructed with a 4-inch i.d. PVC casing for use in aquifer testing. Eighteen wells were constructed as multiple completion wells using 0.5-inch i.d. PVC casing. The multiple completion wells were constructed by setting the 0.5-inch casings at different levels in the filter pack. Each of the multiple completion wells in NAT04, NAT12, and MAU02 was separated by a 4-inch bentonite seal. For all other multiple completion wells, no seal was installed between the completion zones. All the 1998–1999 wells completed in the alluvial aquifer were less than 20 ft in depth. The screened interval for the 4-inch and 2-inch wells is 5 ft. Screened intervals for the 0.5-inch-diameter multiple completion wells is 6 inches. The filter pack was constructed with 10 to 20 sieve silica sand placed in the annular space from the bottom of the borehole to 1 to 3 ft above the top of the well screen. A 1- to 8-ft bentonite seal was placed above the sand pack. Bentonite grout was used to fill the annular space above the seal to the ground surface, and a cement pad was poured to anchor a locking steel protective cover. Examples of well completion diagrams for the 2-inch single completion and 0.5-inch multiple completion wells are shown in Figure 4-2 and Figure 4-3, respectively. Construction details for the wells are summarized in Table 4-1. Completion diagrams for all the wells are in Appendix A.

4.2.2 Wells Installed by DOE Before 1998

In addition to the wells installed in 1998 and 1999, DOE had previously installed two wells as part of an initial site characterization. These wells, designated 0547 and 0548, were installed in June 1986 with a direct rotary drill. Both wells have 2-inch i.d. PVC casings and are 23 ft deep. Well 0547 has a 10-ft screened interval and 0548 has a 5-ft screened interval. Both wells are capped with a locking steel cover. Drilling logs for these wells are included in Appendix A; construction details for DOE wells are summarized in Table 4-1.

4.2.3 Wells Installed by DOE After 1998

Several additional wells were installed during this current phase of characterization. Well 700 was installed in 2001 on the former millsite area to try to pinpoint the maximum concentrations of vanadium. Well 701 was installed in 2001 on the vicinity property to help complete data gaps in this area. Well 715 was drilled in 2002 to determine if contamination existed on the east side of the San Miguel River. And well 716 is currently planned in 2002 as a water well for the family living on the vicinity property.

4.2.4 Water Levels and Temperatures

Seasonal changes in water levels were measured 14 times in all the monitoring wells between October 1998 and June 2000. From November 2000 to March 2001, water levels were only measured in 28 wells. Depth to water was measured from the top of the PVC casing at each well at a set measuring point. Measuring point elevations above sea level are shown in Table 4-2 and were surveyed from a nearby benchmark during well installation to calculate the elevation of the water table. Water levels were monitored continuously with pressure transducers in up to six wells from November 1998 to March 2001. Water level data from the transducers were downloaded, and the instruments were recalibrated quarterly. Figure 4-4 shows the water table elevations and temperatures for wells NAT02, NAT08, and NAT29. Figure 4-5 shows the water table elevations in wells NAT11, NAT23, and NAT25.

Seasonal changes in water temperature was recorded along with water level in wells NAT02, NAT08 and NAT29 and is shown in Figure 4-4. Water temperature was also recorded in wells NAT02, NAT11, NAT19, NAT20, NAT23, NAT26, MAU03, MAU07, MAU08, and the San Miguel River.

4.3 Soil and Sediment Sampling

Soil and sediment samples for lithologic logging and chemical analysis were collected during installation of the ground water monitoring wells. Sediment and soil samples were collected for chemical analysis to determine distribution coefficients (K_d) and mobile fractions of site-related constituents to help characterize contaminant transport. Figure 4-6 shows the soil and sediment sampling locations. All samples were sent to the USGS Research Laboratories in Menlo Park, California, for K_d and batch leachate analysis using strict chain of custody procedures. Chemical analysis of the leachates was performed in Menlo Park and at the USGS National Water Quality Lab in Denver using the methods described in Section 4.7.2.

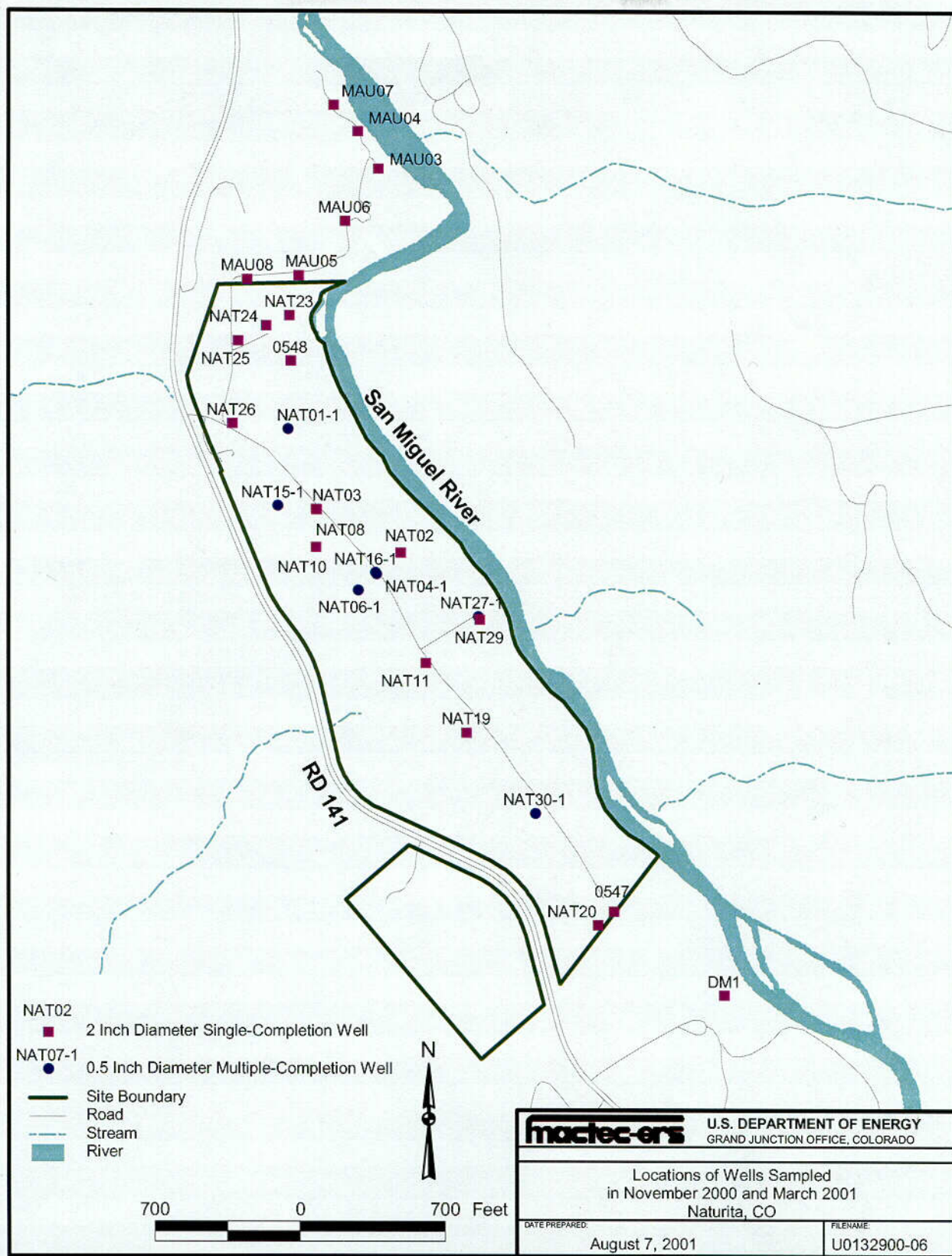


Figure 4-1. Locations of Naturita Wells Sampled in November 2000 and March 2001

C01

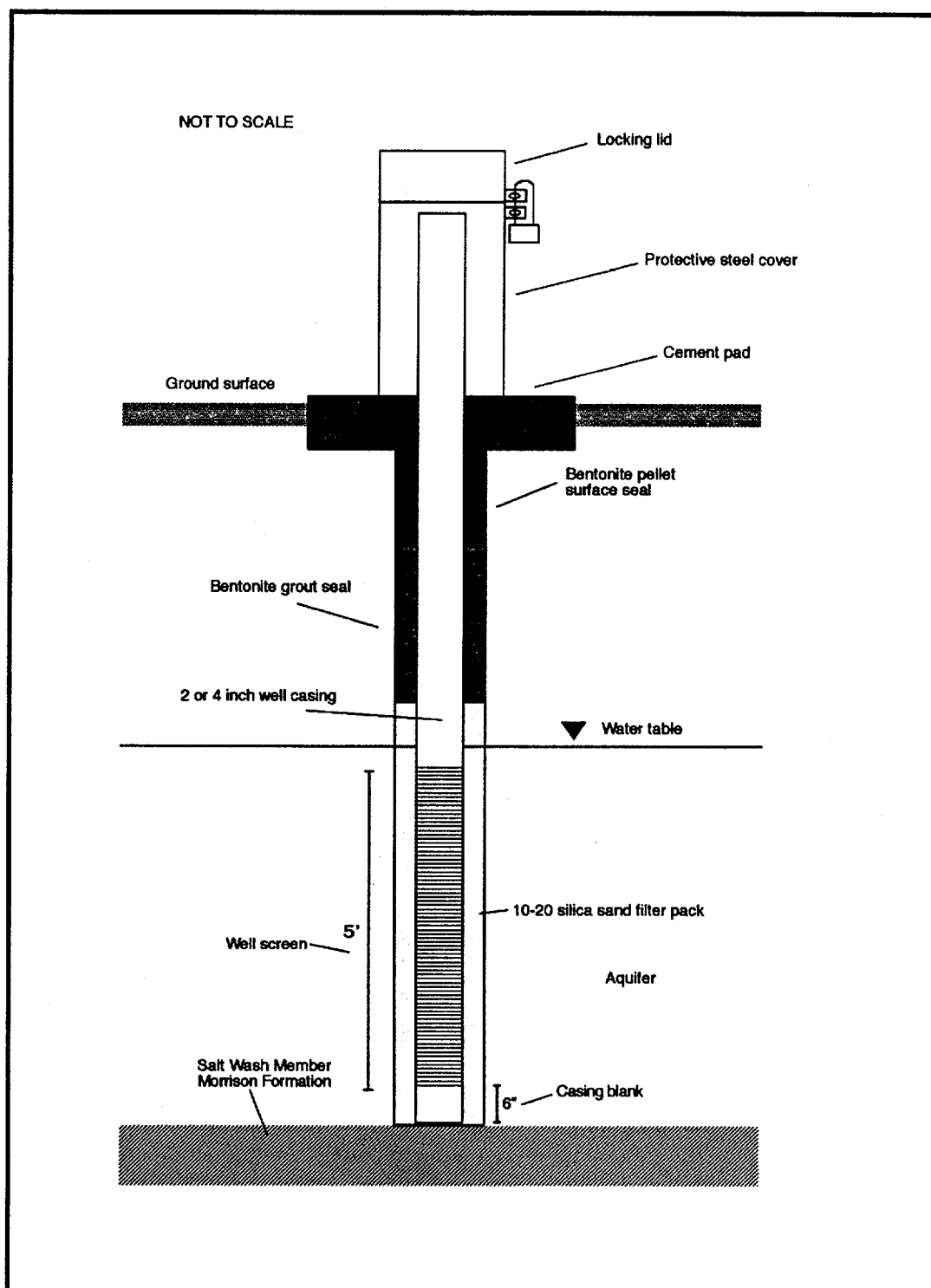


Figure 4-2. Construction Diagram for 2- and 4-inch-Diameter Monitoring Wells Installed at the Naturita Site

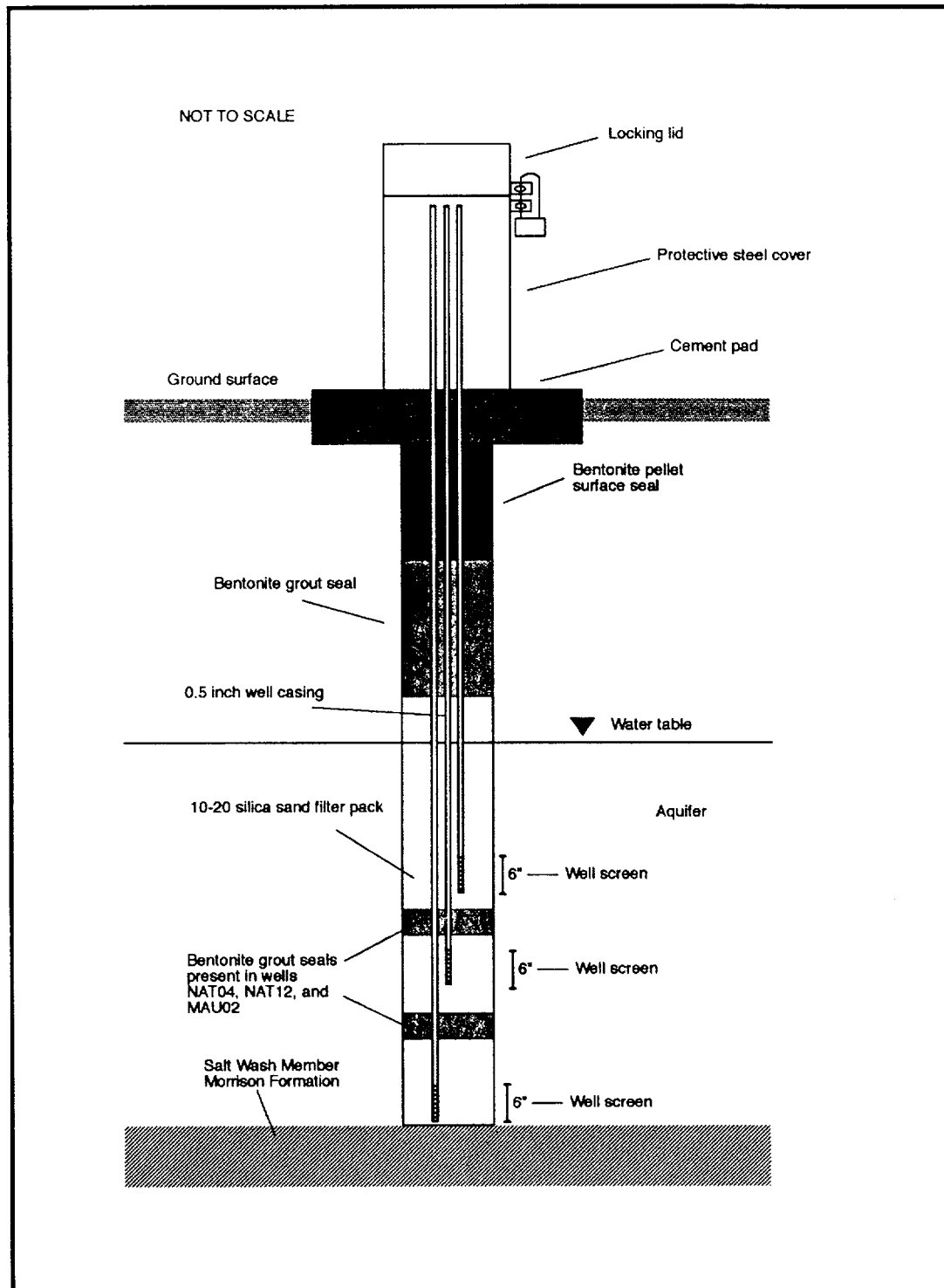


Figure 4-3. Construction Diagram for 0.5-inch-Diameter Multiple Completion Wells Installed at the Naturita Site

Table 4-1. Construction Details for Monitoring Wells Installed at the Naturita UMTRA Site

Location Code	North Coordinate, State Plane	East Coordinate, State Plane	Elevation of Land Surface, ft	Borehole Depth, ft	Borehole Diameter, inches	Elevation of Top of Casing, ft	Casing Length, ft	Casing Diameter, inches	Depth Below Land Surface, ft	Screen length, ft	Flow Code	Zone of Completion	Status
NAT01-1	588657	1106298	5288.11	18.0	14.0	5290.76	20.32	0.5	17.0	0.50	O	AI	Active
NAT01-2	588659	1106298	5288.11	18.0	14.0	5290.61	15.37	0.5	12.2	0.50	O	AI	Active
NAT02	588073	1106846	5287.37	11.5	9.0	5289.42	13.88	2.0	6.5	5.00	O	AI	Active
NAT03	588278	1106435	5286.57	11.6	9.0	5288.37	13.43	2.0	6.3	5.00	O	AI	Active
NAT04-1	587968	1106729	5288.42	12.5	9.0	5290.53	14.78	0.5	12.0	0.50	O	AI	Active
NAT04-2	587968	1106729	5288.42	10.7	9.0	5290.62	13.07	0.5	10.2	0.50	O	AI	Active
NAT04-3	587968	1106729	5288.42	8.7	9.0	5290.62	11.07	0.5	8.2	0.50	O	AI	Active
NAT05	588284	1106251	5287.63	14.0	9.0	5289.73	16.13	2.0	8.7	5.00	O	AI	Active
NAT06-1	587888	1106640	5288.88	12.3	9.0	5291.73	15.32	0.5	11.8	0.50	O	AI	Active
NAT06-2	587888	1106640	5288.88	9.9	9.0	5291.73	12.92	0.5	9.4	0.50	O	AI	Active
NAT06-3	587888	1106641	5288.88	6.1	9.0	5291.71	9.10	0.5	5.6	0.50	O	AI	Active
NAT07-1	588368	1106567	5285.73	12.5	9.0	5287.93	14.87	0.5	12.0	0.50	O	AI	Active
NAT07-2	588368	1106567	5285.73	10.8	9.0	5287.81	13.05	0.5	10.3	0.50	O	AI	Active
NAT07-3	588368	1106567	5285.73	8.7	9.0	5287.63	10.77	0.5	8.2	0.50	O	AI	Active
NAT08	588276	1106438	5286.30	12.0	12.0	5288.00	13.33	4.0	6.0	5.00	O	AI	Active
NAT09	588281	1106432	5286.52	11.0	9.0	5288.42	13.03	2.0	6.3	5.00	O	AI	Active
NAT10	588095	1106437	5287.28	12.0	9.0	5289.18	14.03	2.0	6.8	5.00	O	AI	Active
NAT11	587546	1106970	5291.23	14.0	10.0	5293.73	16.63	2.0	8.8	5.00	O	AI	Active
NAT12-1	588592	1106197	5289.84	14.6	9.0	5291.64	16.57	0.5	14.1	0.50	O	AI	Active
NAT12-2	588592	1106198	5289.84	10.3	9.0	5291.65	12.28	0.5	9.8	0.50	O	AI	Active
NAT13-1	587550	1106965	5291.50	12.5	4.0	5294.22	15.19	0.5	11.8	0.50	O	AI	Active
NAT13-2	587550	1106965	5291.50	10.5	4.0	5294.14	13.11	0.5	9.8	0.50	O	AI	Active
NAT13-3	587550	1106965	5291.50	8.5	4.0	5294.22	11.19	0.5	7.8	0.50	O	AI	Active
NAT14-1	587556	1106961	5291.34	11.7	4.0	5294.58	15.01	0.5	11.0	0.50	O	AI	Active
NAT14-2	587556	1106961	5291.34	10.4	4.0	5294.56	13.69	0.5	9.8	0.50	O	AI	Active
NAT14-3	587556	1106961	5291.34	8.4	4.0	5294.57	11.70	0.5	7.8	0.50	O	AI	Active
NAT15-1	588292	1106251	5287.96	14.5	4.0	5290.25	16.76	0.5	13.8	0.50	O	AI	Active
NAT15-2	588292	1106251	5287.96	12.5	4.0	5290.25	14.76	0.5	11.8	0.50	O	AI	Active
NAT15-3	588292	1106251	5287.96	10.5	4.0	5290.25	12.76	0.5	9.8	0.50	O	AI	Active
NAT16-1	587975	1106725	5288.43	12.3	4.0	5291.16	15.10	0.5	11.7	0.50	O	AI	Active
NAT16-2	587975	1106725	5288.43	10.5	4.0	5291.10	13.14	0.5	9.8	0.50	O	AI	Active
NAT16-3	587975	1106725	5288.43	8.5	4.0	5291.16	11.20	0.5	7.8	0.50	O	AI	Active
NAT17-1	587226	1107161	5293.65	11.3	4.0	5295.97	13.69	0.5	10.7	0.50	O	AI	Active
NAT17-2	587226	1107161	5293.65	9.3	4.0	5295.97	11.69	0.5	8.7	0.50	O	AI	Active
NAT17-3	587226	1107161	5293.65	7.3	4.0	5295.97	9.69	0.5	6.7	0.50	O	AI	Active
NAT18-1	587221	1107166	5293.66	11.3	4.0	5296.34	14.05	0.5	10.7	0.50	O	AI	Active
NAT18-2	587221	1107166	5293.66	9.3	4.0	5296.34	11.05	0.5	8.7	0.50	O	AI	Active
NAT18-3	587221	1107166	5293.66	7.3	4.0	5296.34	10.05	0.5	6.7	0.50	O	AI	Active
NAT19	587215	1107170	5293.82	11.3	4.0	5296.58	14.09	2.0	6.0	5.00	O	AI	Active
NAT20	586300	1107808	5301.43	10.5	4.0	5304.46	13.56	2.0	5.2	5.00	O	AI	Active
NAT21-1	586305	1107804	5301.47	10.0	4.0	5304.27	12.93	0.5	9.3	0.50	O	AI	Active
NAT21-2	586305	1107804	5301.47	8.0	4.0	5304.27	10.77	0.5	7.3	0.50	O	AI	Active
NAT21-3	586305	1107804	5301.47	6.0	4.0	5304.27	8.77	0.5	5.3	0.50	O	AI	Active
NAT22-1	586312	1107800	5301.47	10.0	4.0	5304.27	12.77	0.5	9.3	0.50	O	AI	Active
NAT22-2	586312	1107800	5301.47	8.0	4.0	5304.27	10.77	0.5	7.3	0.50	O	AI	Active
NAT22-3	586312	1107800	5301.47	6.0	4.0	5304.27	8.77	0.5	5.3	0.50	O	AI	Active

Table 4-1 (continued). Construction Details for Monitoring Wells Installed at the Naturita UMTRA Site

Location Code	North Coordinate, State Plane	East Coordinate, State Plane	Elevation of Land Surface, ft	Borehole Depth, ft	Borehole Diameter, inches	Elevation of Top of Casing, ft	Casing Length, ft	Casing Diameter, inches	Depth Below Land Surface, ft	Screen length, ft	Flow Code	Zone of Completion	Status
NAT23	589202	1106300	5283.07	10.0	4.0	5285.43	12.39	2.0	4.7	5.00	O	AI	Active
NAT24	589155	1106188	5285.11	9.5	4.0	5287.70	12.12	2.0	4.2	5.00	O	AI	Active
NAT25	589082	1106053	5289.39	15.5	4.0	5291.88	18.02	2.0	10.2	5.00	O	AI	Active
NAT26	588685	1106027	5293.23	16.0	4.0	5295.54	18.34	2.0	10.7	5.00	O	AI	Active
NAT27-1	587764	1107221	5289.81	7.3	4.0	5292.79	10.35	0.5	6.7	0.50	O	AI	Active
NAT27-2	587764	1107221	5289.81	5.3	4.0	5292.79	8.35	0.5	4.7	0.50	O	AI	Active
NAT27-3	587764	1107221	5289.81	3.3	4.0	5292.79	6.35	0.5	2.7	0.50	O	AI	Active
NAT28-1	587759	1107225	5289.88	7.3	4.0	5292.61	10.10	0.5	6.7	0.50	O	AI	Active
NAT28-2	587759	1107225	5289.88	5.3	4.0	5292.61	8.10	0.5	4.7	0.50	O	AI	Active
NAT28-3	587759	1107225	5289.88	3.3	4.0	5292.61	6.10	0.5	2.7	0.50	O	AI	Active
NAT29	587752	1107229	5290.08	6.8	4.0	5292.89	9.54	2.0	1.4	5.00	O	AI	Active
NAT30-1	586831	1107504	5297.04	8.5	4.0	5300.05	11.48	0.5	7.8	0.50	O	AI	Active
NAT30-2	586831	1107504	5297.04	6.5	4.0	5300.02	9.45	0.5	5.8	0.50	O	AI	Active
NAT30-3	586831	1107504	5297.04	4.5	4.0	5300.00	7.43	0.5	3.8	0.50	O	AI	Active
MAU01	589377	1106207	5283.19	14.5	9.0	5284.89	16.53	2.0	9.5	5.00	D	AI	Active
MAU02-1	589365	1106377	5282.44	16.5	9.0	5284.54	18.77	0.5	16.0	0.50	D	AI	Active
MAU02-2	589365	1106377	5282.46	11.2	9.0	5284.56	13.47	0.5	10.7	0.50	D	AI	Active
MAU02-3	589365	1106377	5282.46	9.6	9.0	5284.56	7.87	0.5	9.1	0.50	D	AI	Active
MAU03	589907	1106726	5275.29	9.5	10.0	5277.64	12.18	2.0	2.5	5.00	D	AI	Active
MAU04	590085	1106620	5274.10	10.5	9.0	5275.80	12.53	2.0	3.5	5.00	D	AI	Active
MAU05	589394	1106342	5282.13	9.0	9.0	5284.33	11.53	2.0	8.5	5.00	D	AI	Active
MAU06	589655	1106565	5279.43	8.8	4.0	5281.85	11.25	2.0	3.5	5.00	D	AI	Active
MAU07	590209	1106507	5273.16	8.3	4.0	5275.90	10.97	2.0	2.9	5.00	D	AI	Active
MAU08	589375	1106097	5283.51	11.5	4.0	5286.44	14.46	2.0	6.2	5.00	D	AI	Active
0502	586923	1106997	5348.90	249.0	6.0	5350.30	249.00	2.0	229.3	20.00	U	JS	Destroyed
0503	586588	1107630	5301.10	165.0	6.0	5302.50	165.00	2.0	140.0	25.00	U	JS	Destroyed
0505	587411	1107326	5297.90	24.0	6.0	5300.90	23.00	2.0	16.0	5.00	O	AI	Destroyed
0506	587257	1107057	5304.70	27.0	6.0	5306.30	27.00	2.0	22.5	5.00	O	AI	Destroyed
0546	586414	1107771	5302.10	23.0	6.0	5304.10	17.00	2.0	10.0	5.00	U	AI	Destroyed
0547	586276	1107988	5303.10	23.0	6.0	5304.80	22.00	2.0	10.0	10.00	U	AI	Active
0548	588903	1106435	5288.70	23.0	2.0	5290.40	14.60	2.0	16.0	5.00	O	AI	Active
0549	586184	1107902	5302.40	15.0	5.6	5304.50	17.00	2.0	11.5	5.00	U	AI	Destroyed
0616	587957	1106403	5288.50	7.6	ND	5290.90	10.00	3.0	2.5	2.50	O	AI	Destroyed
0619	588211	1106716	5288.90	8.0	ND	5291.10	10.00	3.0	7.5	2.50	O	AI	Destroyed
0630	588017	1107115	5289.80	7.5	ND	5292.50	10.00	3.0	7.5	2.50	O	AI	Destroyed
0632	587614	1106880	5289.00	8.0	ND	5291.70	10.00	3.0	7.5	2.50	O	AI	Destroyed
0637	587659	1107178	5288.50	5.5	ND	5291.30	8.00	3.0	5.5	2.50	O	AI	Destroyed
0656	588367	1106400	5287.90	9.0	ND	5288.90	10.00	3.0	7.5	2.50	O	AI	Destroyed
DM1	585970	1108417	5302.74	8.0	4.0	5305.95	11.24	2.0	2.7	5.00	U	AI	Active

Flow Codes

D downgradient

O on site

U upgradient

Zones of Completion

AI Alluvium

JS Jurassic Salt Wash Formation

Table 4-2. Measured Water Table Elevation in Wells at the Naturita Site from November 1998 to March 2001

Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)
NAT01-1	11/18/98	5279.12	NAT04-1 (cont.)	09/20/99	5282.48	NAT06-2 (cont.)	05/13/99	5283.02
	12/18/98	5279.24		11/09/99	5281.99		06/07/99	5282.92
	01/27/99	5279.14		02/28/00	5281.92		09/02/99	5282.81
	02/24/99	5278.85		06/13/00	5282.81		09/20/99	5282.28
	03/22/99	5279.57		11/28/00	5281.80		11/09/99	5281.77
	05/13/99	5280.44		02/28/01	5281.97		02/28/00	5281.73
	06/07/99	5280.39	NAT04-2	11/17/98	5282.03	NAT06-3	06/13/00	5282.63
	09/02/99	5280.14		12/18/98	5282.04		11/17/98	DRY
	09/20/99	5279.68		01/27/99	5281.93		12/18/98	DRY
	11/10/99	5279.26		02/24/99	5281.55		01/27/99	DRY
	02/28/00	5279.10		03/22/99	5282.53		02/24/99	DRY
	06/13/00	5280.07		05/13/99	5283.29		03/22/99	DRY
	11/29/00	5279.02		06/07/99	5283.17		05/13/99	DRY
	02/27/01	5278.99		09/02/99	5283.01		06/07/99	5283.09
NAT01-2	11/18/98	5279.14		09/20/99	5282.52		09/02/99	5282.99
	12/18/98	5279.28		11/09/99	5282.04		09/20/99	5282.95
	01/27/99	5279.16		02/28/00	5281.97		11/09/99	DRY
	02/24/99	5278.87		06/13/00	5282.89		02/28/00	DRY
	03/22/99	5279.58	NAT04-3	11/17/98	5282.00	NAT07-1	06/11/00	DRY
	05/13/99	5280.49		12/18/98	5282.06		11/18/98	5280.25
	06/07/99	5280.41		01/27/99	5281.94		12/18/98	5280.43
	09/02/99	5280.21		02/24/99	5281.55		01/27/99	5280.31
	09/20/99	5279.77		03/22/99	5282.55		02/24/99	5279.91
	11/10/99	5279.28		05/13/99	5283.30		03/22/99	5280.89
	02/28/00	5279.13		06/07/99	5283.19		05/13/99	5281.63
	06/13/00	5280.09		09/02/99	5283.01		06/07/99	5281.51
NAT02	11/17/98	5282.04		09/20/99	5282.52		09/02/99	5281.43
	12/18/98	5282.12	NAT05	11/09/99	5282.04		09/20/99	5280.88
	01/27/99	5282.03		02/28/00	5281.97		11/09/99	5280.48
	02/24/99	5281.60		06/13/00	5282.89		02/28/00	5280.32
	03/22/99	5282.65		11/18/98	5280.23	NAT07-2	06/13/00	5281.25
	05/13/99	5283.38		12/18/98	5280.24		11/18/98	5280.22
	06/07/99	5283.35		01/27/99	5280.18		12/18/98	5280.40
	09/02/99	5283.15		02/24/99	5279.94		01/27/99	5280.27
	09/20/99	5282.58		03/22/99	5280.60		02/24/99	5279.89
	11/10/99	5282.17		05/13/99	5281.54		03/22/99	5280.86
	02/28/00	5282.06		06/07/99	5281.44		05/13/99	5281.60
	06/13/00	5282.94		09/02/99	5281.31		06/07/99	5281.50
	11/29/00	5281.80		09/20/99	5280.79		09/02/99	5281.41
	02/29/01	5281.92		11/09/99	5280.32		09/20/99	5280.86
NAT03	11/18/98	5280.24		02/28/00	5280.17		11/09/99	5280.43
	12/18/98	5280.36	NAT06-1	06/13/00	5281.17		02/28/00	5280.29
	01/27/99	5280.25		11/17/98	5281.83	NAT07-3	06/13/00	5281.22
	02/24/99	5279.89		12/18/98	5281.79		11/18/98	5280.23
	03/22/99	5280.80		01/27/99	5281.68		12/18/98	5280.43
	05/13/99	5281.62		02/24/99	5281.33		01/27/99	5280.30
	06/07/99	5281.52		03/22/99	5282.23		02/24/99	5279.92
	09/02/99	5281.41		05/13/99	5283.03		03/22/99	5280.89
	09/20/99	5280.85		06/07/99	5282.93		05/13/99	5281.63
	11/09/99	5280.43		09/02/99	5282.81		06/07/99	5281.49
	02/28/00	5280.27		09/20/99	5282.28		09/02/99	5281.43
	06/13/00	5281.28	NAT06-2	11/09/99	5281.78		09/20/99	5280.87
	11/29/00	5280.15		02/28/00	5281.73		11/09/99	5280.44
	02/27/01	5280.11		06/13/00	5282.65		02/28/00	5280.30
NAT04-1	11/17/98	5281.95		11/29/00	5281.58	NAT08	06/13/00	5281.23
	12/18/98	5282.00		02/28/01	5281.68		11/18/98	5280.27
	01/27/99	5281.88		11/17/98	5281.81		12/18/98	5280.38
	02/24/99	5281.52		12/18/98	5281.78		01/27/99	5280.26
	03/22/99	5282.49		01/27/99	5281.66		02/24/99	5279.89
	05/13/99	5283.24		02/24/99	5281.31		03/22/99	5280.74
	06/07/99	5283.13		03/22/99	5282.22		05/13/99	5281.57
	09/02/99	5282.98						

Table 4-2 (continued). Measured Water Table Elevation in Wells at the Naturita Site from November 1998 to March 2001

Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)
NAT08 (cont.)	06/07/99	5281.47	NAT12-2 (cont.)	12/18/98	5279.35	NAT15-3 (cont.)	06/13/00	5281.15
	09/02/99	5281.42		01/27/99	5279.38			
	09/20/99	5280.83		02/24/99	DRY	NAT16-1	09/02/99	5282.95
	11/09/99	5280.43		03/22/99	5279.33		09/20/99	5282.45
	02/28/00	5280.30		05/13/99	5280.39		11/09/99	5281.98
	06/13/00	5281.14		06/07/99	5280.33		02/28/00	5281.93
	11/29/00	5280.17		09/02/99	5280.13		06/13/00	5282.82
	02/27/01	5280.14		09/20/99	5279.69		11/28/00	5281.73
				11/10/99	DRY		02/28/01	5281.96
				02/28/00	DRY			
NAT09	11/18/98	5280.27		06/13/00	5280.00	NAT16-2	09/02/99	5282.94
	12/18/98	5280.37					09/20/99	5282.46
	01/27/99	5280.28	NAT13-1	09/02/99	5285.25		11/09/99	5281.99
	02/24/99	5279.91		09/20/99	5284.67		02/28/00	5281.92
	03/22/99	5280.82		11/09/99	5284.12		06/13/00	5282.81
	05/13/99	5281.62		02/28/00	5284.12	NAT16-3	09/02/99	5283.00
	06/07/99	5281.51		06/13/00	5285.08		09/20/99	5282.51
	09/02/99	5281.42					11/09/99	5282.03
	09/20/99	5280.89	NAT13-2	09/02/99	5285.23		02/28/00	5281.98
	11/09/99	5280.42		09/20/99	5284.66		06/13/00	5282.85
	02/28/00	5280.28		11/09/99	5284.10			
	06/13/00	5281.27		02/28/00	5284.08	NAT17-1	09/02/99	5289.57
				06/13/00	5285.07		09/20/99	5288.94
NAT10	11/18/98	5280.62					11/09/99	5288.29
	12/18/98	5280.72	NAT13-3	09/02/99	5285.25		02/28/00	5288.16
	01/27/99	5280.64		09/20/99	5284.67		06/13/00	5289.23
	02/24/99	5280.33		11/09/99	5284.12	NAT17-2	09/02/99	5289.57
	03/22/99	5281.14		02/28/00	5284.11		09/20/99	5288.93
	05/13/99	5281.99		06/13/00	5285.09		11/09/99	5288.29
	06/07/99	5281.91					02/28/00	5288.15
	09/02/99	5281.73	NAT14-1	09/02/99	5285.24		06/13/00	5289.22
	09/20/99	5281.23		09/20/99	5284.69	NAT17-3	09/02/99	5289.57
	11/09/99	5280.73		11/09/99	5284.11		09/20/99	5288.93
	02/28/00	5280.64		02/28/00	5284.11		11/09/99	5288.30
	06/13/00	5281.59		06/13/00	5285.08		02/28/00	5288.15
	11/29/00	5280.56					06/13/00	5289.22
	02/27/01	5280.49	NAT14-2	09/02/99	5285.22	NAT18-1	09/02/99	5289.56
				09/20/99	5284.67		09/20/99	5288.89
NAT11	11/17/98	5283.98		11/09/99	5284.11		11/09/99	5288.28
	12/18/98	5284.15		02/28/00	5284.10		02/28/00	5288.14
	01/27/99	5284.02		06/13/00	5285.07		06/13/00	5289.20
	02/24/99	5283.75	NAT14-3	09/02/99	5285.23	NAT18-2	09/02/99	5289.55
	03/22/99	5284.60		09/20/99	5284.68		09/20/99	5288.88
	05/13/99	5285.52		11/09/99	5284.12		11/09/99	5288.26
	06/07/99	5285.43		02/28/00	5284.11		02/28/00	5288.12
	09/02/99	5285.26		06/13/00	5285.09		06/13/00	5289.19
	09/20/99	5284.67	NAT15-1	09/02/99	5281.35	NAT18-3	09/02/99	5289.55
	11/09/99	5284.11		09/20/99	5280.82		09/20/99	5288.85
	02/28/00	5284.12		11/09/99	5280.37		11/09/99	5288.24
	06/13/00	5285.04		02/28/00	5280.21		02/28/00	5288.11
	11/28/00	5284.05		06/13/00	5281.20		06/13/00	5289.18
	02/28/01	5284.13		11/29/00	5280.15	NAT19	09/02/99	5289.58
				02/27/01	5280.08		09/20/99	5288.90
NAT12-1	11/18/98	5279.14	NAT15-2	09/02/99	5281.32		11/09/99	5288.24
	12/18/98	5279.15		09/20/99	5280.80		02/28/00	5288.13
	01/27/99	5279.09		11/09/99	5280.33		06/13/00	5289.22
	02/24/99	5278.89		02/28/00	5280.19		11/28/00	5287.94
	03/22/99	5279.31		06/13/00	5281.16		02/28/01	5287.99
	05/13/99	5280.33						
	06/07/99	5280.32	NAT15-3	09/02/99	5281.33			
	09/02/99	5280.07		09/20/99	5280.79			
	09/20/99	5279.68		11/09/99	5280.33			
	11/10/99	5279.20		02/28/00	5280.20			
	02/28/00	5279.01						
	06/13/00	5279.98						
NAT12-2	11/18/98	5279.41						

Table 4-2 (continued). Measured Water Table Elevation in Wells at the Naturita Site from
November 1998 to March 2001

Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)
NAT20	09/02/99	5296.64	NAT25 (cont.)	03/01/01	5278.31	NAT30-2 (cont.)	11/09/99	5291.71
	09/20/99	5295.97					02/28/00	5291.70
	11/08/99	5295.12	NAT26	09/02/99	5279.89		06/13/00	5292.44
	02/28/00	5295.18		09/20/99	5279.44	NAT30-3	09/02/99	DRY
	06/13/00	5295.51		11/10/99	5278.97		09/20/99	DRY
	11/28/00	5294.20		02/28/00	5278.79		11/09/99	DRY
	02/28/01	5294.84		06/13/00	5279.74		02/28/00	DRY
				11/29/00	5278.59		06/09/00	DRY
				03/01/01	5278.60			
NAT21-1	09/02/99	5296.66	NAT27-1	09/02/99	5286.04	MAU01	11/19/98	5274.52
	09/20/99	5295.98		09/20/99	5285.40		12/18/98	5274.61
	11/08/99	5295.14		11/09/99	5284.87		01/27/99	5274.60
	02/28/00	5295.20		02/28/00	5284.84		02/24/99	5274.51
	06/13/00	5295.48		06/13/00	5285.77		03/22/99	5274.79
NAT21-2	09/02/99	5296.66		11/28/00	5284.70		05/13/99	5275.78
	09/20/99	5295.98		02/28/01	5284.80		06/07/99	5275.51
	11/08/99	5295.15	NAT27-2	09/02/99	5286.07		09/02/99	5275.31
	02/28/00	5295.22		09/20/99	5285.43		09/20/99	5274.72
	06/13/00	5295.47		11/09/99	5284.92		11/09/99	5274.63
NAT21-3	09/02/99	5296.66		02/28/00	5284.87		02/28/00	5274.59
	09/20/99	5296.01		06/13/00	5285.78		06/13/00	5274.73
	11/08/99	DRY	NAT27-3	09/02/99	DRY	MAU02-1	11/19/98	5274.43
	02/28/00	DRY		09/20/99	DRY		12/18/98	5274.50
	06/09/00	DRY		11/09/99	DRY		01/27/99	5274.49
NAT22-1	09/02/99	5296.63		02/28/00	DRY		02/24/99	5274.38
	09/20/99	5295.97		06/10/00	DRY		03/22/99	5274.72
	11/08/99	5295.11	NAT28-1	09/02/99	5286.06		05/13/99	5275.75
	02/28/00	5295.19		09/20/99	5285.44		06/07/99	5275.45
	06/13/00	5295.45		11/09/99	5284.92		09/02/99	5275.26
NAT22-2	09/02/99	5296.63		02/28/00	5284.87		09/20/99	5274.66
	09/20/99	5295.97		06/13/00	5285.80		11/09/99	5274.55
	11/08/99	5295.12	NAT28-2	09/02/99	5286.06		02/28/00	5274.50
	02/28/00	5295.19		09/20/99	5285.43		06/13/00	5274.61
	06/13/00	5295.46		11/09/99	5284.91	MAU02-2	11/19/98	5274.48
NAT22-3	09/02/99	5296.63		02/28/00	5284.87		12/18/98	5274.57
	09/20/99	5295.95		06/13/00	5285.80		01/27/99	5274.56
	11/08/99	DRY	NAT28-3	09/02/99	DRY		02/24/99	5274.40
	02/28/00	DRY		09/20/99	DRY		03/22/99	5274.77
	06/13/00	DRY		11/09/99	DRY		05/13/99	5275.78
NAT23	09/02/99	5278.44		02/28/00	DRY		06/07/99	5275.47
	09/20/99	5277.85		06/10/00	DRY		09/02/99	5275.30
	11/09/99	5277.53	NAT29	09/02/99	5285.91		09/20/99	5274.69
	02/28/00	5277.38		09/20/99	5285.36		11/09/99	5274.58
	06/13/00	5278.08		11/09/99	5284.87		02/28/00	5274.52
	11/30/00	5277.07		02/28/00	5285.00		06/13/00	5274.71
	02/27/01	5277.10		06/13/00	5285.75	MAU02-3	11/19/98	5274.47
				11/28/00	5284.94		12/18/98	5274.57
				02/28/01	5284.75		01/27/99	5274.56
NAT24	09/02/99	5279.55	NAT30-1	09/02/99	5292.88		02/24/99	5274.43
	09/20/99	5279.06		09/20/99	5292.28		03/22/99	5274.78
	11/09/99	5278.72		11/09/99	5291.66		05/13/99	5275.78
	02/28/00	5278.53		02/28/00	5291.64		06/07/99	5275.47
	06/13/00	5279.41		06/13/00	5292.39		09/02/99	5275.30
	11/30/00	5278.29		11/28/00	5291.02		09/20/99	5274.70
	03/01/01	5278.37		02/28/01	5291.28		11/09/99	5274.58
NAT25	09/02/99	5279.46					02/28/00	5274.52
	09/20/99	5278.99	NAT30-2	09/02/99	5292.93		06/13/00	5274.71
	11/10/99	5278.58		09/20/99	5292.35	MAU03	11/19/98	5271.71
	02/28/00	5278.44					12/18/98	5271.81
	06/13/00	5279.33					01/27/99	5271.80
	11/30/00	5278.27					02/24/99	5271.60

Table 4-2 (continued). Measured Water Table Elevation in Wells at the Naturita Site from November 1998 to March 2001

Well ID	Date	Water Table Elevation (ft above sea level)	Well ID	Date	Water Table Elevation (ft above sea level)
MAU03 (cont.)	03/22/99	5272.05	0547	06/16/86	5295.51
	05/13/99	5272.56	0547 (cont.)	02/24/99	5295.06
	06/07/99	5272.20		03/22/99	5295.15
	09/02/99	5272.34		05/13/99	5296.14
	09/20/99	5271.80		06/07/99	5296.22
	11/09/99	5271.84		09/02/99	5296.63
	02/28/00	5271.82		09/20/99	5295.93
	06/13/00	5271.50		11/09/99	5295.05
	11/30/00	5271.75		02/28/00	5295.12
	03/01/01	5271.85		06/13/00	5295.41
				11/28/00	5294.25
MAU04	11/19/98	5269.58		02/25/01	5294.84
	12/18/98	5269.63	0548	06/17/86	5281.95
	01/27/99	5269.67		02/24/99	5278.41
	02/24/99	5269.56		03/22/99	5279.19
	03/22/99	5269.75		05/13/99	5279.85
	05/13/99	5269.97		06/07/99	5281.70
	06/07/99	5269.75		09/02/99	5279.62
	09/02/99	5269.91		09/20/99	5279.15
	09/20/99	5269.66		11/10/99	5278.72
	11/09/99	5269.75		02/28/00	5278.58
	03/01/01	5269.75		06/13/00	5279.50
	02/28/00	5269.77		11/29/00	5278.48
	06/13/00	5269.35		02/27/01	5278.35
	11/30/00	5269.55	DM1	09/02/99	5298.32
MAU05	11/19/98	5274.37		09/20/99	5297.77
	12/18/98	5274.46		11/10/99	5297.67
	01/27/99	5274.46		02/28/00	5297.83
	02/24/99	5274.33		06/13/00	5297.29
	03/22/99	5274.65		12/01/00	5297.48
	05/13/99	5275.63		03/02/01	5297.90
	06/07/99	5275.34			
	09/02/99	5275.16			
	09/20/99	5274.57			
	11/09/99	5274.47			
	02/28/00	5274.47			
	06/13/00	5274.56			
	11/30/00	5274.18			
	03/01/01	5274.38			
MAU06	09/02/99	5274.22			
	09/20/99	5273.57			
	11/09/99	5273.61			
	02/28/00	5273.60			
	06/13/00	5273.27			
	11/30/00	5273.36			
MAU07	03/01/01	5273.56			
	09/02/99	5269.61			
	09/20/99	5269.22			
	11/09/99	5269.38			
	02/28/00	5269.37			
	06/13/00	5268.82			
MAU08	12/01/00	5269.08			
	03/01/01	5269.47			
	09/02/99	5276.28			
	09/20/99	5275.76			
	11/09/99	5275.62			
	02/28/00	5275.56			
	06/13/00	5275.89			
	11/30/00	5275.34			
	03/01/01	5275.55			

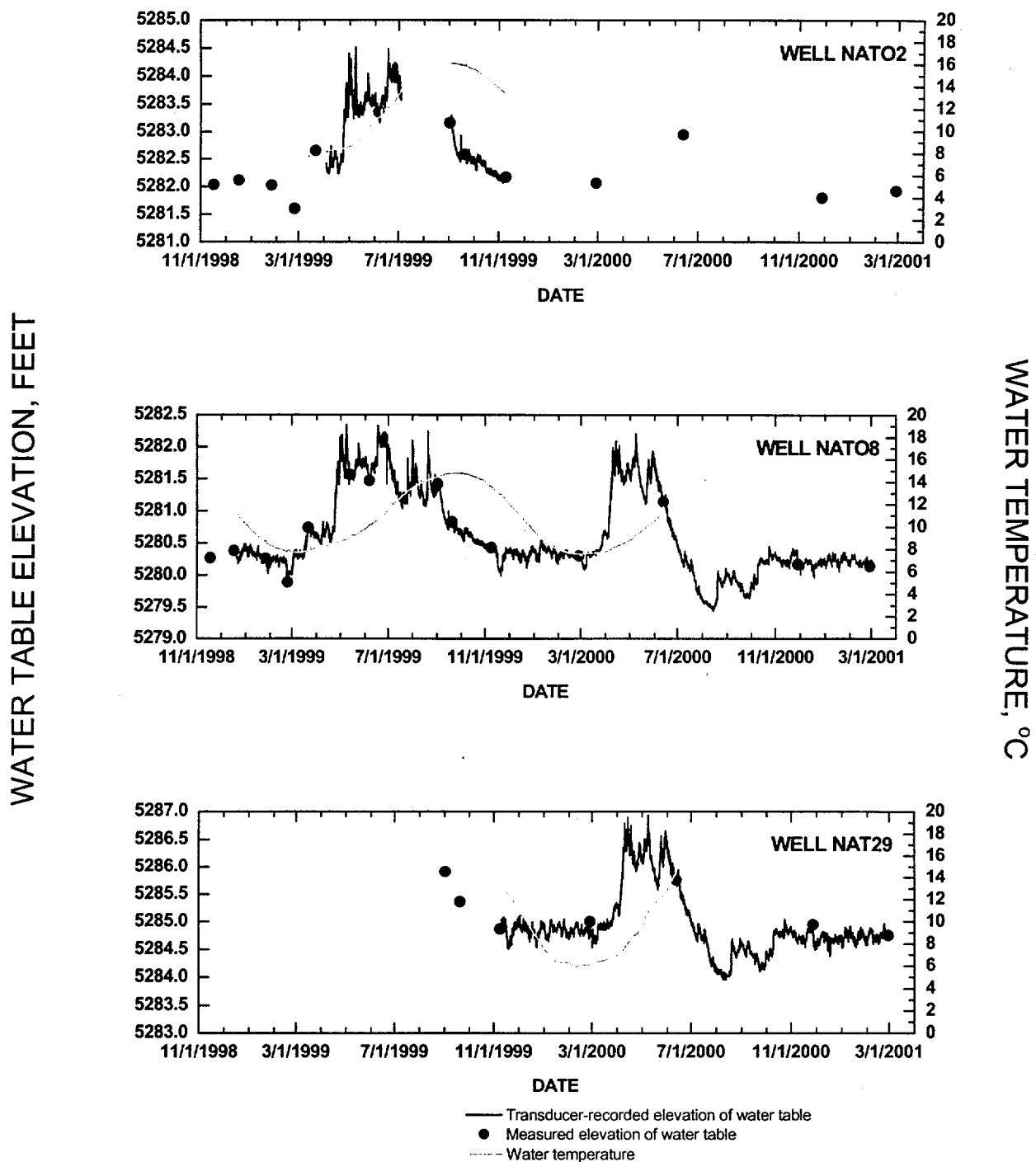
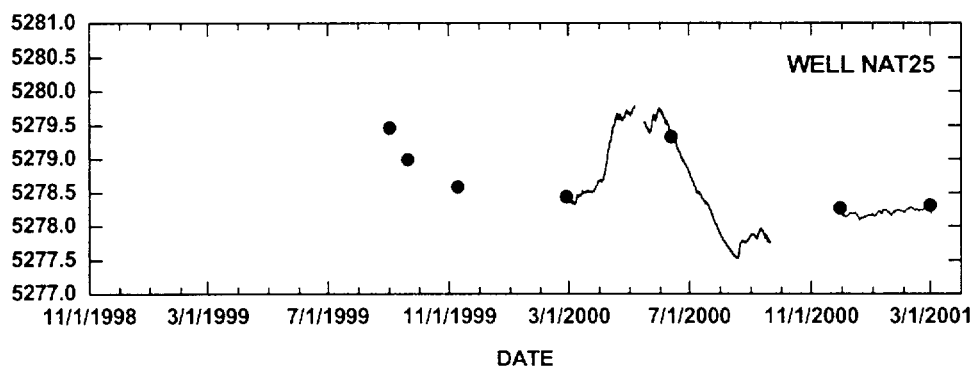
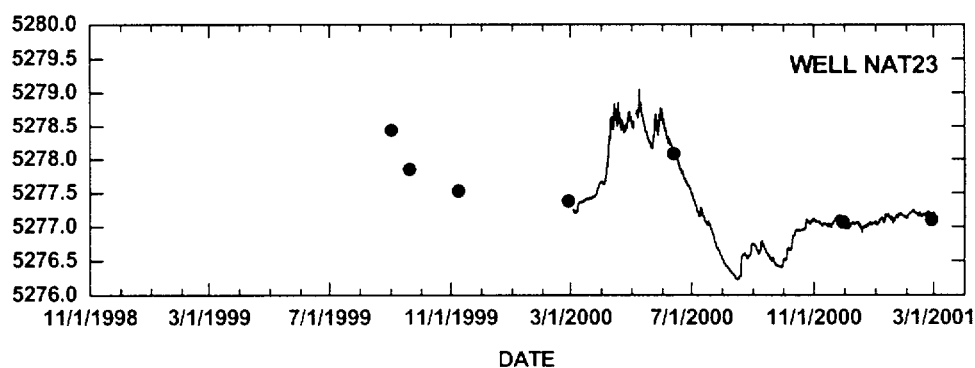
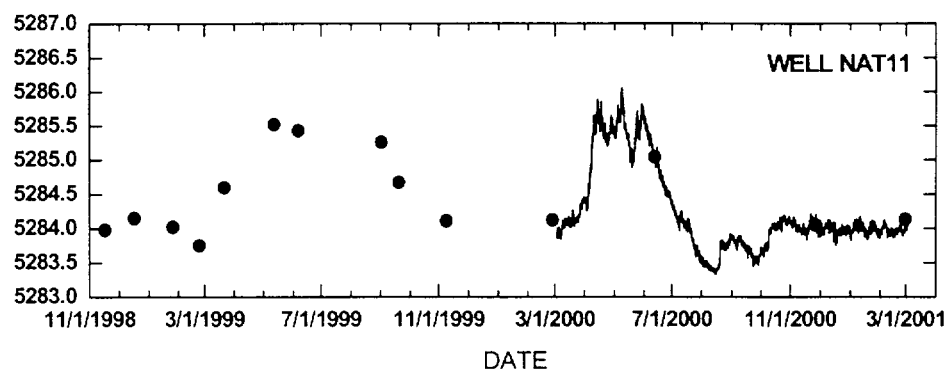


Figure 4-4. Water Level and Water Temperature Recorded in Wells NAT02, NAT08, and NAT29 at the Naturita Site

WATER TABLE ELEVATION, FEET



— Transducer-recorded elevation of water table
● Measured elevation of water table

Figure 4-5. Water Table Elevation for Wells NAT11, NAT23, and NAT25

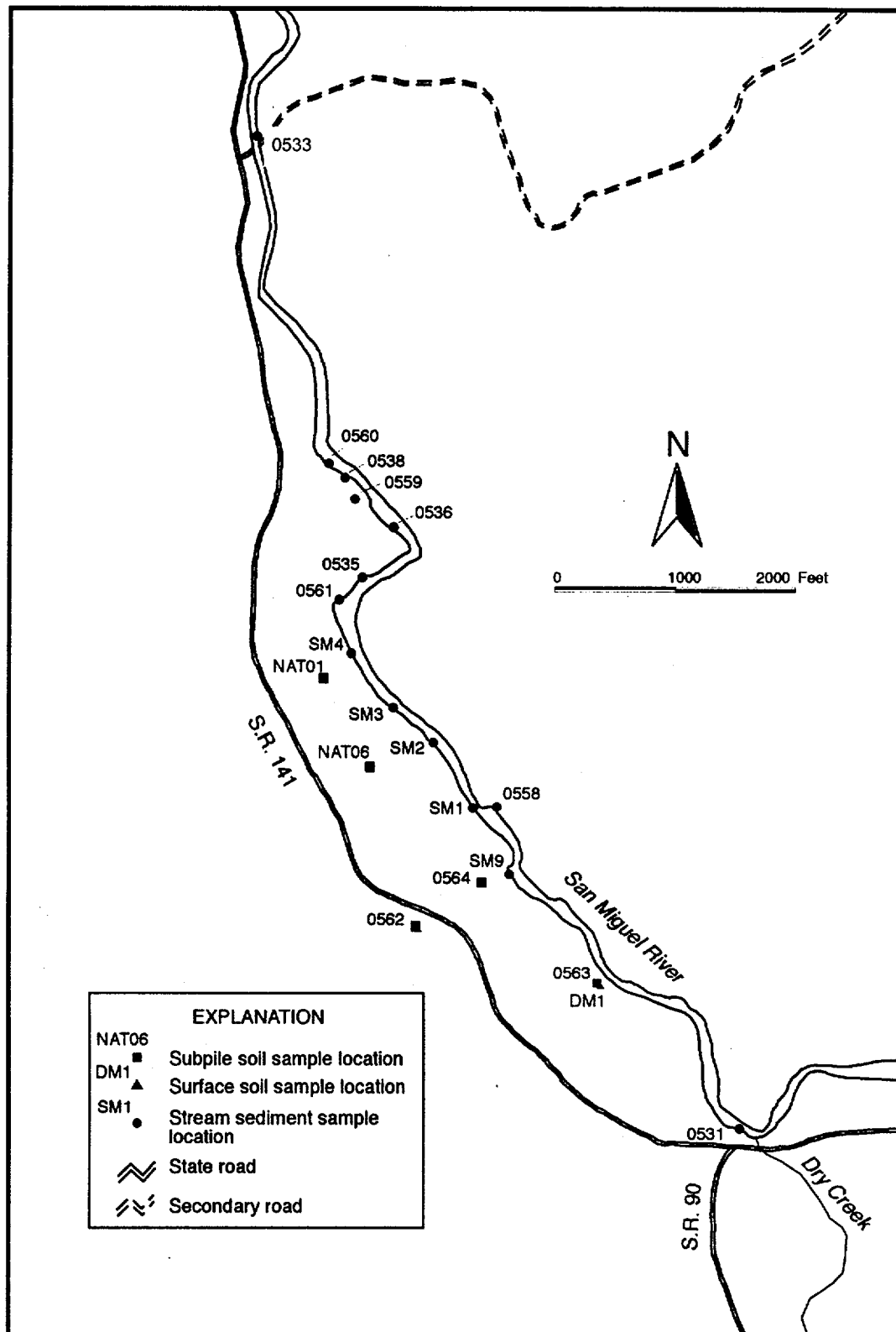


Figure 4-6. Soil and Sediment Sampling Locations

On July 16 and 17, 1998, a background sediment sample was collected from saturated alluvium about half way between well 0547 and well DM1 (Figure 4–6). The sample was screened in the field to remove cobbles larger than about 65 millimeter (mm), and it was estimated visually that about 30 to 50 percent of the material scooped by the backhoe did not pass the 65 mm screen.

Uranium-contaminated material from the saturated zone of the alluvial aquifer was collected from auger flights during installation of monitoring wells in October 1998. The subsurface material was air dried and sieved through 3-mm sieves.

DOE collected additional soil samples in March 2001 with a backhoe. Samples from locations 0564 and 0563 were collected at the water table, which was at a depth of 6 and 5 ft below land surface, respectively. At location 0562, which is southwest of the site and above the alluvial aquifer, the sample was collected from below the fill material at a depth of 2 ft below land surface. This location is a former ore storage area that was remediated under the surface program. Samples were collected from the backhoe bucket and placed in a sealed plastic bag. During excavation, the clean fill that had been emplaced during reclamation was placed in one pile and the native subsurface material in another. When the hole was refilled, the native material was replaced first and clean fill was used to cover it.

Surface composite and stream bottom sediment samples were collected during December 2000 and January 2001. Surface and stream sediment samples were collected with a clean shovel and placed in a sealed plastic bag. Samples were composited from a 10-ft radius at each sample location. Approximately 2.5 pounds of sample were collected at each site.

4.4 Lithologic Logging

Lithologic descriptions of the alluvial material were recorded from drill cuttings during installation of monitoring wells NAT13 through NAT30, DM1, MAU07, and MAU08 in June 1999. No attempt was made at split barrel sampling due to the difficulty in retrieving unconsolidated silt, sand, and gravel. No attempt was made at lithologically logging the underlying Salt Wash Member of the Morrison Formation. Appendix A presents the lithologic well logs recorded by the site geologist.

4.5 Distribution Coefficient (K_d) Analysis

The K_d is a bulk parameter that has been used with some success to describe the retardation of contaminant movement in an aquifer system. Laboratory measurements to estimate the K_d for selected analytes were performed on alluvial material to support computer-modeling efforts in characterizing subsurface contaminant transport at the Naturita site. The analysis presented here was performed by the Grand Junction Office (GJO) Environmental Sciences Laboratory according to standard procedures used at UMTRA Ground Water Project sites (DOE 1999b). Analyses using a somewhat different methodology were also performed by the USGS; these are presented in Appendix E.

4.5.1 Method of Solution

Laboratory analyses were performed according to procedure MAC 3017 (DOE 1999b), which is slightly modified from American Society for Testing and Materials (ASTM) procedure D 4646–87 (ASTM 1993), for two site-related contaminants of potential concern (COPCs): uranium and vanadium. This procedure is a 24-hour test and obtains a parameter that is an estimate of the

K_d —the distribution ratio (R_d). K_d and R_d are defined identically, though K_d s are considered to be equilibrium values and R_d s may or may not represent equilibrium. R_d is one of the most commonly used estimates for the K_d .

The procedure involves placing a sample representative of a location (e.g., soil, sediments, cuttings, core) into a solution representative of contaminated ground water with which the material is likely to come in contact. The ground water solution is agitated for 24 hours and then centrifuged. The supernatant solution is analyzed and compared to the contaminant concentrations of the original solution. The difference between the two is assumed to be adsorbed to the sample. The linear adsorption isotherm distribution coefficient is generally defined as

$$C_{\text{soil}} = K_d \times C_{\text{water}}, \text{ which can be rearranged to } K_d = C_{\text{soil}}/C_{\text{water}},$$

or the ratio of the concentration of the contaminant in soil (or other material of interest) to the concentration of the contaminant in water at equilibrium. Therefore, the higher the K_d , the greater the retardation of contaminant movement in ground water.

The procedure requires analysis of only the solutions (and no actual soil samples) used in the experiments. Site samples collected from background areas or uncontaminated site samples are generally used, and all contaminant loss in the final solution is attributed to sample adsorption.

4.5.1.1 Sample Selection

A sample of background alluvial material (>5 kilograms [kg]) was collected above the water table approximately 30 ft west of background well DM1 (Figure 4–6) on August 22, 2001. The sample was considered uncontaminated because concentrations of dissolved uranium in water samples from well DM1 (and decommissioned DOE wells nearby) were always near the background uranium concentrations in the San Miguel River. The background sample of alluvium was screened in the field to remove cobbles larger than about 65 mm, and it was visually estimated that about 50 percent of the material scooped by the backhoe did not pass the 65-mm screen.

4.5.1.2 Sample Preparation and Processing

The sample was air dried at room temperature. The greater than 6.6-mm fraction was removed based on visual examination. The remainder of the sample was sieved to separate the <2 mm fraction. Of the sample submitted for laboratory analysis, approximately 51 percent of the grain size was <2 mm, 15 percent was between 6.6 mm and 2 mm, and the remaining 34 percent was >6.6 mm.

A 2.5 liter (L) sample of San Miguel River water was collected for use in the K_d determinations. Because the San Miguel River is the primary source of recharge for the alluvial aquifer, it is assumed that river water upgradient of the site is representative of uncontaminated alluvial aquifer water. The water sample was filtered through a 0.45 micrometer (μm) filter and refrigerated until ready for use. An aliquot of the San Miguel River sample was spiked with vanadium and uranium to produce a 1 mg/L concentration of each. Three spiked water samples were retained as control samples—one sample was simply refrigerated before analysis; the other two were processed in the same manner as the samples for K_d determinations but without inclusion of soil.

To prepare samples for K_d analysis, 8 samples of soil ranging from 0.5 g to 30 gram (g) were each placed in 125-milliliter (mL) Nalgene bottles; 100 mL of spiked water was added to each sample. These samples, along with the two spiked water samples without soil, were placed on a rotating stir bar (8 revolutions per minute [rpm]) for 24 hours. Samples were then removed from the stir bar, centrifuged, filtered through a 0.45 μ m filter, and acidified before submission to the Analytical Chemistry Laboratory for uranium and vanadium analysis. Unprocessed water samples were also analyzed as control samples.

4.5.1.3 Sample Results

Analytical results are presented in Tables 4–3 and 4–4. Table 4–3 contains results of the control sample analysis. Results indicate that only minor amounts of uranium and vanadium occur in San Miguel River water. Little difference exists between processed and unprocessed spiked samples; concentrations of uranium and vanadium in sample NAT-DM1-B1 were determined to be suitable for use as initial concentrations for purposes of performing K_d calculations.

Table 4–3. Laboratory Analytical Results for Control Water Samples

Sample ID	Sample Description	Solution Volume (mL)	Target Concentration (mg/L)		Analyzed Concentration (mg/L)	
			U	V	U	V
NAT-DM1-R	Unprocessed San Miguel River (SMR) water—no spikes	100	na	na	0.0024	0.0061
NAT-DM1-P	Unprocessed SMR with spikes	100	1.0	1.0	0.913	0.971
NAT-DM1-B1*	Processed spiked SMR water	100	na	na	0.91	0.98
NAT-BM1-B2	Processed spiked SMR water	100	na	na	0.925	0.982

*Used for initial concentrations

na = not applicable

Note: initial pH of spiked SMR sample was 6.94; alkalinity was 110 mg/L CaCO_3

Table 4–4 presents the analyses of final solutions contacted with differing masses of site soils. Based on the volume and concentration of water samples used, the mass of sorbed uranium and vanadium was calculated for each sample.

Table 4–4. Analytical Results for Soil-Contacted Solutions

Sample ID	Solution Volume (mL)	Sample Mass (g)	Final Solution Concentration (mg/L)		Mass Sorbed (mg)	
			U	V	U	V
NAT-DM1-0.5	100	0.5	0.89	0.9	0.002	0.008
NAT-DM1-1.0	100	1.0	0.885	0.781	0.0025	0.0199
NAT-DM1-2.5	100	2.5	0.861	0.568	0.0049	0.0412
NAT-DM1-5	100	5.0	0.808	0.327	0.0102	0.0653
NAT-DM1-10	100	10.0	0.746	0.149	0.0164	0.0831
NAT-DM1-20	100	20.0	0.66	0.0627	0.025	0.09173
NAT-DM1-25	100	25.0	0.643	0.0496	0.0267	0.09304
NAT-DM1-30	100	30.0	0.616	0.038	0.0294	0.0942

4.5.1.4 R_d Calculation

R_d s are calculated using the analytical data summarized in Table 4-4 and the equation:

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

where

- A = total initial concentration (mg/L) of the COPCs in the test solution,
- B = final concentration of the COPCs in the solution after 24 hours in contact with the soil sample (mg/L),
- V = volume of solution (mL),
- M_s = mass of soil sample (grams), and
- R_d = distribution ratio (milliliters per gram [mL/g]).

Results of the calculations are presented in Table 4-5.

Table 4-5. Results of R_d Calculations

Sample ID	SampleMass (g)	R_d —Uranium mL/g	R_d —Vanadium mL/g
NAT-DM1-0.5	0.5	4.49	17.78
NAT-DM1-1.0	1.0	2.82	25.48
NAT-DM1-2.5	2.5	2.28	29.01
NAT-DM1-5	5.0	2.52	39.94
NAT-DM1-10	10.0	2.20	55.77
NAT-DM1-20	20.0	1.89	73.15
NAT-DM1-25	25.0	1.66	75.03
NAT-DM1-30	30.0	1.59	82.63

Results of the R_d calculations show considerable variation, particularly for vanadium. The variation appears to be, in part, correlated with mass of soil used in the procedure. Higher R_d values were obtained with smaller soil masses for uranium; the opposite relationship is noted for vanadium. Results are generally consistent with those obtained at other UMTRA Ground Water Project sites. Uranium typically has a higher mobility than vanadium and is found over a greater areal extent; vanadium plumes are normally more confined. At the Naturita site, the uranium plume extends off site for a considerable distance downgradient; elevated concentration of vanadium are restricted to the site itself (see Section 5.3.3.2 for further discussion).

Because the procedure for estimating K_d values uses only the <2 mm fraction, it is likely that the K_d s overestimate adsorptive properties of the entire aquifer system (Kaplan and others 2000; EPA 1999b). A common way of modifying the values to account for this is to assume that the >2 mm fraction has a K_d of 0 and to adjust the values proportionally. For the Naturita site, it was noted that approximately 50 percent of the alluvial material collected for analysis was greater than 2 mm in size; therefore, a more realistic estimate of K_d s for the site may be considerably less than the calculated R_d values. The major quantitative use for the K_d estimates is in the ground water fate and transport modeling. To account for uncertainty in K_d estimates, a stochastic model was used that incorporates a range of K_d values.

4.6 Soil and Sediment Analysis

All radioactive tailings were removed from the Naturita site during 1977 to 1979. Contaminated soils and surface materials were removed from the site in 1997, and the excavated areas were backfilled with clean, clay-sized material. At that point, no radioactive materials were left. However, it is possible that contaminants have leached into the soils below the depth of remediation. These soils could contaminate infiltrating ground water and prolong the cleanup effort.

4.6.1 Subpile Soil Sample Selection

Samples were collected from two boreholes drilled in October 1998 and from three DOE excavations in March 2001. Section 4.3 describes the sample collection methods. Uranium-contaminated borehole samples from wells NAT01 and NAT06 were collected in the area of the former tailings pile. Location 0562 is in an old ore storage location; 0563 represents an upgradient background site; and 0564 is in the former mill yard area. Figure 4–6 shows these sampling locations.

4.6.2 Surface Soil and Sediment Sample Selection

Surface soil samples were collected from two locations to verify complete removal of contaminated material from the site. The samples were collected from a former ore storage area at location 0562 and from an off-site location within a 10-ft radius of well DM1 to represent background (location 0563). Because the alluvial aquifer at the site discharges to the San Miguel River, it is important to characterize any potential for contamination to the river. Therefore, stream sediment samples were collected near the riverbank at locations 0531, SM9, 0558, SM1, SM2, SM3, SM4, 0561, 0535, 0536, 0560, and 0533. Sediment samples were also collected from a ground water seep in an abandoned river channel near the San Miguel River at sites 0538 and 0559 (Figure 4–6).

4.6.3 Sediment and Soil Sample Preparation and Extraction

Chemical extractions were used to evaluate the potential leachable amount of contaminants present. Each sample was extracted using a 5 percent nitric acid solution. The acid solution is used to remove most amorphous oxides that most likely contain adsorbed contaminants. The solution will not remove contaminants locked in recalcitrant minerals such as apatites or other heavy mineral grains. The acid treatment also dissolves carbonate minerals and releases any adsorbed cations.

The following extraction procedure was used at the USGS lab in Menlo Park:

1. Air dry the sample (no oven heat).
2. If desired, sieve the sample. Samples are usually sieved to less than 2 mm because sieved samples are easier to work with; also, because the contamination is more concentrated in the finer fractions, the sieved samples provide a more sensitive indicator of the contamination.
3. Place $2 \text{ g} \pm 10 \text{ mg}$ of soil in a centrifuge tube (or divide evenly between two 50-mL centrifuge tubes; use a riffle splitter so that both splits are equivalent).

4. Place 100 mL (or 50 mL in each of the 50-mL tubes) of the test solution (e.g., 5 percent nitric acid) in the centrifuge tube.
5. Agitate end over end for 4 hours \pm 20 minutes.
6. Remove the tubes from the shaker and centrifuge for sufficient time to settle most of the 2 μ m particles (about 30 minutes at 3,000 rpm).
7. Decant into a 200-mL volumetric flask.
8. Add a second 100-mL portion of test solution to the residue.
9. Agitate end over end for 30 \pm 5 minutes.
10. Remove the tubes from the shaker and centrifuge for sufficient time to settle most of the 2 μ m particles (about 30 minutes at 3,000 rpm).
11. Decant into the same 200-mL volumetric flask (step 7).
12. Fill to volume with test solution.
13. Filter the 200-mL decantate through a 0.45 μ m filter.
14. Measure pH and oxidation-reduction potential.
15. Preserve as needed and submit for chemical analysis.
16. Calculate the soil concentration in milligrams per kilogram (mg/kg) from the concentration in the decantate:

$$\frac{200 \text{ mL solution}}{2 \text{ g soil}} \times \frac{\mu\text{g decantate}}{\text{L}} \times \frac{\text{L}}{1,000 \text{ mL}} \times \frac{\text{mg}}{1,000 \mu\text{g}} \times \frac{1,000 \text{ g}}{\text{kg}} = \text{mg/kg}$$

4.6.4 Stream and Seep Sediment Concentration Results

Table 4–6 shows a summary of contaminant concentrations from stream sediment and ground water seep sediment samples collected at the Naturita site in November and December 2000. Figure 4–7 through Figure 4–12 show concentrations of arsenic, cadmium, molybdenum, selenium, uranium, and vanadium, respectively, in these sediments. Appendix D presents analytical results of the constituents measured in the samples and in one blank extraction.

4.6.4.1 Arsenic in Sediments

Concentrations of arsenic shown in Figure 4–7 are at or near background concentrations measured at location 0531. Concentrations from all samples are below the common range of soil concentrations cited by Rose, Hawkes, and Webb (1979). This suggests that there has been no transport of arsenic surficially or by ground water to the stream sediments.

4.6.4.2 Cadmium in Sediments

Figure 4–8 shows that concentrations of cadmium in the stream sediment samples were generally elevated over the background level measured at location 0531. Concentrations at the sample locations were also higher than the range commonly found in soils (Rose, Hawkes, and Webb 1979). Sediments and samples collected from the ground water seep area have concentrations that are in the normal range and near background for stream sediment. Surface soil collected at background location 0563 had the highest concentration of cadmium measured, and the concentration in the subpile soil was very close to the detection limit. No cadmium was detected at any subpile soil sampling location. The elevated cadmium concentrations in the stream sediment samples may be due to windborne transport or surface runoff from the former tailings pile.

Table 4-6. Mass of Contaminant Extractable by 5 percent Nitric Acid Solution per Mass of Sediment

Sample Site	Sample type	Location	As (mg/kg)	Cd (mg/kg)	Fe (mg/kg)	Mo (mg/kg)	Mn (mg/kg)	Se (mg/kg)	U (mg/kg)	V (mg/kg)
0531	stream sediment	Upgradient Samples San Miguel River	1.83	0.56	2,307	<0.40	367	0.18	0.53	6.56
		On-Site Samples								
0538	stream sediment	ground water seep	2.60	0.62	1,921	1.51	721	0.14	8.90	9.54
0559	stream sediment	ground water seep	2.83	0.53	1,532	2.19	278	0.14	12.50	7.94
0535	stream sediment	San Miguel River	1.80	0.62	2,104	0.78	413	0.19	0.67	5.96
0536	stream sediment	San Miguel River	1.91	0.65	3,004	0.74	389	0.24	0.80	5.20
0558	stream sediment	San Miguel River	1.87	0.47	2,699	0.76	278	0.23	1.27	6.11
0560	stream sediment	San Miguel River (main channel)	1.94	0.60	3,519	0.62	479	0.26	2.27	5.97
0561	stream sediment	San Miguel River	2.01	0.60	2,514	0.70	428	0.21	1.45	7.06
SM1	stream sediment	San Miguel River	1.27	0.75	2,541	0.47	291	0.26	0.76	1.22
SM2	stream sediment	San Miguel River	1.66	0.88	3,256	0.55	341	0.27	1.78	1.70
SM3	stream sediment	San Miguel River	2.15	1.13	2,608	0.50	372	0.23	0.77	1.74
SM4	stream sediment	San Miguel River	1.60	0.85	2,899	0.45	357	0.25	0.80	0.77
SM9	stream sediment	San Miguel River	1.98	1.07	3,186	0.60	427	0.26	0.82	0.44
		Downgradient Samples								
0533	stream sediment	San Miguel River	2.14	0.70	3,148	0.54	498	0.24	1.00	5.26

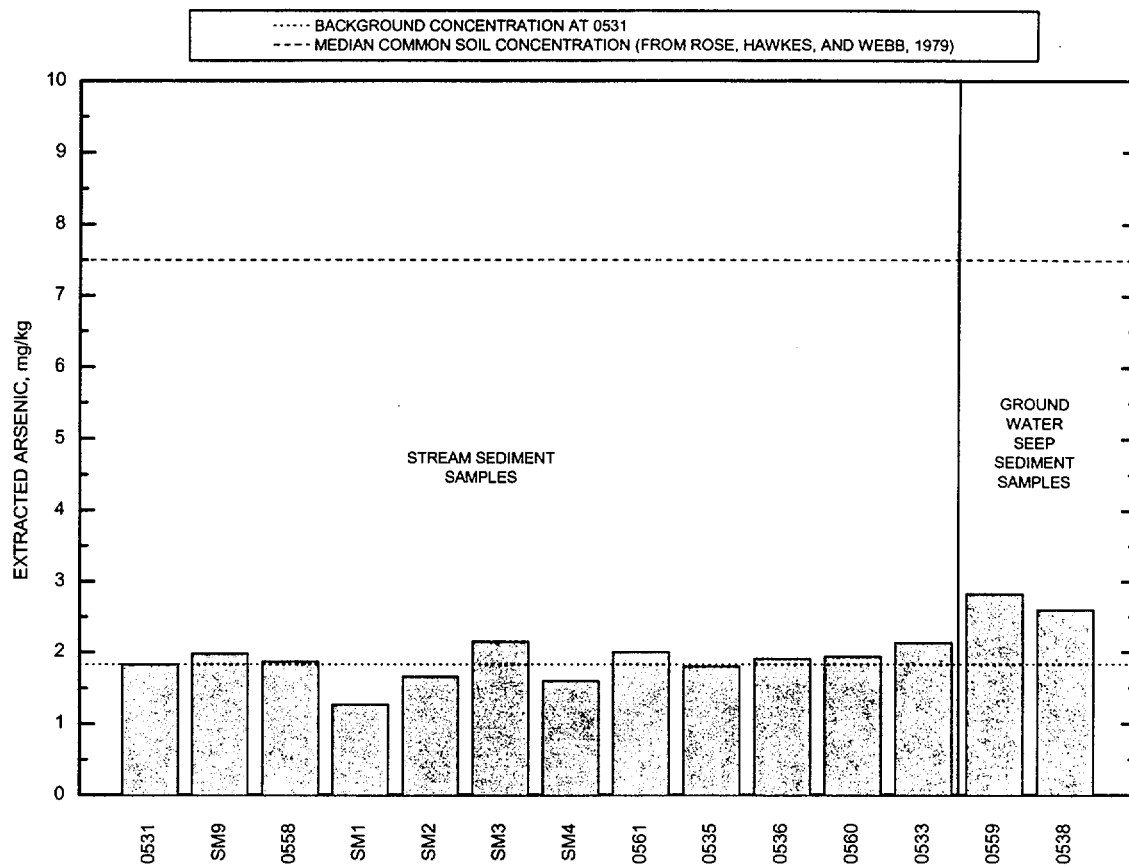


Figure 4-7. Arsenic Concentrations in Sediment

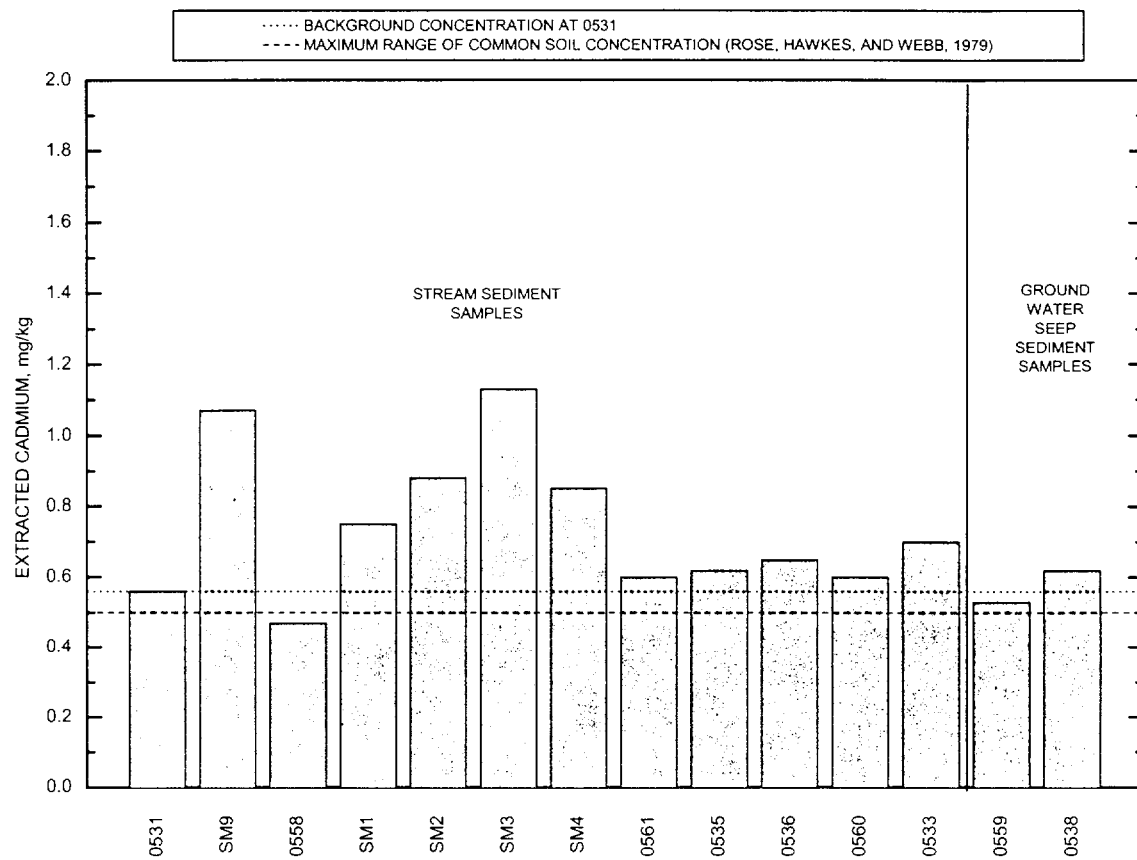


Figure 4-8. Cadmium Concentrations in Sediment

4.6.4.3 Molybdenum in Sediments

Concentrations of molybdenum (Figure 4–9) were all above the background value measured at location 0531 (concentration was below detection limit at 0531). However, concentrations were all lower than those in typical soils (Rose, Hawkes, and Webb 1979). The highest concentrations were in samples from the ground water seep sediments. This suggests a small amount of molybdenum may be transported by the alluvial aquifer, but very little is being retained by the sediments, making them an insignificant source of contamination.

4.6.4.4 Selenium in Sediments

As shown in Figure 4–10, selenium concentrations in all stream sediment samples were slightly elevated above the background concentration measured at location 0531. Concentrations in sediment from the ground water seep area were below background concentrations, and concentrations at all locations were lower than those in typical soils (Rose, Hawkes, and Webb 1979). This suggests that no site-related selenium is in the stream sediments.

4.6.4.5 Uranium in Sediments

Uranium concentrations in all samples of stream sediment and ground water seep sediment were elevated over those measured at background location 0531 (Figure 4–11). Samples from locations 0558, SM2, 0561, and 0560 all had uranium concentrations greater than typical soil concentrations (Rose, Hawkes, and Webb 1979). The highest concentrations were in the ground water seep sediments. Concentrations in the seep sediment samples were approximately 17 to 24 times greater than those measured in the upgradient stream sediment background sample. Because this is a low-lying area of the river floodplain, the potential exists for these contaminated sediments to be transported downstream during flooding.

4.6.4.6 Vanadium in Sediments

Concentrations of vanadium shown in Figure 4–12 are all near or below the background value measured at location 0531. Concentrations are also much lower than those in typical soils (Rose, Hawkes, and Webb 1979). This suggests that there is no site-related contamination from vanadium in stream sediments or surface soils.

4.6.5 Surface and Subpile Soil Concentration Results

Table 4–7 shows a summary of contaminant concentrations from surface and subpile soil samples collected at the Naturita site. Figure 4–13 through Figure 4–16 show concentrations of arsenic, selenium, uranium, and vanadium, respectively, in these soils. Appendix D presents a complete listing of the constituents measured in the samples and in one blank extraction.

4.6.5.1 Arsenic in Surface and Subpile Soils

With the exception of samples NAT01 and NAT06, which were collected in the area of the former tailings pile, all arsenic concentrations in soil were below the background value measured at location 0563 (Figure 4–13). No surficial arsenic contamination appears to be present at background location 0563 or in the former ore storage area at location 0562. Arsenic concentration in a sample from location 0564, which is in the former mill yard area, was lower than the background level. Concentrations in samples from NAT01 and NAT06 were only

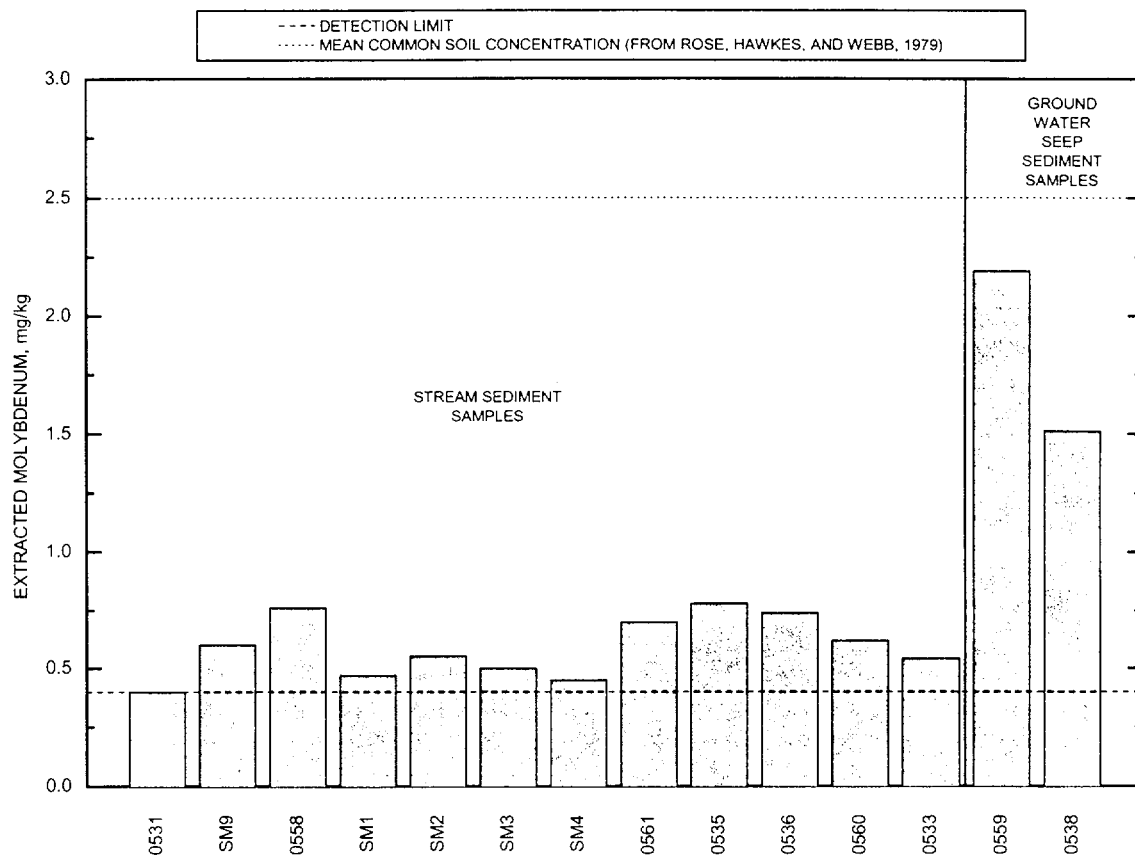


Figure 4-9. Molybdenum Concentrations in Sediment

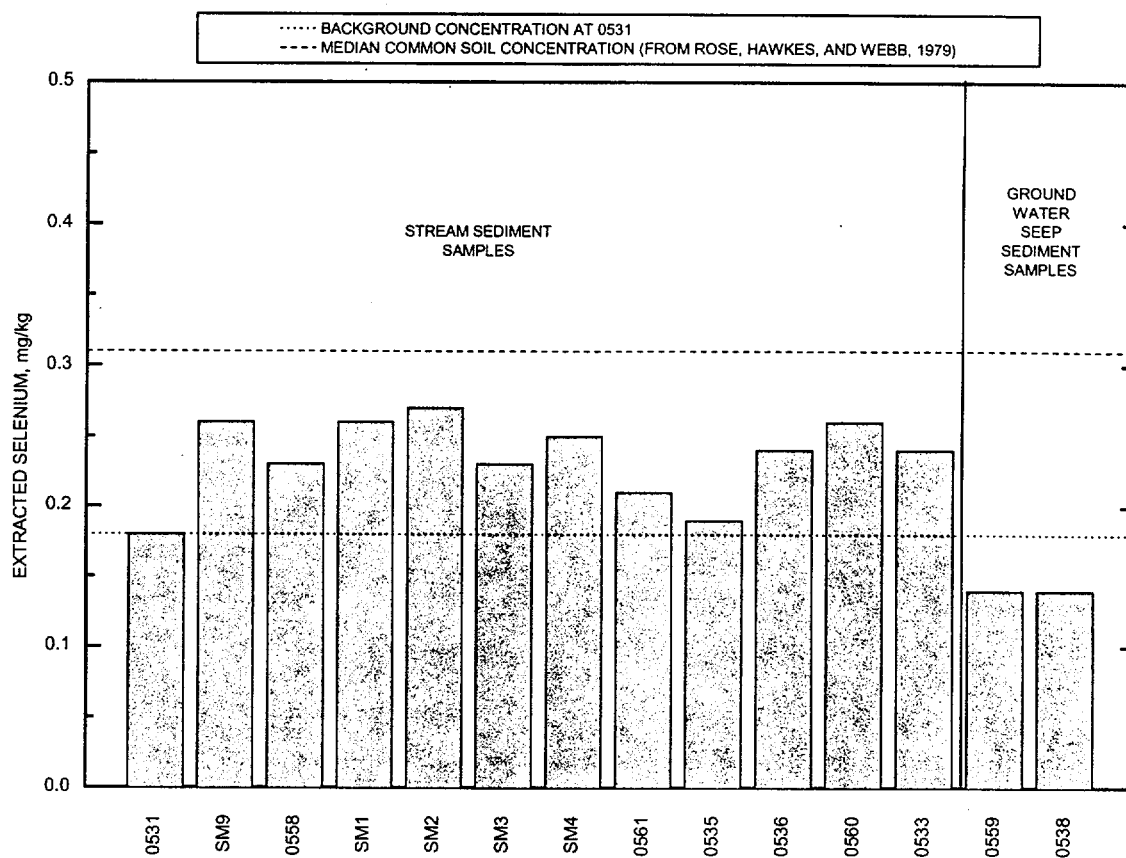


Figure 4-10. Selenium Concentrations in Sediment

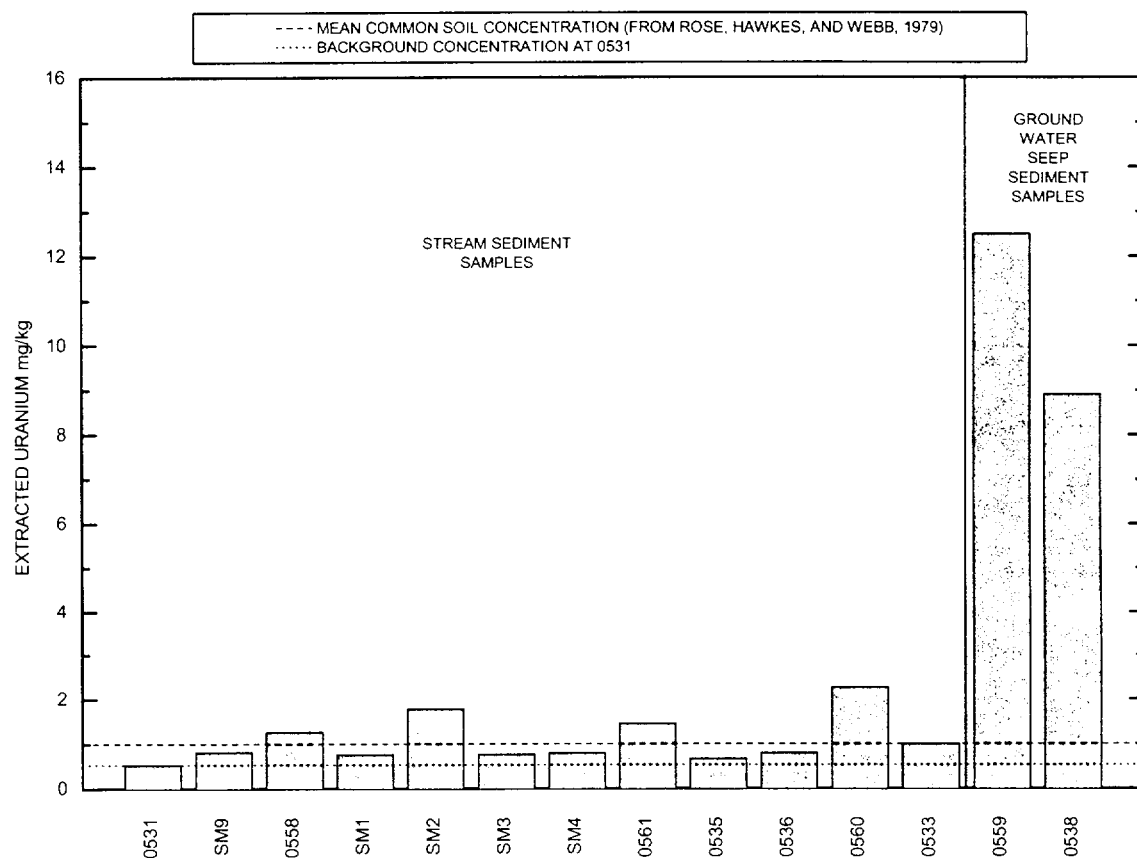


Figure 4-11. Uranium Concentrations in Sediment

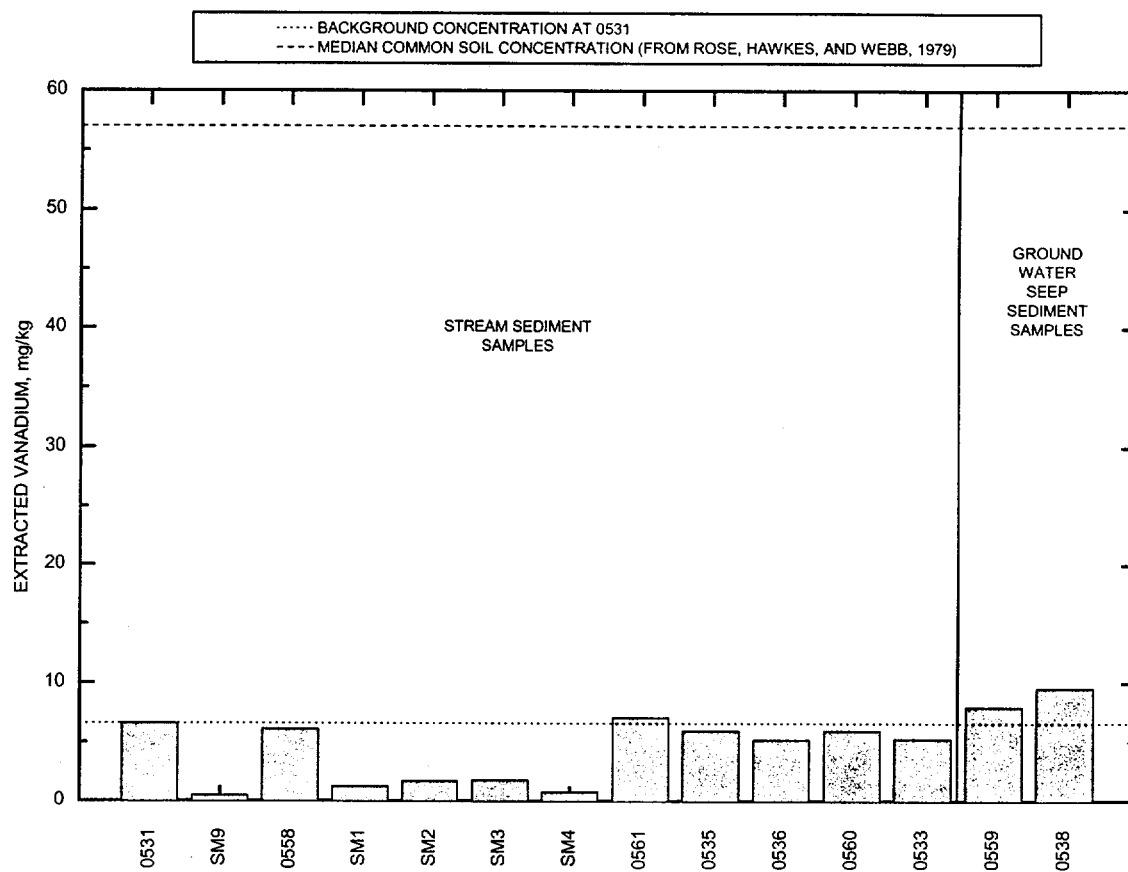


Figure 4-12. Vanadium Concentrations in Sediment

Table 4-7. Mass of Contamination Extraction by 5 Percent Nitric Acid Solution per Mass of Soil

Sample Site	Sample type	Location	As (mg/kg)	Cd (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Mo (mg/kg)	Se (mg/kg)	U (mg/kg)	V (mg/kg)
		Upgradient Samples								
DM1	surface soil	background soil	3.19	1.66	1,535	427	0.49	0.21	3.23	9.28
0563	subpile soil	background soil near DM1	18.9	0.44	1,415	195	<0.4	1.40	1.00	6.05
		On-Site Samples								
0562	surface soil	former ore storage area	0.52	<.40	410	224	1.21	0.20	3.30	9.74
0562	subpile soil	former ore storage area	4.50	<0.40	310	285	<0.4	5.80	0.34	1.76
0564	subpile soil	former mill yard area	8.70	<0.40	1,198	361	<0.4	1.30	1.28	8.37
NAT01	subpile soil	former tailings area	20.9	<0.40	1,874	259	<0.4	1.80	6.02	5.35
NAT06	subpile soil	former tailings area	24.0	<0.40	2,071	117	<0.4	5.70	6.50	412

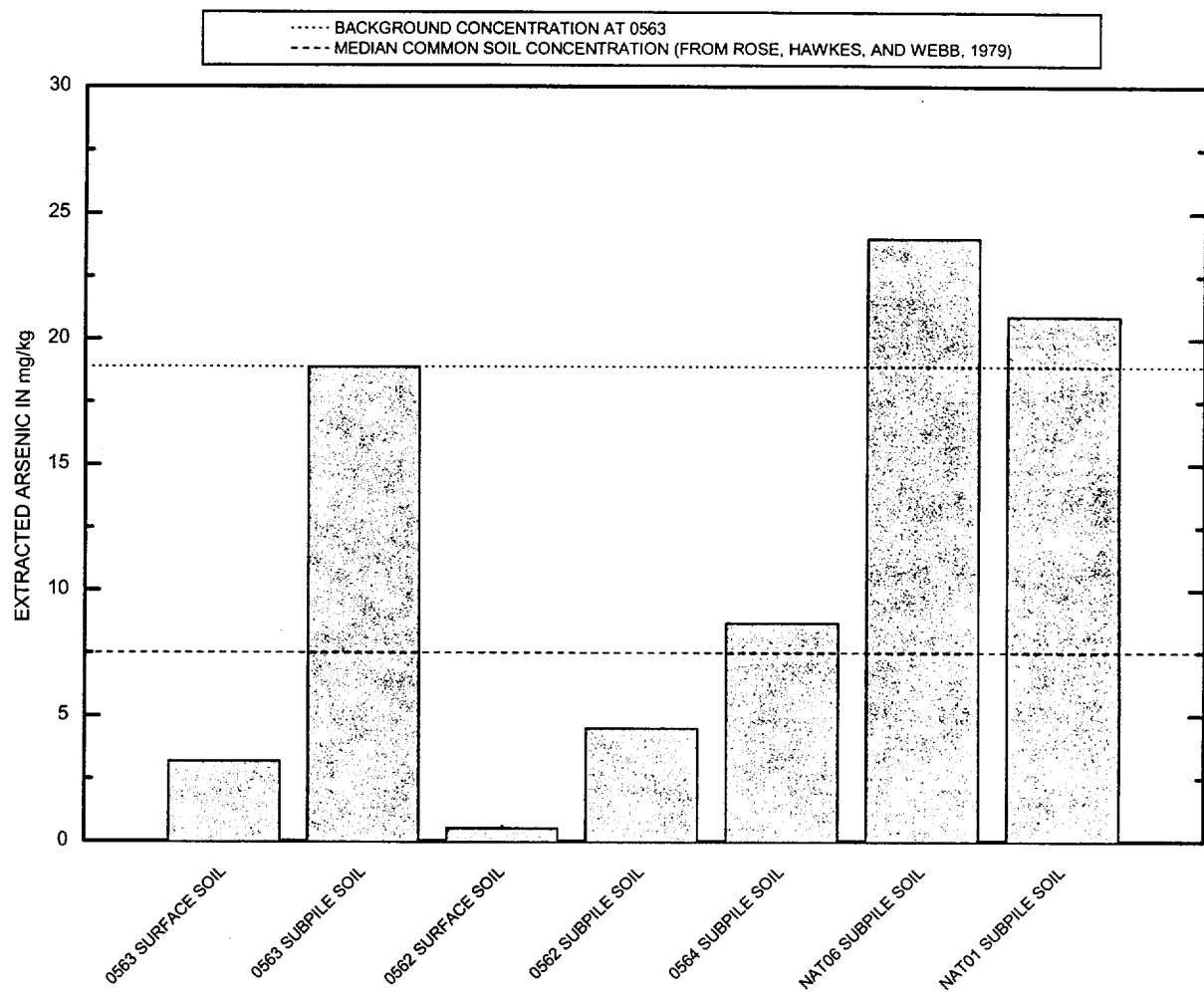


Figure 4-13. Arsenic Concentrations in Surface and Subpile Soil Samples

slightly higher than background values, and any future contamination from those sources would be difficult to distinguish from the natural background concentration.

4.6.5.2 Cadmium in Surface and Subpile Soils

Measurable cadmium was only detected in soil samples from locations DM1 and 0563 (Table 4–7). The subpile concentration was very close to the detection limit, but the surface concentration was almost four times greater. Although no cadmium was measured in any other soil sample, it was detected in most stream sediment samples (Section 4.6.4.2). This suggests that cadmium was transported to the river and location 0563 by wind or surface runoff.

4.6.5.3 Molybdenum in Surface and Subpile Soils

No molybdenum was detected in any of the subpile soil samples collected at the Naturita site (Table 4–7). The two surface soil samples at locations 0562 and DM1 had concentrations of 0.49 and 1.21 mg/kg molybdenum, respectively. These concentrations are in the range of average soil abundance cited by Rose, Hawkes, and Webb (1979).

4.6.5.4 Selenium in Surface and Subpile Soils

Selenium concentrations in all subpile soil samples depicted in Figure 4–14 are 4 to 18 times greater than the median typical soil concentration (Rose, Hawkes, and Webb 1979). Concentrations at locations 0562, NAT01, and NAT06 are all elevated over the background concentrations measured at location 0563. Location 0562 is not connected to the alluvial aquifer, and contaminants in soil at that location do not pose a significant future threat to ground water. Samples from location NAT01 had selenium levels that were only slightly elevated over the background concentration. Location NAT06 is in the area of the former tailings pile and has the highest concentration of selenium of any of the alluvial aquifer subpile soils. However, due to the reducing conditions of the ground water at this location, it is believed that most of the selenium will remain adsorbed to the sediments. Increased flushing of the alluvial aquifer could change the oxidation-reduction potential of the ground water and potentially desorb selenium from sediments near well NAT06.

4.6.5.5 Uranium in Surface and Subpile Soils

Concentrations of uranium in surface soil at background location 0563 and the former ore storage area at 0562 are approximately the same and are elevated over the background level at location 0563 (Figure 4–15). The fact that both values are elevated over those of their respective subpile soil analyses suggests some degree of windborne contamination. Location 0564, which is in the area of the former mill yard (Table 4–7), has only slightly higher concentrations of uranium than that measured in the background sample. Samples taken at NAT01 and NAT06 in the area of the former tailings pile have the highest concentrations of uranium. This indicates that significant leachable uranium is still present in subpile soils and could represent a future source of uranium contamination.

4.6.5.6 Vanadium in Surface and Subpile Soils

The subpile soil sample collected at well NAT06 had a significantly higher concentration of vanadium than any other sampled location at the Naturita site (Figure 4–16). Samples from all locations except NAT06 had vanadium concentrations that were at or near the background

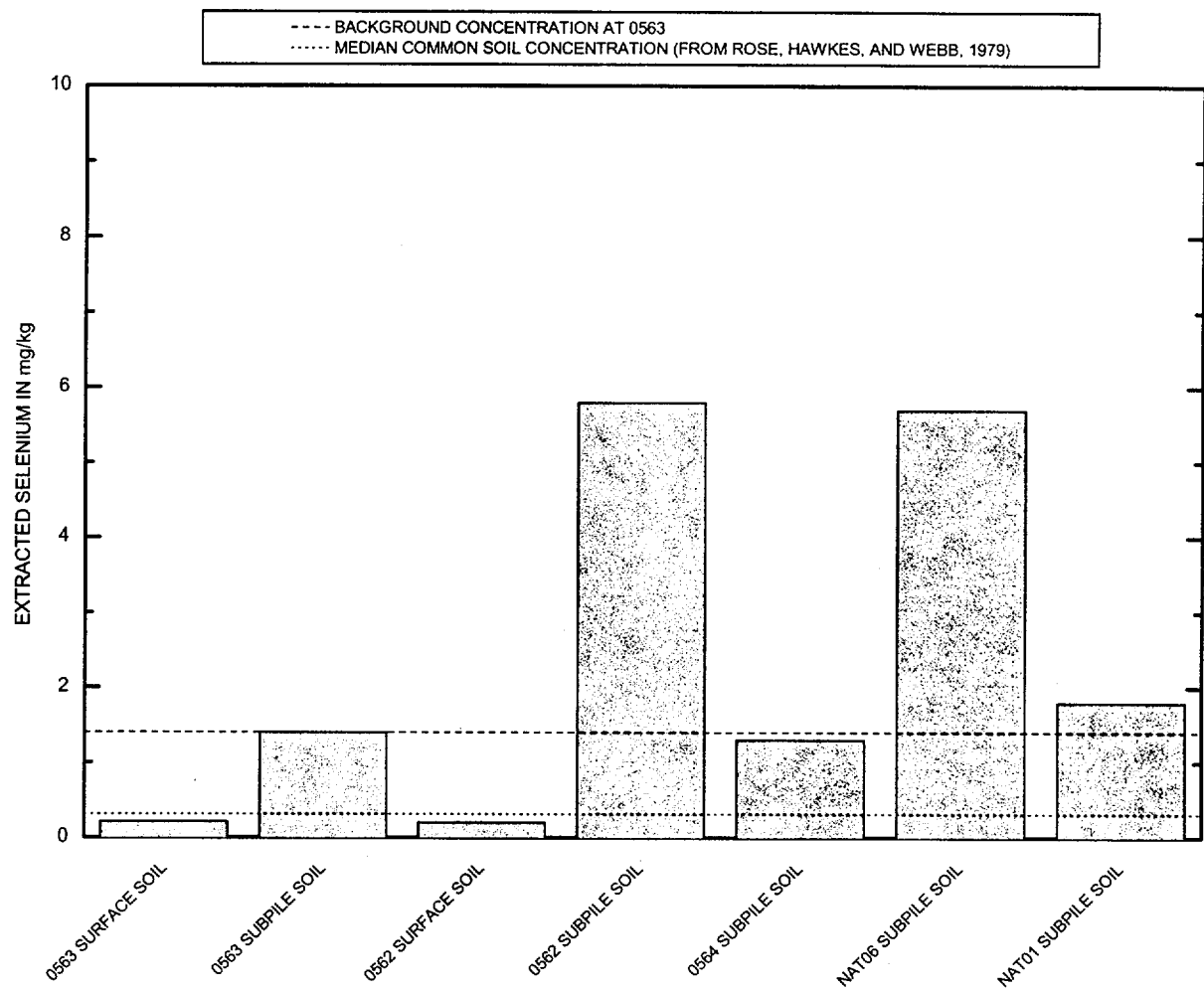


Figure 4-14. Selenium Concentrations in Surface and Subpile Soil Samples

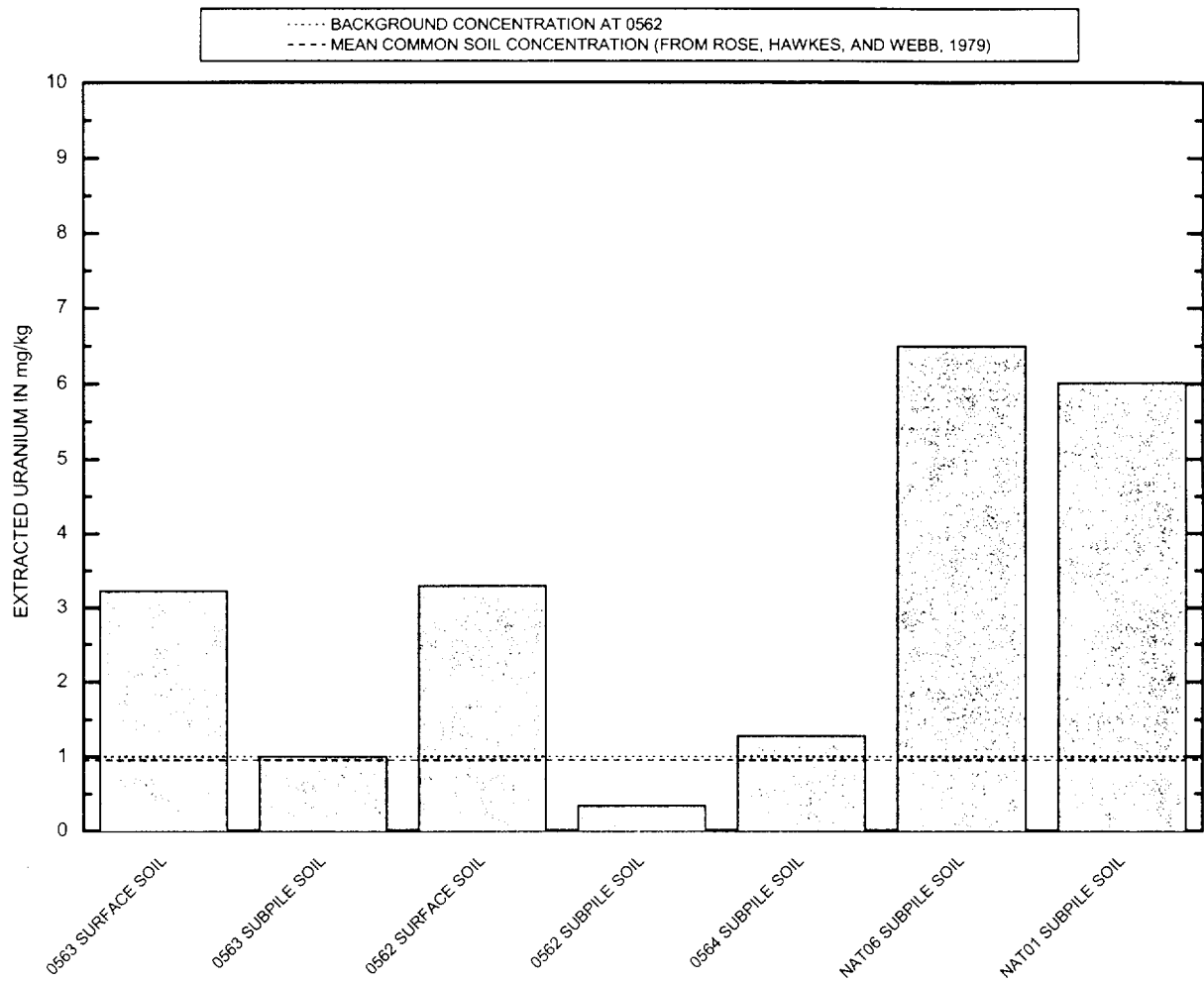


Figure 4-15. Uranium Concentrations in Surface and Subpile Soil Samples

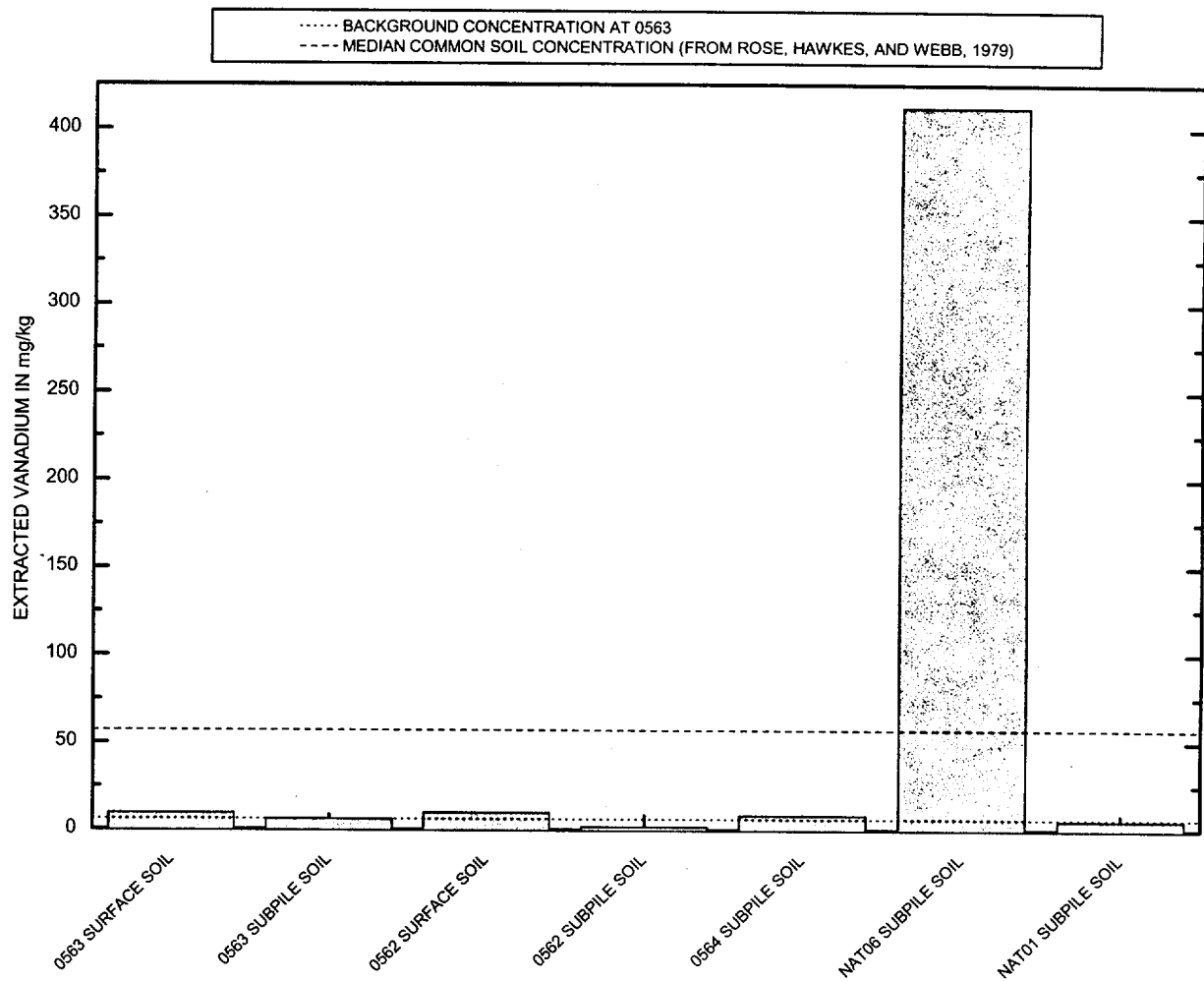


Figure 4-16. Vanadium Concentrations in Surface and Subpile Soil Samples

concentration. Drill cuttings from well NAT06 had a vanadium concentration an order of magnitude greater than background levels. Due to its low mobility, the vanadium contamination in the subpile soils is probably limited to the extent of the former tailings pile area and will most likely remain there for a considerable length of time.

4.7 Water Sampling and Analysis

From August 1998 through June 2000, ground water at the Naturita site was sampled to support research by the USGS for the NRC on surface complexation modeling. During November 2000 and March 2001 and continuing into June and September 2001, samples were collected to monitor the nature and extent of ground water contamination at the site for the DOE UMTRA Ground Water Project. Because the two projects have different goals, different sets of wells were sampled. Also, at times, different sampling and analytical procedures were used. All sampling during the NRC sampling period was performed in accordance with the *U.S. Geological Survey National Field Manual for the Collection of Water-Quality Data* (USGS 1998). All sampling during the DOE UMTRA Ground Water Project monitoring phase was performed in accordance with the *Sampling and Analysis Plan for the UMTRA Ground Water Project* (DOE 1999c).

Monitoring wells and surface water sites were sampled quarterly. Sampling for the surface complexation modeling study was conducted from August 1998 through June 1999. Samples from wells 0547 and 0548 were collected in August 1998. Samples were collected from 22 wells and one surface water location during November 1998. Six wells were dry and could not be sampled. Twenty-four ground water samples and one surface water sample were collected in March 1999. Four wells were dry and could not be sampled. During June 1999, 26 wells and one surface water location were sampled. Two wells did not contain water and could not be sampled. In late June and early July 1999, additional monitor wells were installed at the site. In September 1999 and March 2000, 60 ground water wells and one surface water site were sampled. During that time, 12 wells were dry and were not sampled. Well DM1 also was not sampled at that time. Seventy-four ground water wells, including DM1 and one surface water location, were sampled in June 2000. The wells that were dry were always the shallowest of a nested set of wells. Alluvial water was present at all locations during each sampling round.

DOE funded and the USGS conducted monitoring during November 2000 and February 2001. For that monitoring phase, 28 ground water and 14 surface water samples were collected. None of the wells selected by DOE for monitoring were dry during the November 2000 and February 2001 sampling. Additional sampling is planned for June and September 2001.

4.7.1 Ground Water Sampling Procedures

Before samples were collected, about three casing volumes of water were purged from each well with a peristaltic pump. Two-inch-diameter wells were purged and sampled through dedicated 0.5-inch-diameter PVC tubes with a 6-inch screen on the bottom. These tubes were set in the casing to sample 2.5 ft from the bottom of the well where possible. This depth is set at the middle of the screened interval. Half-inch-diameter wells were connected directly to the pump tubing. Samples from these wells were collected from the 6-inch screened interval at the bottom of the well casing. All purging and sampling was done through a peristaltic pump using low-diffusion Norprene tubing. All field measurements except turbidity (pH, specific conductance, oxidation-reduction potential, water temperature, and dissolved oxygen) were monitored continuously during purging with a flow-through chamber attached to a Hydrolab Mini-Sonde Water Quality Multi-probe. Turbidity was measured with a Hach portable turbidity monitor

every half gallon in 0.5-inch-diameter wells, and every gallon in 2-inch-diameter wells. Turbidity was only monitored during the DOE UMTRA monitoring phase of the project. After purging was completed, water samples for anion analysis were filtered on site using a 0.45- μ m capsule filter and collected in field-rinsed, 4-ounce polyethylene bottles. Samples for cation analysis were also filtered on site and collected in 4-ounce, acid-rinsed bottles. After collection, these samples were preserved with ultra-pure concentrated nitric acid. During the DOE monitoring phase, an additional nutrient sample was filtered and collected in an amber polyethylene bottle that was kept on ice until analysis. Ferrous iron (Fe^{2+}) was measured colorimetrically in the field using a Chemetrics photometer. This was done by first filling a small vial with unfiltered sample water, then immediately breaking a small ampoule containing a reactive solution in the vial. The ampoule is under a negative pressure and therefore draws sample water into the ampoule where it mixes with the reactive solution. After a one minute reaction time, the vial is placed in the photometer, which measures the ionic concentration of the constituent. Alkalinity as CaCO_3 in filtered (0.45 μ m) water samples was generally measured on site with a Hach digital titrator and 1.6 normal sulfuric acid. During the February 2001 sampling, alkalinity was measured in the lab using an auto-titrator due to malfunction of equipment in the field.

4.7.2 Analytical Laboratory Sample Analysis

Water analyses were conducted at the USGS Research Laboratories in Menlo Park, California, and at the USGS National Water Quality Lab (NWQL) in Denver. Dissolved uranium was measured by kinetic phosphorescence analysis (KPA) at the Menlo Park laboratory aluminum, arsenic, boron, barium, bromine, calcium, cadmium, cobalt, chromium, copper, iron, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, selenium, silicon, strontium, vanadium, and zinc concentrations were measured by inductively coupled plasma optical emission spectrometry (Standard Methods 1992). The potassium concentration was measured by direct air-acetylene flame atomic absorption spectrometry. Chloride, nitrate, and sulfate concentrations were measured by ion chromatography (Standard Methods 1992). For comparison during the DOE UMTRA monitoring phase, 10 samples were sent to the NWQL for uranium analysis by inductively coupled plasma-mass spectrometry (ICP-MS). All samples collected for DOE UMTRA monitoring were analyzed for arsenic and selenium at the NWQL using ICP-MS. Table 4-8 presents a summary of the methods used for water analysis at the two labs. Results from all surface and ground water analyses are listed in Appendices C and B, respectively.

4.7.3 Quality Assurance and Quality Control Samples

One process blank sample and one field replicate were collected for each sampling trip during the NRC sampling period. During the DOE UMTRA monitoring, a process blank and field replicate were collected for every 20 samples. Field replicates were collected immediately after collection of a regular sample using the same filter and equipment. Process blanks were collected from a bottle of USGS-prepared inorganic blank standard by pumping through the Norprene tubing and 0.45 μ m filter with the peristaltic pump.

Table 4–8. Summary of Methods Used for Water Analysis

Analyte	Detection Limit	Analytical Instrument	Lab	Sample phase
Al	0.14 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
As	0.18 µg/L	ICP-MS	USGS-NWQL	DOE UMTRA
As	0.14 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
B	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Ba	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Br	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Ca	0.065 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Cd	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Co	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Cr	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Cu	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Fe	0.015 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Li	0.014 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Mg	0.08 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Mn	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Mo	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Na	0.06 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Ni	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
P	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Pb	0.10 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Se	0.36 µg/L	ICP-MS	USGS-NWQL	DOE UMTRA
Se	0.14 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Si	0.01 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Sr	0.14 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
U	0.018 µg/L	ICP-MS	USGS-NWQL	DOE UMTRA
U	0.50 µg/L	KPA	USGS-Menlo	NRC, DOE UMTRA
V	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
Zn	0.02 mg/L	ICP-OES	USGS-Menlo	NRC, DOE UMTRA
K	0.01 mg/L	AA	USGS-Menlo	NRC, DOE UMTRA
Cl	0.005 mg/L	IC	USGS-Menlo	NRC, DOE UMTRA
NO ₃	0.01 mg/L	IC	USGS-Menlo	NRC, DOE UMTRA
SO ₄	0.005 mg/L	IC	USGS-Menlo	NRC, DOE UMTRA

USGS-Menlo

USGS Menlo Park Research Lab

USGS-NWQL

USGS National Water Quality Lab

KPA

Kinetic phosphorescence analysis

ICP-MS

Inductively coupled plasma–mass spectrometry

ICP-OES

Inductively coupled plasma–optical emission spectrometry

AA

Atomic absorption spectrometry

IC

Ion chromatography

mg/L

milligrams per liter

µg/L

micrograms per liter

4.8 Alluvial Aquifer Tests

Estimates of the alluvial aquifer properties are necessary to develop a better understanding of the site hydrogeologic characteristics that could influence contaminant migration in ground water and to develop input parameters in a ground water flow and solute transport model. Both hydraulic and bromide tracer tests were conducted at the Naturita site to determine aquifer properties.

4.8.1 Aquifer Test Procedure

Slug tests were performed on wells at the Naturita site during November 9 through 11, 1999, and during May 17 through 19, 2000. Three to four slug test replicates were done on each well. To perform the tests, a pressure transducer was suspended in the well. A slug with a known displacement volume attached to a thin rope was lowered into the well and the water level was allowed to stabilize. The displacement volume of the slug used in each well was dependent on the height of the water column in the well. The slug was then rapidly removed from the well, and water level recovery and elapsed time were recorded with a pressure transducer. Replicate slug tests were performed after water levels recovered to their pre-test equilibrium values.

Actual displacement of each slug was usually smaller than the measured displacement in the well for the first 0.5 to 0.75 second. After 0.75 to 0.9 second, disturbance of the water surface ceased, and measured displacement was more in line with the actual displacement. The effective casing radius for most tests seemed to be the actual casing radius. Elapsed time and normalized displacement data for each slug test were then analyzed with AQTESOLV software. The Bouwer-Rice solution (Bouwer and Rice 1976) for unconfined aquifers was used to determine all hydraulic conductivity values.

4.8.2 Aquifer Test Analysis

The Bouwer-Rice slug test solution was used in AQTESOLV to compute hydraulic conductivity. A "double straight line" effect can be seen in displacement-time graphs for wells NAT03 (tests 1 and 2), NAT19, and NAT24. In this situation, it is believed that the water levels dropped sufficiently below the top of the screened intervals to allow direct drainage from the sand packs into the well casings (Bouwer 1989). The initial straight line is the result of sand pack drainage. The second straight line in the graphs was controlled by the hydraulic conductivity of the aquifer, and hydraulic conductivity values were derived from the slopes of these lines.

4.8.3 Aquifer Test Results

Table 4-9 summarizes hydraulic conductivity values computed for each slug test along with the mean, standard deviation, and standard error of the tests performed. No attempt was made to compute hydraulic conductivity values for wells NAT20 and NAT23 due to suspect data. Conductivity values for wells MAU03 (May 2000) and MAU04 should be regarded as estimates due to the shapes of the displacement-time graphs, which made analysis problematic. Hydraulic conductivity averages for wells analyzed at the Naturita site ranges from 18.9 ft/day in well MAU04 to 333 ft/day in well NAT09. The average hydraulic conductivity measured during the November 1999 tests is 83 ft/day. The average hydraulic conductivity measured during the May 2000 test is 106 ft/day. This range of values is typical for an alluvial aquifer characterized by mixed sand and gravel. Domenico and Schwartz (1990) report a range of hydraulic conductivities from 0.24 to 137 ft/day for medium sand and from 82 to 8,200 ft/day for gravel.

Table 4–9. Summary of Hydraulic Conductivity Values Determined from Slug Tests

Well	Date	Slug Test 1, ft/day	Slug Test 2, ft/day	Slug Test 3, ft/day	Slug Test 4, ft/day	Average Hydraulic Conductivity, ft/day	Standard Deviation, ft/day	Standard Error %
MAU03	May-00	17	38	22	nd	26	11	42.7
MAU03	Nov-99	85	70	104	nd	86	17	19.6
MAU04	May-00	27	18	12	nd	19	7	38.3
MAU07	Nov-99	16	27	26	nd	23	6	26.2
NAT02	Nov-99	nd	29	41	nd	35	8	24.1
NAT03	May-00	104	90	nd	nd	97	10	10.0
NAT03	Nov-99	96	85	nd	nd	91	8	9.0
NAT05	May-00	66	84	60	nd	70	13	18.1
NAT05	Nov-99	76	67	nd	nd	72	6	8.7
NAT09	May-00	288	325	386	nd	333	50	14.9
NAT10	Nov-99	38	30	27	nd	32	6	18.3
NAT11	May-00	108	115	105	nd	109	5	4.7
NAT11	Nov-99	93	81	90	95	90	6	6.8
NAT19	May-00	153	107	128	nd	129	23	17.8
NAT23	Nov-99	246	313	295	nd	285	35	12.2
NAT24	May-00	23	66	67	nd	52	25	48.8
NAT25	May-00	113	126	116	nd	118	7	5.8
NAT-25	Nov-99	24	44	32	nd	33	10	29.9

nd No data

4.8.4 Bromide Tracer Tests

In addition to the hydraulic conductivity values measured directly with slug tests, bromide tracer tests were conducted in June and July 1999 to estimate the hydraulic conductivity of the aquifer. The tracer tests were performed by first pumping 60 gallons of water from a well, then adding a measured amount of potassium bromide to the water, then injecting the water back into the well. Samples were collected from the injection well at regular intervals to monitor the disappearance of bromide from the well. In some tests, downgradient wells were also sampled to monitor bromide migration.

The estimated hydraulic conductivity values obtained from the bromide disappearance tests were calculated by first developing an empirical correlation between hydraulic conductivity and bromide disappearance half-life. The correlation shown in Figure 4–17 was developed from eight wells where both slug tests and bromide tracer tests were performed. Additional hydraulic conductivity values were then estimated using the equation shown in Figure 4–17 at wells NAT06–1, NAT07–1, NAT09, NAT11, NAT12–1, NAT20, NAT26, and NAT30–1 where bromide disappearance tests had been conducted. Table 4–10 shows the half-life for bromide disappearance for each well tested and the estimated hydraulic conductivity.

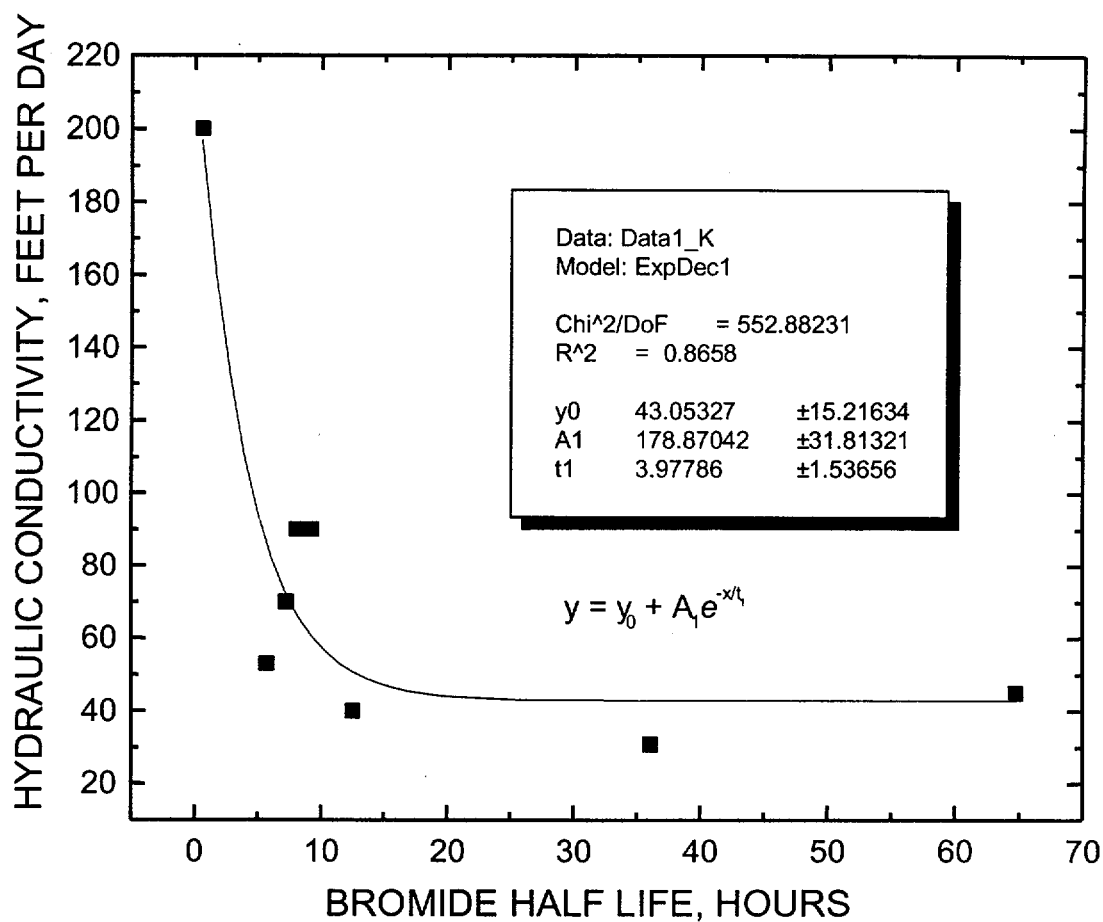


Figure 4-17. Plot Showing Relationship Between Hydraulic Conductivity and Bromide Injection Half-life

Table 4-10. Summary of Hydraulic Conductivity Values Estimated from Bromide Tracer Tests

Well	Bromide Half-Life, hours	Estimated hydraulic conductivity, ft/day
NAT06-1	5.5	88
NAT07-1	14.9	47
NAT12-1	22.1	44
NAT20	0.2	215
NAT26	46.5	43
NAT30-1	0.9	184

4.8.5 Hydraulic Conductivity Estimated from Tritium-Helium Results

In June 2000 a subset of the wells at the Naturita site was sampled for the purpose of determining the age of the ground water. Twelve wells were sampled for age dating by the tritium-helium method (see Section 5.3.4 for a detailed description of the tritium-helium age dating technique). Table 4–11 shows the tritium-helium ages for eight wells. The age of ground water is defined as the time since water was isolated from the atmosphere (Freeze and Cheery 1979). Table 4–11 also shows flow path lengths calculated with MODPATH. Although flow modeling suggests long path lines for wells MAU04 and MAU07, the geochemical signature of the ground water in these wells suggests a significant inflow of fresh water from the San Miguel River (see Section 5.3.3.2). Therefore, the path lines from wells MAU04 and MAU07 may actually originate near NAT25. Average velocities listed in Table 4–11 were calculated using the recharge age and the MODPATH calculated flow path lengths. The estimated velocities range from 0.21 ft/day at MAU07 (along the short flow path) to approximately 2.4 ft/day at DM1 and at MAU04 (along the long flow path). The hydraulic conductivity values calculated from Darcy's law, a porosity of 0.25, and an average sitewide gradient of 0.0044 ft/ft are also listed in Table 4–11. The values range from 12 to 139 ft/day with a mean of 61 ft/day.

Table 4–11. Velocities and Hydraulic Conductivities Estimated from the Tritium-Helium Age Dating Results

Location	Tritium/ Helium Age	Length of Recharge Path(ft)	Average Velocity (ft/day)	Hydraulic Conductivity (ft/day)	Comments
DM1	0.2	174	2.38	135	
MAU04	5.6	4,991	2.44	139	
		840 ^a	0.41	23	Assumes recharge from bend in river
MAU07	12.4	5,466	1.21	69	
		944 ^a	0.21	12	Assumes recharge from bend in river
NAT19	9.2	2,955	0.88	50	
NAT23	13.5	5,520	1.12	64	
NAT24	33.9	5,465	0.44	25	
NAT25	28.2	5,440	0.53	30	
NAT29	5.8	2,202	1.04	59	

^aValues are based on the assumed shorter flow path to MAU04 and MAU07.

4.8.6 Hydraulic Conductivity Summary

Figure 4–18 shows a map of hydraulic conductivity values from slug tests, bromide tracer tests, and tritium-helium age dating that were measured and estimated at the Naturita site. When plotted spatially, the hydraulic conductivity at the Naturita site is roughly distributed into two zones, a “high K zone” located at the southern end of the site with values greater than 100 ft/day, and a “low K zone” at the northern end with values less than 100 ft/day. The boundary between the two zones falls roughly at the extent of the former tailings area.

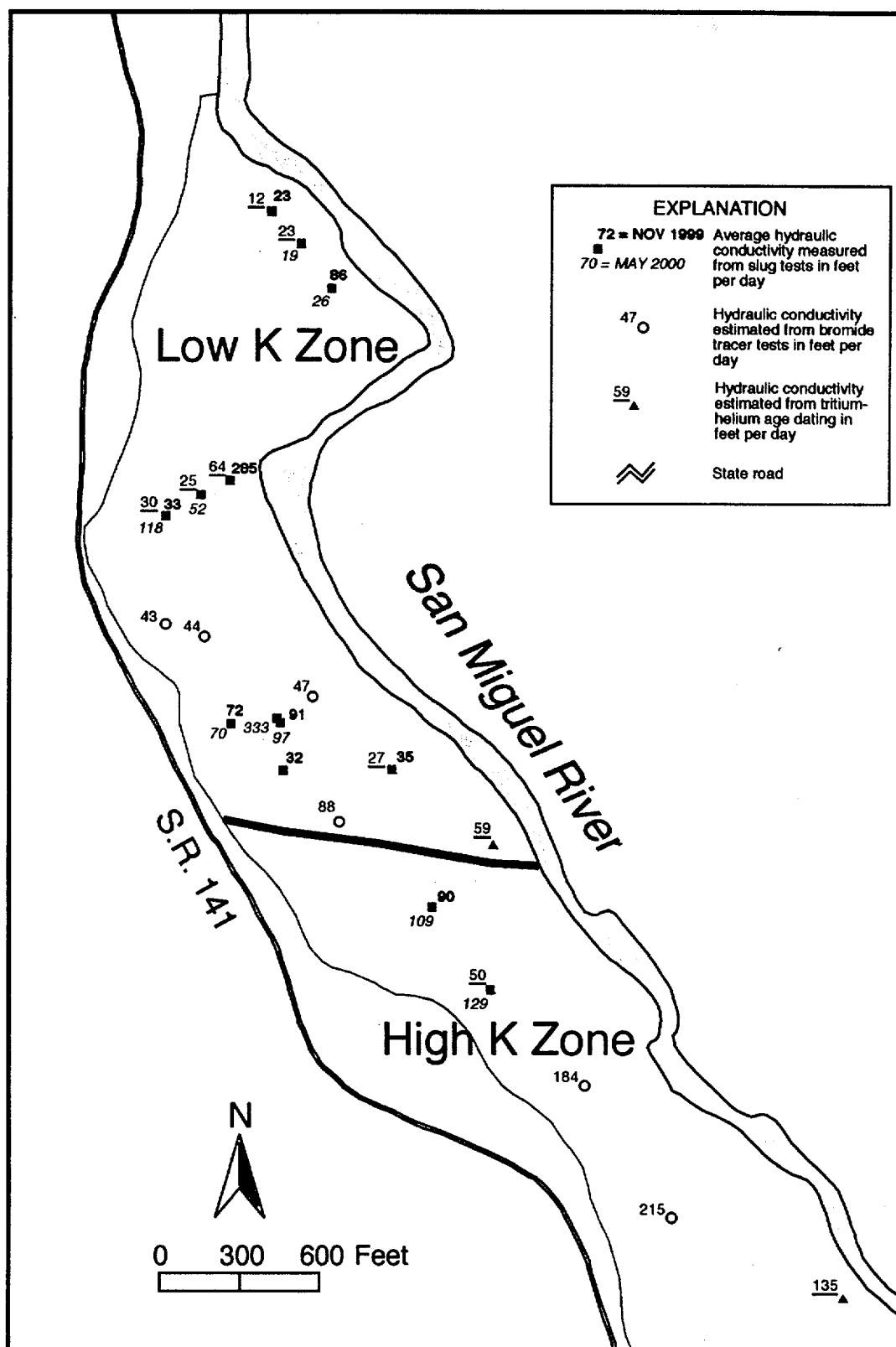


Figure 4-18. Hydraulic Conductivity Values Calculated from Slug Tests and Estimated from Bromide Tracer Tests and Tritium-Helium Age Dating

4.9 Surface Flow Measurements

The Naturita site is bordered on the east by the San Miguel River. It is believed that ground water in the alluvial aquifer is recharged mainly by inflow from the river upstream of the UMTRA site. The aquifer also discharges back to the river downstream of the site. The San Miguel River drains an area of approximately 1,500 square miles, beginning in the San Juan Mountains and discharging into the Dolores River, about 25 miles downstream from the Naturita site. Surface flow of the San Miguel River has been historically recorded at two USGS gaging stations: Brooks Bridge, located 4.5 miles upstream of the Naturita site, and at Uravan, located 15 miles downstream from the site. In addition, stream elevations were surveyed at nine sites along the San Miguel River at the Naturita site. These measuring points are shown in Figure 4–19.

River stage was also recorded at location Stage 1 (Figure 4–19) near well NAT29 for comparison to changes in ground water levels. The stage was recorded during the period November 1999 to March 2001 using an Omnidata Data Logger pressure transducer. No attempt was made to quantify flow of surface water. The paired stage–water table data were collected to quantify the effects and lag times of river stage on the alluvial aquifer. Figure 4–19 shows two ephemeral streams that cross the site from the slope on the western side of the site. These streams have been observed to flow during large storm events and are believed to be a source of intermittent areal recharge. Also, after heavy rainfall, the soil in these areas often remain saturated for several days.

4.9.1 San Miguel River at Brooks Bridge near Nucla, Colorado

USGS maintains a gaging station on the San Miguel River at the Brooks Bridge near Nucla. The gage is located approximately 4.5 miles upstream from the Naturita site. Figure 4–20 shows a hydrograph for the period March 31, 1995, to September 30, 1999. Stream discharge ranges from a base flow of approximately 3 cubic ft per second (cfs) to 100 cfs. Peak flows range from 1,000 to 2,500 cfs. However, these ranges are only based on 4 years of data, recorded from 1996 to 1999. The peak flows result from snow melt in the San Juan mountains at the head of the watershed and generally start in the first week of April and continue until early summer. Low-flow conditions are generally constant and occur between roughly the first week of August to the end of March, although rainfall can cause short-term increases in stream flow.

4.9.2 San Miguel River at Uravan, Colorado

USGS maintains another gaging station on the San Miguel River at Uravan. The gage is located approximately 15 miles downstream from the Naturita site. Figure 4–20 shows a hydrograph for the period August 30, 1996, to September 30, 1999. Base flow ranges from 20 to 100 cfs, and peak flows typically range from 2,000 cfs to a historical high of 8,910 cfs on September 6, 1970 (not shown on hydrograph). These ranges are based on records dating back to 1954. As shown in Figure 4–20, the San Miguel River exhibits the same pattern of flow at Uravan as at Brooks Bridge, with peaks and base flows occurring at the same time of year. Dry Creek is a perennial stream that enters the San Miguel River about a mile upstream from the site. This stream and numerous ephemeral streams are the main sources of discharge to the river between the Brooks Bridge and Uravan gaging stations.

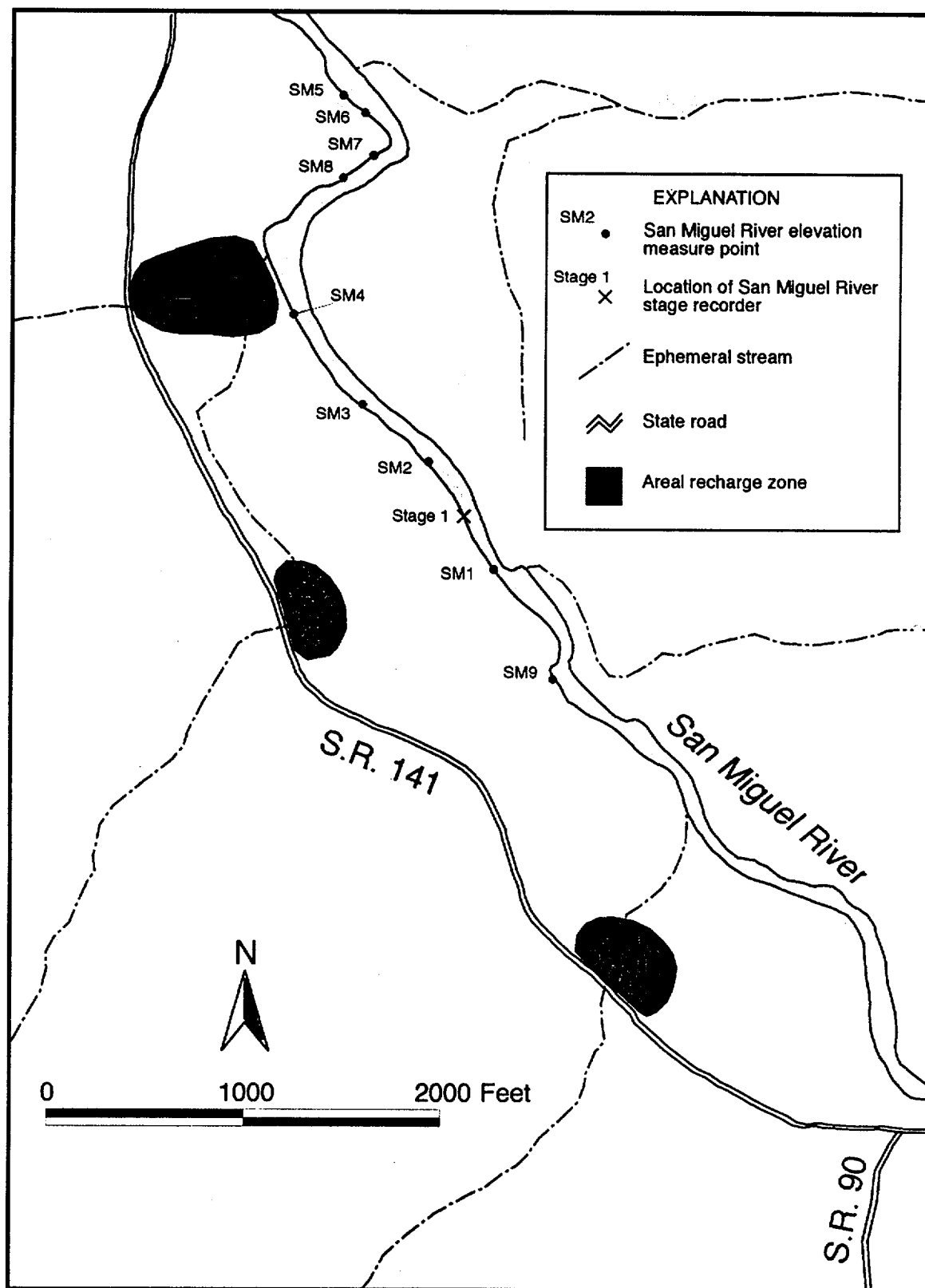


Figure 4-19. Locations of San Miguel River Elevation Measuring Points, Stage Recorder, and Zones of Areal Recharge at the Naturita UMTRA Site

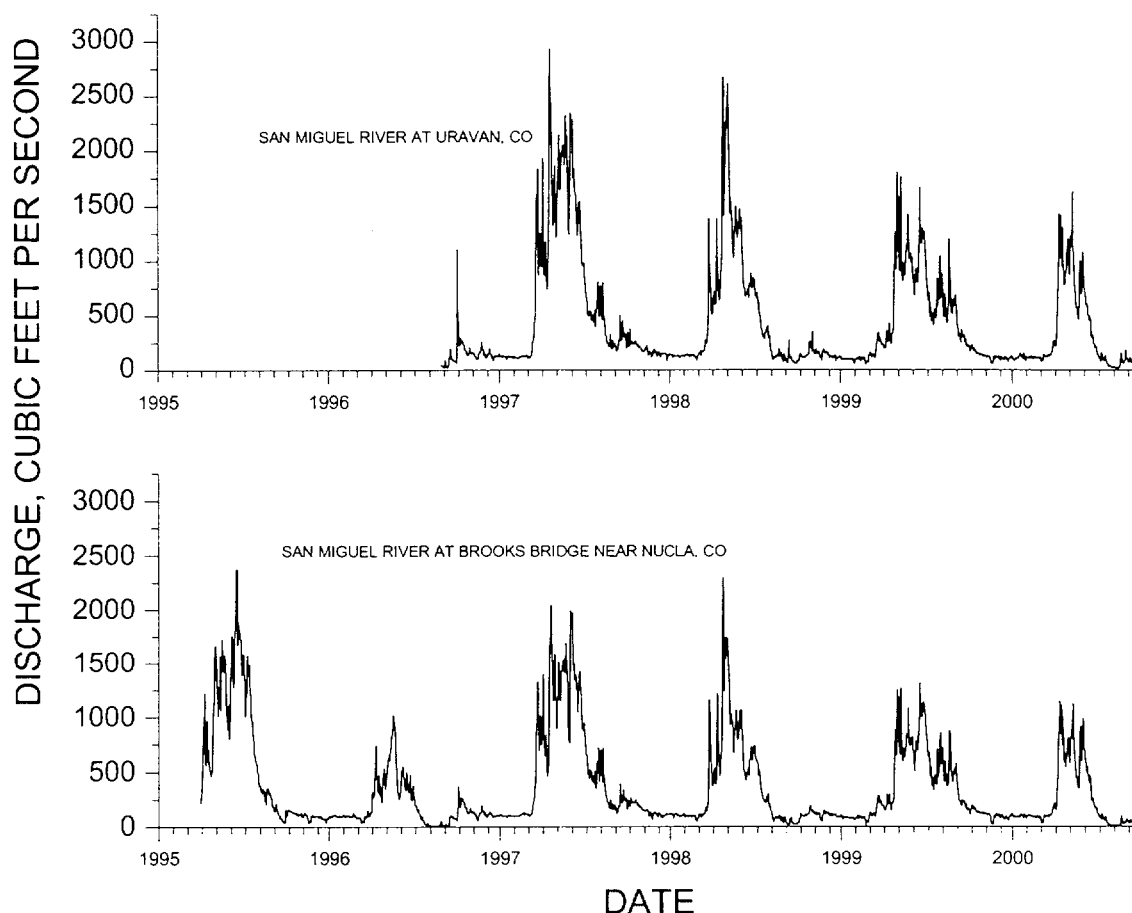


Figure 4-20. Hydrographs from USGS Gaging Stations on the San Miguel River near the Naturita UMTRA Site

4.9.3 Stage Recorder and Surface Water Elevation Measurements

Flow from the San Miguel River is believed to be the most important source of recharge to the alluvial aquifer. This is supported by the close coupling between the stage in the San Miguel River and the observed heads in several of the wells in the aquifer. Figure 4-19 shows the location of the stage recorder. No gauge was installed at the site to relate stream stage changes to a set datum. Figure 4-21 shows the changes seen in the river stage in well NAT29, which is 138 ft from the river, and in well NAT11, which is 445 ft from the river. Figure 4-22 illustrates the correlation between temporal variations in the river stage and the head in NAT08 (380 ft from the river). Figure 4-23 shows the same correlation in wells NAT25 (380 ft from the river) and NAT23 (100 ft from the river). The head changes more slowly at NAT23 and NAT25 relative to NAT29, NAT11, and NAT08. This is probably because NAT23 and NAT25 are located farther down the ground water flow path and are more hydraulically removed from the river than the other wells. This effect would tend to dampen out small changes seen in the river stage.

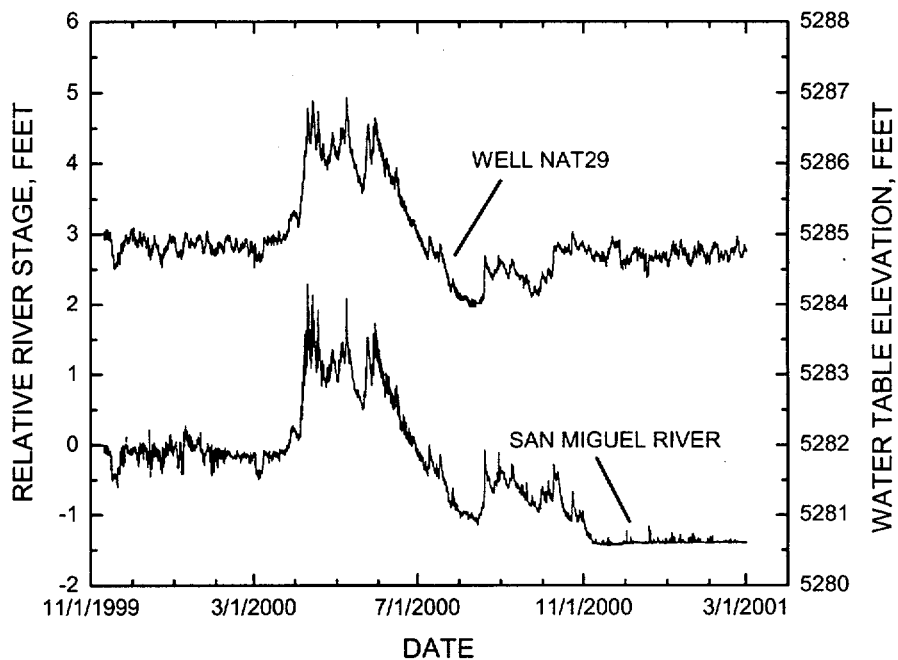
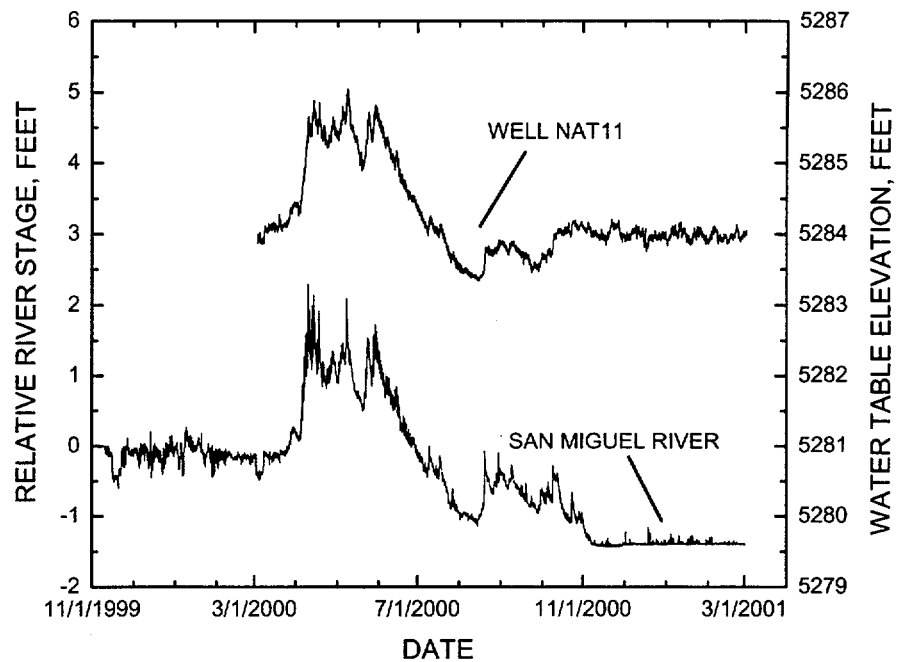


Figure 4-21. Correlation Between Water Table Elevation in Wells NAT11 and NAT29 and Relative Stage of the San Miguel River Measured at Location Stage 1

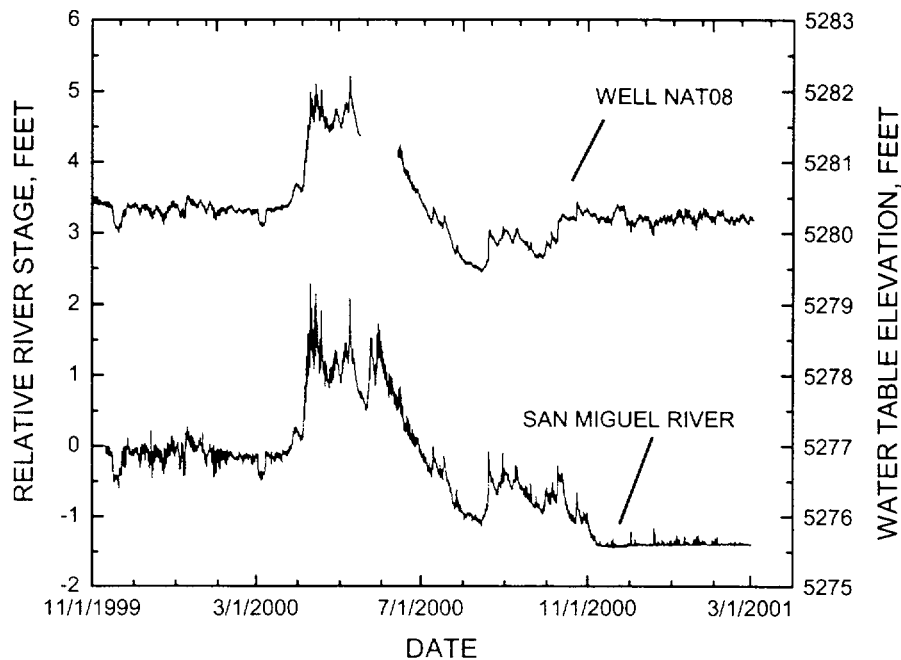


Figure 4–22. Correlation Between Water Table Elevation in Well NAT08 and Relative Stage of the San Miguel River Measured at Location Stage 1

Reference elevation points were installed and surveyed at nine points along the San Miguel River adjacent to the Naturita site. The points are shown as SM1 through SM9 in Figure 4–19. Table 4–12 shows the elevations measured for each reference point. Figure 4–24 shows a hydrograph comparing the relative change in river stage as recorded by the river pressure transducer to the elevation of the San Miguel River measured at location SM1.

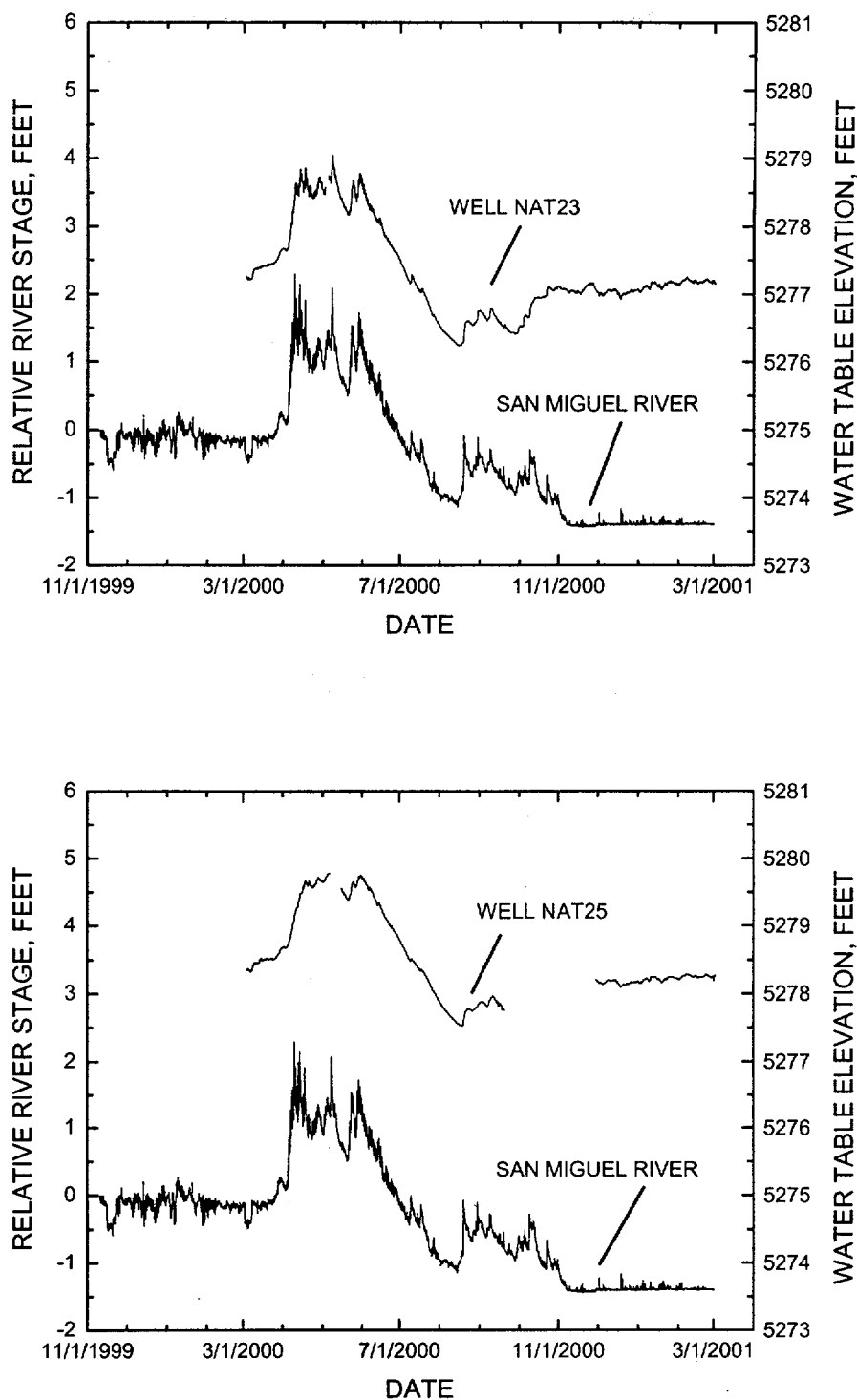


Figure 4-23. Correlation Between Water Table Elevation in Wells NAT23 and NAT25 and Relative Stage of the San Miguel River Measured at Location Stage 1

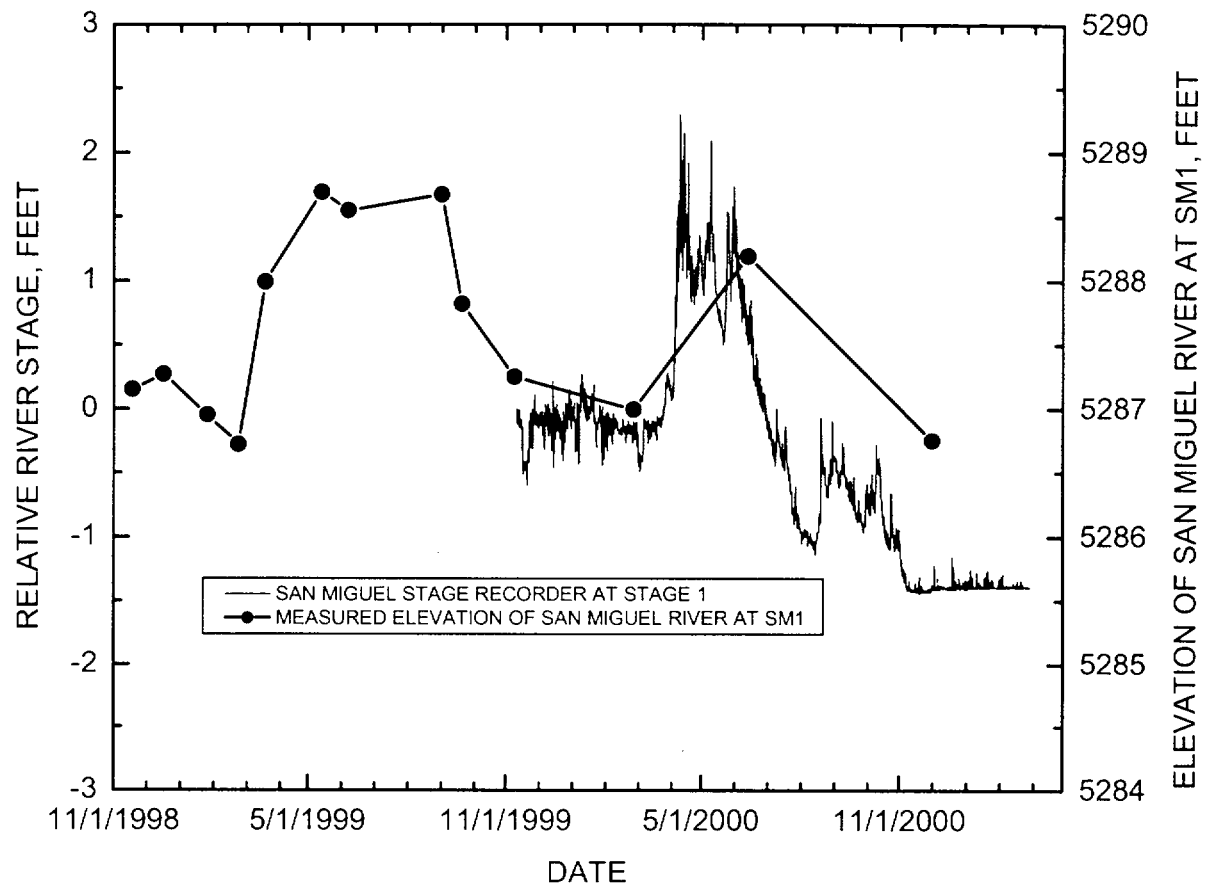


Figure 4-24. Relative Stage of the San Miguel River Recorded at Location Stage 1 and Measured Elevation of the San Miguel River at Location SM1

Table 4-12. Elevation of the San Miguel River at Locations SM1 through SM9

Date	SM1	SM2	SM3	SM4	SM5	SM6	SM7	SM8	SM9
11/18/98	5287.15	5284.25	5281.86	5278.93	5271.16	nd	nd	nd	nd
12/17/98	5287.27	5284.45	5281.88	5279.11	5271.19	nd	nd	nd	nd
01/27/99	5286.95	5284.17	5281.75	5278.92	5271.05	5271.36	5273.73	5273.97	5291.34
02/25/99	5286.72	5283.98	5281.65	5278.67	5270.89	5271.12	5273.60	5273.83	5291.00
03/22/99	5287.99	5284.82	5282.36	5279.64	5271.61	5272.06	5274.31	5274.76	5292.17
05/13/99	5288.69	5286.67	5284.40	5281.32	nd	5272.78	5274.89	5275.41	5292.72
06/07/99	5288.55	5285.39	5282.95	5280.24	5272.13	5272.62	5274.75	5275.33	5292.60
09/02/99	5288.67	5285.46	5283.00	5280.31	5272.14	5272.70	nd	5275.41	5292.82
09/21/99	5287.82	5284.83	5282.29	5279.50	5271.56	5271.99	5274.33	5274.79	5292.06
11/09/99	5287.25	5284.25	5281.93	5279.16	5271.31	5271.55	5273.87	5274.39	5292.54
02/28/00	5286.99	5284.21	5281.83	5279.00	5271.11	5271.40	5273.87	5274.23	5291.32
06/13/00	5288.19	5285.19	nd	5281.58	5271.94	5272.44	5274.79	5275.25	5292.36
12/01/00	5286.75	nd	5281.75	5279.02	5270.95	5271.34	5273.87	5274.17	5291.18
02/26/01	5286.66	nd	5281.72	5278.85	5270.95	5271.33	5273.62	5274.03	5291.04

nd = no data

4.10 Ecological Field Investigations

In general, the goal of ecological field investigations under the UMTRA Project is to acquire data to determine if site-related contamination may adversely affect ecological receptors (flora and fauna). The ecology of the former millsite and surrounding areas has been characterized to support the assessment of potential ecological risks associated with site-related contaminated ground water and to update the *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site Near Naturita, Colorado* (BLRA, DOE 1995). Data needed to evaluate potential risks include faunal and floral species composition, ecological interactions, contaminated media, contaminant concentrations within specific media, and exposure pathways. This section summarizes the data collected and identifies any additional data needs. Section 6.2 of this SOWP evaluates the data and draws conclusions as to the level of risk presented by site-related contamination to ecological receptors.

Because UMTRCA does not specify an ecological risk assessment protocol, the UMTRA Ground Water Project adopted EPA's 1992 risk assessment guidance (EPA 1992) as a best management practice. The BLRA preceded EPA's 1998 risk assessment guidelines (EPA 1998). The data and subsequent evaluation (Section 6.2) have been developed to support a risk-based compliance strategy that is protective of the environment. It includes a discussion of the ecological contaminants of potential concern (E-COPC), potential receptors, and potential adverse effects. A defensible ecological risk assessment (ERA) will provide a sound basis for development of a risk-based compliance strategy. The following sections provide descriptions of ecological field activities conducted to date.

4.10.1 Site Ecological Setting

The Naturita site lies in the Canyonlands section of the Colorado Plateau physiographic province and borders the San Miguel River to the northeast. The USGS reports that average low flow of the San Miguel River is about 60 cfs. The San Miguel River joins the Dolores River approximately 20 miles downstream from the site. Site-related ground water contamination moves in a generally northeast direction toward the river. Ground water flow from the site terminates in the San Miguel River along a stretch approximately 500 ft long. Seeps are evident along the northeastern boundary of the site, directly adjacent to the river. The most prominent seep at sampling location 0538 forms a small pond within the river channel during low flow, which empties into the river. This area presents the greatest potential for receptors to access contaminated media.

4.10.1.1 Site Flora and Fauna

The flora and fauna of the Naturita millsite and surrounding areas were investigated between 1986 and 1994. Section 7.2 of the BLRA describes the potential ecological receptors in detail. Additional information is provided in the *Environmental Assessment of Remedial Action at the Naturita Uranium Processing Site Near Naturita, Colorado* (DOE 1994), which documents the results of the investigations and lists the potential ecological receptors, including threatened or endangered species. Ecological characterization and surveys targeted terrestrial ecological receptors, with an emphasis on riparian plant communities and associated wildlife along the San Miguel River.

The BLRA also identifies and discusses six federally listed threatened or endangered species, one federally proposed species, and nine federal candidate species that may occur in the vicinity of the site. Of the species listed, the area may provide suitable habitat for only the southwestern willow flycatcher (*Empidonax traillii extimus*).

Plant Ecology Characterization

The San Miguel River valley includes the riparian community along the river surrounded by moderate to steep hillsides. Surrounding areas include two other major community types: piñon-juniper woodland and sagebrush-grass communities. Figure 7.1 of the BLRA shows the plant communities in the vicinity of the site at the time of remediation. In October 2000, vegetation of the former millsite was assessed using a semiquantitative relevé technique. With this method, representative stands of each vegetation type are subjectively chosen and traversed. The vegetation types are differentiated on the basis of the two dominant species present in each one. A list of all the plant species in the stand is made, and the percent cover of each species is estimated. A value for one of six cover class percentages is assigned to each species, and the percent cover is not measured precisely.

The goal of the investigation was to identify potential exposure pathways and ecological receptors. Field characterization activities focused on the identification of phreatophytic species that may be rooted into areas of site-contaminated ground water, in both riparian and upland communities.

Results

The Naturita site is dominated by upland plants that are mostly grasses and annual weeds. However, several areas have phreatophytes, or plants that can root into ground water. Phreatophytic species include willows (*Salix* spp.), cottonwoods (*Populus* spp.), tamarisk (*Tamarix* spp.), and greasewood (*Sarcobatus vermiculatus*). A strip of riparian and wetland vegetation growing along the San Miguel River includes willows and cottonwoods. Tamarisk and willows grow along a ditch through the site at the north end. An island of shrubby vegetation around a group of power poles in the field includes greasewood. Altogether, there are four riparian/wetland vegetation types and three upland vegetation types, as shown in Figure 4–25.

A willow-dominated riparian area is at the north end of the site along the river. Sandbar willow (*Salix exigua*) up to 8 ft tall is the main species; the understory is smooth brome (*Bromus inermis*), thistle (*Cirsium* sp.), common reed (*Phragmites australis*), Woods rose (*Rosa woodsii*), and aster species.

The south end of the riparian area has two distinct vegetation types. One has an abundance of mature lanceleaf cottonwoods (*Populus accuminata*), with an herbaceous understory of scratchgrass muhly (*Muhlenbergia asperifolia*) and sweet clover (*Melilotus officinalis*). The other is a mixture of willows and cottonwoods, both juvenile and mature, with a variety of grasses and forbs underneath.

The final wetland vegetation type is a 10-ft-wide strip along a ditch toward the north end of the site. The vegetation is mostly 6–8-ft-tall sandbar willow (*Salix exigua*) with some Canada thistle (*Cirsium arvense*), tamarisk, and common reed (*Phragmites australis*).

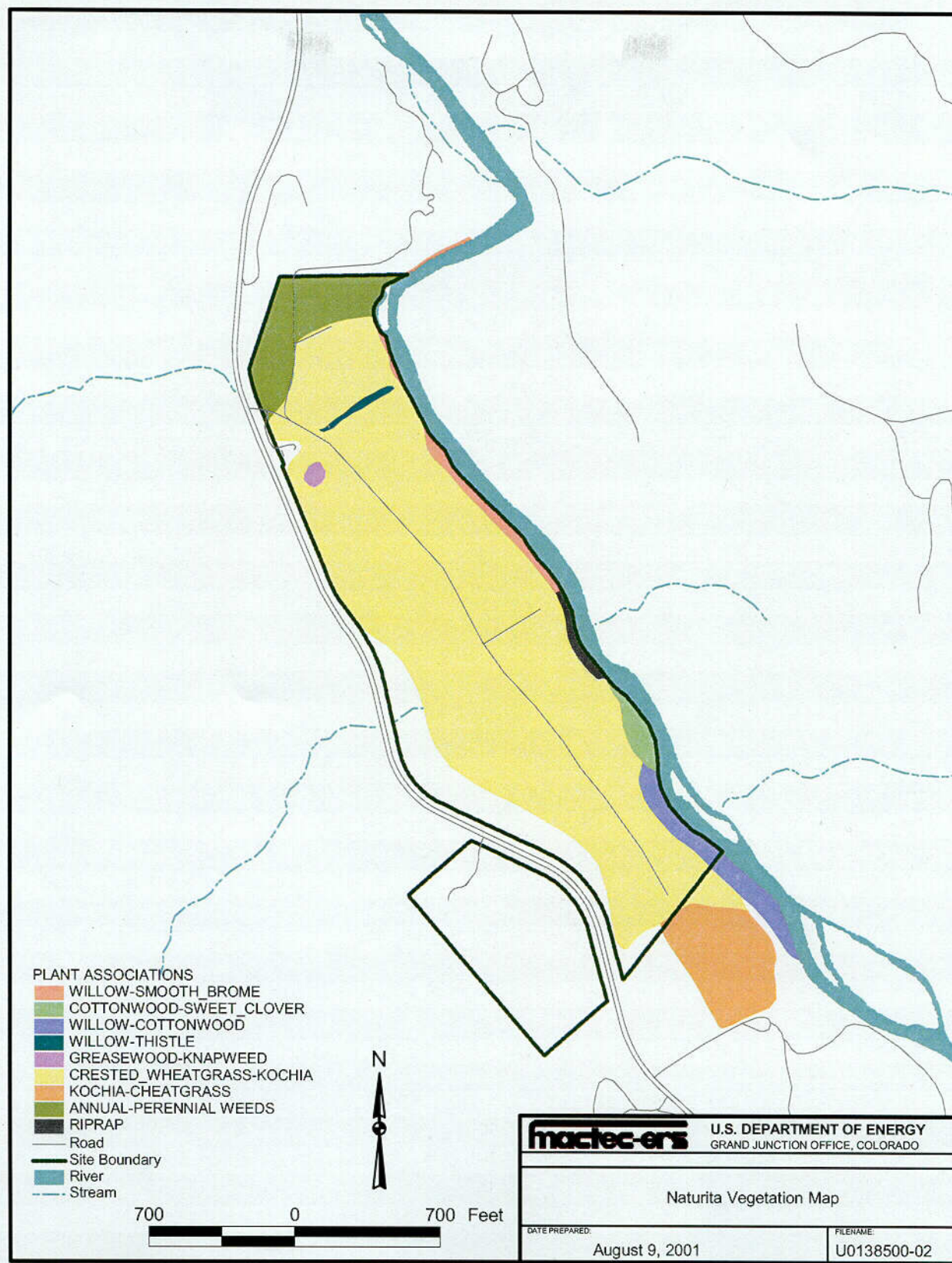


Figure 4-25. Vegetation Map of the Naturita Millsite

C02

The major upland type is the reseeded portion of the field. It is approximately 50 percent bare, and the main vegetation consists of crested wheatgrass (*Agropyron cristatum*) and kochia (*Kochia scoparia*), both under 6 inches tall. The far north end of the field is dominated by annual and perennial weeds, including Russian thistle (*Salsola iberica*), Russian knapweed (*Centaurea repens*), and cheatgrass (*Anisantha tectorum*). The knapweed will be treated and this portion of the site will be reseeded in September 2001. Small islands around the power poles in the field contain mostly greasewood and Russian knapweed. The south end of the upland area is a weedy field with kochia and cheatgrass. Grazing restrictions will be implemented by installing fencing to improve the condition of the upland vegetation at the site.

4.10.2 Sampling and Analysis

4.10.2.1 BLRA Results

Ground water was sampled and analyzed to determine if concentrations of site-related contaminants exceeded background or maximum concentration limits established in 40 CFR 192. If ground water concentrations exceeded background, the contaminant was evaluated for potential ecological risks. Table 3.1 of the BLRA summarizes the ground water characterization results for key contaminants. Section 3.4 and Table 3.3 of the BLRA identified 27 E-COPCs that, based on the median concentrations, exceeded background ground water concentrations. Table 4-13 lists the 23 inorganic and 4 radionuclides identified in the BLRA as E-COPCs. No explanation is provided as to why three constituents (tin, zinc, and radium-226), which had concentrations that exceeded background in Table 3.1 of the BLRA, were not identified as exceeding background. It is assumed that tin and zinc were excluded because they only slightly exceeded background. It is assumed that radium-226 was excluded because the median concentration (4.9 pCi/L) within the contaminated area is just under the maximum concentration limit of 5 pCi/L (40 CFR 192). However, Table 3.3 of the BLRA, which lists E-COPCs, included radium-226 but excluded thorium-230. Tin and zinc were also excluded as E-COPCs in Table 3.3.

Because soil was remediated to standards in 40 CFR 192 under the surface remediation program, both soil and air are eliminated as media of concern for ecological receptors. However, ground water presents a possible secondary source and exposure medium. The primary concern is the possibility that contaminated ground water may be hydrologically connected to surface water, thereby creating the potential to contaminate the adjacent river or ponds. Because the San Miguel River is close to the ground water contamination, it is included for evaluation. Therefore, ground water, surface water, and associated sediments are the media of interest for ecological risk assessment. These media were selected because both direct and indirect pathways to ecological receptors are possible.

4.10.2.2 Abiotic Sampling and Analysis

Ground water data were used to determine E-COPCs for terrestrial receptors. Surface water and sediment sampling was conducted to determine E-COPCs for both terrestrial and aquatic receptors, but primarily for aquatic receptors. This section summarizes the data reported in Sections 3.0 and 7.0 of the 1995 BLRA.

Table 4-13. E-COPCs that Exceeded Background Ground Water Concentrations

Inorganics	Radionuclides
Aluminum	Lead-210
Ammonium	Polonium-210
Antimony	Radium-226
Arsenic	Radium-228
Barium	
Boron	
Calcium	
Chloride	
Fluoride	
Magnesium	
Manganese	
Molybdenum	
Nitrate	
Phosphate	
Potassium	
Selenium	
Silica	
Silver	
Sodium	
Strontium	
Sulfate	
Uranium	
Vanadium	

Ground Water

Ground water sampling at the site was conducted between 1986 and 2001. However, BLRA data and interpretation addressed only the period from 1986 through 1994. Data gathered after 1995 are addressed in Section 6.2, the BLRA update. Table 4-14 lists the ground water sampling locations that were sampled from 1986 through 1994. Ground water locations 0547 and 0548 are the only locations of the 12 historical sampling locations that continue to be monitored.

Table 4-14. Ground Water Sampling Locations from 1986 through 1994

Location Number	Description	Dates Sampled	References/Comments
0505	Mill Yard/On site	1986-94	BLRA Table 3.2
0506	Tailings Pile/On site	1986-94	BLRA Table 3.2
0546 ^a	Upgradient/Off site	1986-92	BLRA Table 3.2
0547 ^a	Upgradient/Off site	1986-94	BLRA Table 3.2
0548	Downgradient/Off site	1986-94	BLRA Table 3.2
0549 ^a	Upgradient/Off site	1987-92	BLRA Table 3.2
0616	Tailings Pile/On site	1989-92	BLRA Table 3.2
0619	Tailings Pile/On site	1989-92	BLRA Table 3.2
0630	Tailings Pile/On site	1989-92	BLRA Table 3.2
0632	Tailings Pile/On site	1989-92	BLRA Table 3.2
0637	Tailings Pile/On site	1989-92	BLRA Table 3.2
0656	Tailings Pile/On site	1990-92	BLRA Table 3.2

^aBackground Location

BLRA = Baseline Risk Assessment

Surface Water

On the basis of the E-COPCs, surface water sampling locations 0531, 0532, and 0533 were initially established in the San Miguel River channel to determine if ground water was affecting the quality of surface water. Both filtered and unfiltered samples were collected. Location 0531 was used to establish background concentrations. Four additional locations 0534, 0535, 0536, and 0538 were added in 1994 (Table 4–15). Location 0538, which is referred to as a spring in the BLRA, is actually a seep that feeds into a small pond in the river floodplain. The pond eventually discharges to the river approximately 200 ft downstream. Because the seep was believed to be ground water discharging to the surface, location 0538 was discussed in the ground water section of the BLRA. The BLRA also refers to other ponds that no longer exist due to fluctuations and changes in the river's channel. All four 1994 locations were only sampled once.

Table 4–15. Surface Water Locations from 1986 to 1994.

Location Number	Description	Dates Sampled	References/Comments
0531	S.M. River/upstream	1986–94	BLRA Fig. 3.5/Table 3.5
0532	S.M. River/middle of site	1986–94	BLRA Fig. 3.5/Table 3.5
0533	S.M. River/downstream	1986–94	BLRA Fig. 3.5/Table 3.5
0534	S.M. River/south end of site	1994	BLRA Fig. 3.5/Table 3.5
0535	S.M. River/north end of site	1994	BLRA Fig. 3.5/Table 3.5
0536	S.M. River/north end of site	1994	BLRA Fig. 3.5/Table 3.5
0538	Floodplain/north end of site	1994	BLRA Fig. 3.5/Table 3.1

BLRA = Baseline Risk Assessment

Although data showed the potential for a slight increase over background for three site-related constituents (sodium, sulfate, and uranium), initial sampling and statistical evaluations indicated that the San Miguel River was not being affected. Therefore, no E-COPCs were identified for surface water at that time. However, additional sampling and analysis was recommended. Section 3.6 of the BLRA details the results of sampling.

Sediments

Sediment samples were collected at all seven surface water locations (Table 4–16) in one round of sampling in 1994. Sediment benchmarks were found for nine of the E-COPCs. The benchmarks are updated in the current ecological risk assessment in Section 6.2 of this SOWP. A qualitative assessment showed that concentrations of uranium, sulfate, and zinc appeared to be higher in downstream sediments than in upstream. Zinc was the only constituent that showed a noticeable increase over background at location 0538. The BLRA recommended that additional data be collected to confirm the results. However, it was also noted that it may not be possible to distinguish between the site-related contribution of elevated concentrations (e.g., uranium) and naturally occurring contributions.

Table 4–16. Sediment Samples Collected in 1994

Location Number	Description	Dates Sampled	References/Comments
0531 ^a	S.M. River/upstream	1994	BLRA Fig. 3.5/Table 3.6
0532	S.M. River/middle of site	1994	BLRA Fig. 3.5/Table 3.6
0533	S.M. River/downstream	1994	BLRA Fig. 3.5/Table 3.6
0534 ^a	S.M. River/south end of site	1994	BLRA Fig. 3.5/Table 3.6
0535	S.M. River/north end of site	1994	BLRA Fig. 3.5/Table 3.6
0536	S.M. River/north end of site	1994	BLRA Fig. 3.5/Table 3.6
0538	Floodplain/north end of site	1994	BLRA Fig. 3.5/Table 3.6

^aBackground location

BLRA = Baseline Risk Assessment

4.10.2.3 Biotic Sampling

With the exception of wetland plants, no sampling of benthic, terrestrial, or aquatic organisms was conducted at the site before 1995. Therefore, there is no information in the BLRA or site documents addressing the analysis of these organisms.

Wetland plants were sampled once at six locations (0531–0536) in 1994. Samples were collected in areas influenced by the site-related contaminated ground water, the millsite floodplain, and in reference areas. Reference areas, or background areas, resemble the site ecologically—landform, soil, and vegetation are similar—but lack the influence of millsite-related ground water contamination. Reference areas were used for baseline chemical data for the ERA and to help project possible successional pathways. The reference areas used to evaluate risk for the millsite vegetation were locations 0531 and 0534. Spikerusk (*Eleocharis* spp.) was sampled in saturated substrate at each location. On the basis of the limited data, no consistent difference between background reference sites and site sample concentrations was noted. Table 7.2 of the BLRA lists the results for 10 selected constituents. No explanation is provided as to why these constituents were selected. It is assumed that they were selected due to the higher concentrations in on-site ground water. In addition, ground water concentrations in the alluvial aquifer were compared to screening benchmarks for terrestrial plants (BLRA, Table 7.5). Additional sampling was recommended.

4.10.3 Update

No sampling of any media was conducted between 1995 and 1997. In 1998, sampling and analysis resumed. Several additional locations were added and some of the historical locations were no longer used. Changes in sampling locations and target analytes were made on the basis of pre-1995 sampling. Details of the changes are provided in the following sections.

4.10.3.1 Abiotic Sampling and Analysis

Ground Water

Thirty-nine sampling locations were added between 1998 and 2000. Only two locations, 0547 and 0548, were retained from the original 12 (Figure 4–1), bringing the total number of ground water locations to 41. The 2001 Statement of Work reduced the list of wells to be monitored to 28. Table 4–17 summarizes monitor well locations retained for monitoring.

Table 4-17. Monitor Well Locations Retained for Monitoring

Location Number	Description	Dates Sampled	References/Comments
0547 ^a	Upgradient/off site	1986-94, 1999-2001	BLRA Table 3.2/USGS data
0548	Downgradient/off site	1986-94, 1999-2001	BLRA Table 3.2/USGS data
DM1 ^a	Upgradient/off site	2000-01	USGS Data
MAU03	Downgradient/off site	1998-01	USGS Data
MAU04	Downgradient/off site	1998-01	USGS Data
MAU05	Downgradient/off site	1998-01	USGS Data
MAU06	Downgradient/off site	1999-01	USGS Data
MAU07	Downgradient/off site	1999-01	USGS Data
MAU08	Downgradient/off site	1999-01	USGS Data
NAT01	Off site/downgradient	1998-01	USGS Data
NAT02	On site	1998-01	USGS Data
NAT03	On site	1998-01	USGS Data
NAT04	On site	1998-01	USGS Data
NAT06	On site	1998-01	USGS Data
NAT08	On site	1999-01	USGS Data
NAT10	On site	1998-01	USGS Data
NAT11	On site	1998-01	USGS Data
NAT15	On site	1999-01	USGS Data
NAT16	On site	1999-01	USGS Data
NAT19	On site	1999-01	USGS Data
NAT20	Upgradient/off site	1999-01	USGS Data
NAT23	Downgradient/off site	1999-01	USGS Data
NAT24	Downgradient/off site	1999-01	USGS Data
NAT25	Downgradient/off site	1999-01	USGS Data
NAT26	Downgradient/off site	1999-01	USGS Data
NAT27	On site	1999-01	USGS Data
NAT29	On site	1999-01	USGS Data
NAT30	On site	1999-01	USGS Data

^aBackground Location

On the basis of the BLRA and subsequent evaluation, DOE determined that only 19 of the original 27 E-COPCs would be sampled for during the 1998 through 2000 sampling events (Table 4-18). Ammonium, antimony, fluoride, and silver were the nonradionuclides excluded. No explanation is provided in previous documentation as to why these and the four radionuclides identified in the BLRA were not retained for further sampling. Iron and zinc were added to the list for risk assessment purposes, bringing the total number of constituents to 21 (Table 4-18). For the eight constituents excluded from current sampling, the analysis of ecological risk is completed on the basis of historical (pre-1998) data.

Table 4-18. E-COPCs Selected for Analysis in the 1998-2000 Ground Water Samples

Inorganics	Radionuclides
Aluminum	None
Arsenic	
Barium	
Boron	
Calcium	
Chloride	
Iron	
Magnesium	
Manganese	
Molybdenum	
Nitrate	
Phosphate	
Potassium	
Selenium	
Silica	
Sodium	
Strontium	
Sulfate	
Uranium	
Vanadium	
Zinc	

In the *Statement of Work for Ground Water Characterization at the Naturita, Colorado UMTRA Site* (DOE 2001) for work conducted by USGS for DOE, 11 constituents were identified for future sampling (Table 4-19). Those denoted with an asterisk in the table were sampled for ecological risk assessment.

Table 4-19. Summary of 11 E-COPCs Retained for Sampling in the 2001 Statement of Work

E-COPCs Retained	E-COPCs Not Retained
Arsenic	Aluminum
Barium*	Ammonium
Boron*	Antimony
Manganese	Calcium
Molybdenum	Chloride
Nitrate	Fluoride
Selenium	Iron
Sulfate	Lead-210
Uranium	Magnesium
Vanadium	Phosphate
Zinc	Polonium-210
	Radium-226 and 228
	Silica
	Silver
	Sodium
	Strontium
	Thorium-230

The 17 E-COPCs excluded are evaluated for risk in Section 6.2 on the basis of historical data. Those retained will be evaluated based on data collected from 2000 through 2001.

Surface Water

Nine sampling locations (0558–0561, SM1–SM4, and SM9) were added from 1998 through 2001 (Figure 4–6). Four locations (0531, 0533, 0536, 0538) of the original seven were also retained, bringing the total number of surface water sampling locations to 13 through 2001. Table 4–20 summarizes surface water locations from 1998 through 2001. The 11 analytes listed in Table 4–19 for ground water were also identified for surface water analysis. Therefore, the evaluation of potential ecological risks associated with surface water for these constituents is based on 1998–2001 sampling data. E-COPCs that are not currently being analyzed are evaluated in Section 6.2 based on historical data.

Table 4–20. Surface Water Locations Sampled Between 1998 and 2001

Location Number	Description	DOE	USGS	Dates Sampled	References/ Comments
0531	S.M. River/upstream	X		1986–94, 2000–2001	BLRA Fig. 3.5/Table 3.5
0533	S.M. River/downstream	X		1986–94, 2001	BLRA Fig. 3.5/Table 3.5
0535	S.M. River/north end of site	X		1994, 2001	BLRA Fig. 3.5/Table 3.5
0536	S.M. River/north end of site	X		1994, 2001	BLRA Fig. 3.5/Table 3.5
0538	Floodplain/north end of site	X		1994, 2000–2001	BLRA Fig. 3.5/Table 3.1
0558	S.M. River/middle of site	X		2000–2001	2001 SOW
0559	S.M. River/north end of site	X		2000–2001	2001 SOW
0560	S.M. River/north end of site	X		2000–2001	2001 SOW
0561	S.M. River/middle of site	X		2000–2001	2001 SOW
SM1	S.M. River/middle of site		X	1998–2001	2001 SOW
SM2	S.M. River/middle of site		X	2000–2001	2001 SOW
SM3	S.M. River/middle of site		X	2000–2001	2001 SOW
SM4	S.M. River/middle of site		X	2000–2001	2001 SOW
SM9	S.M. River/middle of site		X	2000–2001	2001 SOW

BLRA = Baseline Risk Assessment

SOW = Statement of Work

S.M. = San Miguel

Filtered surface water samples were collected. The filtered sample represents the soluble component for aquatic receptors. Each sample bottle was first rinsed with the surface water; the rinse water was then discarded prior to sample collection. A sample was collected by immersing the bottle just below the water surface and filling to just below the mouth of the bottle. Samples were then filtered using a 0.45- μ m filter and acidified for preservation.

Sample labels showing the date, time, location, laboratory bar code, sampler, analyses requested, preservatives, and comments were applied to each container and secured with clear plastic tape. All sample containers were placed in coolers containing ice for transport to the GJO Analytical Chemistry Laboratory. All samples were maintained under strict chain of custody.

Sediments

Nine sediment sampling locations (0558–0561, SM1–SM4, and SM9) were co-located with surface-water samples from 1998 through 2001 (Figure 4–6). Four locations (0531, 0533, 0536, and 0538) of the original seven were also retained, bringing the total number of sediment locations sampled through 2001 to 13.

The area for sample collection was typically a circle with a radius less than 5 ft. Excess organic matter and larger rocks and pebbles were removed from the sample prior to compositing. The contents of one stainless-steel auger (i.e., one subsample) were collected at each composite location and placed in a large stainless steel mixing pan. The material in the mixing pan was mixed thoroughly with a stainless steel spoon, and about 4 ounces (114 g) of material was removed for metals analysis.

Sample labels were applied to each container and secured with clear plastic tape. All sample containers were placed in coolers containing ice for transport to the GJO Analytical Chemistry Laboratory. All samples were maintained under strict chain of custody. The preparation method for the sediment samples included a complete acid digestion rather than an acid leach as was used for some previous sediment analyses.

4.10.3.2 Biotic Sampling and Analysis

No biotic sampling was conducted between 1998 and 2001, no further sampling of vegetation or other biota is currently planned. If future ecological risks are suspected, DOE will consider further sampling at that time.

5.0 Site Conceptual Model

The site conceptual model discusses the important processes that influence the distribution, present levels, and estimated future conditions of contamination at the Naturita site. Results of information gathered during the past year and a review of previous information were used to construct the model. The compliance strategies will be based on information in the site conceptual model.

5.1 Geology

5.1.1 Regional Geologic Setting

The Naturita site is in the Canyonlands physiographic region, along the northeastern side of the Colorado Plateau. This area is characterized by canyons deeply incised into red sandstones of Mesozoic age with isolated mesas. The plateau was uplifted about 10 million years ago, causing rivers to entrench as the uplift proceeded, and may still be experiencing some uplift (Cater 1970). The Uncompahgre Plateau is the dominant structure along the eastern side of the site that was reactivated during the Pliocene and possibly later (Cater 1970). It is a broad northwest-trending upwarp bounded on the west by the north-flowing San Miguel and Dolores Rivers. To the west is the Paradox Basin, a large Pennsylvanian basin that formed concurrently with the ancestral uplift along the Uncompahgre Plateau (Barrs and Stevenson 1981). The basin is characterized by numerous folds and faults produced by compressional forces during the Laramide orogeny. This event allowed lower salt beds to mobilize into elongated upward-piercing diapirs that produced anticlines. Later, the compressional forces were relaxed, allowing tension and the structural failure of the anticlines. Subsequent uplift of the entire region caused erosion and exposed the failed salt anticlines that weathered and produced further collapse and formation of the modern salt valleys. *The Remedial Action Plan for the Inactive Uranium Processing Site at Naturita, Colorado* (DOE 1998a) presents a more detailed description of the geologic setting.

5.1.2 Local Geology and Stratigraphy

Locally, the San Miguel River valley follows part of the Nucla Syncline, a broad gentle downwarp off the eastern flank of the Salt Valley Anticline (a collapsed salt anticline) located to the west. Bedrock dips in the area of the site are subtle, 1 to 2 degrees to the northeast (DOE 1995).

The stratigraphy at the site is simple. Figure 5-1 shows a generalized geologic cross section trending from the south center of the site to the northwest and across Highway 141. The cross section was constructed from wells used during surface remediation; and NAT-30 and DM-1 constructed during this phase of characterization. Unconsolidated alluvium deposited by the San Miguel River fills the valley floor. This material consists of clayey gravel to sandy cobbles, interbedded with layers of silty to sandy clay that pinch off against the bedrock highs on the west and attain a thickness of 23 ft at well 0548. Toward the west side of the site, red to chocolate-colored clayey to sandy colluvium from weathering of Brushy Basin and stratigraphically higher sediments fill drainages entering from the west. Figure 5-2 shows the approximate bedrock surface below the site. Figure 5-3 (alluvium thickness) shows a thicker area of alluvium along the south side of the site where a gravel pit is currently operating. Another thick area of alluvium occurs farther north near the bend of the river. This contouring is based on one well log, well 0548, which recorded the top of the Brushy Basin at 23 ft, much deeper than in surrounding wells.

Bedrock underlying the alluvium consists of the Brushy Basin and Salt Wash Members of the Jurassic Morrison Formation that range up to 820 ft in thickness in the Naturita area. This is the same formation that yielded most of the uranium and vanadium ore from the Uravan district and is unusually thick in this area. The upper Brushy Basin Member contains numerous sequences of variegated bentonitic fluvial to lacustrine mudstones, siltstones, claystones, and some sandstones that range in color from brown to red, green, and gray. It has been partly eroded away below the site but is still 120 to 150 ft thick and can be twice to three times this thickness (Williams 1964). Below the Brushy Basin is the Salt Wash Member, consisting of fluvial sandstones with some siltstone and conglomerate lenses. It sometimes contains carbonaceous plant fragments, which can act as a reducing agent that causes the precipitation and concentration of uranium and vanadium. This member contains several prominent sands and can be up to 300 ft thick (Williams 1964).

Above the Brushy Basin sediments are the sandstones and conglomerates of the Lower Cretaceous Burro Canyon Formation and above them the sandstones of the late Cretaceous Dakota Sandstone. The remnant of a coal mine high on the hillside on the east side of the San Miguel River near the site is in the Dakota Sandstone. These formations have little influence on the millsite.

5.2 Hydrologic System

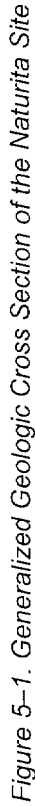
5.2.1 Surface Water Hydrology

The San Miguel River is the dominant source of surface water at the site. It is a perennial stream that originates in the San Juan Mountains near Telluride and joins the Dolores River about 20 miles downstream from Naturita. A USGS gauging station at Naturita records an average maximum flow of 2,000 cfs and an average minimum of 60 cfs (DOE 1994). Maximum flows occur during the spring runoff usually in June and during summer storm events. The only current use of river water near the former millsite is for irrigation and livestock watering.

Several arroyos on the west side of Highway 141 drain Sawtooth Ridge and periodically contribute water and sediment to the site. A culvert near the middle of the site drains one of these valleys to the west. Water from summer storms in 2000 eroded the culvert, and it was repaired in 2001. Figure 3-1, an aerial photograph from 1954, shows a prominent delta deposit on the floodplain produced by another drainage located farther north.

Dry Creek enters the San Miguel River about 0.5 mile upgradient of the site and drains Mancos Shale and Dakota Sandstone in Dry Valley. It flows during the spring and intermittently during other parts of the year. Water from Dry Creek is usually turbid and increases the suspended sediment load in the San Miguel River near the site.

A distributary cutoff on the Maupin property is the source of several small ponds fed by springs. Surface location 0538 is recorded as a spring in the BLRA and is part this system. Figure 3-3 from 1974 shows the main course of the San Miguel River was located farther south and occupied the present seep/pond area of 0538. By 1986 (Figure 3-4) the current course of the river had shifted to the north, and by 1998 (Figure 3-7) the present course of the river had left the former channel as a low scarp along an expanding riparian willow-sapling zone.



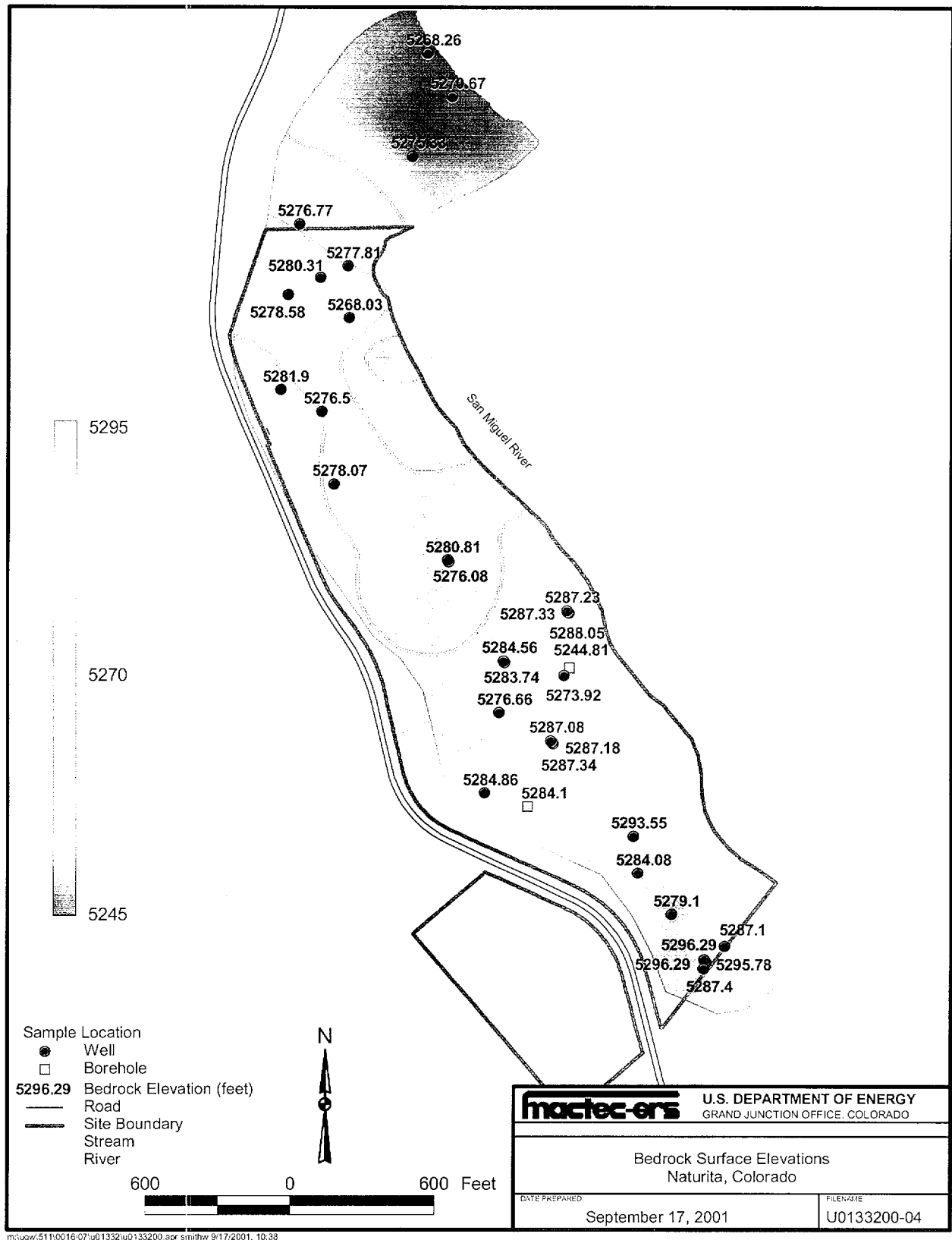


Figure 5-2. Bedrock Surface Elevations at the Naturita Site

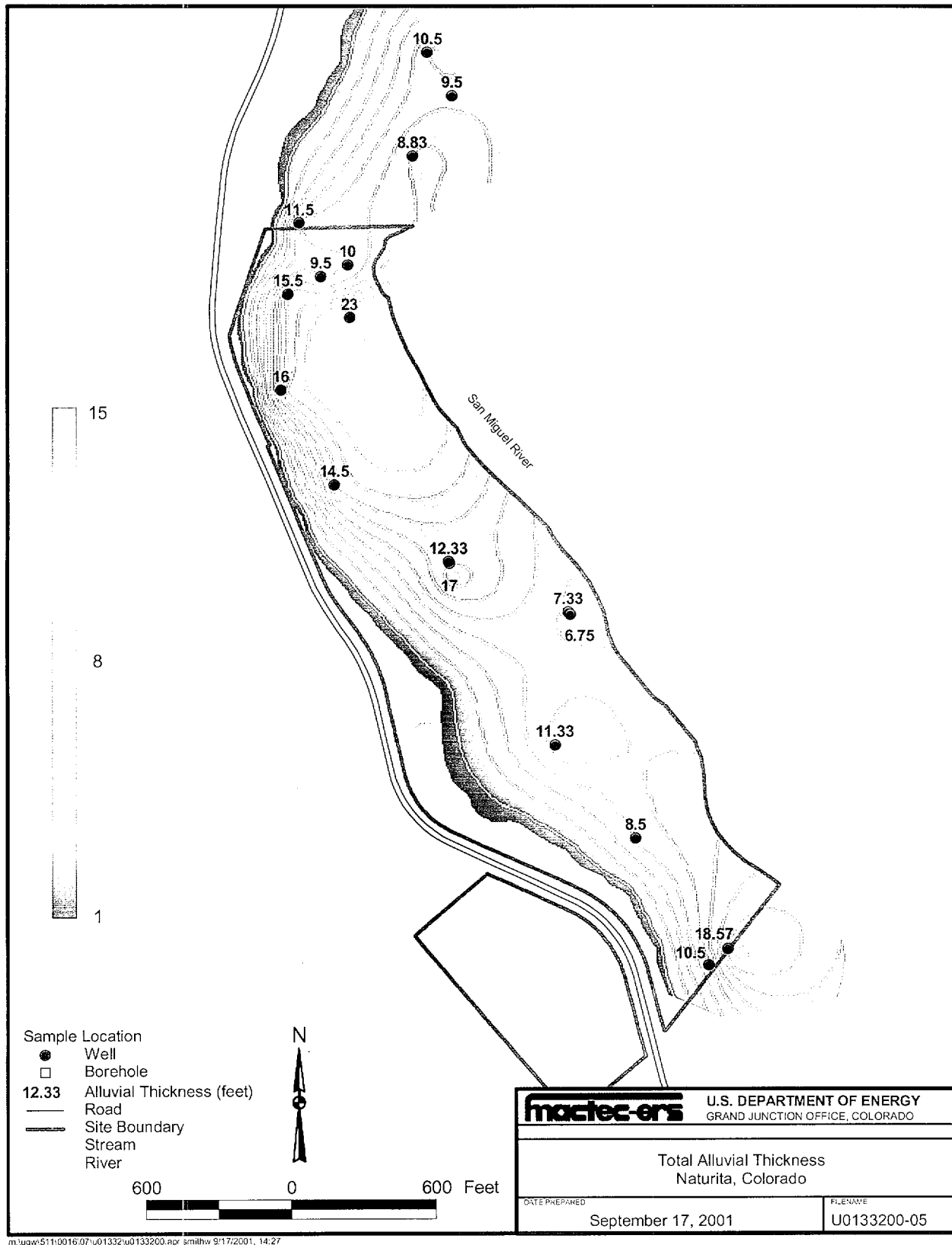


Figure 5-3. Thickness of the Alluvium at the Naturita Site

5.2.2 Alluvial Aquifer

The alluvial aquifer is the uppermost aquifer at the Naturita site and consists of the saturated portion of the river-lain alluvium. It is the only aquifer of concern for ground water contamination because the underlying Brushy Basin Member of the Morrison Formation has an upward hydraulic gradient. The alluvial aquifer is a wedge of sediment that varies in thickness from zero as it pinches out along the western bedrock to about 23 ft along the San Miguel River near the northern portion of the site (Figure 5-3 and Figure 5-4). However it generally ranges from only about 5 to 10 ft in thickness over most of the site. The section of interest underlying the site is approximately 4,000 ft long and 700 ft wide. Recharge and discharge occur along the length of the San Miguel River depending on the river level. However, the primary recharge zone is thought to be a 600-ft strip from the San Miguel River about 2,400 ft south of the site near the confluence of Dry Creek, where the river makes a sharp bend. From there, water migrates slowly northwest through the aquifer until it finally exits back into the San Miguel River north of the site along a 500-ft zone where the river intersects bedrock on the Maupin property. The aquifer pinches off against the San Miguel River at that point. Another source of water entering the alluvial aquifer is from arroyos draining from the west. Their significance is probably greater locally where water from these drainages could contribute to flushing contaminants in the aquifer near the western edge of the site. The last source of recharge is infiltration of rainfall. The Hopkins-Montrose airport in Nucla 2.5 miles east of the site receives approximately 11 inches of rain per year. The surficial aquifer below the site contains approximately 30,000,000 gallons (4 million cubic feet) of water at any one time.

Hydraulic characteristics of the alluvial aquifer were determined by water age determinations, stable isotope and chloride measurements, falling head slug tests, and bromide tracer tests. Ground water age determination studies using tritium-helium and chlorofluorocarbon methods generally indicate increases in the age of water near the western side of the site. Flow paths are generally parallel to the San Miguel River (Figure 5-42), and older ages suggest slower flow rates along the western side of the site. This agrees well with ground water surface contour map shown in Figure 5-5. Lines of equal elevations are generally perpendicular to the San Miguel River and flow directions perpendicular to the elevation contours. Discussion of the methods for determining ground water age and comparison of results of ground water ages are in Section 5.3.4. The results of the age determinations agree with modeling results that show the "dog-leg" portion of the aquifer in the northwestern part of the site has slower ground water flow rates than areas along the eastern side of the site. The open gravel pit at the southern end of the site intersects ground water. Chloride and stable isotope studies suggest that this dewatering of the upgradient head of the aquifer will have an important, although negative, effect on potential natural flushing or pumping of contaminated water at the site. Section 5.4.6 discusses this in greater detail.

Falling head slug tests were performed for 13 wells in November 1999 and May 2000. The hydraulic conductivity ranged from 19 ft/day (MAU04) to 333 ft/day (NAT09) and averaged 95 ft/day. Bromide tracer tests were performed on six wells. These results indicated hydraulic conductivities that ranged from 43 ft/day to 215 ft/day. No recognized pumping tests were performed for the site.

5.2.3 Bedrock Aquifer

Two wells, 0502 and 0603, were drilled through the Brushy Basin Member and penetrated the Salt Wash Member of the Morrison Formation during the surface program. Falling head slug tests were conducted in the wells to estimate hydraulic conductivities in the Salt Wash and alluvial aquifers. Results indicated a low hydraulic conductivity in the Brushy Basin Member and a vertical hydraulic gradient from the Salt Wash Member into the Brushy Basin Member. This combination prevents any downward migration of contaminated water into the Salt Wash aquifer and demonstrates that the Brushy Basin acts as an effective aquitard. Appendix B of the Remedial Action Plan for the Naturita site (DOE 1998a) provides details of the bedrock aquifer.

5.3 Geochemistry

5.3.1 Source Areas and Contaminants

The sources of contamination at the Naturita site were ores hauled from the surrounding area, mostly within a 50-mile radius, from 1939 to 1958 and processed at the mill. These ores typically contained, in addition to uranium and vanadium, elevated concentrations of arsenic, molybdenum, selenium, and sulfate. During the period from 1947 to 1963, 704,000 tons of ore were processed at the site. Sulfuric acid, bases, and other chemicals were used to process the ores. Estimated volumes of production water and wastewater were not found in a search of the literature, but millions of gallons of contaminated water may have seeped into the ground.

Tailings at the Naturita site were hauled away for further processing in the late 1970s, and the site underwent surface remedial action to remove approximately 771,000 cubic yards of RRM from 1993 to 1998. A number of areas containing contaminated soils were left in place under the application of supplemental standards. The most contaminated ground water on the site is below the former tailings pile area. There, vanadium concentrations still reflect the footprint of the former surface contamination.

5.3.2 Surface Water Quality

The only permanent surface water features at the Naturita site are the San Miguel River and a ground water seep that discharges near location 0559 and flows to the San Miguel River near location 0538. Contaminated alluvial ground water from the site has the potential to discharge to these two areas, both of which are downgradient of the former tailings area. Impacts to these surface water locations are evaluated by comparison to water quality measurements at locations that are unaffected by site-related contamination.

5.3.2.1 Background Surface Water Quality

Background surface water quality samples were collected from the San Miguel River at location 0531 during November 2000 and March 2001. Location 0531 is upstream and upgradient from the site (Figure 5-6). Table 5-1 summarizes the analytical results of these background samples.

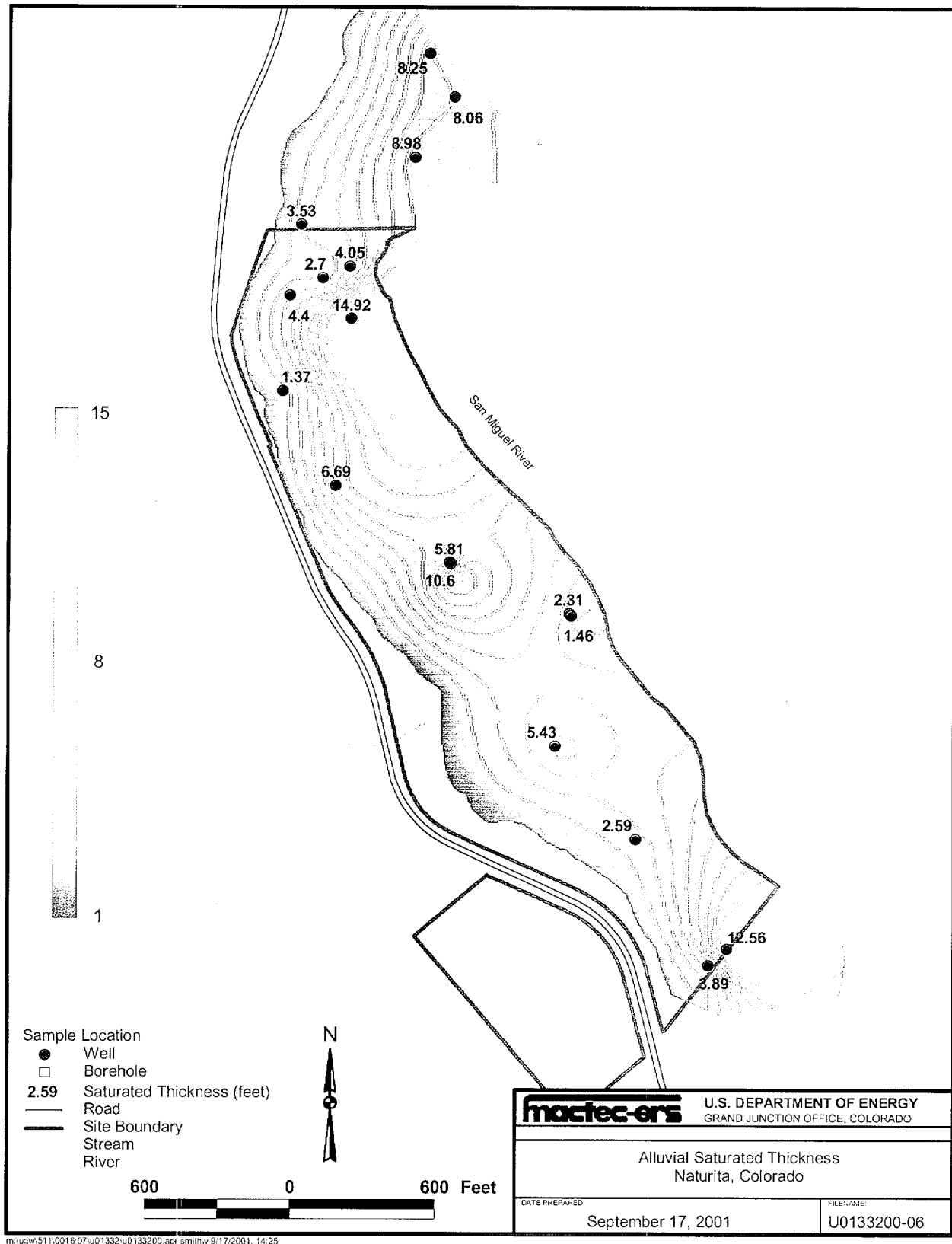


Figure 5-4. Thickness of Saturated Alluvium at the Naturita Site

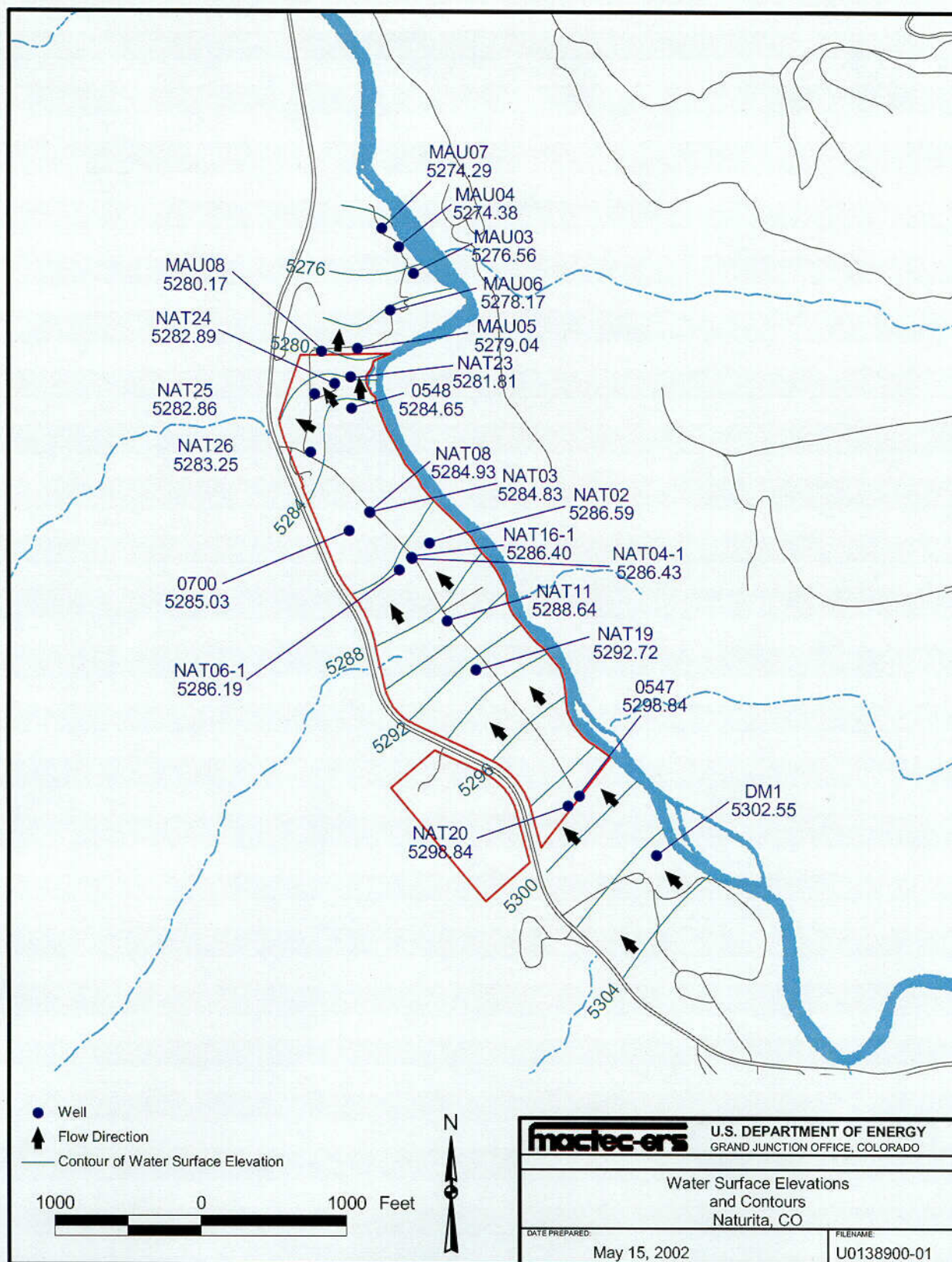


Figure 5-5. Water Surface Elevations and Contours

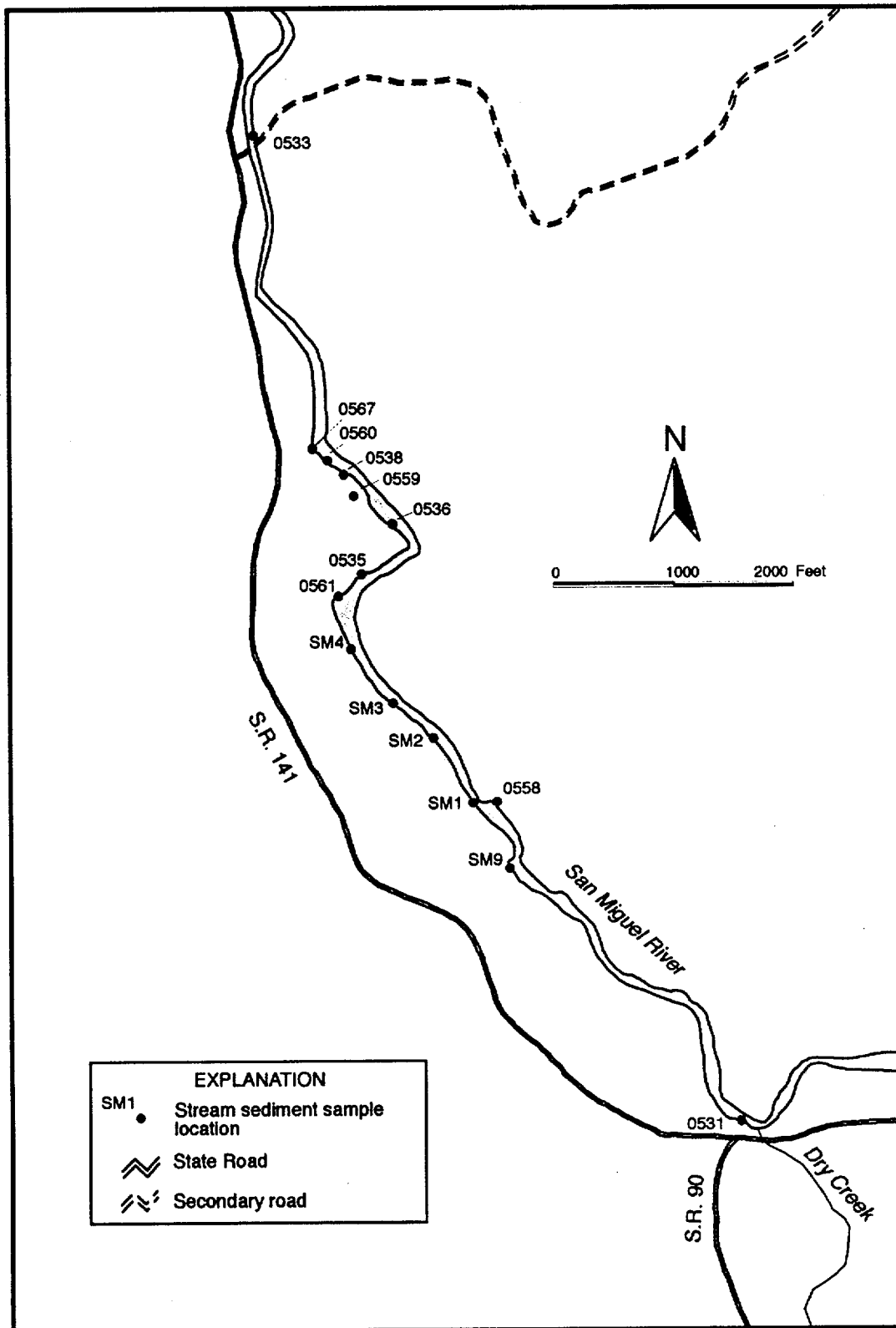


Figure 5-6. Locations of Surface Water and Sediment Samples at the Naturita Site

Table 5-1. Background Surface Water Quality at Location 0531

		Concentration		
Analyte	Units	November 2000	Feb/Mar 2001	Average
Major Ions				
Calcium	mg/L	54	82	68
Chloride	mg/L	0.40	8.4	4.40
Magnesium	mg/L	29	27	28.2
Nitrate	mg/L	0.05	<0.02	
Potassium	mg/L	1.7	1.8	1.74
Sodium	mg/L	23	28	25.4
Sulfate	mg/L	236	239	238
Metals				
Aluminum	mg/L	<0.28	<0.28	
Arsenic	mg/L	0.0007	0.0007	0.0007
Cadmium	mg/L	<0.04	<0.04	
Chromium	mg/L	<0.04	<0.04	
Cobalt	mg/L	<0.04	<0.04	
Copper	mg/L	<0.04	<0.04	
Iron	mg/L	<0.03	<0.03	
Lead	mg/L	<0.20	<0.20	
Manganese	mg/L	<0.04	<0.04	
Molybdenum	mg/L	<0.04	<0.04	
Nickel	mg/L	<0.04	<0.04	
Selenium	mg/L	0.0008	0.001	0.0009
Uranium	mg/L	0.0029	0.0023	0.0026
Vanadium	mg/L	<0.04	<0.04	
Zinc	mg/L	<0.04	<0.04	
Other				
Barium	mg/L	0.08	0.05	0.06
Boron	mg/L	<0.04	0.09	
Bromide	mg/L	6.6	0.05	3.33
Lithium	mg/L	<0.03	<0.03	
Phosphorus	mg/L	<0.04	<0.04	
Silicon	mg/L	3.4	2.4	2.90
Strontium	mg/L	1.2	1.1	1.15
Field Measurements				
Alkalinity as CaCO ₃	mg/L	134	108	121
Dissolved oxygen	mg/L	10.8	13.6	12.2
Oxidation-Reduction Potential	mV	290	361	325
pH	standard units	8.43	8.48	8.46
Specific Conductance	µS/cm	730	816	773
Temperature	°C	1.57	3.82	2.70

Notes:

The mean was not calculated if at least one result was below detection limit.

Specific conductance, oxidation-reduction potential, and pH were measured on unfiltered samples; samples for all other measurements were filtered through a 0.45 µm filter.

µS/cm = microsiemens per centimeter

mV = millivolts

5.3.2.2 Site Impacts on Surface Water

Samples were collected adjacent to the millsite at locations SM9, SM1, 0558, SM2, SM3, SM4, 0561, 0535, 0536, 0560 and downgradient of the site at location 0533 to evaluate the effects of ground water contaminants on the San Miguel River. Samples were also collected from a ground water seep at locations 0559 and 0538. Ponded water at location 0567 was collected in March 2001.

A comparison of San Miguel River sampling results from on-site, upgradient, and downgradient locations generally indicates that water quality is unaffected by discharge from the contaminated alluvial aquifer.

Figure 5-7 through Figure 5-11 show concentrations of arsenic, chloride, selenium, sulfate, and uranium, respectively, at surface water locations along the San Miguel River. Vanadium, molybdenum, and nitrate concentrations were at or below detection limits at all locations and are not shown. Most arsenic (Figure 5-7), selenium (Figure 5-9), and uranium (Figure 5-11) concentrations at locations adjacent to and downstream of the former tailings area are all near the background concentration measured at location 0531. However, samples collected during March 2001 at locations 0567 and 0561 have elevated concentrations of most constituents, including uranium, which exceeded the maximum concentration limit established for the UMTRA Project. These samples were collected during low-flow conditions in pools close to the bank of the river. These values most likely represent concentrations of discharging ground water before it is diluted with river water. Some further concentration of contaminants may have occurred through evaporation. At low river stage, flow from these pools to the river is minimal. When the river rises in the spring and summer, this contaminated water should be diluted and flushed out of the stagnant pool areas.

Figure 5-12 through Figure 5-17 compare arsenic, chloride, selenium, and sulfate concentrations, sulfate/chloride ratio, and uranium concentrations, respectively, in samples from the ground water seep locations. Because the chemistry of water discharging from the seep more closely resembles that of ground water than surface water, the concentrations shown in Figure 5-12 through Figure 5-16 are compared to background ground water concentrations measured at well DM1. The water is similar in chemistry to that of nearby wells MAU03, MAU04, and MAU07, which are also shown for comparison. Water quality results from the ground water seep at locations 0559 and 0538 show that concentrations of most constituents exceed the background concentrations measured at location 0531 and well DM1. Vanadium, molybdenum, and nitrate concentrations were at or below detection limits at all locations and are not shown.

Concentrations of arsenic, chloride, and selenium in the ground water seeps shown in Figure 5-12 through Figure 5-14, respectively, are at or near background concentrations measured at location 0531 and well DM1. These values are also well below the UMTRA Project maximum concentration limits. Water in well MAU07 is thought to reflect millsite contamination due to concentrations of chloride, sulfate, and uranium above background values. This may be from deposits of tailings washed in by the San Miguel River many decades ago and deposited in an old channel of the river.

Figure 5-15 shows sulfate concentrations in samples from the ground water seep locations. Almost all concentrations exceed background values measured at location 0531 and DM1 and exceed the Colorado secondary drinking water standard. An exception is the sample collected in

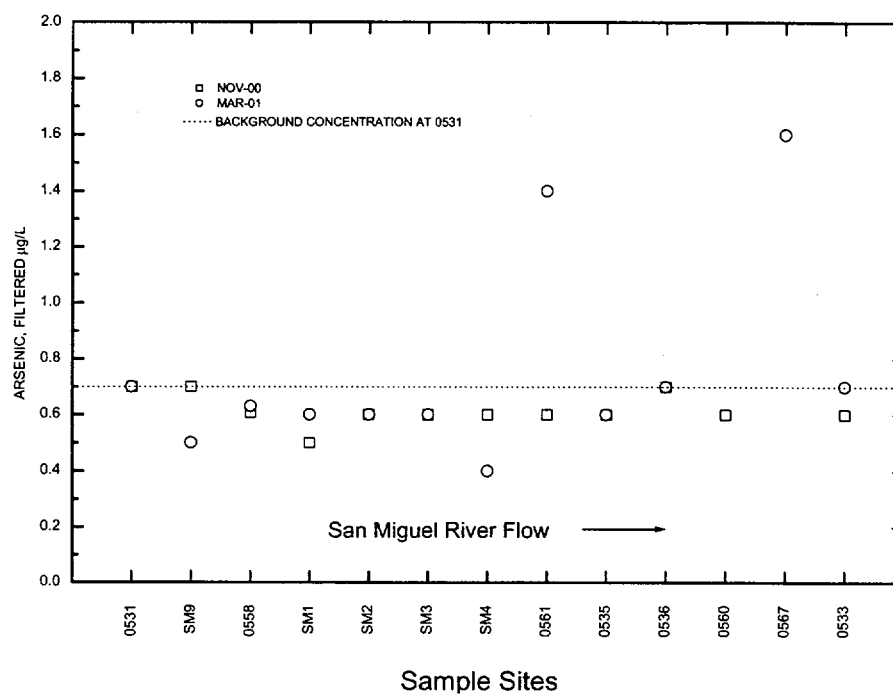


Figure 5-7. Arsenic Concentrations at Surface Water Sampling Locations Along the San Miguel River

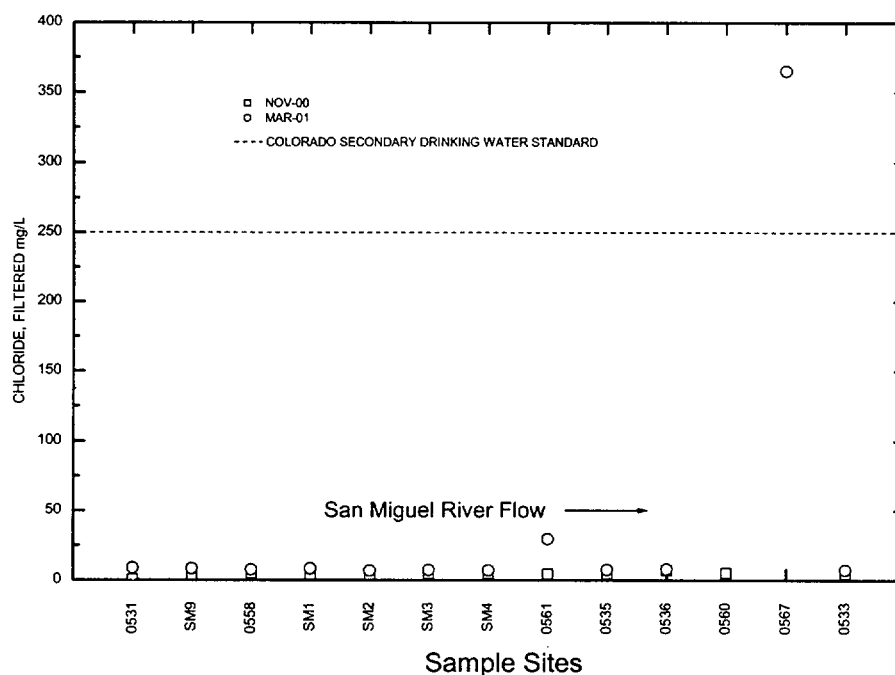


Figure 5-8. Chloride Concentrations at Surface Water Sampling Locations Along the San Miguel River

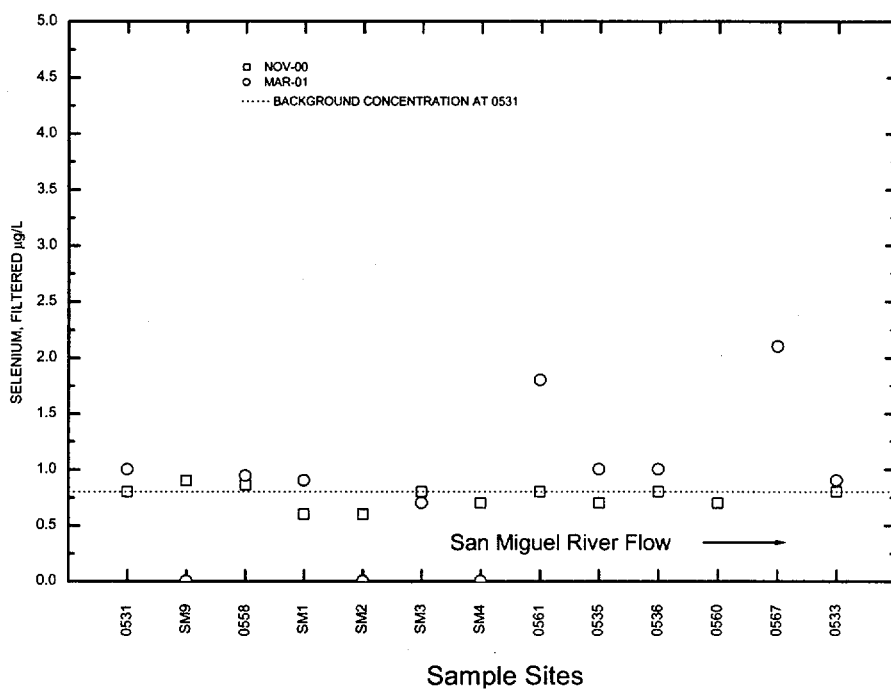


Figure 5–9. Selenium Concentrations at Surface Water Sampling Locations Along the San Miguel River

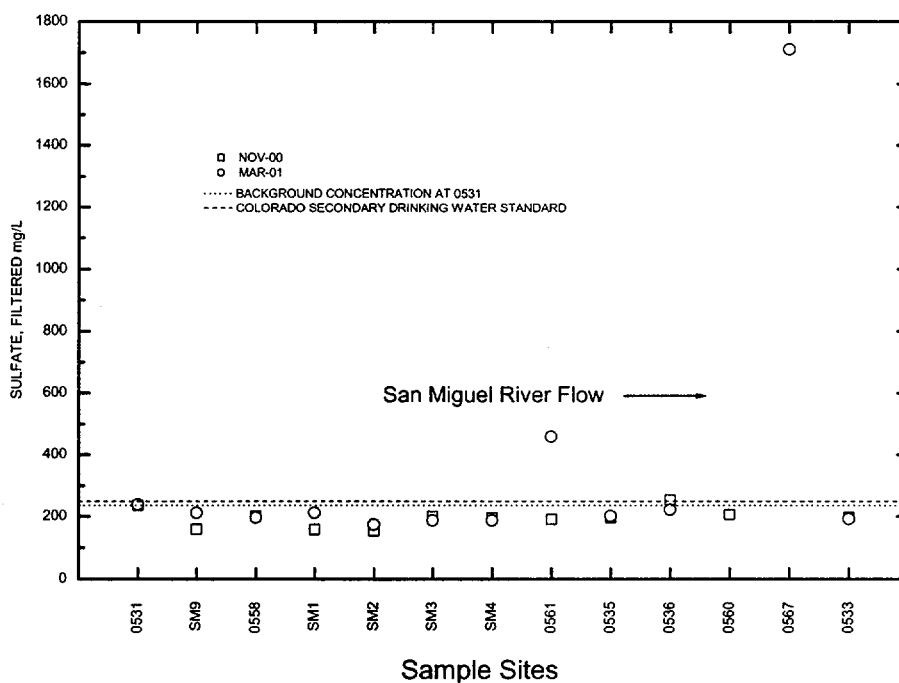


Figure 5–10. Sulfate Concentrations at Surface Water Sampling Locations Along the San Miguel River

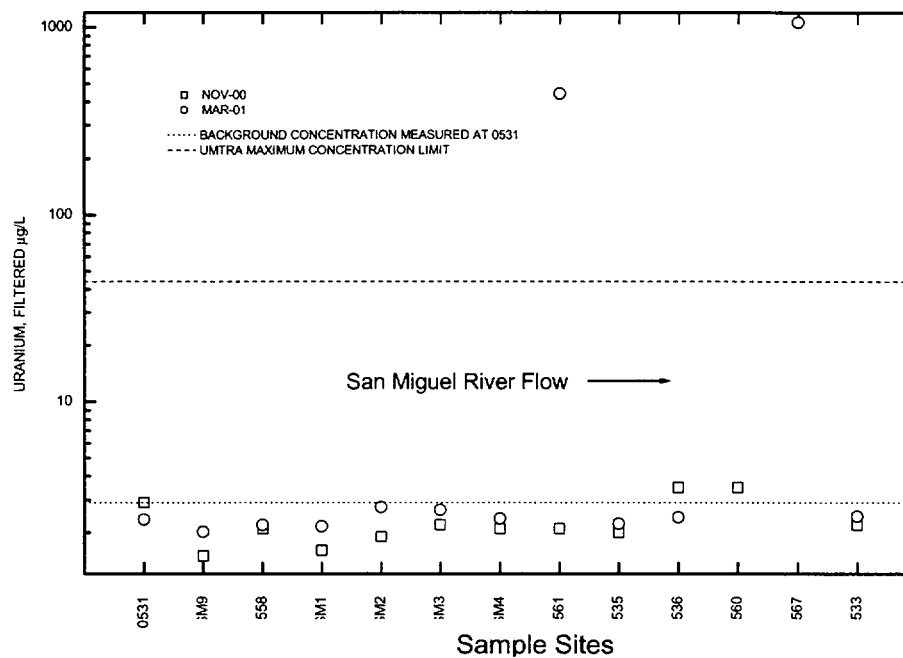


Figure 5-11. Uranium Concentrations at Surface Water Sampling Locations Along the San Miguel River

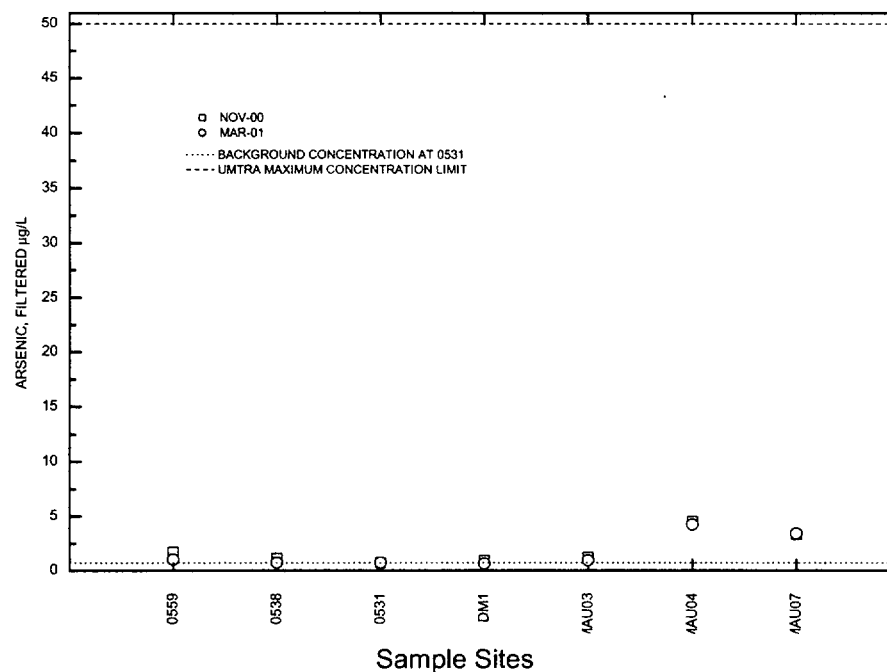


Figure 5-12. Arsenic Concentrations at the Ground Water Seep Locations

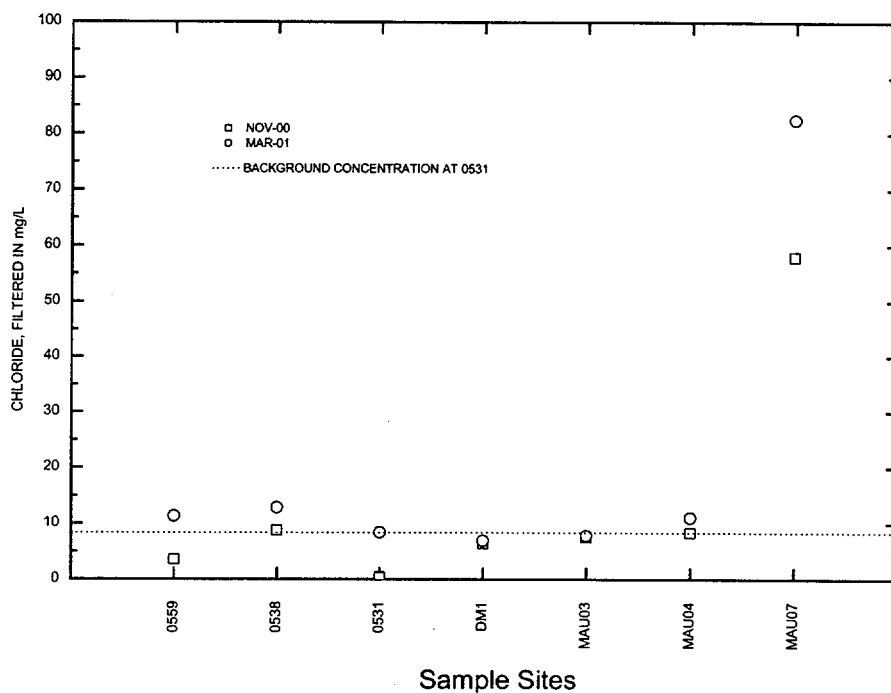


Figure 5-13. Chloride Concentrations at the Ground Water Seep Locations

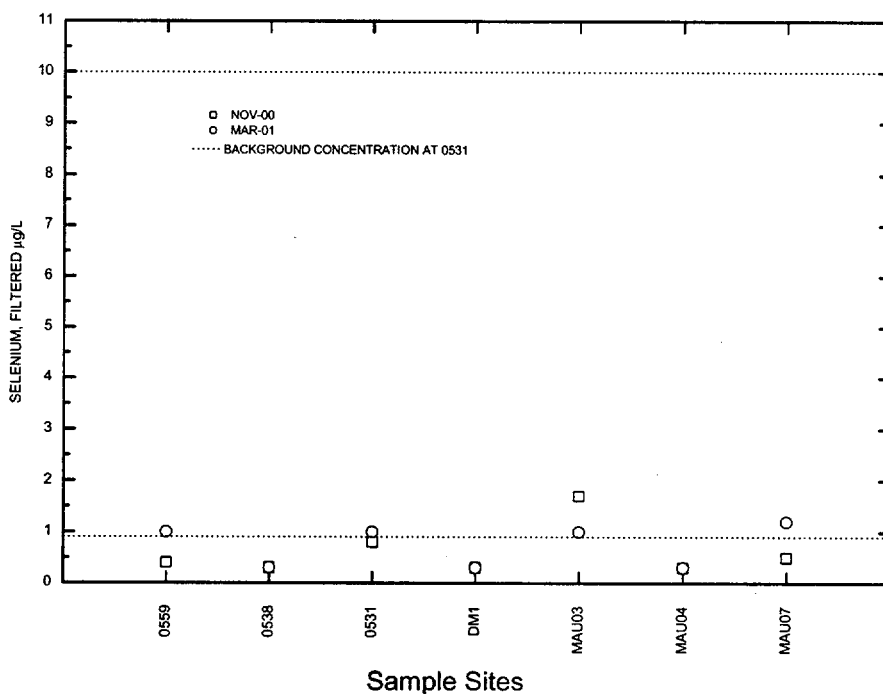


Figure 5-14. Selenium Concentrations at the Ground Water Seep Locations

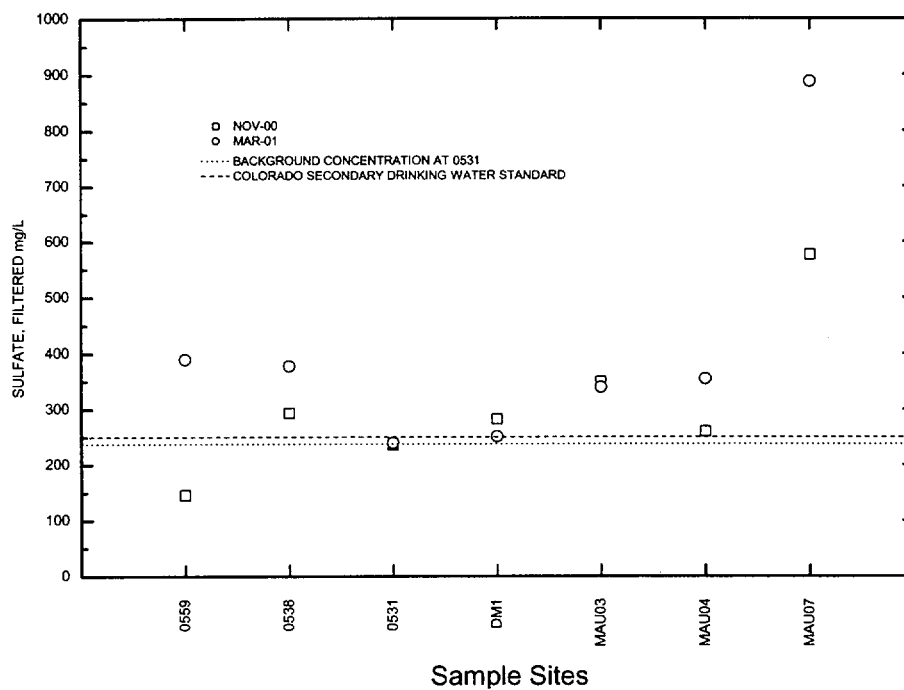


Figure 5-15. Sulfate Concentrations at the Ground Water Seep Locations

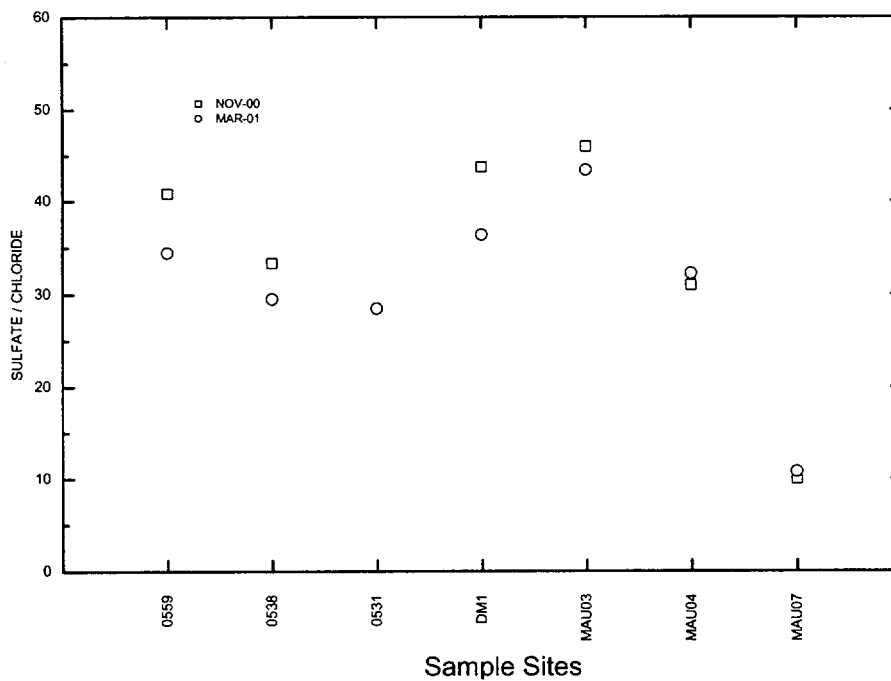


Figure 5-16. Sulfate/Chloride Ratio at the Ground Water Seep Locations

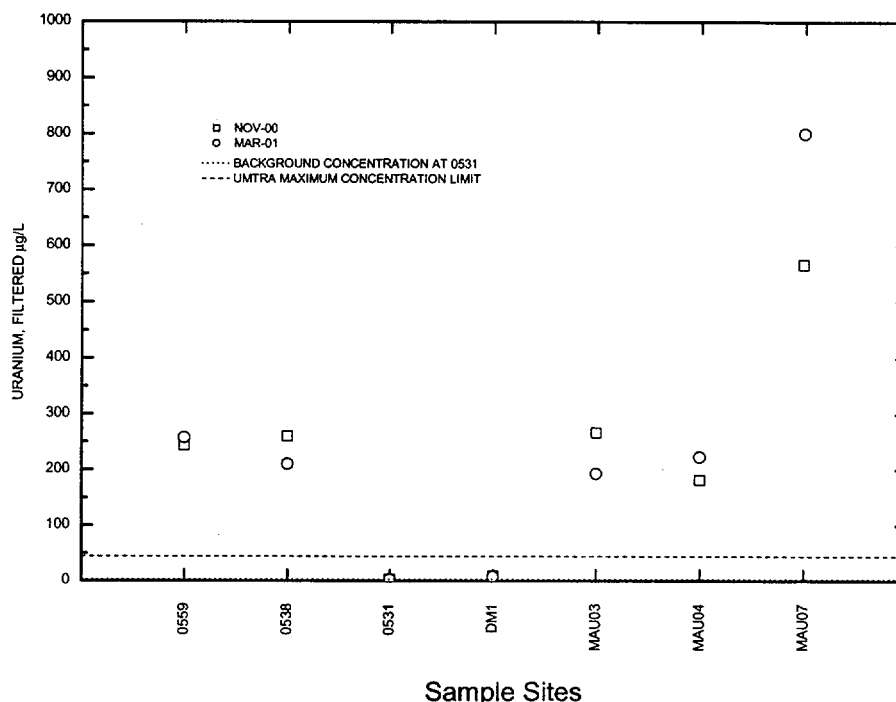


Figure 5-17. Uranium Concentrations at the Ground Water Seep Locations

November 2000, which has less sulfate than that measured in 0538 and in the background samples. During March 2001, sulfate concentrations were above background levels and were similar to those measured at location 0538. A similar pattern can also be seen in chloride concentrations shown in Figure 5-13. Figure 5-16 shows the sulfate/chloride ratio in the ground water seeps. The ratio for the two sites is similar to that calculated for the San Miguel River and nearby wells MAU03 and MAU04. Well MAU07 has a lower sulfate/chloride ratio than the ground water seeps and is more typical of the ratio found in the contaminated area of the alluvial aquifer away from the San Miguel River (see Section 5.3.3.2). This suggests that ground water in the area of the seeps, MAU03, and MAU04 has a greater influence from surface water than that located at MAU07.

As seen in Figure 5-17, uranium concentrations exceed background concentrations and exceed the UMTRA Project maximum concentration limit. Concentrations in the seeps are similar to those in nearby wells MAU03 and MAU04. Uranium concentration in well MAU07 is much higher than in the ground water seeps. The sulfate/chloride ratio indicates that ground water in the area of MAU03, MAU04, and the ground water seeps has a significant component of surface water from the San Miguel River that has been contaminated by buried uranium tailings near surface water location 0535 (Figure 5-6). Because samples were collected from the ground water seep locations only in November 2000 and March 2001, no historical trend in uranium concentration can be inferred. However, USGS has collected data at nearby wells MAU03 and MAU04 since November 1998 and at MAU07 since September 1999. As shown in Figure 5-18, Figure 5-19, and Figure 5-20, respectively, uranium concentrations in wells MAU03, MAU04, and MAU07 have not decreased with time, but rather appear to be controlled by the water table, which is controlled by river stage. Uranium concentrations at location 0559 show a trend similar to that observed in the wells, that is, concentration was greater in March 2001 than in November 2000; location 0538 shows the opposite trend in comparison to the wells (uranium

concentration was greater in November 2000 than in March 2001). Additional data are needed to determine if the uranium concentration in the ground water seeps varies directly with river stage and with uranium concentrations in nearby wells.

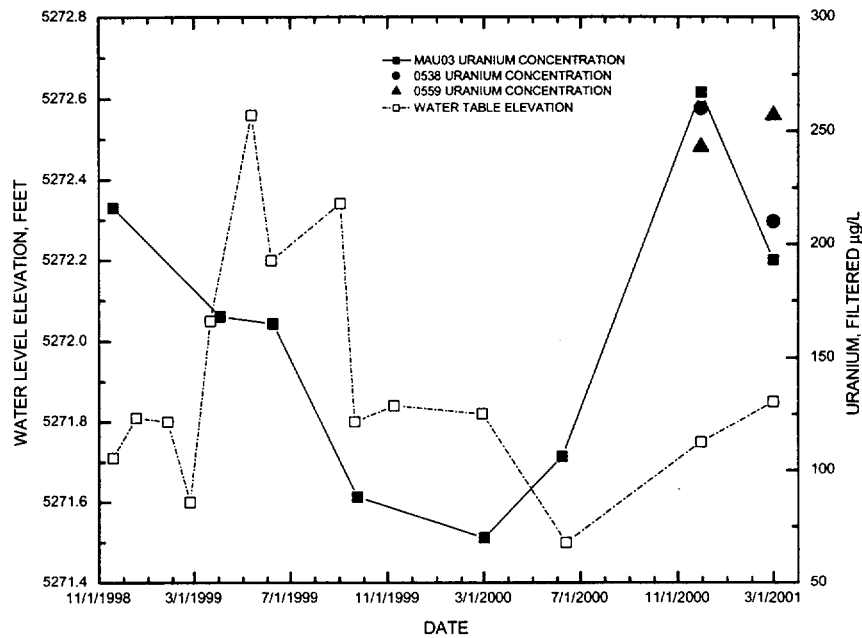


Figure 5-18. Uranium Concentrations and Water Table Elevation in Well MAU03

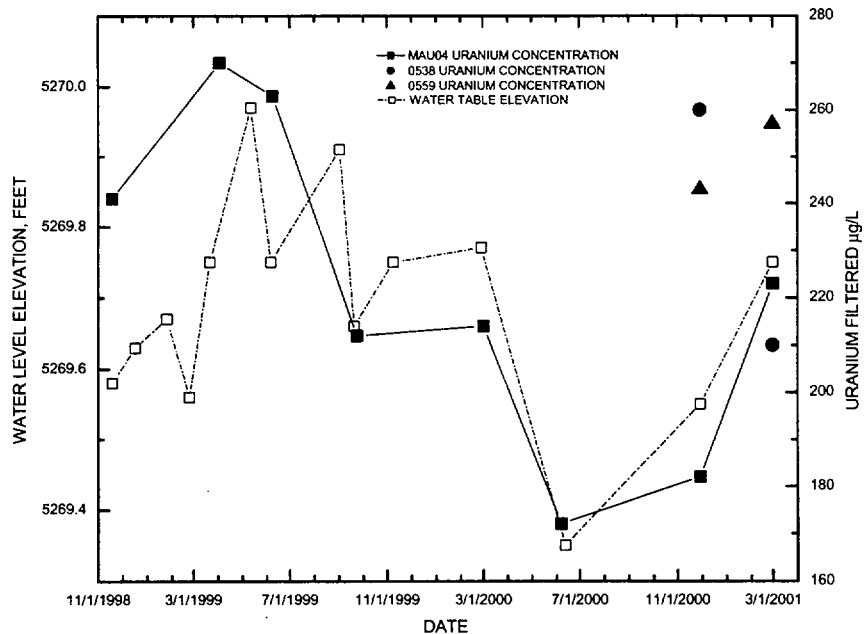


Figure 5-19. Uranium Concentrations and Water Table Elevation in Well MAU04

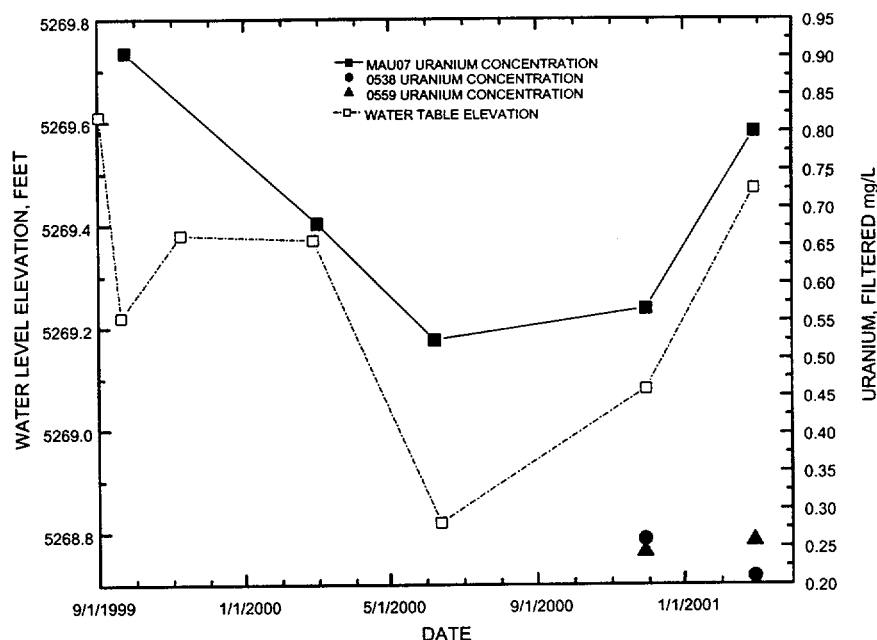


Figure 5-20. Uranium Concentrations and Water Table Elevation in Well MAU07

5.3.3 Alluvial Aquifer Water Quality

USGS has collected ground water quality data at the Naturita site since November 1998 as part of a uranium transport study. The most recent samples were collected in November and December 2000 and in February and March 2001 to support DOE's monitoring of ground water quality.

5.3.3.1 Background Alluvial Ground Water Quality

Background ground water quality is characterized by samples from a site located in the same aquifer upgradient from the former millsite (Figure 5-21). Data from these samples are summarized in Table 5-2; Appendix B is a complete list of ground water monitoring results.

Background ground water quality at the Naturita site is generally good, with slightly high levels of sulfate and manganese. Sulfate concentration at background location DM1 exceeded the Colorado secondary drinking water standard of 250 mg/L during November 2000 and March 2001. Mean background concentrations are lower than the UMTRA Project maximum concentration limits for arsenic (0.05 mg/L), cadmium (0.01 mg/L), molybdenum (0.1 mg/L), nitrate (44 mg/L as NO_3), selenium (0.01 mg/L), and uranium (0.044 mg/L). Vanadium concentrations were below detection. Concentrations of all the trace elements and nitrate were at or near detection limits. Chloride and iron concentrations are also below the limits set by the Colorado secondary drinking water standard of 250 mg/L and 0.3 mg/L, respectively.

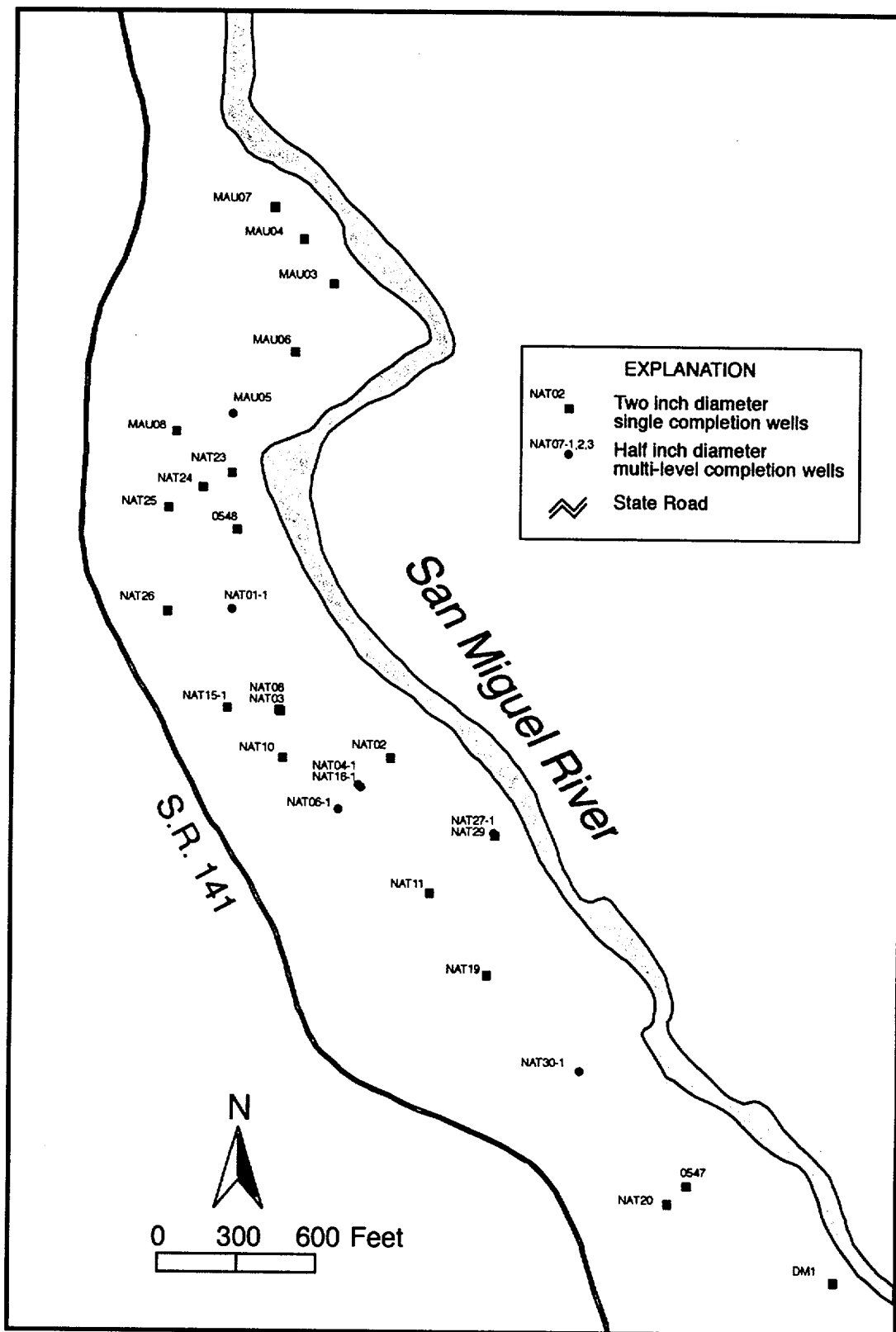


Figure 5-21. Locations of Naturita Wells Sampled in November 2000 and March 2001 During the DOE UMTRA Phase

Table 5-2. Background Concentrations in Well DM1

Analyte ^a	Units	June 2000	November 2000	March 2001	DM1 Mean ^b
Major					
Calcium	mg/L	54.1	111	109	91.4
Chloride	mg/L	4.70	6.45	6.90	6.02
Magnesium	mg/L	20.3	28.9	27.2	25.5
Nitrate	mg/L	NA ^c	0.05	0.05	0.05
Potassium	mg/L	1.85	1.76	1.44	1.68
Sodium	mg/L	18.2	25.1	25.1	22.8
Sulfate	mg/L	131	282	251	221
Metals					
Aluminum	mg/L	<0.29	0.18	0.34	0.22
Arsenic	mg/L	ND ^d	0.0009	0.0006	0.00075
Cadmium	mg/L	<0.04	<0.02	<0.04	
Iron	mg/L	0.29	0.08	0.09	0.15
Lead	mg/L	<0.21	<0.10	<0.20	
Manganese	mg/L	0.32	0.29	0.19	0.27
Molybdenum	mg/L	<0.04	<0.02	<0.04	
Selenium	mg/L	ND ^d	<0.0003	<0.0003	
Uranium	mg/L	0.00432	0.0087	0.00707	0.0067
Vanadium	mg/L	<0.04	<0.02	<0.04	
Other					
Silicon	mg/L	4.64	4.05	4.07	4.25
Strontium	mg/L	0.83	1.28	1.10	1.07
Field Measurements					
Alkalinity	mg/L CaCO ₃	227	156	159	180
Dissolved oxygen	mg/L	0.35	0.16	0.25	0.25
Oxidation-Reduction Potential	mV	138	210	214	187
pH	standard units	7.12	7.13	7.33	7.19
Specific Conductance	µS/cm	589	851	852	764

Detection limits may vary due to sample dilution during analysis

^aSpecific conductance, pH, and oxidation-reduction potential were measured on unfiltered samples; all other analysis were performed on samples that were filtered through a 0.45µm filter.

^bFor results less than the detection limit, one-half the detection limit was used to calculate the mean of the three sampling rounds. If at least two of the three values were below the detection limit, the mean was not calculated.

^cNA = not analyzed.

^dND = Not detected. Method detection limit was too high to be used. Subsequent samples were analyzed using a different method to achieve a lower detection limit.

In general, background anions are dominated by sulfate, and the cations are composed of a calcium-sodium-magnesium mixture in which calcium is the most abundant. Background alkalinity as calcium carbonate ranges from 156 to 227 mg/L. Sulfate concentrations range from 131 to 282 mg/L. Calcium concentrations range from 54 to 111 mg/L. Sodium concentrations range from 18 to 25 mg/L. Magnesium concentrations range from 20 to 29 mg/L. The pH ranges from 7.1 to 7.3 with a mean value of 7.2. Oxidation-reduction potential referenced to the standard hydrogen electrode ranges from 138 to 214 mV and averages 187 mV, which is slightly oxidizing.

5.3.3.2 Nature and Extent of Alluvial Ground Water Contamination

From August 1998 through June 2000, USGS sampled ground water at the Naturita site to provide data for the surface complexation modeling being performed for the NRC. During November 2000 and March 2001, sampling was done to monitor the nature and extent of ground water contamination at the site to support this Site Observational Work Plan. Results from all the sampling activities are listed in Appendix B and are summarized in Table 5-3. Locations of the monitoring wells are shown in Figure 5-21.

All the constituents listed in Table 5-3 except nitrate, aluminum, cadmium, lead, and molybdenum are fairly prevalent in the aquifer, as shown by the high frequency (greater than 50 percent) of constituents with concentrations that exceeded the upper limit of the background concentration range. Constituents that exceeded background concentration in less than 50 percent of the wells (nitrate, aluminum, cadmium, lead, and molybdenum) were most often present in quantities below detection limit.

Uranium, chloride, and vanadium exceed background concentrations by the greatest amount. The maximum uranium concentration of 2.51 mg/L detected in well NAT26 is 289 times greater than the background concentration measured in well DM1. The maximum vanadium concentration of 7.55 mg/L detected in well NAT08 is 189 times greater than background. The maximum chloride concentration of 632 mg/L was also detected in well NAT26 and is 92 times greater than background. The remaining constituents show less contrast; arsenic exceeds the background concentration by a factor of 71, sodium exceeds by a factor of 47, selenium exceeds by a factor of 46, potassium exceeds by a factor of 22, manganese exceeds by a factor of 20, and iron exceeds by a factor of 19.

Concentrations of arsenic, molybdenum, selenium, and uranium all exceed their UMTRA maximum concentration limits (Table 2-1). Chloride and sulfate concentrations both exceed the Colorado secondary drinking water standard of 250 mg/L, although the background range of sulfate also slightly exceeds this value. Vanadium concentrations are elevated above risk-based levels for drinking water (see Section 6.1). These constituents have been selected for the remainder of this discussion.

Several wells were added during 2001 and 2002 for various reasons. These wells are shown on Plate 1. Well 700 was placed in an area that was thought to be the center of the vanadium plume. Concentrations were not higher than those found in nearby wells. Well 701 was established to determine the level of ground water contamination in an area of supplemental standards on the vicinity property. Contaminant concentrations were not higher at well 701 than in other wells on the vicinity property farther downgradient. Other boreholes in this area (702, 703, 704, and 705) were not completed as wells.

Well 715 was drilled in March 2002 to determine if contamination had traveled under the San Miguel River and into the alluvial aquifer on the east side of the river. Analyses of water from the well demonstrated that uranium concentrations range up to 0.080 mg/L, or about twice the UMTRA standard. A map in Section 3 of the Naturita Remedial Action Plan (DOE 1998a) labeled "Final Contaminated Material Excavation Plan" shows areas containing millsite related contamination on the east side of the San Miguel River and downgradient of the millsite on this vicinity property. A part of this area underwent remedial action and other portions of this property received supplemental standards. This figure shows that millsite contamination and

potentially associated ground water contamination could extend as far downgradient as the Calamity Bridge, about 3,750 feet downgradient of the millsite. Another possibility is that the plume found on the west side (the millsite side) of the San Miguel River has traveled below the river and has contaminated the alluvial aquifer on the east side at well 715. The entire area designated for potential supplement standards application was included in the institutional control boundary.

Well 716 is a water well that will be drilled approximately 600 feet into the Entrada Sandstone aquifer to supply potable water to the family living on the vicinity property. The well will be drilled through about 480 feet of Morrison Formation mudstones, shales, siltstones, and sandstones that contain poor quality water and could contain concentrations of uranium above the UMTRA standard. To guard against possible cross contamination of the potable water below, the first portion of the well will be drilled through the Morrison Formation into the underlying shales of the Summerville Formation, which will act as an aquitard. This section of the well will be sealed off to the surface using steel casing. The well will be drilled another 100 feet and completed in the Entrada Sandstone below Summerville Formation.

Arsenic

Figure 5-22 shows the concentrations of arsenic measured during the November 2000 and March 2001 sampling. Arsenic concentrations at most wells were near the detection limit of 0.00018 mg/L, and concentrations in the March 2001 samples exceeded the UMTRA maximum concentration limit of 0.05 mg/L in only three wells (NAT03, NAT08, and NAT11). The maximum concentration was detected in well NAT08, which is near the center of the former tailings area. These three samples all show an increase in arsenic concentration from the November 2000 sampling. This pattern is also seen in well NAT16-1. However, concentrations in samples from wells NAT04-1, NAT06-1, NAT10, and NAT08 all decreased slightly. As shown in Figure 5-23, the highest concentrations of arsenic have not migrated beyond the area of the former tailings pile. This is most likely due to the low mobility of arsenic under the reducing conditions found in this area. Under these conditions, arsenic is readily adsorbed onto iron hydroxides that may coat sediments.

Molybdenum

Most measurements of molybdenum were near the detection limit (Figure 5-24). Concentrations in samples from wells NAT15-1, NAT01-1, NAT26, and in one sample from well MAU05 were over the UMTRA maximum concentration limit of 0.1 mg/L. The maximum concentration of 0.18 mg/L was detected in well NAT26. All these wells except MAU05 are located in the area of the former tailings pile. Figure 5-25 shows the distribution of molybdenum concentrations.

Selenium

As Figure 5-26 shows only well NAT26 had selenium concentrations that were greater than the UMTRA maximum concentration limit of 0.01 mg/L. Most wells located near the former tailings area had concentrations of selenium that were in the range found in upgradient wells 0547 and NAT20 (Figure 5-27). As with arsenic, selenium is also less mobile under reducing conditions, and any selenium contamination that came from the former tailings area should still be present at the site.

Table 5-3. Ground Water Quality at the Naturita Site, August 1998 to March 2001

Analyte ^a	Units	Mean ^b	Range	Max Well	Number of Samples	Percent of Samples Over Background	Background Range
Major Ions							
Calcium	mg/L	202	60.2-492	NAT01-2	315	94	54.1-111
Chloride	mg/L	74	0.05-632	NAT26	315	98	4.70-6.90
Magnesium	mg/L	59.1	16.2-145	NAT01-2	315	96	20.3-28.9
Nitrate	mg/L		<0.02-3.56	NAT26	54	9	0.05
Potassium	mg/L	10.5	1.41-40.2	MAU08	315	99	1.44-1.85
Sodium	mg/L	211	20.8-1,170	NAT26	315	99	18.2-25.1
Sulfate	mg/L	735	120-1,930	NAT01-2	315	95	131-282
Metals							
Aluminum	mg/L		0.15-0.74	MAU08	315	30	0.18-0.29
Arsenic	mg/L	0.0136	0.0005-0.064	NAT08	54	74	0.0006-0.0009
Cadmium	mg/L		<0.04		315		<0.04
Iron	mg/L	0.41	<0.02-5.54	NAT01-2	315	76	0.08-0.29
Lead	mg/L		<0.1-<0.65		315		<0.04
Manganese	mg/L	1.30	<0.04-6.46	MAU05	315	87	0.19-0.32
Molybdenum	mg/L		<0.02-0.18	NAT26	121	30	<0.04
Selenium	mg/L	0.00182	<0.0003-0.014	NAT26	54	94	<0.0003
Uranium	mg/L	0.727	0.003-2.510	NAT26	315	98	0.00432-0.0087
Vanadium	mg/L	1.48	<0.02-7.55	NAT08	315	56	<0.04
Other							
Silicon	mg/L	7.98	3.43-12.4	MAU01	315	99	4.05-4.64
Strontium	mg/L	2.44	0.64-6.35	NAT01-2	315	88	0.83-1.28
Field Measurements							
Alkalinity	mg/L CaCO ₃	343	124-596	MAU01	306	93	156-227
Dissolved oxygen	mg/L	0.31	<0.1-1.73	NAT09	296	27	0.16-0.35
Oxidation-Reduction Potential	mV	198	-12-426	MAU01	282	43	138-214
pH	standard units	7.10	6.54-7.53	MAU06	307	8	7.12-7.33
Specific Conductance	μS/cm	2,060	615-5,730	NAT26	307	92	589-852

Detection limits may vary due to sample dilution during analysis

^aAll measurements were performed on filtered samples except specific conductance, pH, and oxidation-reduction potential.

^bOne-half the detection limit was used to calculate the mean; mean was not calculated if concentrations in more than half the samples were below detection limit.

Uranium

Figure 5-28 shows uranium concentrations in selected wells at the Naturita site. There is a large range in concentration, from 0.003 mg/L in well 0547, which is upgradient from the former tailings area, to 2.510 mg/L in well NAT26. As shown in Figure 5-29, concentrations in all wells located downgradient from well NAT30 exceed the UMTRA maximum concentration limit for uranium (0.044 mg/L). This is the approximate extent of the former mill yard area. Uranium concentration continues to increase as ground water moves downgradient into the former tailings area. Concentrations decrease slightly near the bend in the San Miguel River at the northern end of the site. Chloride and sulfate concentrations along with ground water age and flow modeling suggest that ground water in wells MAU06, MAU03, and MAU04 comes mainly from recent recharge by the San Miguel River, and well MAU07 is a mixture of fresh river water and contaminated water from the alluvial aquifer. However, wells MAU06, MAU03, and MAU04 have uranium concentrations that are orders of magnitude greater than that of the San Miguel River. This contamination is most likely due to buried tailings located near well 0700.

As discussed in Section 5.3.2.2, uranium concentrations in wells MAU03, MAU04, and MAU07 have not been observed to decrease with time, but rather appear to be influenced by the water table and river stage. Wells in the alluvial aquifer can be divided into four groups based on the response of uranium concentration to water level. Figure 5-30 shows the locations of these zones. Zone A wells are located away from the San Miguel River in the central portion of the aquifer and include wells NAT01-1, NAT05, NAT15-1, NAT25, NAT26, and MAU08. Figure 5-31 shows a time-concentration plot and water level at well NAT25 from this group. These wells typically have the highest concentrations of uranium. Zone B wells are also located in the central region of the study area but closer to the river than wells in Zone A. These wells show a fluctuation in uranium that lags behind fluctuations in water level. In this case, water level peaks are followed by high uranium concentrations a few months later. This trend is apparent in well 0548, shown in Figure 5-32. Zone C wells are located closest to the San Miguel River in the central portion of the study area. Small spikes in uranium concentration can be seen following water level peaks similar to the wells in Zone B; however, these spikes are much less pronounced than those in Zone B wells. Zone C wells also show a general decrease in uranium over time. Figure 5-33 illustrates this trend, which is observed in well NAT02. Zone D wells are located near the bend in the river at the northern end of the site. Uranium concentrations appear to fluctuate more quickly in this region in response to changes in water level. This is best seen in well MAU04 (Figure 5-19).

From these trends it appears that wells in Zone C receive the greatest inflow of fresh water from the San Miguel River and should be the first to be decontaminated by natural flushing. Wells in Groups B and D are also undergoing natural flushing; however, they are still receiving an intermittent inflow of ground water uranium that is coupled with water level. On the timescale of the measurements made, wells in Zone A show no signs of natural flushing. There is no evidence in this area that changes in water level will affect uranium concentrations.

Two mechanisms have been proposed to explain the changes in uranium concentration with water level. The first involves desorption of uranium from sediments as the water table rises. This desorbed uranium is then transported to downgradient wells where it is measured a few months later. If this is the dominant process, then attempts to induce a greater degree of natural flushing may result in short-term increases in the mass of uranium being desorbed from sediments in the vadose zone. This effect should be much more pronounced in Zones B and D than in Zone C. Zone A wells should not show a significant change.

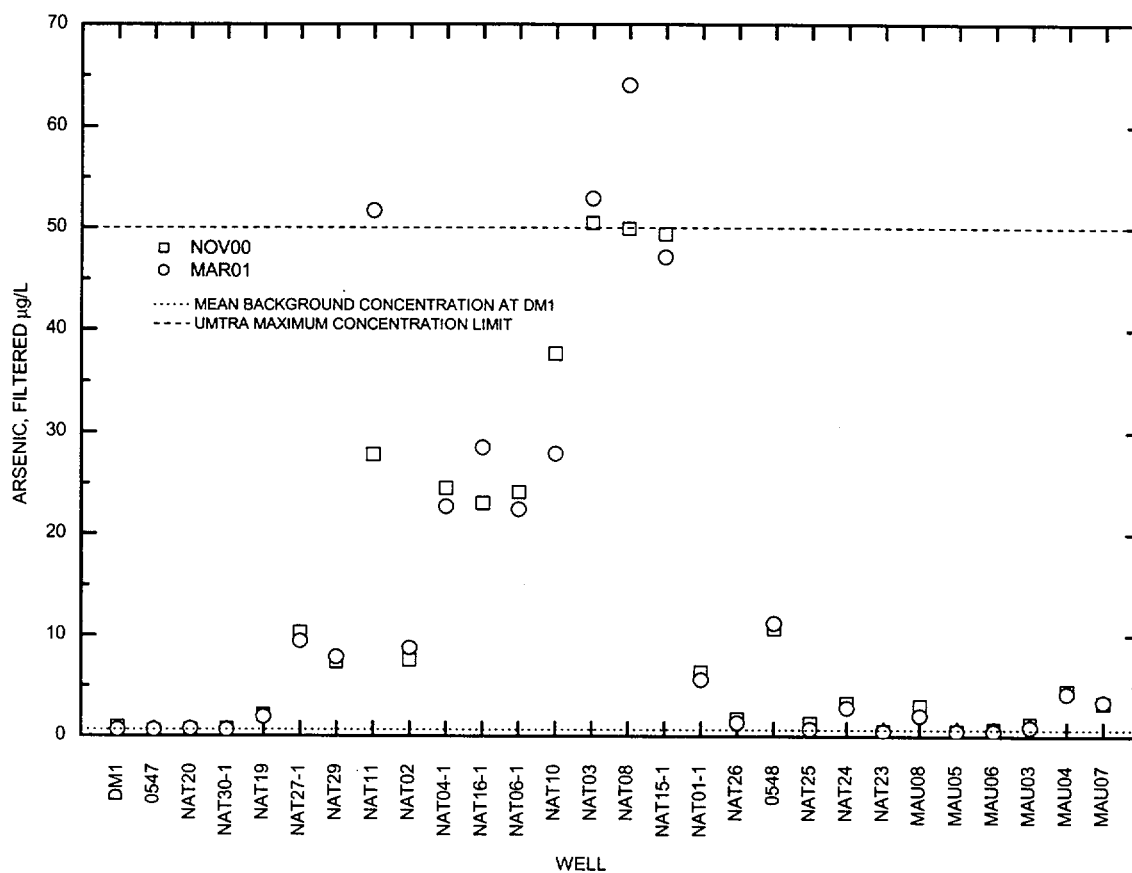


Figure 5-22. Arsenic Concentrations in Selected Wells at the Naturita Site Measured During November 2000 and March 2001

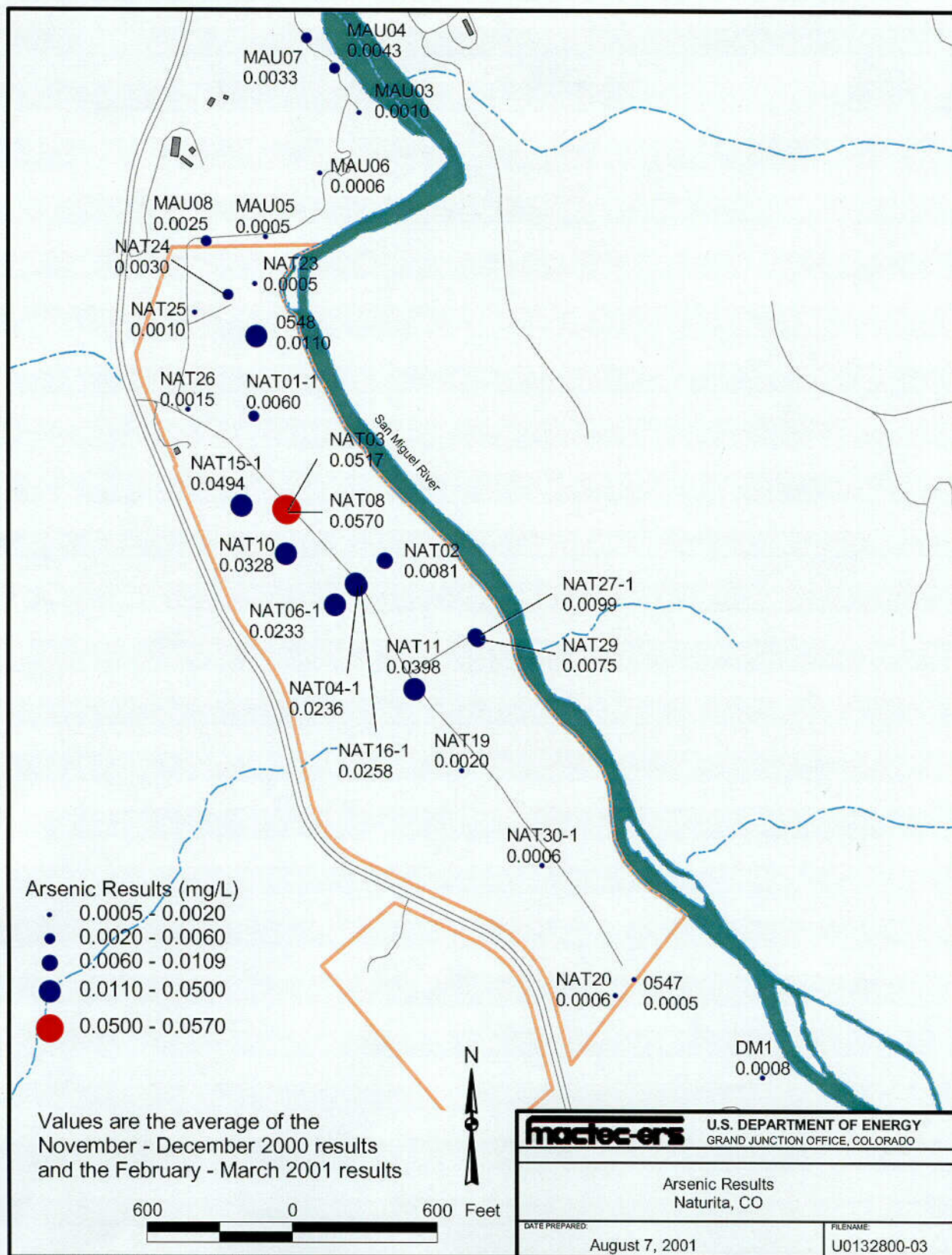


Figure 5-23. Average Arsenic Concentrations Measured in November and December 2000 and February and March 2001

CO4

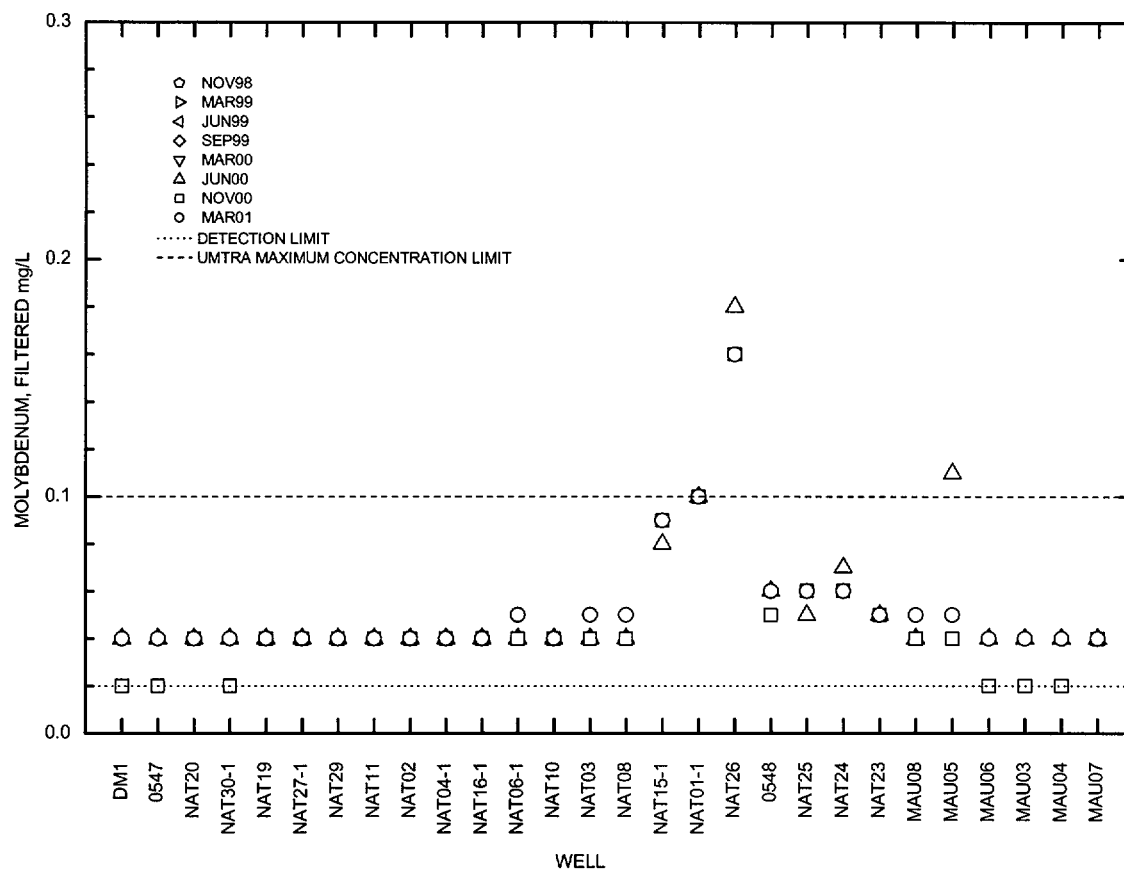


Figure 5-24. Molybdenum Concentrations in Selected Wells at the Naturita Site Measured from November 1998 to March 2001

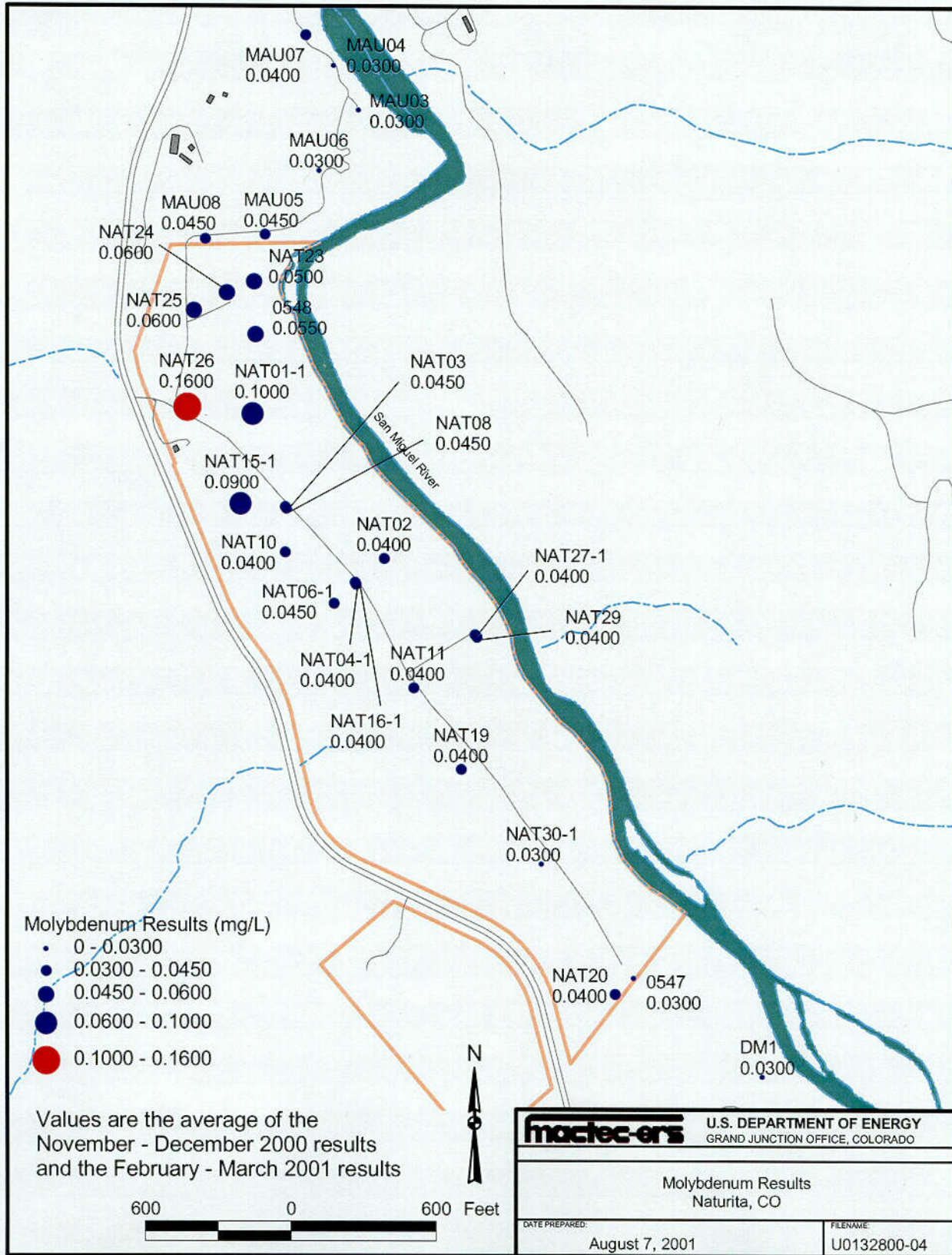


Figure 5-25. Average Molybdenum Concentrations Measured in November and December 2000 and February and March 2001

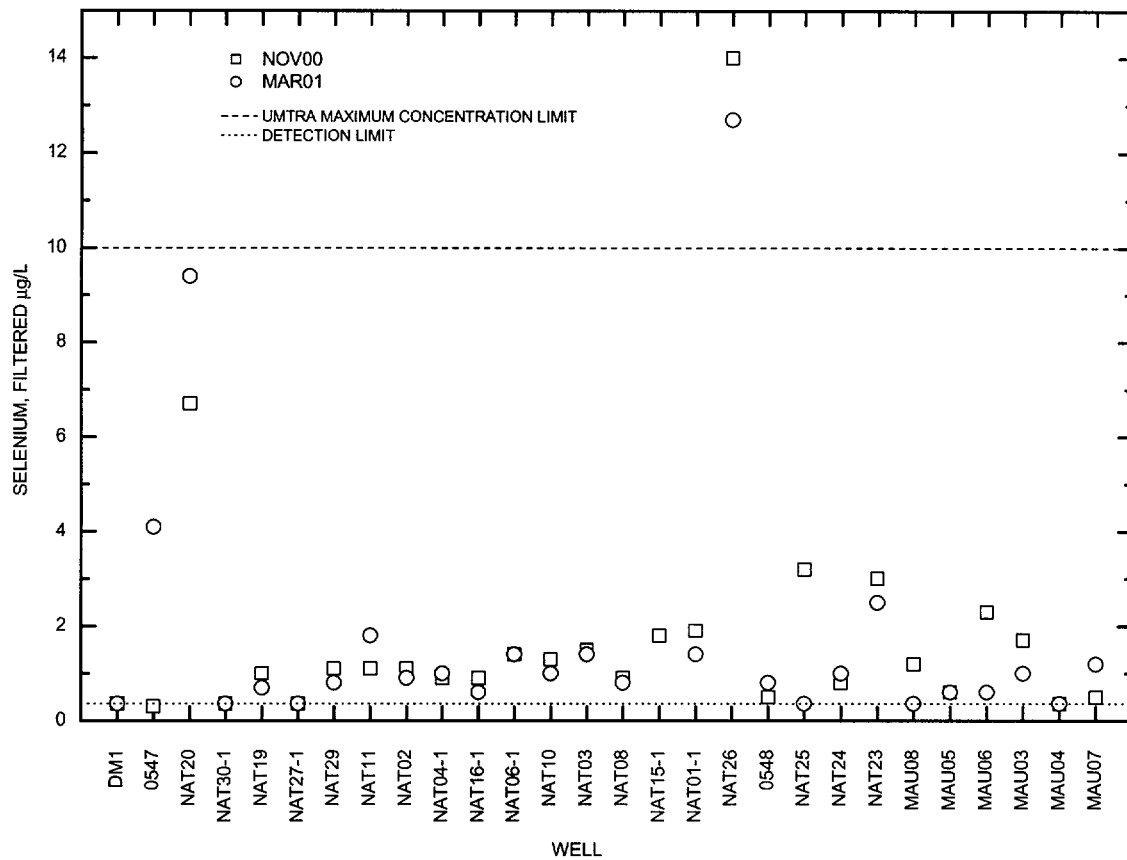
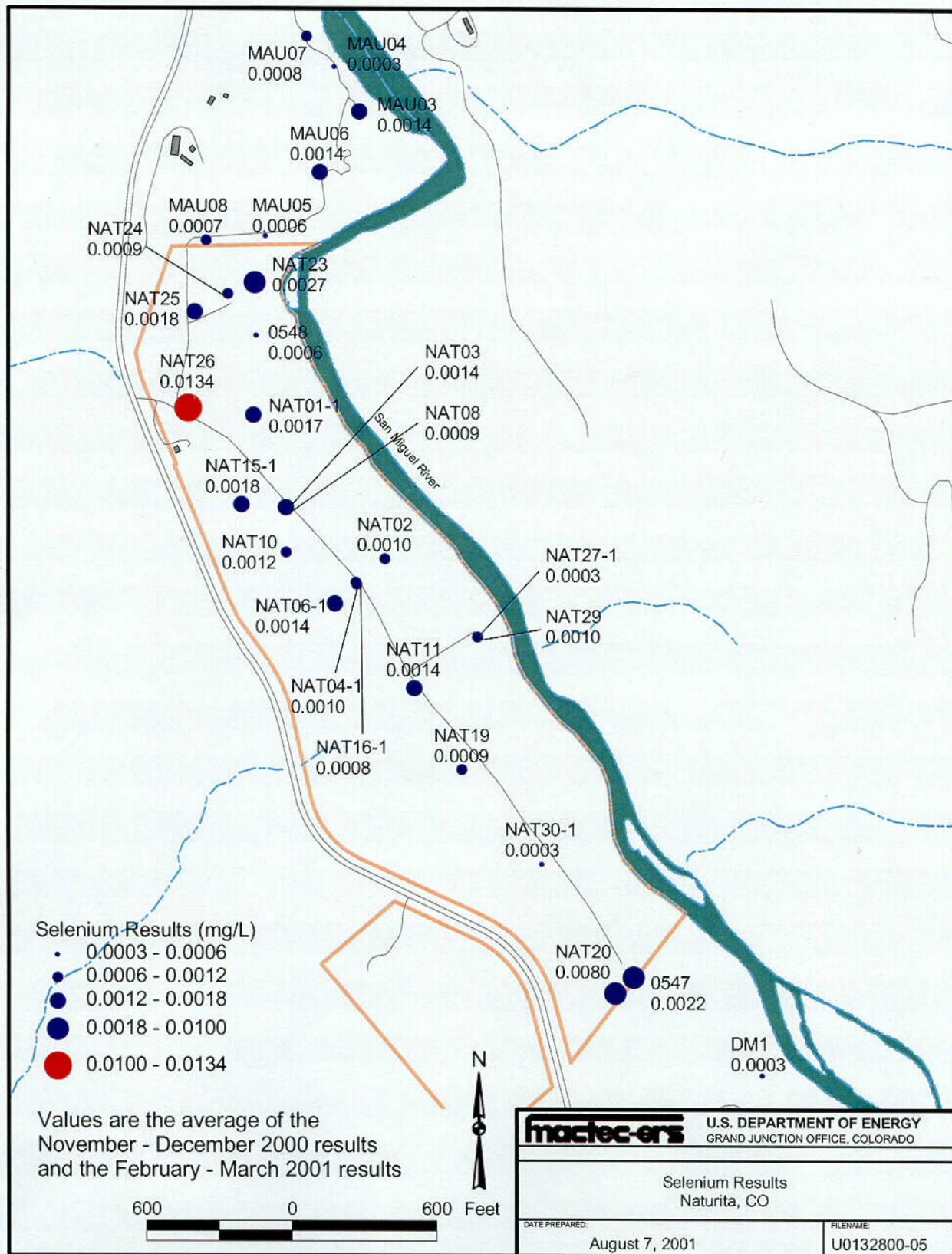


Figure 5-26. Selenium Concentrations in Selected Wells at the Naturita Site Measured During November 2000 and March 2001



COL6

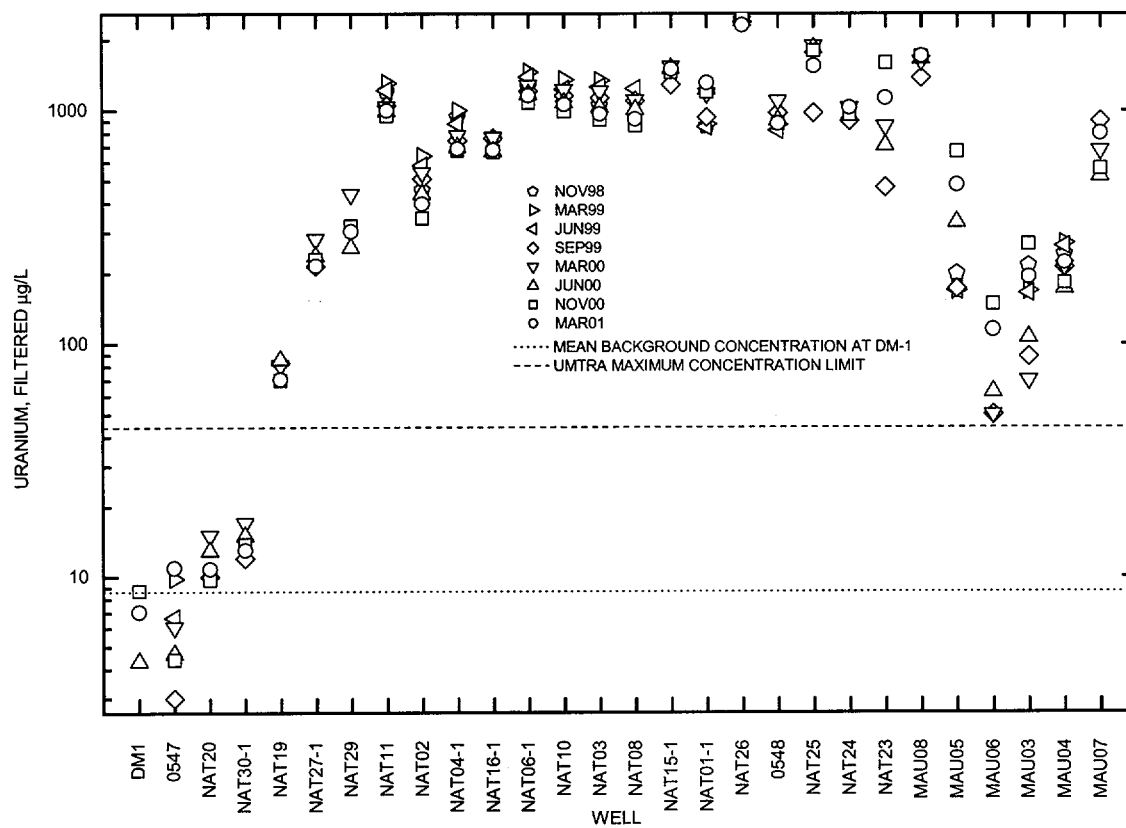


Figure 5-28. Uranium Concentrations in Selected Wells at the Naturita Site Measured from November 1998 to March 2001

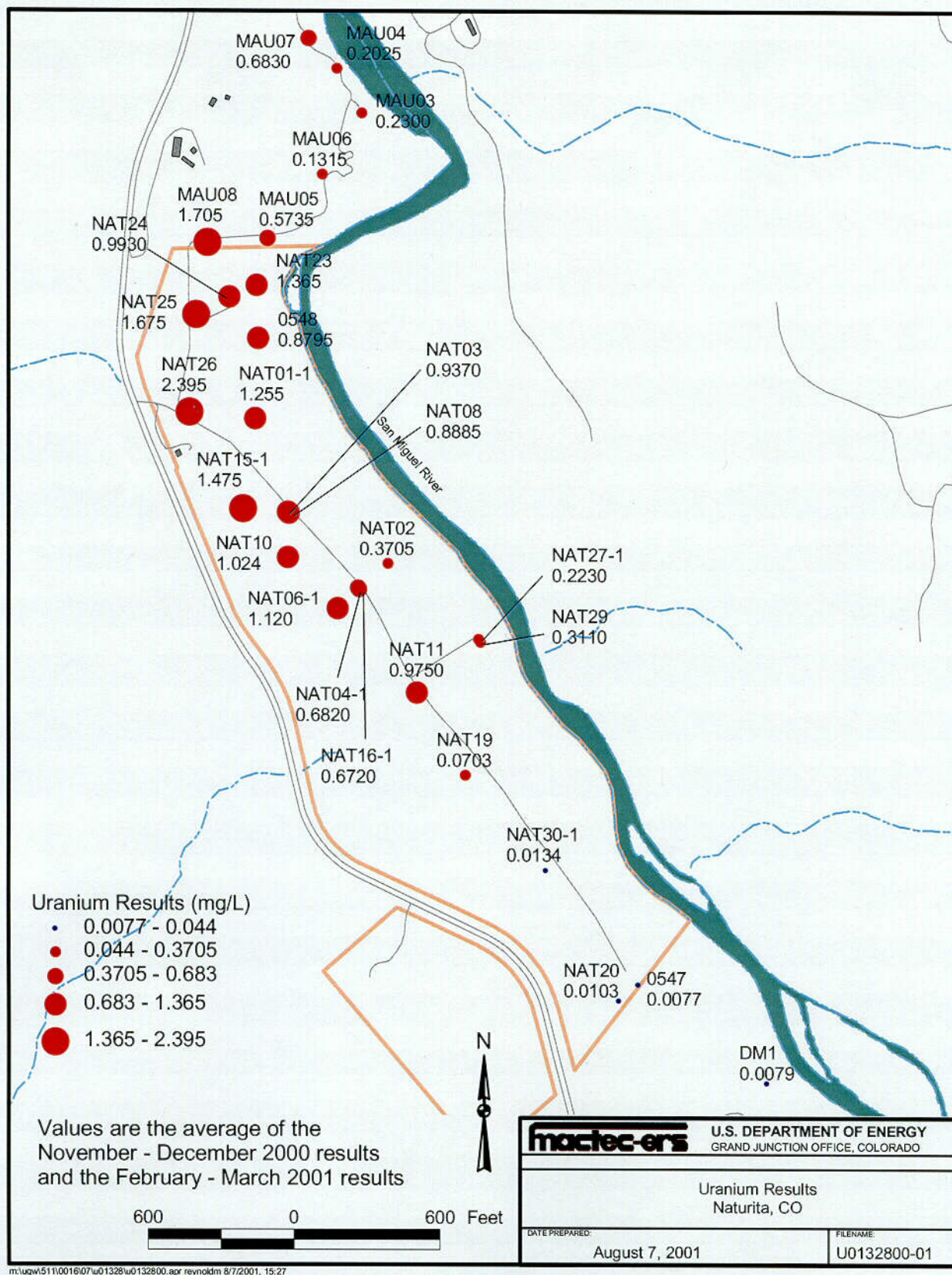


Figure 5-29. Average Uranium Concentrations Measured in November and December 2000 and February and March 2001

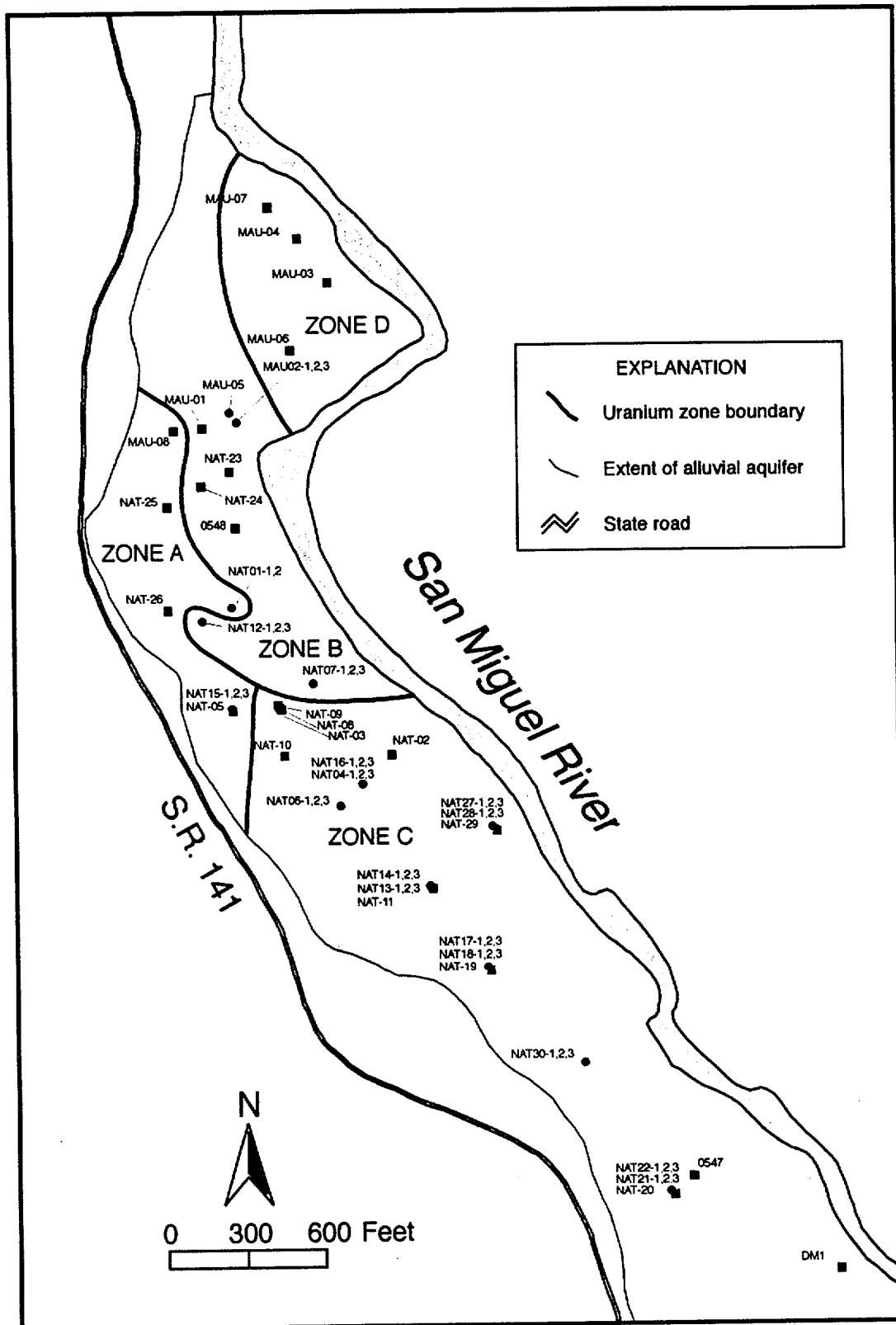


Figure 5-30. Alluvial Aquifer Zones Based on the Response of Uranium Concentration to Changes in Water Level

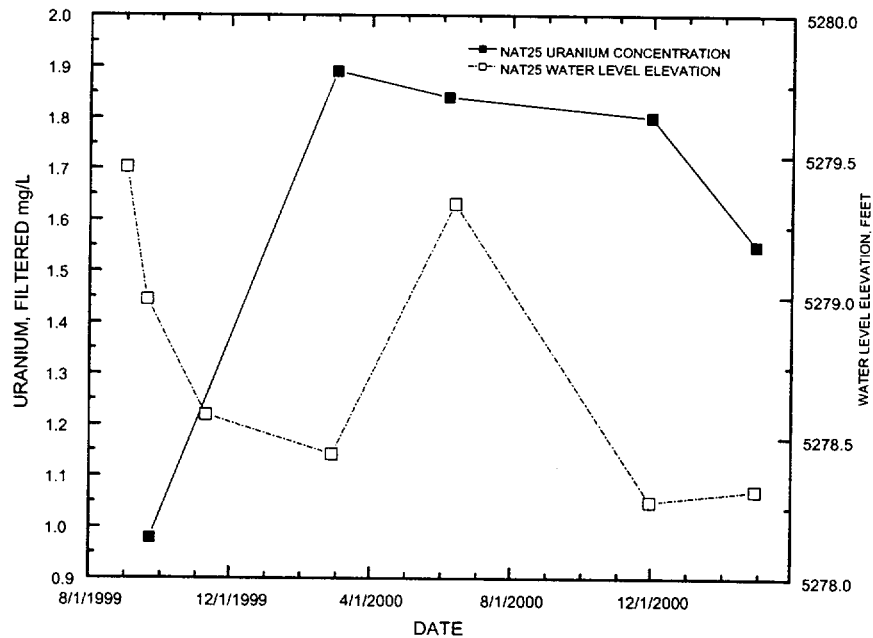


Figure 5-31. Time-Concentration Plot for Uranium and Water Level at Well NAT25

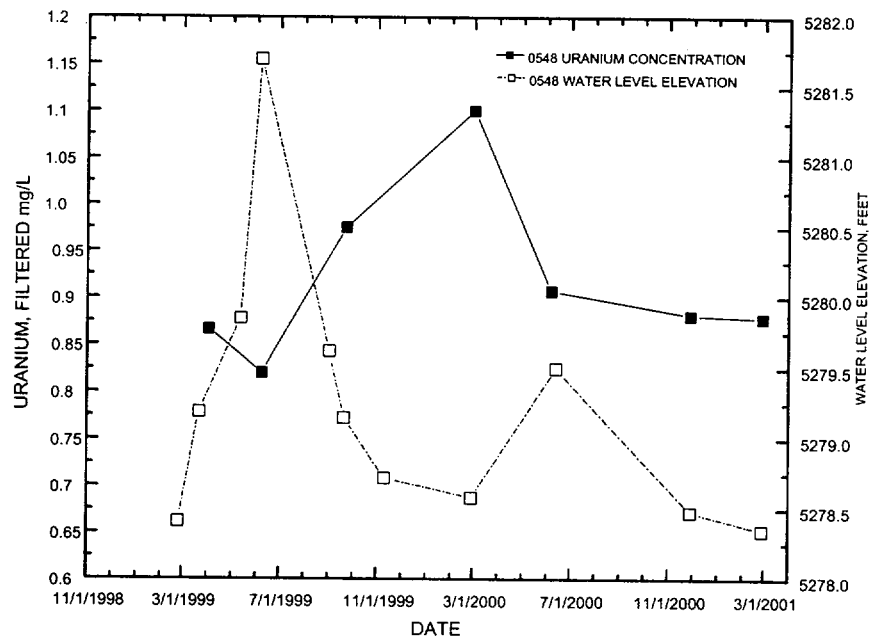


Figure 5-32. Time-Concentration Plot for Uranium and Water Level at Well 0548

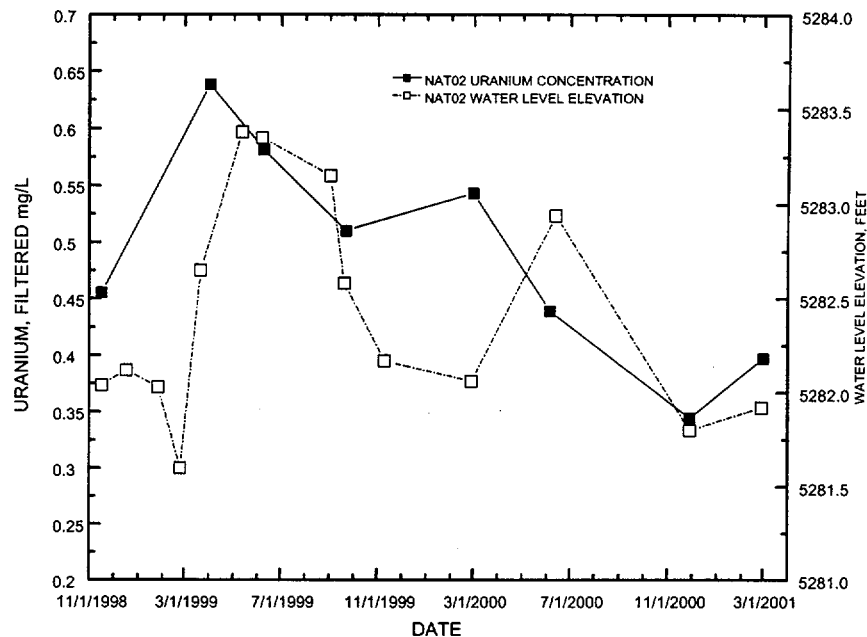


Figure 5-33. Time-Concentration Plot for Uranium and Water Level at Well NAT02

The second proposed mechanism involves lateral fluctuations of the uranium-contaminated zone due to increased inflow from the San Miguel River. When the water level is high, more fresh water flows to the Zone B wells, effectively diluting uranium concentration. This fresh water does not reach the Zone A wells, and they are therefore unaffected. When the water level is low, there is a greater degree of flow from the highly contaminated area to the Zone B wells, increasing the uranium concentration. A small amount of this ground water with high uranium levels may reach the Zone C wells. This is shown by small increases in uranium concentrations as water level decreases. If natural flushing were to be augmented in this case by increasing irrigation and raising the water table, changes in uranium concentration may depend strongly on where the irrigation is applied. For instance, if the water table is raised in Zone A, this may increase uranium concentrations in wells in Zones B and C. If water is applied to Zone C, however, wells in Zone B should continue to show decreasing uranium concentrations. It is unclear whether water applied in this area would clean up wells in Zone A.

If the first mechanism is the dominant process, uranium and other sorbed ions should be the only species to increase in concentration following an increase in water level. Conservative ions like chloride should have been removed from the sediments at an early stage. However, Figure 5-34 shows an increase in chloride concentration with uranium, which suggests that changes in uranium concentration in Zone B wells is most likely due to a greater influx of contaminated water from Zone A. In addition to the close correlation of uranium and chloride, there is also a good correlation between uranium and specific conductance (Figure 5-35). Because of this strong correlation, specific conductance can be used as a proxy to monitor uranium concentrations at the site. This could be done continuously over extended periods using a data recorder with a specific conductance meter.

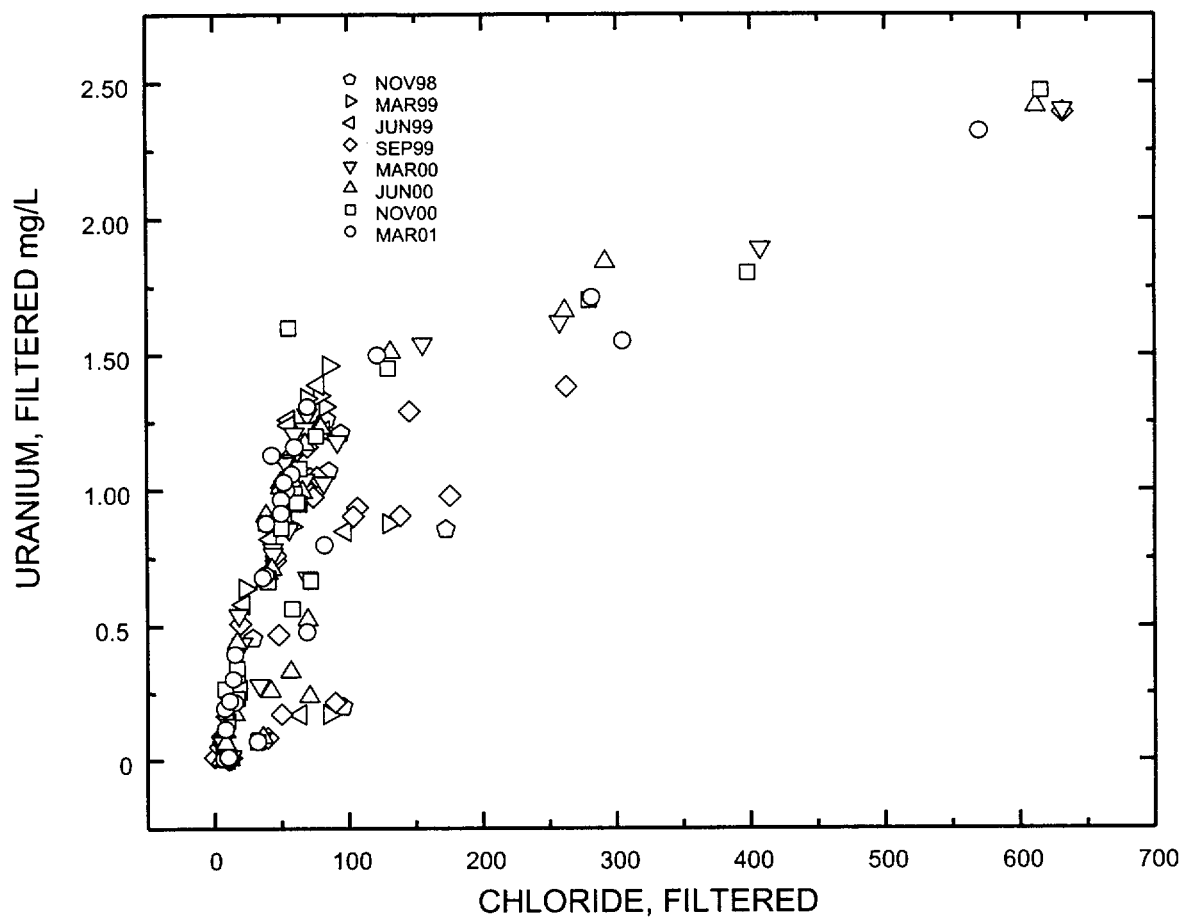


Figure 5-34. Uranium Versus Chloride Concentration in Ground Water

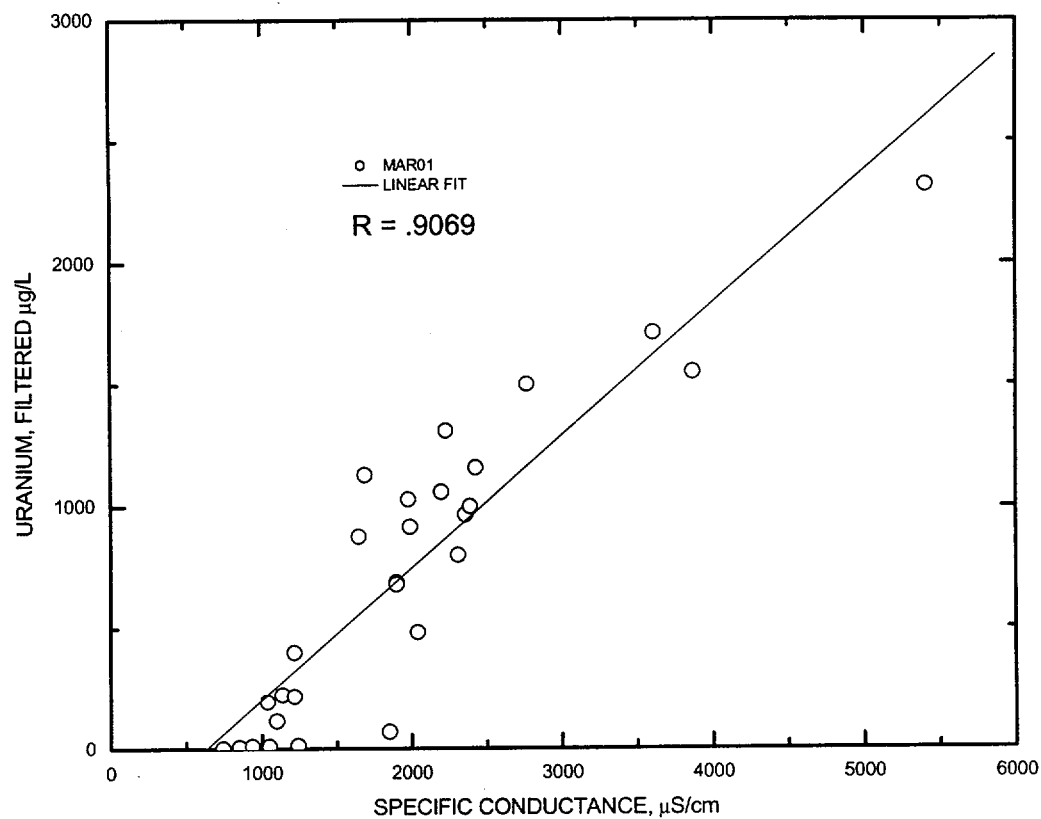


Figure 5-35. Uranium Concentration Versus Specific Conductance in Ground Water.
 R = Correlation Coefficient

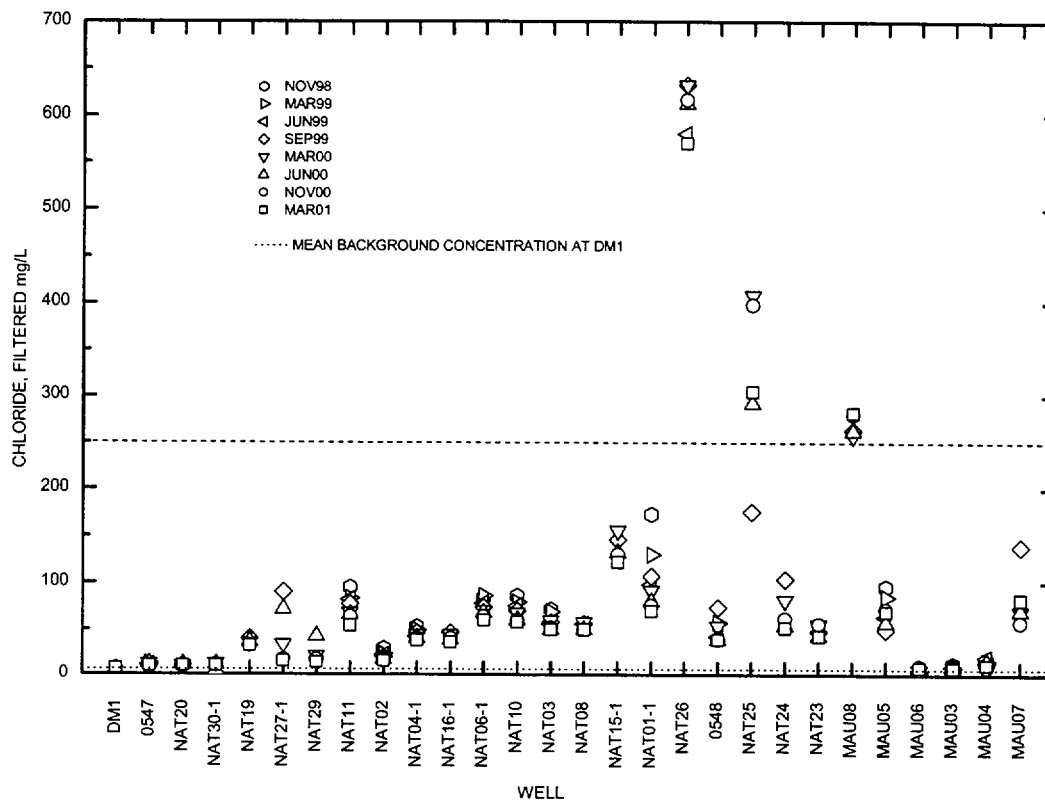


Figure 5-36. Chloride Concentrations in Selected Wells at the Naturita Site Measured from November 1998 to March 2001

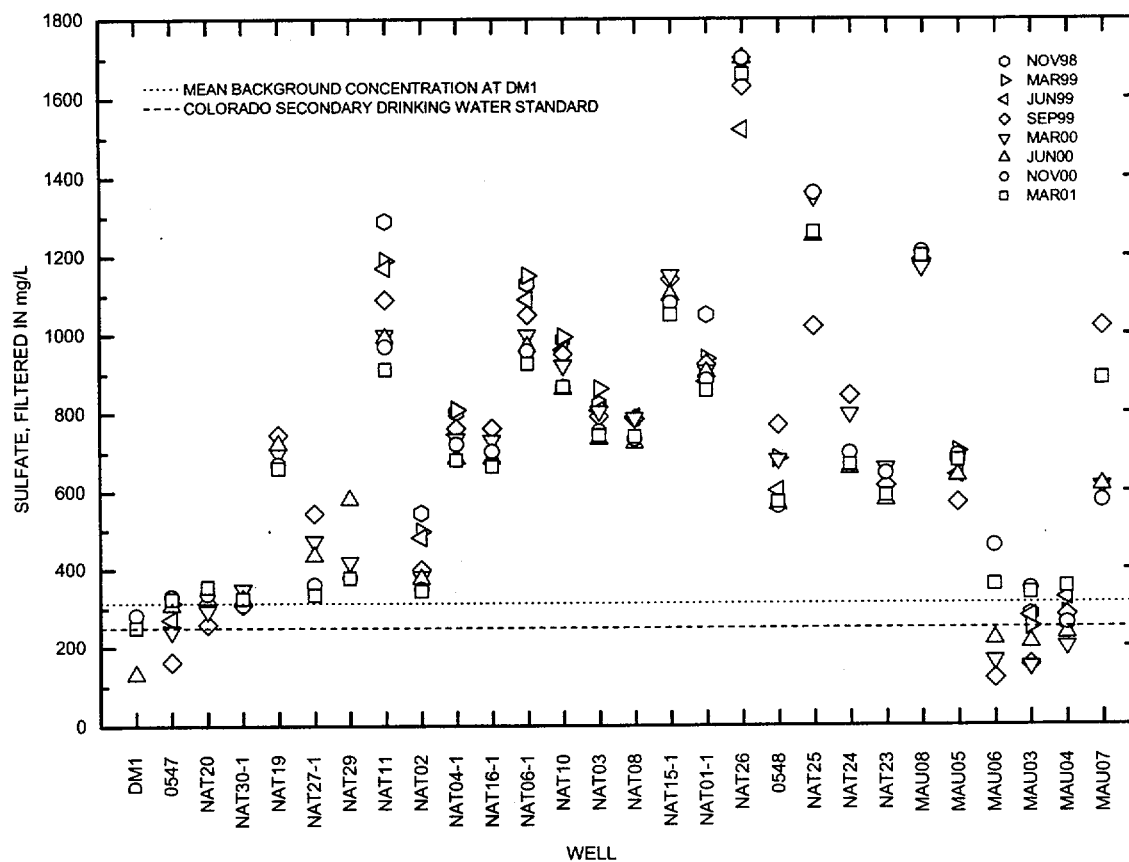


Figure 5–37. Sulfate Concentrations in Selected Wells at the Naturita Site Measured from November 1998 to March 2001

Chloride

When sampled in March 2001, wells NAT25, NAT26, and MAU08 were the only wells with chloride concentrations that exceeded the Colorado secondary drinking water standard of 250 mg/L. However, almost all the wells downgradient of well NAT30–1 had significantly more chloride than the concentration measured in background well DM1 (Figure 5–36). The increase in chloride concentration from inflow of San Miguel River water ranges from 1.72 to 11.3 mg/L; therefore, concentrations greater than this range indicate another source of chloride. The main source of additional chloride comes from the sodium chloride used during processing of the uranium ore (DOE 1995). Because chloride is considered a conservative species and is largely unaffected by adsorption, it is a good indicator of the degree of natural flushing taking place in the aquifer. The wells with the highest chloride concentrations are located in the western portion of the alluvial aquifer. This area corresponds to Zone A (Figure 5–30). Wells closer to the San Miguel River on the eastern portion of the site have lower concentrations of chloride (less than 100 mg/L). This distribution is the result of two factors. The first that more alkaline tailings were deposited on the western half of the site, and acidic tailings were deposited on the eastern portion closest to the river (DOE 1995). The second factor is that the eastern zone receives a greater degree of fresh water inflow from the San Miguel River and undergoes a greater degree of natural flushing. Wells MAU03, MAU04, and MAU06 have chloride concentrations ranging

from 3.8 to 19.8 mg/L, indicating they receive most of their inflow directly from the nearby river. Concentrations in well MAU07, which is just downgradient from well MAU04, range from 58 to 139 mg/L. The higher chloride concentration in MAU07 suggests that this well receives some component of ground water from the contaminated alluvial aquifer. A simple mixing calculation using chloride concentrations can be made by assuming a binary mixture of water from the contaminated alluvial aquifer near well MAU08 and from the San Miguel River. During June 2000 the concentration of chloride in well MAU08 was 262 mg/L, and the concentration in the river was 1.72 mg/L. The concentration in well MAU07 was 70 mg/L. This indicates that 26 percent of the water in well MAU07 came from the contaminated alluvial aquifer, and 74 percent came from the river. This ratio should be considered a maximum inflow from the river, because these values were recorded during high river stage. The values measured during March 2001, which corresponds to a period of low flow, indicate that 27 percent of the flow came from ground water and 73 percent came from surface water. This is a small percentage change over a large difference in flow.

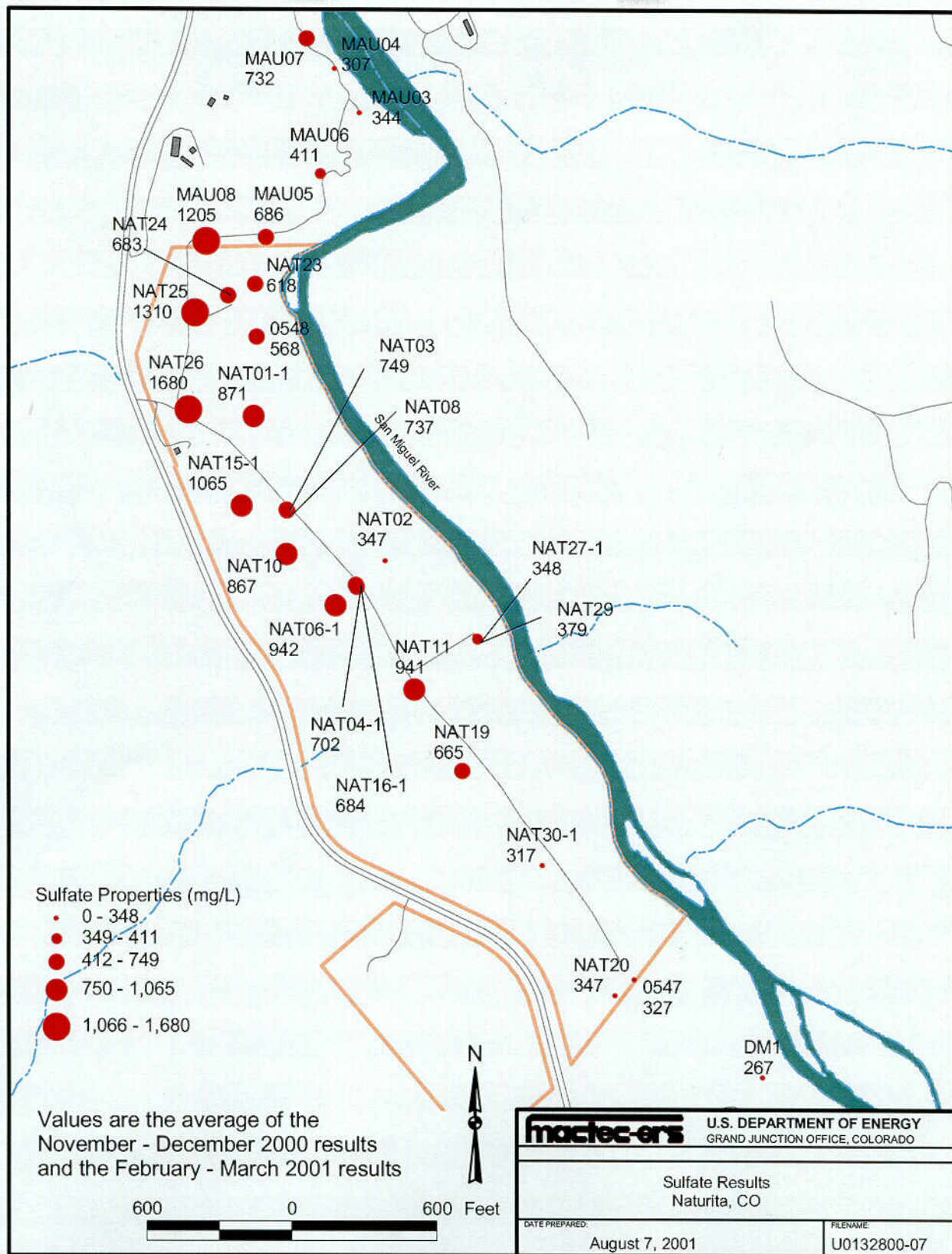
Sulfate

Between August 1998 and March 2001, sulfate concentrations exceeded background levels in 95 percent of the samples collected at the site (Table 5-3) and exceeded the Colorado secondary drinking water standard of 250 mg/L in 97 percent of the samples. As shown in Figure 5-37, concentrations range from 120 mg/L to 1,930 mg/L. Figure 5-38 shows that the distribution of sulfate concentrations is similar to that of chloride and uranium; the highest levels are in the west-central portion of the alluvial aquifer. Wells in the northern section near the bend in the river show a mixing trend similar to that of the chloride concentrations.

As Figure 5-39 shows the sulfate/chloride ratio is also a good indicator of the influence of surface water from the river. Wells near the river or upgradient from the contaminated zone have larger sulfate/chloride ratios and show a broader range of ratios. With the exception of well MAU07, this group corresponds to Zones C and D (Figure 5-30). Wells located in the contaminated area (Zones A and B) have a much narrower range of sulfate/chloride ratios, and the ratios are generally lower than those in Zones C and D. Although located near the San Miguel River, water in well MAU07 has a sulfate/chloride ratio that is more typical of the ratio in ground water from the contaminated area of the alluvial aquifer. As discussed in the chloride section, it is believed that this well receives a significant inflow of water from the contaminated portion of the alluvial aquifer, which gives it a different sulfate/chloride ratio than that of other wells in the area.

Vanadium

Vanadium concentrations range from below the detection limit (0.02 mg/L) to 7.55 mg/L and are shown in Figure 5-40. The highest value was measured in September 1999 in well NAT08, the same well in which the maximum level of arsenic was detected. Figure 5-41 shows the distribution of vanadium concentrations. Due to its lower mobility, the vanadium has not been transported as far downgradient as other constituents such as uranium (Figure 5-29), and the higher concentrations are generally confined to the area of the former tailings pile. This distribution is similar to that of arsenic (Figure 5-23).



C08

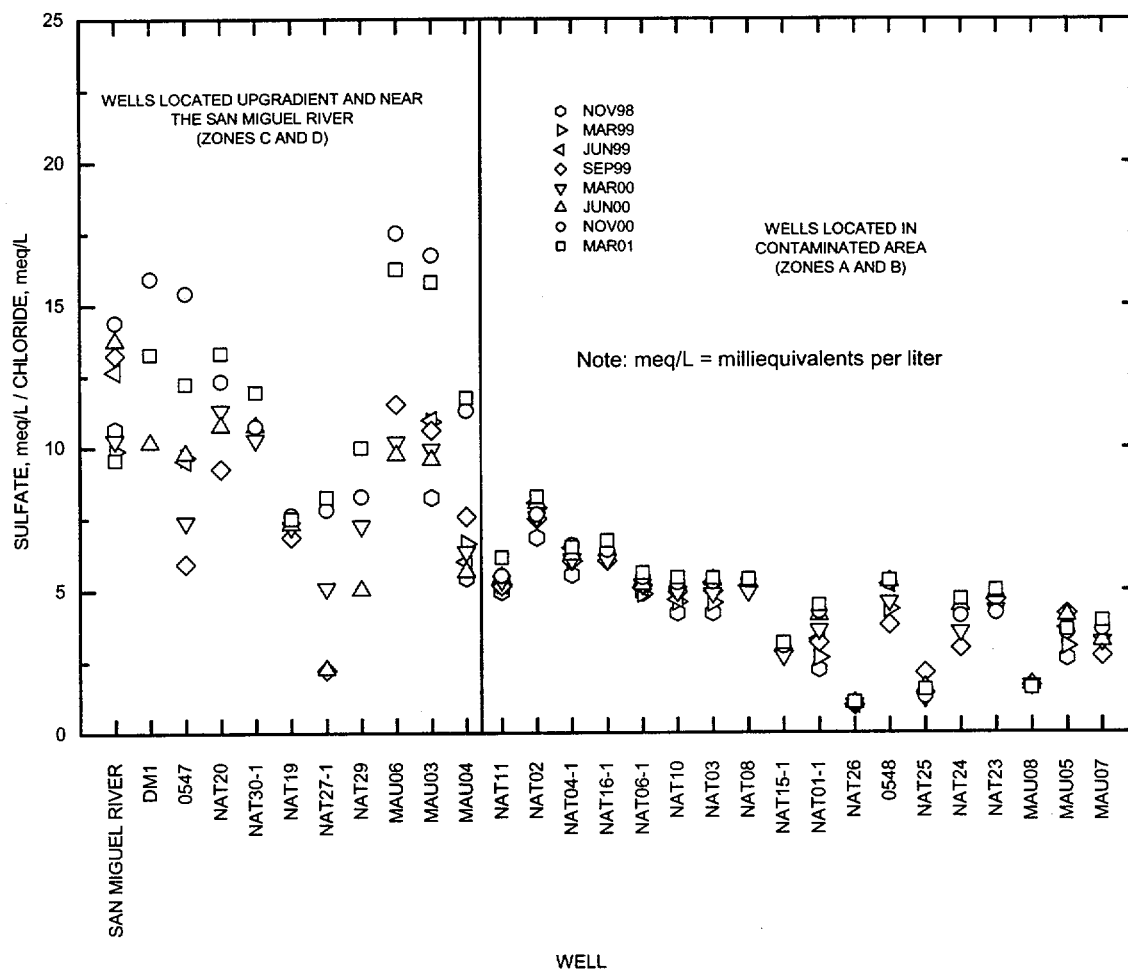


Figure 5-39. Sulfate/Chloride Concentration Ratio in Selected Wells at the Naturita Site Measured from November 1998 to March 2001

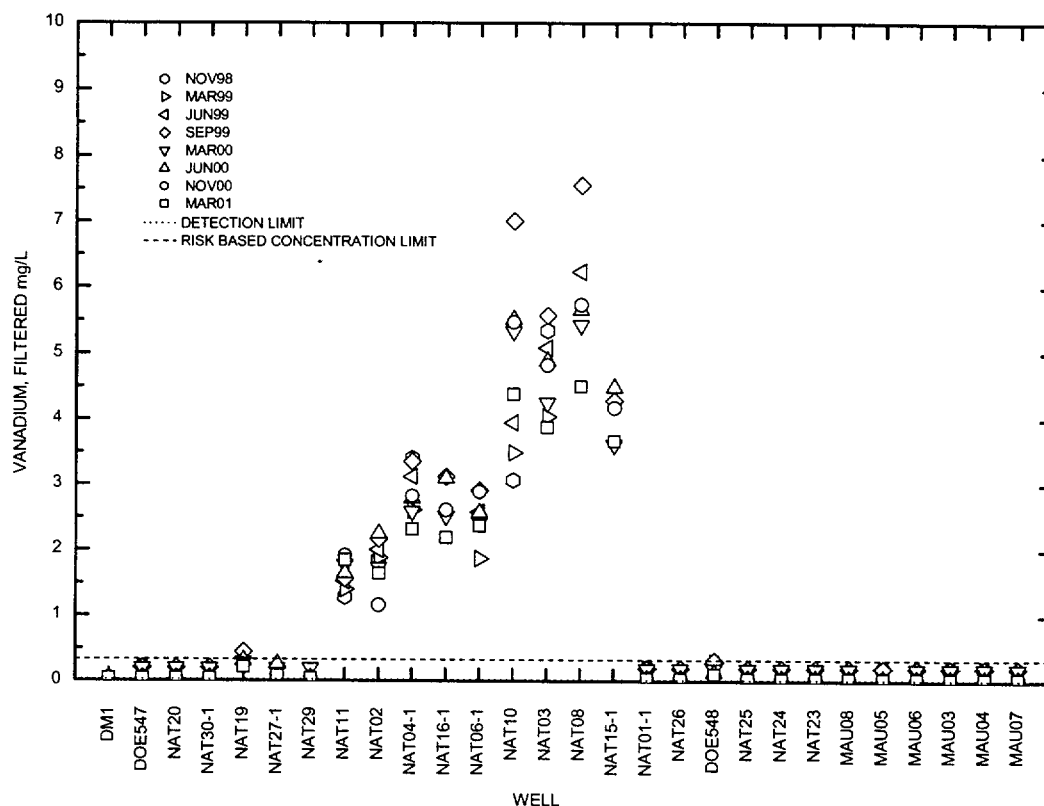


Figure 5–40. Vanadium Concentrations in Selected Wells at the Naturita Site Measured from November 1998 to March 2001

5.3.4 Age Dating Alluvial Ground Water

To better understand flow paths and travel times of alluvial ground water at the Naturita site, samples were collected in June 2000 to age date ground water. The age of ground water is defined as the time since water was isolated from the atmosphere (Freeze and Cherry 1979). Two techniques were used to determine the age of ground water at Naturita. The first involves measuring the ground water concentration of chlorofluorocarbons (CFCs). Because the solubility of CFCs is known, and the air concentration of CFCs for the past 50 years is also known (or reconstructed), ground water age can be measured based on the concentration of dissolved CFCs. The second method measures the ratio of hydrogen-bomb-produced tritium (^3H) to its decay product helium-3 (^3He) in ground water. Both methods have been used successfully at a number of sites to date relatively young ground water (less than 60 years old) (Plummer and Busenberg 2000; Solomon and Cook 2000).

All the wells at Naturita with 2-inch-diameter casings and one site along the San Miguel River were sampled for CFCs; samples were analyzed by the USGS at the Reston Chlorofluorocarbon Laboratory. Twelve of these wells were also sampled for $^3\text{H}/^3\text{He}$ analysis. These samples were analyzed at the Lamont-Doherty Earth Observatory at Columbia University. In addition to the 2-inch-diameter wells, 6 CFC samples were collected from 0.5-inch-diameter wells and were analyzed at the University of Utah Department of Geology and Geophysics. Table 5–4 presents a complete list of the samples collected at each well.

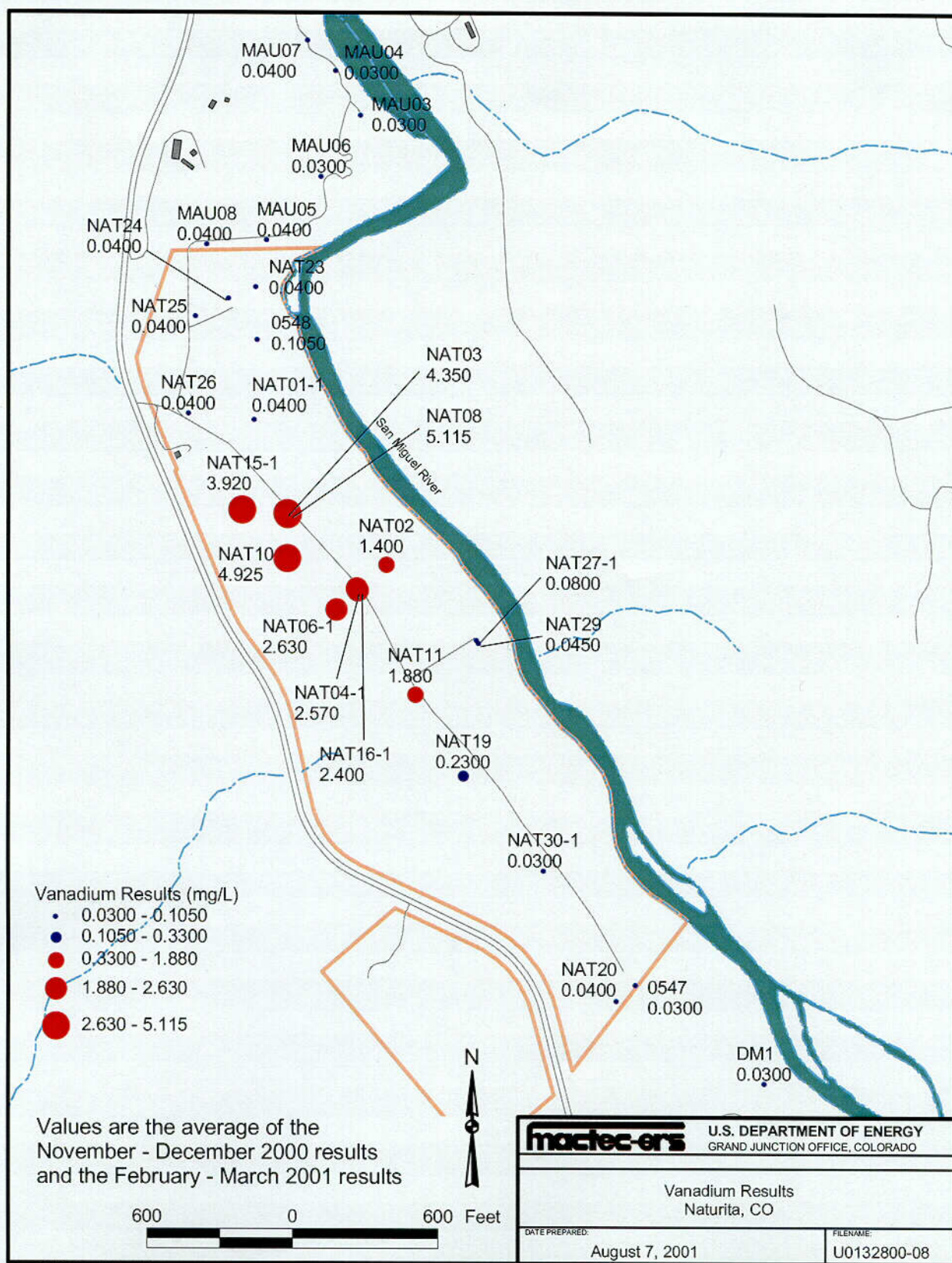


Figure 5-41. Average Vanadium Concentrations Measured in November and December 2000 and February and March 2001

Table 5-4. Samples Collected During June 2000 for Age Dating of Ground Water at the Naturita Site

Location	Sample Date	USGS Analyzed Samples	University of Utah Analyzed Samples	Tritium-Helium-3 Samples
DM1	6-7-2000	x		x
0547	6-7-2000	x		
0548	6-7-2000	x		
MAU01	6-8-2000	x		
MAU02-2	6-12-2000		x	
MAU03	6-8-2000	x		
MAU04	6-8-2000	x		x
MAU06	6-8-2000	x		
MAU07	6-8-2000	x		x
MAU08	6-8-2000	x		x
NAT02	6-6-2000	x		x
NAT03	6-7-2000	x		
NAT05	6-6-2000	x		x
NAT06-1	6-11-2000		x	
NAT08	6-7-2000	x		
NAT09	6-7-2000	x		
NAT10	6-7-2000	x		
NAT11	6-7-2000	x		
NAT15-1	6-12-2000		x	
NAT15-2	6-12-2000		x	
NAT15-3	6-12-2000		x	
NAT19	6-6-2000	x		x
NAT20	6-10-2000	x		
NAT23	6-8-2000	x		x
NAT24	6-8-2000	x		x
NAT25	6-7-2000	x		x
NAT26	6-6-2000	x		x
NAT29	6-6-2000	x		x
NAT30-1	6-9-2000		x	
San Miguel River	6-8-2000	x		

5.3.4.1 Tritium-Helium Data

Tritium-Helium Sampling

Twelve ground water samples were collected for $^3\text{H}/^3\text{He}$ age dating from the alluvial aquifer at Naturita (Table 5-4). The samples were collected from 2-inch-diameter wells using a Bennett gas-piston pump driven by compressed nitrogen. Three well casings were purged before samples were collected. Collecting water samples for $^3\text{H}/^3\text{He}$ determination requires filling a special copper sample tube that is sealed with pinch-off clamps. The copper tube sample is used for dissolved helium and neon analysis, determination of the $^3\text{H}/^3\text{He}$ isotope ratio, and tritium concentration. If the tritium concentration is low, a more accurate determination can be made using the helium-ingrowth method. In case this analysis was needed, a duplicate sample was collected in a 500-mL bottle with a polyseal lid. The samples were analyzed at the Lamont-Doherty Earth Observatory at Columbia University.

Tritium-Helium Results

Table 5-5 shows the calculated age and recharge year for nine samples collected for $^3\text{H}/^3\text{He}$ analysis; analytical results were not yet available for samples MAU08, NAT05, and NAT26. Ages range from 0.2 years to 33.9 years. As Figure 5-42 shows ground water generally increases in age as it moves downgradient. This is consistent with ground water flow modeling results that indicate water recharges the aquifer from the San Miguel River and flows downgradient parallel to the river. Ground water age decreases downgradient from well NAT24 and in wells NAT23, MAU04, and MAU07. These younger ages are most likely the result of influx of young water from the San Miguel River in that area. Figure 5-42 also shows inferred flow paths based on ground water ages and chloride concentrations. These flow paths indicate that water is entering the alluvial aquifer all along the San Miguel River. This figure is really a snapshot of the ground water ages and concentrations during June 2000. Beyerle et al. (1999) have shown that the amount and area of infiltration of river water to a shallow aquifer, and thus the ground water ages, can fluctuate seasonally. This fluctuation is seen mainly in the area nearest to the river. Parts of the aquifer that are deeper and farther removed from the river typically show less of an influence from young recharge (Beyerle et al. 1999)

Helium-4 (^4He) is produced in the aquifer by radioactive decay of uranium and thorium. As minerals and dissolved uranium release ^4He to ground water, the ^4He concentration in the water increases. If the ^4He release rate to the aquifer can be quantified, and other sources of ^4He are accounted for, the ^4He concentration should be proportional to the ground water travel time (Solomon and Cook 2000). As seen in Figure 5-43, a strong correlation can be made between ^4He - and $^3\text{H}/^3\text{He}$ -based ground water ages at the Naturita site. Because high concentrations of uranium are dissolved in the ground water or sorbed onto the surfaces of mineral grains, this curve represents the release rate of ^4He directly to the ground water. Therefore, ground water at the Naturita site can be dated directly by measuring the ^4He concentration. Sampling and measuring ^4He is cheaper and easier than other common age-dating methods such as CFCs and $^3\text{H}/^3\text{He}$, so this may be an important tool to further quantify ground water travel times at Naturita.

As suggested by the chloride and sulfate concentrations, well MAU07 is most likely a mixture of older ground water from the contaminated portion of the aquifer and fresh, younger water from the San Miguel River (Section 5.3.3.2). If it is assumed that the water at MAU07 is a binary mixture of older water from the alluvial aquifer and younger water (age 0 to 5 years) from the river, the mixing ratios can be calculated using ^4He as a tracer. Assuming the input concentration of ^4He from the aquifer is equal to that in well NAT25 ($70.27 \times 10^{-8} \text{ cm}^3$ (standard temperature and pressure) g^{-1}), and the younger concentration is similar to that measured in well MAU04 ($14.14 \times 10^{-8} \text{ cm}^3$ (STP) g^{-1}), well MAU07 receives approximately 22 percent of its water from the alluvial aquifer. This roughly agrees with the mixing ratio calculated using chloride (26 percent alluvial, 74 percent river).

Table 5-5. Tritium-Helium Age-Dating Results.

Location	Tritium/Helium Age (years)	Tritium/Helium Recharge Year	Tritium in Tritium Units	$^4\text{He } 10^{-8} \text{ cm}^3 \text{ (STP) /g}$
DM1	0.2	2000	10.58	5.42
NAT02	15.1	1985	10.9	30.97
NAT05	nd	nd	10.18	nd
NAT19	9.2	1991	10.33	17.12
NAT23	13.5	1987	10.54	25.8
NAT24	33.9	1966	10.68	79.42
NAT25	28.2	1972	10.36	70.27
NAT26	nd	nd	11.01	nd
NAT29	5.8	1994	10.61	5.2
MAU04	5.6	1994	10.61	14.14
MAU07	12.4	1988	10.39	26.4
MAU08	nd	nd	10.27	nd

All samples were collected June 6 through 8, 2000.

nd = No data.

As shown in Figure 5-44, a strong correlation can also be made with ground water age and uranium concentration ($R = .81531$). This is not surprising, because uranium concentration generally increases along the ground water flow path. However, this would suggest that uranium concentration could be used as an estimation of ground water age (higher uranium concentration equals greater age). Comparing ground water ages with uranium concentration can give an idea of the extent of natural attenuation at the site. If natural flushing of uranium is occurring, there should be relatively old ground water present with low uranium concentrations. Figure 5-44 shows increasing uranium with age, suggesting natural flushing at these wells has not yet begun. More detailed age dating of the aquifer could possibly show areas where natural flushing is occurring.

5.3.4.2 Chlorofluorocarbon Data

CFC Sampling

CFC samples were collected from each of the 2-inch-diameter wells using a Bennett gas-piston pump driven by compressed nitrogen. Three well casings were purged before five replicate samples were collected. To isolate samples from the modern atmosphere, the samplers collected them in sealed borosilicate glass ampoules that were flushed with ultra-high-purity nitrogen. The samples were analyzed at the USGS Reston Chlorofluorocarbon Laboratory by purge-and-trap gas chromatography using an electron capture detector. Busenberg and Plummer (1992) provide a more detailed description of the sampling procedure. CFC samples from the 0.5-inch-diameter wells were collected in copper tubes sealed with pinch-off clamps. During sampling, a peristaltic pump was attached to a 3/8-inch-diameter copper pipe that was inserted into the well. The well was purged of at least 3 gallons before sampling. A 3/8-inch copper sample tube similar to those used in tritium-helium sampling (see Section 5.3.4.1) was connected to the sample pipe and to the intake side of the pump head. Once flushed with ground water to remove any trapped air, the copper sample tube was sealed with pinch off-clamps. Three replicate samples were collected at each well. These samples were analyzed at the University of Utah Department of Geology and Geophysics by purge-and-trap gas chromatography using an electron capture detector. Wilkowske (1998) presents a more detailed description of the copper tube sampling technique.

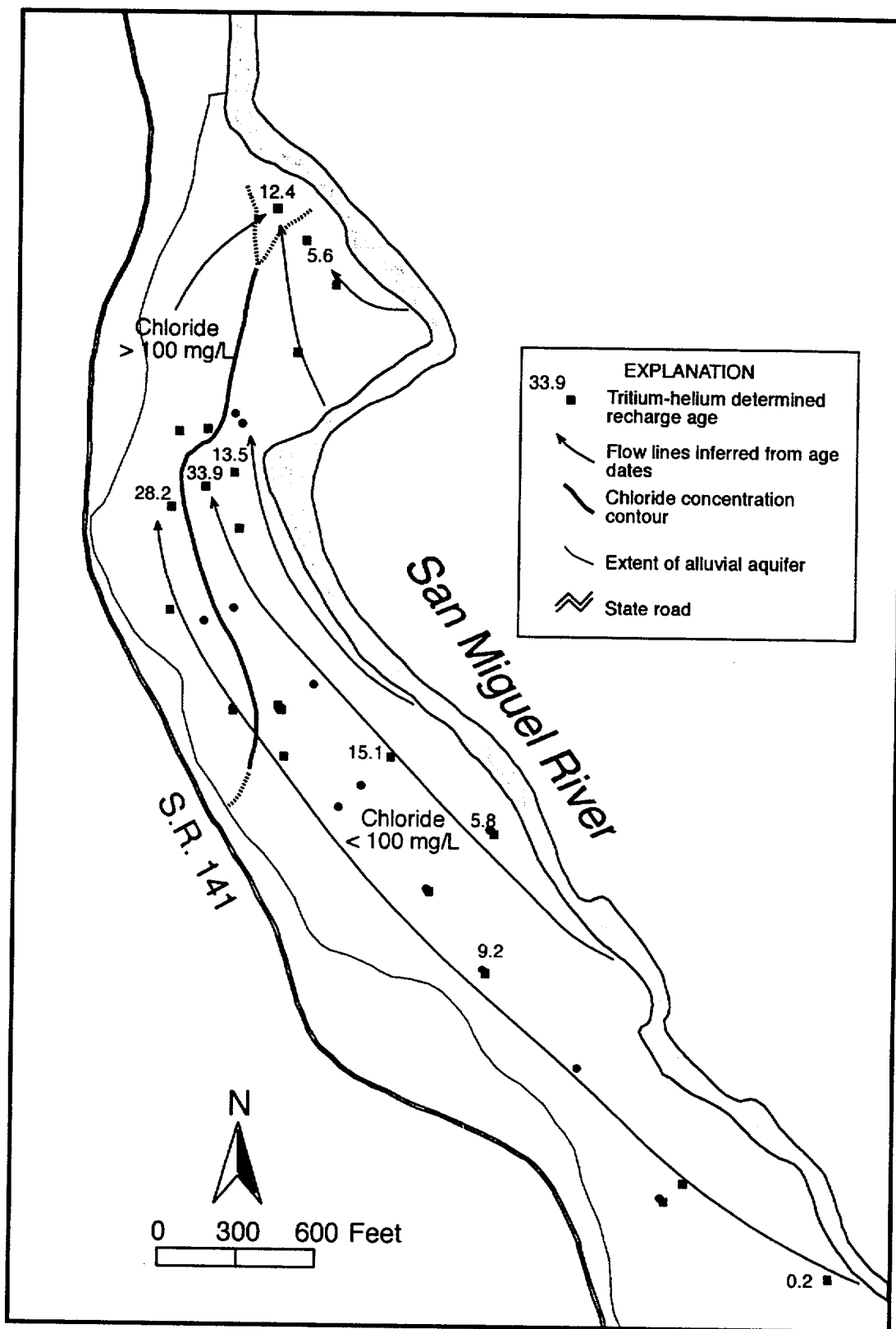


Figure 5-42. Tritium-Helium-Determined Recharge Ages and Inferred Flow Paths at the Naturita Site

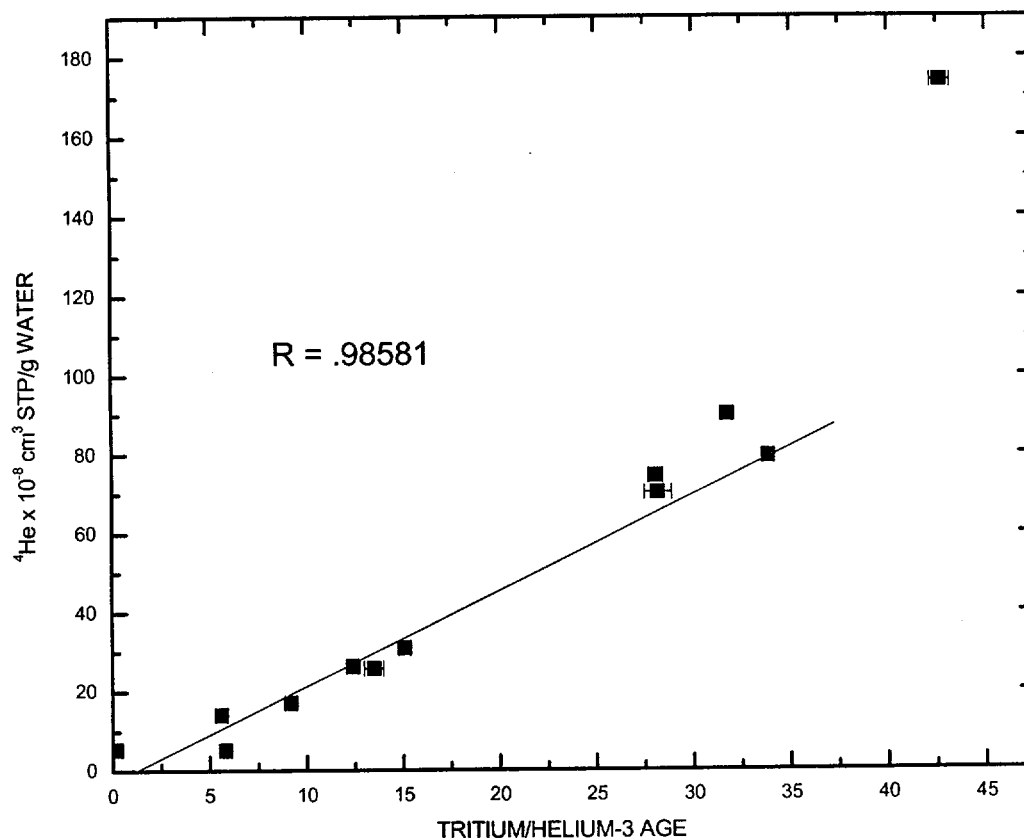


Figure 5-43. ^4He Concentration versus Ground Water Age as Determined by $^3\text{H}/^3\text{He}$ Dating

Calculation of Recharge Temperature

The calculated equivalent air concentration of CFCs is based on the solubility of CFCs in water and is therefore temperature dependent. It is important to get a good estimate of the temperature of the water at the time it recharged the aquifer. To measure the recharge temperature, samples were collected from well MAU06 for dissolved gas analysis at the USGS Reston

Chlorofluorocarbon Laboratory. The analyses included dissolved nitrogen, argon, methane, carbon dioxide, and oxygen. The concentration, as well as the ratios of concentrations of these gases, can be used to calculate the recharge temperature of a ground water sample. Based on the N_2/Ar ratio, the calculated recharge temperature for the Naturita aquifer is 16°C . This is similar to the value of 13°C , which was the average temperature of the San Miguel River during peak flow in May and June 2000.

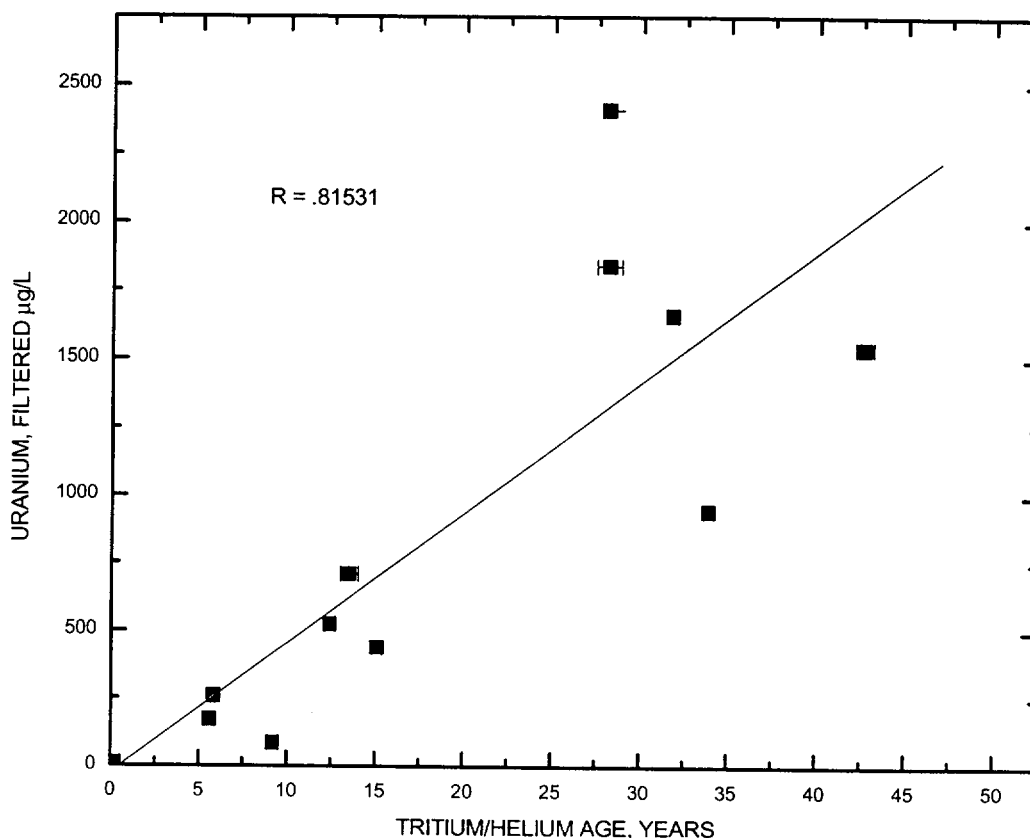


Figure 5-44. Uranium Concentration versus Age as Determined by $^3\text{H}/^3\text{He}$ Dating

CFC Age Dating Results

CFC samples were analyzed for three compounds: CFC-11 (trichlorofluoromethane, CFCl_3), CFC-12 (dichlorodifluoromethane, CF_2Cl_2), and CFC-113 (trichlorotrifluoroethane, $\text{C}_2\text{F}_3\text{Cl}_3$). Figure 5-45 shows the average CFC concentration for each of the three species and their modeled recharge age. Because tritium-helium age dating is unaffected by factors such as biodegradation, sorption, and urban contamination, these dates are considered to more accurately model the recharge age of ground water. Figure 5-45 shows that recharge ages modeled from CFC-11 and CFC-12 values are too young in comparison to $^3\text{H}/^3\text{He}$ ages. This suggests either biodegradation of both CFC species or mixing of old CFC-free water that is presumably upwelling through the underlying consolidated rock. This mixing would effectively dilute the CFC concentration and give an apparent older recharge age. Degradation of CFC-11 and CFC-12 under anaerobic conditions is well documented (Plummer and Busenberg 2000). Degradation of CFC-11 is typically more pronounced than that of CFC-12, which is the case with the samples from the aquifer at Naturita (Figure 5-45). In a water sample with no biodegradation that is a mixture of old CFC-free water and young water containing CFCs, the CFC-11 and CFC-12 ages should match. Therefore, it is apparent that CFC-11 has been significantly degraded and cannot be used for age determination.

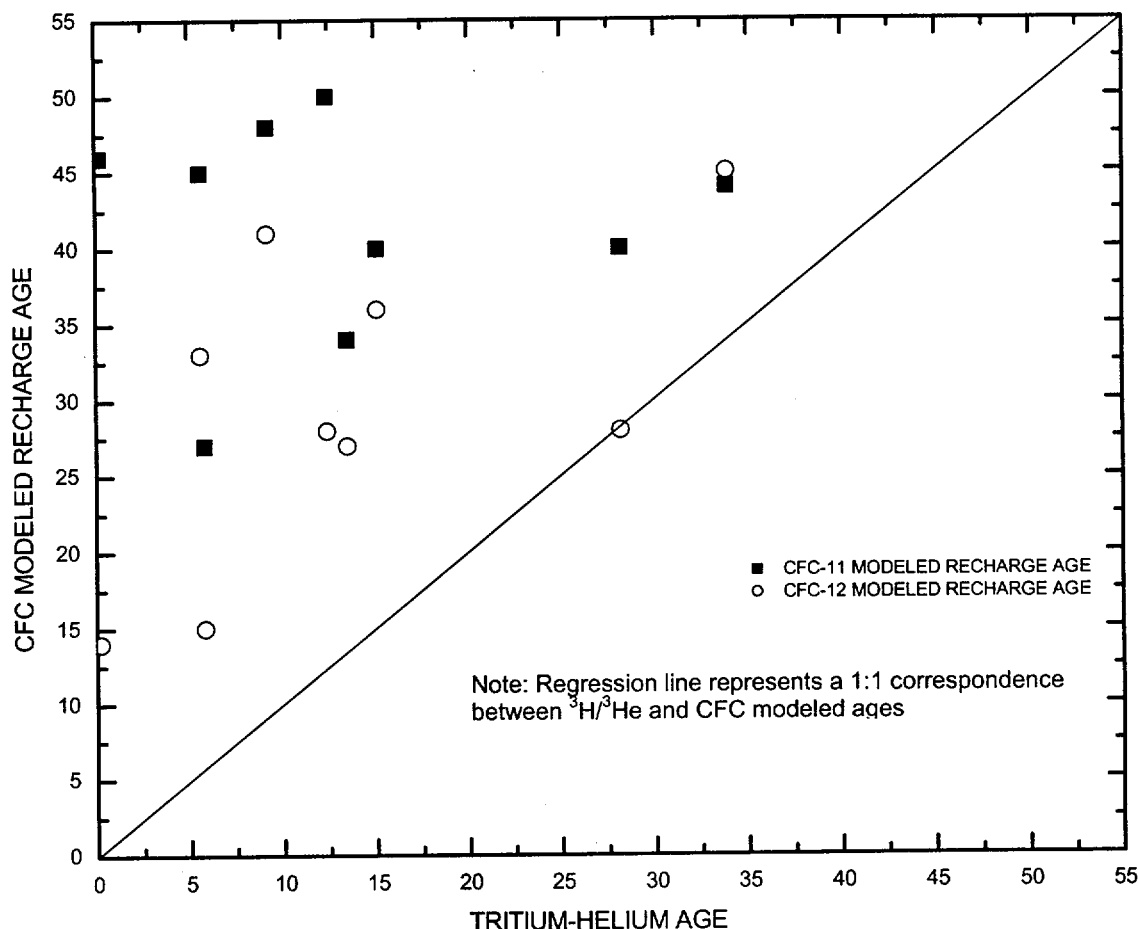


Figure 5-45. Recharge Age Modeled from CFC-11 and CFC-12 Data Compared to $^3\text{H}/^3\text{He}$ Age

The deep ground water from the Morrison Formation has high chloride concentrations, and the head gradient between the deep and alluvial aquifer is upward. Simple mixing calculations can be made to evaluate the percentage of water in the alluvial aquifer that could have originated from the deep, and presumably old, ground water. These calculations assume that (1) chloride is conservative, (2) the end member waters are the San Miguel River and the deep ground water, and (3) there are no other chloride sources. Table 5-6 summarizes these mixing calculations. These calculations suggest that upgradient of the former mill yard, less than 2 percent of the water is from the deep aquifer. In the contaminated area, the calculations are approximate because of contamination from sodium chloride used in processing the ore (Section 5.3.3.2). This is evident from the high chloride concentrations observed in historical data from abandoned well 0656. Well NAT03 is located close to the former location of well 0656. If the assumption is made that the 6 years from 1992 to 1998 and the surface soil remediation were sufficient to flush the mill-related chloride from the NAT03 area, then the deep ground water could have accounted for 7.6 percent of the total water. Because much of the chloride in this area could very likely be left from contamination, this value should be considered as a maximum amount of mixing. The results at NAT04, which is several hundred meters upgradient of NAT03, are similar to the results at NAT03.

Table 5–6. Chloride Concentrations and Mixing Ratios in Different Waters at the Naturita Site

Location	Measurement Period	Concentration mg/L	Percentage of Water from the Deep Aquifer
River			
SM1	1998–2001	5.2	0
Deep Aquifer			
0502	1986–1995	699	100
Upgradient Wells			
0547	1986–1997	9.0	0.5
0547	1998–2001	11	0.8
NAT20–22	1999–2001	10	0.7
Contaminated Wells			
0656	1990–1992	155	21.6
NAT03	1998–2001	58	7.6
NAT04	1998–2001	44	5.6

The $^3\text{H}/^3\text{He}$ age-dating technique only dates the young, tritium-containing fraction of ground water, because the isotope ratio is nearly independent of dilution with old tritium-free water (Plummer et al. 1998b). Therefore, these ages should be comparable to the CFC dates of the young water fraction. This fraction can be calculated using the mixing ratios from the chloride concentrations. Assuming that the water at well NAT02 is mixed with 7.6 percent old CFC-free water, the remaining young fraction should have a CFC-12 apparent age of 1986. The tritium-helium recharge age at this well is 1994. At well NAT29, assuming a mixing ratio of 7.6 percent old water, the young fraction should have an apparent CFC-12 recharge age of 1965. The $^3\text{H}/^3\text{He}$ recharge age at well NAT29 is 1985. In order to match the $^3\text{H}/^3\text{He}$ recharge ages at well NAT02 to the CFC-modeled ages, San Miguel River water would have to be mixed with about 85 percent old CFC-free water. Well NAT29 would need to be mixed with about 25 percent old water. Because the maximum amount of older water based on chloride concentrations is about 7.6 percent, it would appear that the CFC-12 ages are affected by some other process, such as biodegradation, and also cannot be used for age determination.

CFC-113 also proved unacceptable for ground water age dating. All samples except those from NAT09, NAT11, NAT24, and the San Miguel River were contaminated with CFC-113. CFC-113 contamination is defined by a sample concentration that is greater than would be present if the sample were equilibrated with modern air.

5.3.5 Contaminant Fate and Transport

5.3.5.1 Ground Water Flow and Transport Modeling

A ground water flow and transport model was developed to evaluate if natural processes will reduce concentrations of site-related COPCs to regulatory levels in the alluvial aquifer within 100 years. Two versions of the model were developed and employed to address conditions at the site. A steady state deterministic flow and transport model was used as the basis for the steady state stochastic flow and transport model. The steady state stochastic flow and transport model was used to quantify the uncertainty in flow and transport parameters. Modeling results indicate that natural flushing is not an acceptable compliance strategy to reduce ground water concentrations of uranium and vanadium to acceptable levels within 100 years.

The USGS was contracted to develop a steady state deterministic flow model for the Naturita site. The existing ground water flow pattern at the site was modeled using the MODFLOW software (McDonald and Harbaugh 1988), a multilayered, three-dimensional hydrologic flow model published by USGS. USGS uses the Argus Open Numerical Environments family of products for the pre- and post-processing for MODFLOW. The calibrated MODFLOW files created by the Argus ONE products were then converted to a format compatible with the version of MODFLOW in GWVistas.

The gravel mining operation upgradient of the former site has recently expanded and it is likely that there will be future expansions. This operation was not considered in the USGS flow model and subsequently not considered in the transport model. The recent and future expansion of this operation could significantly impact the ground water flow and the transport of contaminants. Without modeling the impacts from the gravel mining operation, the predicted concentrations of the COPCs in this report are most likely underestimated.

The calibrated steady state deterministic flow model of the USGS was used as a basis for a steady state stochastic flow model developed using GWVistas. The steady state deterministic and stochastic transport models were developed using GWVistas.

Output from the flow model was used as input to MT3DMS (Zheng and Wang 1999), a version of a modular three-dimensional transport model to simulate advection, dispersion, and chemical reactions of contaminants in the ground water system. A steady state deterministic transport model was developed to predict future concentrations of COPCs. Sensitivity analysis of the flow and transport parameters, within the deterministic models, determined that hydraulic conductivity and recharge are sensitive and affect the transport simulation results. These two flow parameters and the transport parameters of porosity, longitudinal dispersivity, and the K_d were treated as uncertain for stochastic simulation.

Section 4.5.1.4 briefly discusses the determination of K_d values from R_d values. The K_d values of 0.6078 and 12.46 mL/g for uranium and vanadium, respectively, that are used for the deterministic modeling are 25 percent of the average R_d value. For the stochastic modeling the estimated range of values is 25 percent of the minimum and maximum R_d values. For uranium the estimated range of values is from 0.3975 to 1.1225 milliliters per gram (mL/g). For vanadium the estimated range of values is from 4.445 to 20.6575 mL/g.

Details of the model construction, steady state calibration, and steady state stochastic parameters are presented in Appendix F. The codes used are fully described in the references cited and have been verified, benchmarked, and approved for use by most government and regulatory agencies. The following sections present a summary of the modeling results.

Steady State Deterministic Model

Predicted uranium concentrations in ground water after 100 years are presented in Figure 5-46. The simulation predicts that the maximum concentration will decrease to 0.23654 mg/L, which is above the UMTRA Project MCL of 0.044 mg/L. Vanadium simulations show similar results. Vanadium concentrations in ground water after 100 years are presented in Figure 5-47. The simulation predicts the maximum concentration will decrease to 4.3286 mg/L, which is well above the risk-based concentration of 0.33 mg/L. Simulation results show that at 10 years the maximum remaining arsenic concentration is 0.045 mg/L, which is below the UMTRA Project MCL of 0.05 mg/L.

Steady State Stochastic Model

The steady state stochastic modeling predicts similar results. Only uranium was modeled using the stochastic models. Figure 5–48 presents the results for uranium after 100 years. Maximum average concentrations are above the standard at 0.12087 mg/L. The stochastic simulations predict that after 100 years there is a 49 percent probability that the maximum concentration will be greater than the proposed standard over a significant area of the alluvial aquifer, as shown in Figure 5–49.

5.4 Pattern Recognition Modeling of Natural Attenuation Processes

The first step in documenting the natural removal of contaminants in ground water systems is to identify the “footprint” of the natural attenuation process (National Research Council 2000). The mechanisms that destroy or sequester the constituents cannot be observed directly; however, the removal process can leave a number of footprints that are directly related to the loss of the contaminant (National Research Council 2000). Multiple chemical and physical footprints of a specific natural attenuation process are usually required to provide a defensible link between cause and effect. Some footprints can be obscured by reactions that produce or use the footprint materials. For example, dissolution of calcareous materials along a ground water flowpath could mask the footprints of biodegradation reactions that change the total inorganic carbon concentration in the ground water (National Research Council 2000). These same principles are applicable to documenting the geochemical and hydrologic footprints of the natural attenuation of selected contaminants at the Naturita site.

Statistical techniques collectively referred to as pattern recognition modeling are useful in extracting chemical information from large, multivariate databases that may otherwise be difficult or impossible to interpret (Meglan 1988). Pattern recognition modeling uses statistical and graphical techniques to chemically fingerprint groups of multivariate data that have undergone similar geochemical and hydrologic processes. These techniques can be used to efficiently identify the footprints related to natural attenuation processes at the Naturita site.

The objectives of this section are to (1) describe how pattern recognition modeling techniques were used to model multivariate data from the Naturita site, and (2) interpret the results of pattern recognition modeling with respect to the geochemical and hydrologic footprints controlling uranium removal at the site.

5.4.1 Methodology

Pattern recognition modeling techniques were applied to the multivariate data matrix collected from the Naturita site during June 2000 (Table 5–7 and Appendix G). The data set consists of 66 locations (Figure 5–50) and 23 chemical, physical, and isotopic constituents. The constituents in the data set are aluminum, alkalinity as calcium carbonate, boron, bromide, calcium, chlorine, dissolved oxygen (DO), iron, potassium, magnesium, manganese, sodium, oxidation-reduction potential, pH, silicon, sulfate, specific conductance, strontium, temperature, uranium, vanadium, delta oxygen-18 ($\delta^{18}\text{O}$), and delta deuterium (δD). The pattern recognition modeling of the database consisted of (1) hierarchical cluster analysis (HCA) and (2) principal component analysis (PCA) combined with data visualization techniques using the software package PIROUETTE 3.01 (Infometrix 2000).

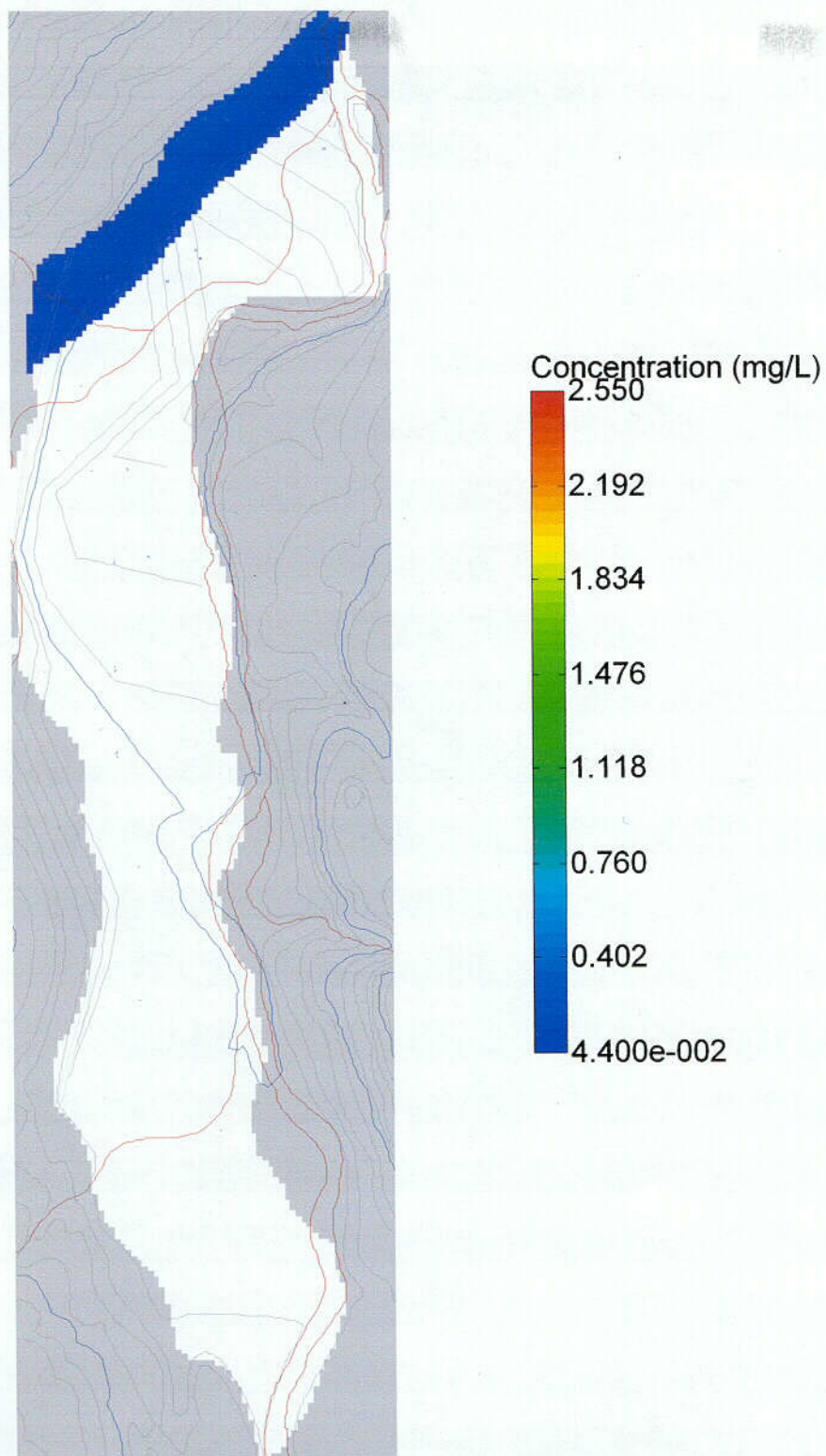


Figure 5-46. Predicted Uranium Concentrations in Ground Water After 100 Years
(steady state deterministic model)

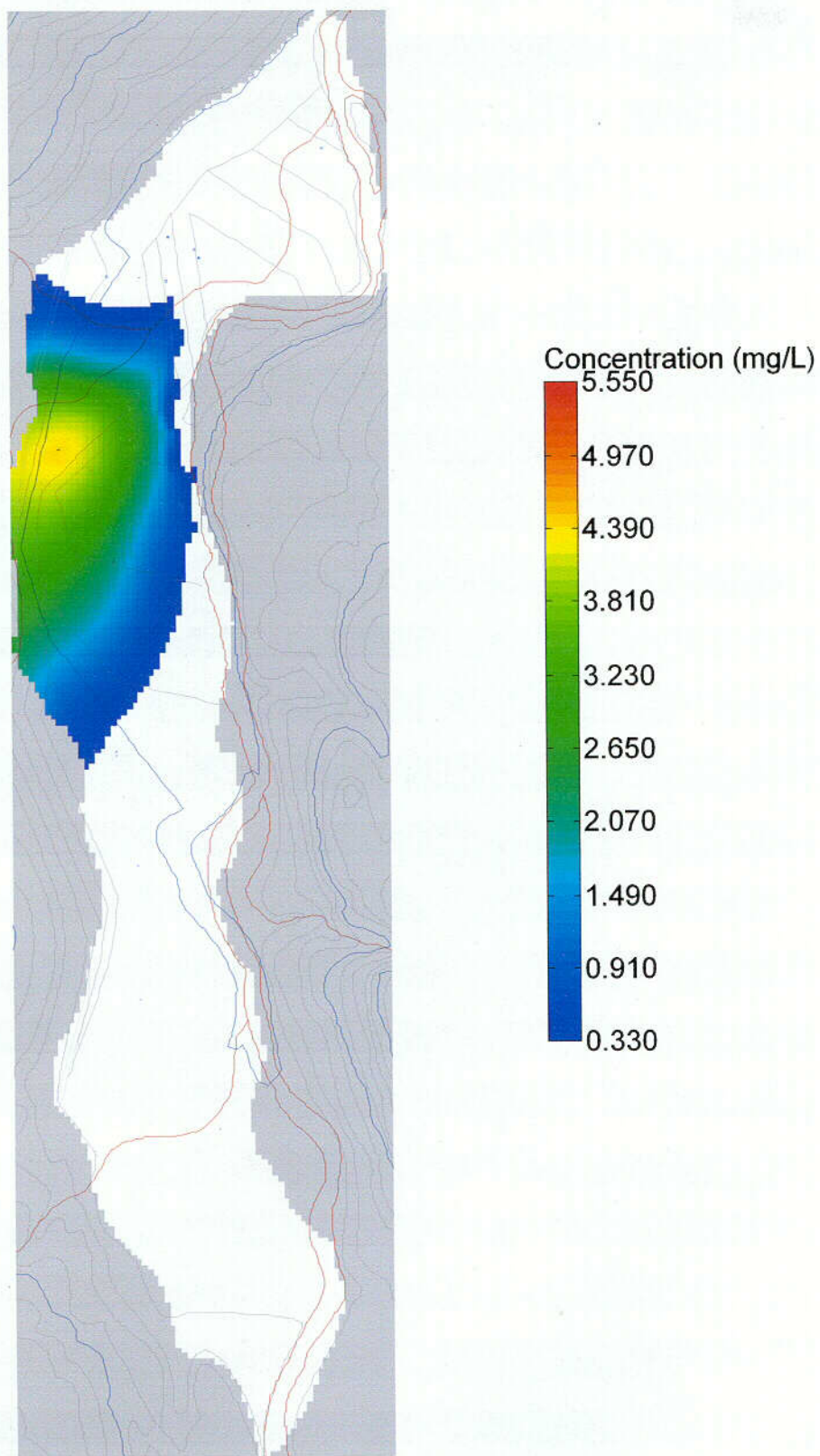


Figure 5-47. Predicted Vanadium Concentrations in Ground Water After 100 Years
(steady state deterministic model)

C11

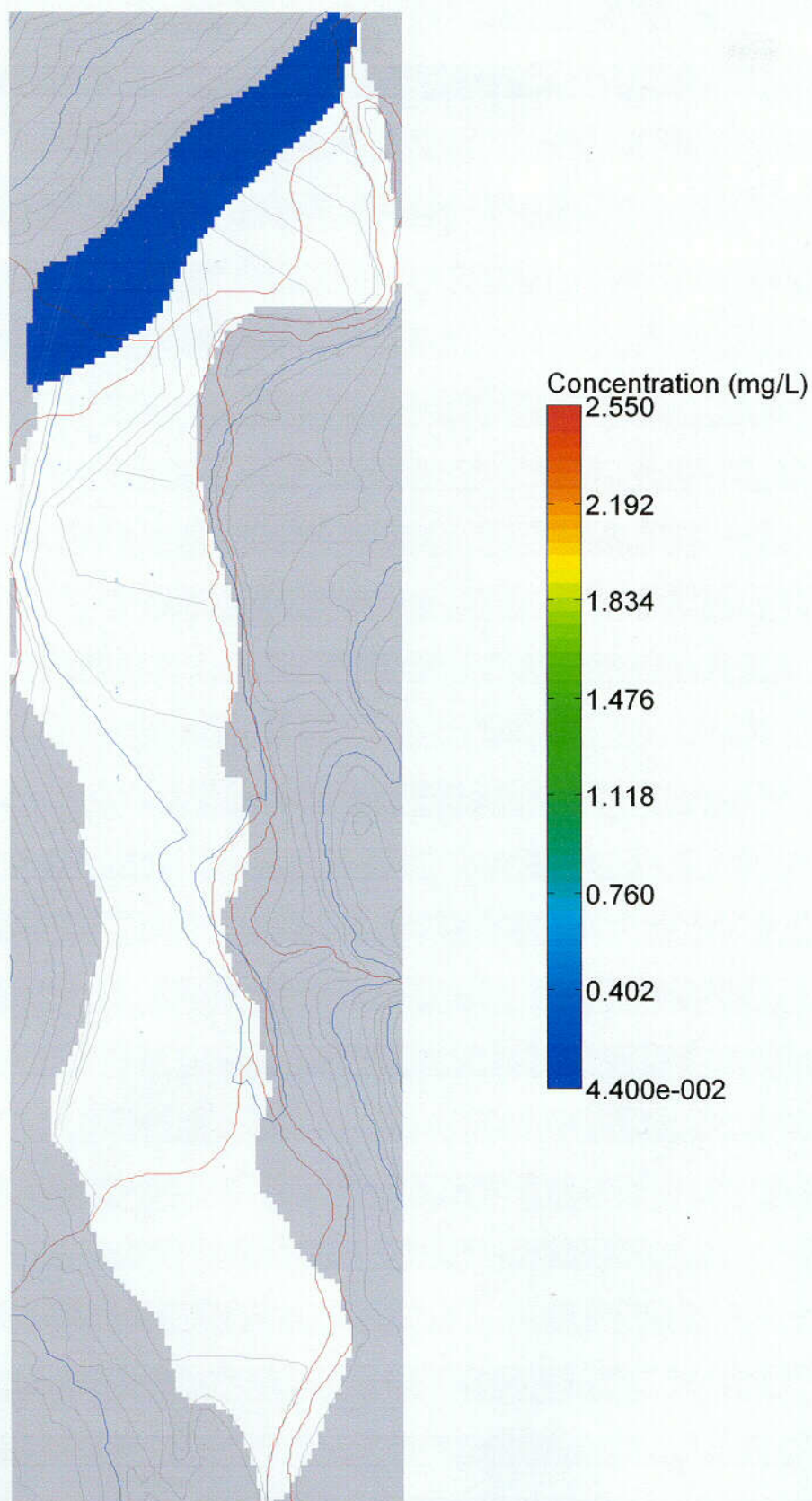


Figure 5-48. Predicted Uranium Concentrations in Ground Water After 100 Years
(steady state stochastic model)

C12

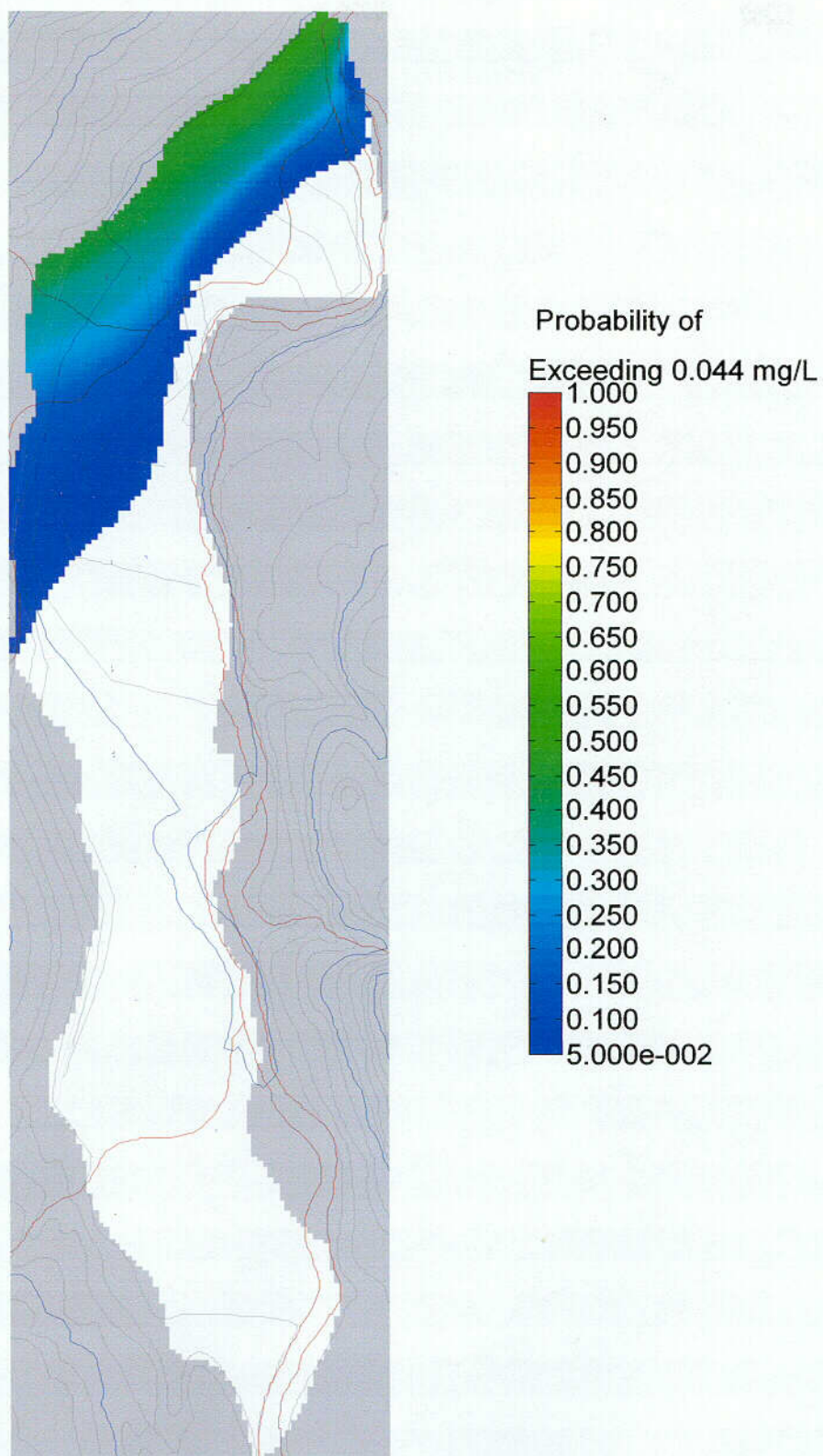


Figure 5-49. Probability of Exceeding 0.044 mg/L After 100 Years

Table 5–7. Principal Component Loadings of Each Chemical Constituent Used in Pattern-Recognition Modeling of Geochemical Data at the Naturita Site

Chemical Constituent	Principal Component 1 Loadings, Unitless	Principal Component 2 Loadings, Unitless	Principal Component 3 Loadings, Unitless
Aluminum	0.170188	-0.017381	0.003615
Alkalinity as CaCO ₃	0.274251	-0.113037	-0.031143
Boron	0.244010	0.147747	0.175510
Bromide	0.141018	0.302378	0.280969
Calcium	0.270638	-0.006266	-0.048917
Chloride	0.249546	-0.001928	0.146143
Dissolved oxygen	-0.086892	0.310780	0.291254
Iron	0.036257	-0.255583	-0.316834
Potassium	0.243880	0.198122	0.064084
Magnesium	0.281352	-0.063129	0.091898
Manganese	0.199061	0.097277	-0.252004
Sodium	0.281358	-0.073263	0.046984
Oxidation-reduction potential	-0.048781	0.175063	0.195769
pH	-0.134528	0.391981	0.102914
Silicon	0.247714	0.025142	-0.100777
Sulfate	0.280173	-0.103272	0.067179
Specific conductance	0.283692	-0.069284	0.090751
Strontium	0.268836	0.014925	0.180447
Water temperature	-0.100691	0.155468	0.376458
Uranium	0.267012	0.141107	-0.084516
Vanadium	0.132422	0.131755	-0.201817
Delta deuterium	-0.007406	-0.458933	0.377873
Delta oxygen-18	-0.049736	-0.425400	0.406542

Note: Loadings greater than 0.20 or less than -0.20 best explains the most probable geochemical processes controlling the elemental distribution in each principal component.

5.4.2 Hierarchical Cluster Analysis Results

The purpose of HCA is to group multivariate data so that underlying links between the groups can be discerned (Davis 1973; Meglan 1991). This grouping is accomplished by calculating a similarity distance of all variables in the data set between all possible pairs of samples. After sample distances have been computed, the two most similar samples are linked, and this linkage continues until all the samples and clusters have been linked. Identical samples would have a similarity value (SV) of 1.0, and the most dissimilar sample/cluster in the data set would have a SV of 0.0. Prior to HCA, the data were autoscaled and the complete linkage method was used to calculate the SVs between sample pairs (Infometrix 2000). Results of the HCA are displayed in the form of a dendrogram constructed with the SV scale on top decreasing from 1.0 (most similar) to 0.0 (least similar) (Figure 5–51).

Six distinct data clusters (designated groups 1, 2, 3, 4, 5, and 6 & 7) were distinguished using a SV = 0.66 and defined by the vertical line on the dendrogram (Figure 5–51). Sample locations in each of the groups plot in distinct geographic regions of the site (Figure 5–50) that are related to similar geochemical and hydrologic processes. Group 1 is surface water in the San Miguel River. Group 2 is associated with water samples from wells at the southern edge of the site, immediately downgradient of the gravel pits and upgradient of the historical tailings and

associated facilities. Group 3 consists of water samples from well DM1 upgradient of the gravel pits and south of the study area boundary plus wells MAU03, MAU04, and MAU06 at the north end of the study area. Group 4 consists of water samples from wells in the center of the site and adjacent to the river. Group 5 consists of water samples from wells in the central part of the site; however, they are farther away from the San Miguel River than wells belonging to Group 4. Water samples from wells MAU01, MAU08, NAT25, and NAT26 are members of group 6&7 and are located in the northern half of the study and are, in general, farther removed from the San Miguel River than Group 5 wells.

The uranium concentrations for each group are distinctly different (Figure 5–52). The median uranium concentrations are lowest (median concentration < 14 µg/L) for locations in groups 1 and 2. Geographically, these locations represent the San Miguel River or areas upgradient of the former uranium processing facilities. Higher median uranium concentrations are present in locations classified in Group 3 (median concentration = 172 µg/L) and Group 4 (median concentration = 466 µg/L). Both Group 3 and 4 locations are downgradient from the former uranium processing facilities, but close to the San Miguel River where elevated river stage during seasonal snowmelt tends to create some localized flushing zones that could dilute the uranium concentration in the ground water. The uranium concentrations are highest at locations in groups 5 and 6&7 (median concentrations = 908 and 1,660 µg/L). Geographically, these locations are both downgradient of the former millsite and farther removed from the mixing influence of the San Miguel River than locations in groups 1–4 (Figure 5–50).

Age dating of water in each of the groups supports the interpretation of interaction with the San Miguel River and the observed uranium concentrations (Figure 5–52). Because water samples belonging to Group 1 represent surface water in the San Miguel River, they are assumed to have an age date of 2000. Unfortunately, no age dating was done on water samples from wells belonging to Group 2. Wells from Groups 3 and 4 are close to the San Miguel River and have relatively young recharge ages (1985 to 2000) and low median uranium concentrations, indicating significant mixing with recently recharged water from the San Miguel River. In contrast, Group 5 and Group 6&7 wells that are farther away from the San Miguel River have older recharge ages (1966 to 1991) and higher median uranium concentrations, indicating less mixing with recently recharged water from the San Miguel River. The youngest recharge age measured in Group 5 wells was 1991 and was measured in water from well NAT17, which is the farthest upgradient well in Group 5.

5.4.3 Principal Component Analysis Results

Results from the HCA of the multivariate data set (Table 1, Appendix G) indicate a significant clustering of the data that is directly related to the geographic distribution of the wells in terms of distance from the San Miguel River and relation to the tailings material. PCA was applied to the same data set and data groupings identified in the HCA to determine the underlying geochemical and hydrologic processes that may be controlling the observed variations in the individual chemical, isotopic, and physical constituents that were analyzed.

The goal of PCA is to find a new set of coordinate axes that are mutually orthogonal, onto which the multivariate data can be projected. Each new axis is referred to as a principal component (PC) and is independent of the other PCs. The number of PCs used to represent the multivariate data set is not exact; however, the first two or three PCs generally explain most of the variance from the original data matrix.

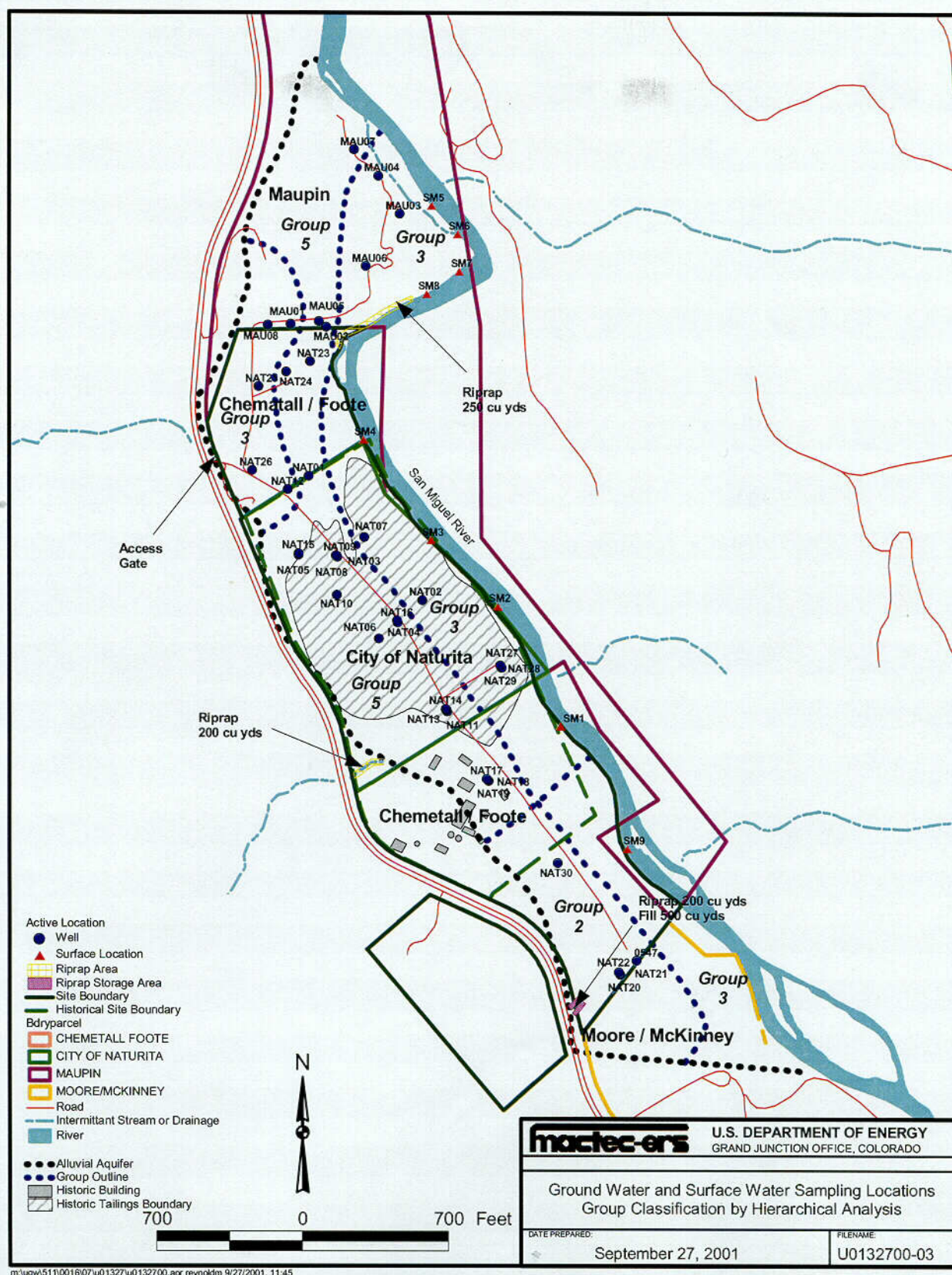


Figure 5-50. Location of Ground and Surface Water Sampling in Relation to Group Classification by Hierarchical Cluster Analysis

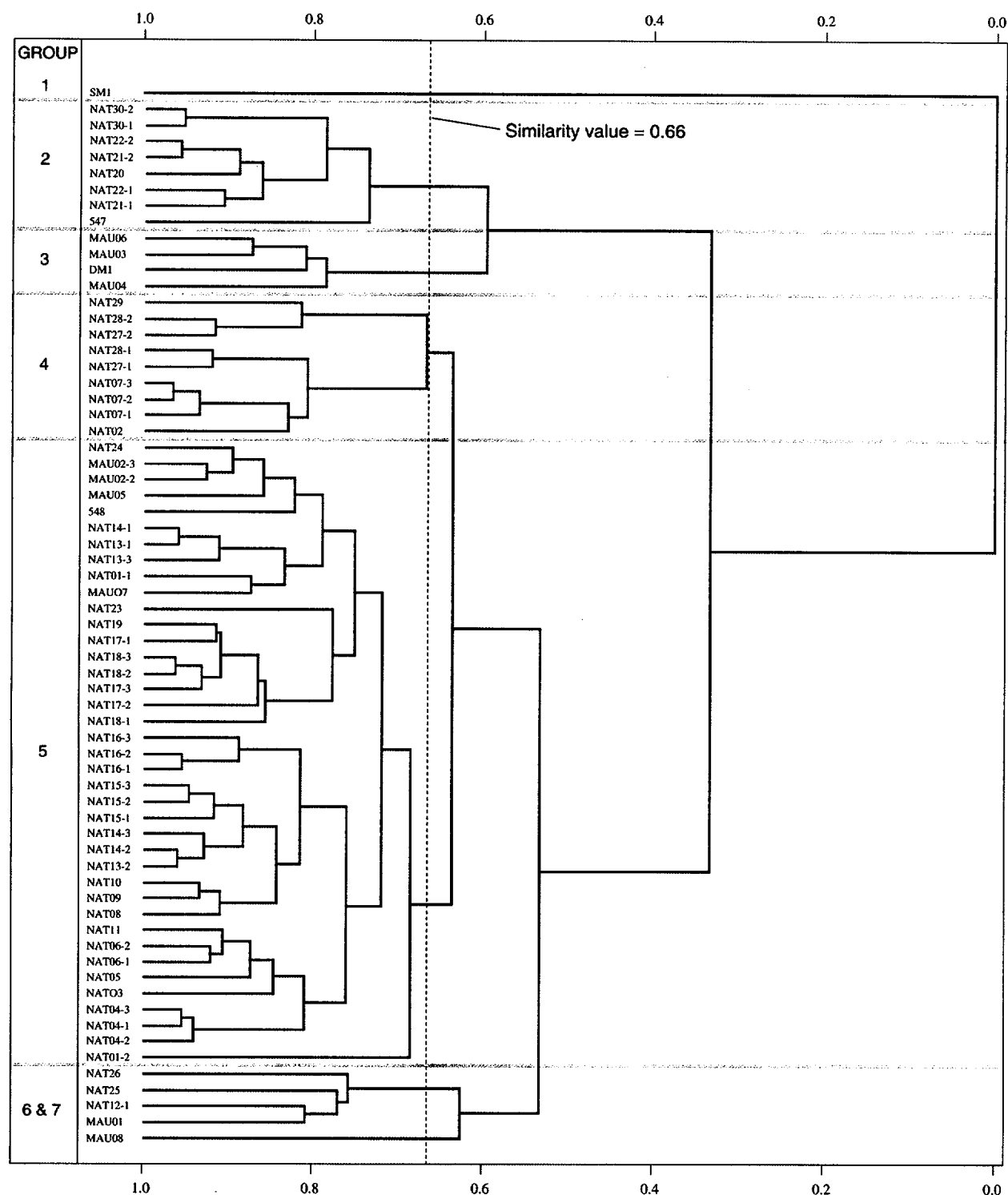


Figure 5-51. Dendrogram Showing the Results of the Hierarchical Cluster Analysis Performed on the Multivariate Data Set Collected During June 2000, Naturita, Colorado. Each Group Consists of One or More Sample Sites Within the Study Area.

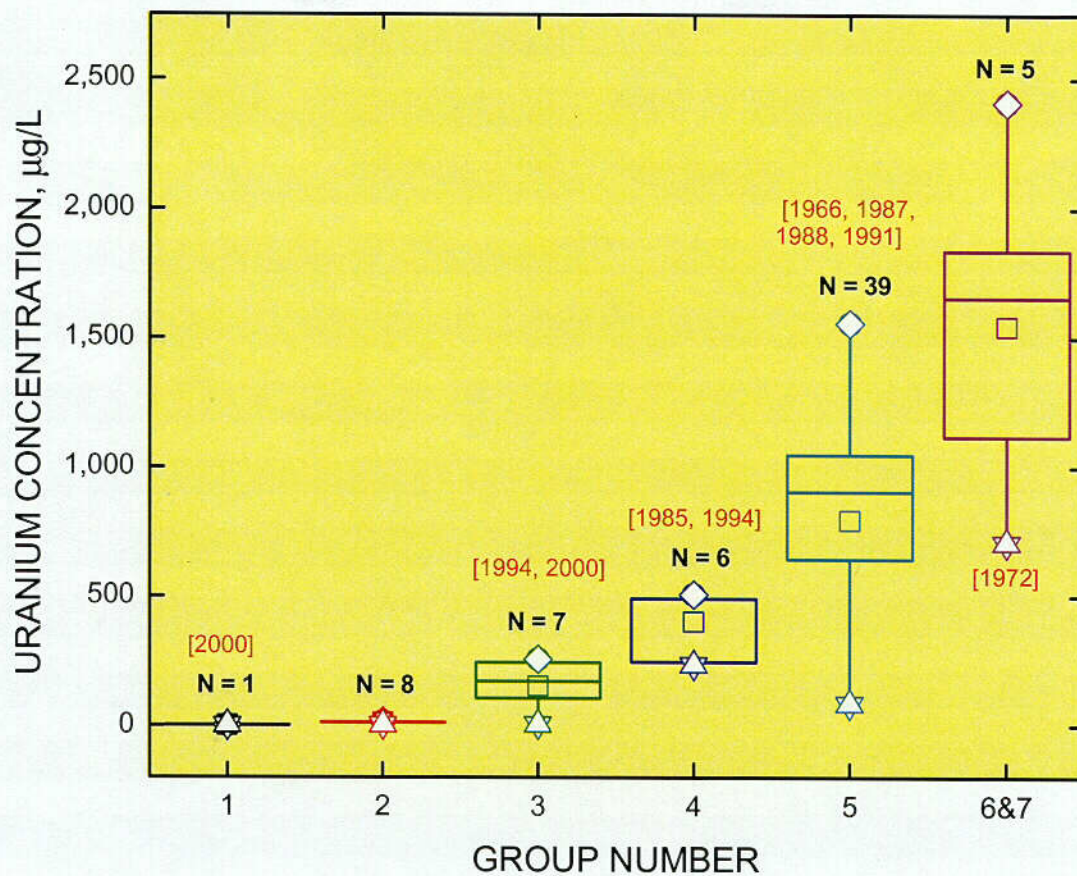


Figure 5-52. Box Plots Comparing the Uranium Concentrations and Dates of Ground Water Recharge for Each Group Identified by the Hierarchical Cluster Analysis of Ground and Surface Water Data Collected at the Naturita Site

During PCA, the multivariate data set is decomposed into two matrices consisting of loadings and scores for each of the PCs that were selected. The product of the scores and loadings matrices will reproduce the original data set. For example, if three PCs were selected to represent the original data matrix, each PC would have a loading value between ± 1.0 for each of the original variables. The PC loadings near -1.0 and $+1.0$ are considered significant and are used to identify the chemical, physical, and isotopic constituents that compose each PC. The PC scores are simply the coefficients of the loadings used to transform the original responses from each data point onto the PC axis. Prior to PCA, the original data matrix was transformed into the base 10 logarithm of the original value and autoscaled. The first three PCs were found to best explain the original data set and accounted for 73 percent of the total variance.

Figure 5–53 shows the PC 1 and PC 2 scores. The two axes are linear combinations of the original multivariate data set consisting of 23 variables and 66 samples and can be thought of as a new set of plotting axes. Instead of each axis representing the concentration of a particular trace metal or other inorganic constituent, each axis represents combinations of the different chemical, physical, and isotopic constituents in the water samples, thereby representing geochemical or hydrologic footprints that could provide insight into natural attenuation processes at the site.

The suite of chemical constituents contained in each plotting axis can be used to determine what geochemical and hydrologic process is represented, such as the effect of uranium mill tailings or natural flushing from the San Miguel River. The x-axis in Figure 5–53 is referred to as PC 1 and best represents the ground water contamination from tailings material. Chemical constituents making a substantial positive contribution to PC 1 include alkalinity, boron, calcium, chlorine, potassium, magnesium, manganese, sodium, silicon, sulfate, specific conductance, strontium, and uranium (Table 5–7). Uranium is derived from the leaching of tailings material. The positive sulfate loading is probably related to the use of sulfuric acid in the ore processing and the dissolution of sulfate mineral phases in the soil below the mill tailings. Dissolution of carbonate mineral phases in the soil zone beneath the tailings pond could result in the elevated loadings for calcium, alkalinity, and strontium. The substantial positive -loadings for sodium and chloride may be related to the use of sodium chloride during salt roasting of the ore material at the site. Positive loadings for boron, chloride, magnesium, sodium, and specific conductance could also be related to the evaporation of tailings process water at the surface before infiltration into the alluvial aquifer.

The y-axis in Figure 5–53 is referred to as PC 2 and represents river flushing with limited evaporation. Chemical, physical, and isotopic constituents making a substantial positive and negative contribution to PC 2 include Br, dissolved oxygen, Fe (negative loading), K, pH, δD (negative loading), and $\delta^{18}O$ (negative loading) (Table 5–7). The geochemical association in PC 2 is consistent with what would be expected from significant amounts of river water flushing into the alluvial aquifer at the site. Water from the San Miguel River has pH values that are greater than 8.0 units and dissolved oxygen concentrations that exceed 8.0 mg/L (Table 1, Appendix G). The substantial negative loading for iron in PC 2 is consistent with the low solubility of iron under the oxidizing conditions characteristic of the San Miguel River. The substantial negative loadings for δD and $\delta^{18}O$ are reflective of the isotopically light values of water from the San Miguel River derived from high elevation snowmelt, prior to evaporative enrichment. The positive loading for bromide may be the result of domestic sewage effluent containing elevated concentrations of bromide entering the San Miguel River upstream of the site (Vengosh and Pankratov 1998, Davis and others 1998). It is also possible that part of the bromide and

potassium sources could be residual tracer that was injected into selected wells during May 2000; however, the concentration of the injected tracer compared to natural concentrations is not known.

The individual points in Figure 5–53 represent where individual water samples plot on the newly defined axes (PC 1 and PC 2). Samples from the six groups identified in the HCA show distinct clusters with respect to their PC 1 (tailings contamination) and PC 2 (river flushing) scores. Water samples belonging to Group 1 represent water from the San Miguel River and have the largest PC 2 scores (river flushing) and lowest PC 1 scores (tailings contamination) of all 66 samples. Water samples belonging to Groups 3 and 4 contain the largest overall river flushing scores, which are confirmed by their proximity to the San Miguel River. Water samples belonging to Group 2 have low PC 1 and 2 scores, indicating limited flushing from the San Miguel River and limited influence from uranium mill tailings. This classification is consistent with the location of Group 2 samples, which is upgradient of the historical tailings area and offset at least 250 ft from the San Miguel River and downgradient from a gravel pit (Figure 5–50).

Group 5 and 6&7 samples have the overall largest PC 1 scores (tailings contamination) (Figure 5–53). With the exception of wells NAT23, MAU02, MAU05, and MAU07, all the wells in these groups are relatively distant from the flushing influence of the San Miguel River and downgradient from the historical tailings area (Figure 5–50). Group 6+7 water samples have the largest PC 1 (tailings contamination) scores relative to all six-sample groups.

The PC 3 scores for the 66 water samples are plotted on the y-axis in Figure 5–54 and compared to PC 1 scores (tailings contamination) plotted on the x-axis. Water samples having large PC 3 scores appear to be influenced by strong evaporative effects. Chemical, physical, and isotopic constituents making a substantial positive or negative contribution to PC 3 include bromide, iron (negative loading), manganese (negative loading), dissolved oxygen, oxidation-reduction potential, water temperature, vanadium (negative loading), δD , and $\delta^{18}O$ (Table 5–7). The geochemical association in PC 3 is consistent with what would be expected from evaporation of surface water from the San Miguel River. The positive loadings for dissolved oxygen and oxidation-reduction potential, in combination with negative loadings for iron and manganese, indicate an oxidizing surface water source. The negative loadings for δD and $\delta^{18}O$ and positive loading for water temperature are consistent with isotopic enrichment of surface water by evaporation. As with PC 2, the positive loading for bromide may be an indicator of a domestic sewage component in water from the San Miguel River or could be related to the bromide that was used in a series of tracer tests at selected wells with low hydraulic conductivity during May 2000. Because of the conservative nature of bromide, evaporative processes could substantially increase its concentration in water. The negative loading for vanadium in PC 3 is not apparent.

The individual points in Figure 5–54 represent where individual water samples plot on the newly defined axes (PC 1 and PC 3). Water samples in Groups 2, 4, and 6+7 have the largest PC 3 scores. Group 2 water samples were collected from wells immediately downgradient from a series of gravel pits at the southern part of the site (Figure 5–50). The gravel pits intercept the water table in the alluvial aquifer and expose recently recharged water from the San Miguel River to potentially large amounts of evaporation (Figure 5–55). In general, PC 3 scores in Group 2 wells decrease in a downgradient direction from the gravel pits (Figure 5–54), which could be the result of mixing evaporated water from the gravel pit with nonevaporated water resident in the alluvial aquifer.

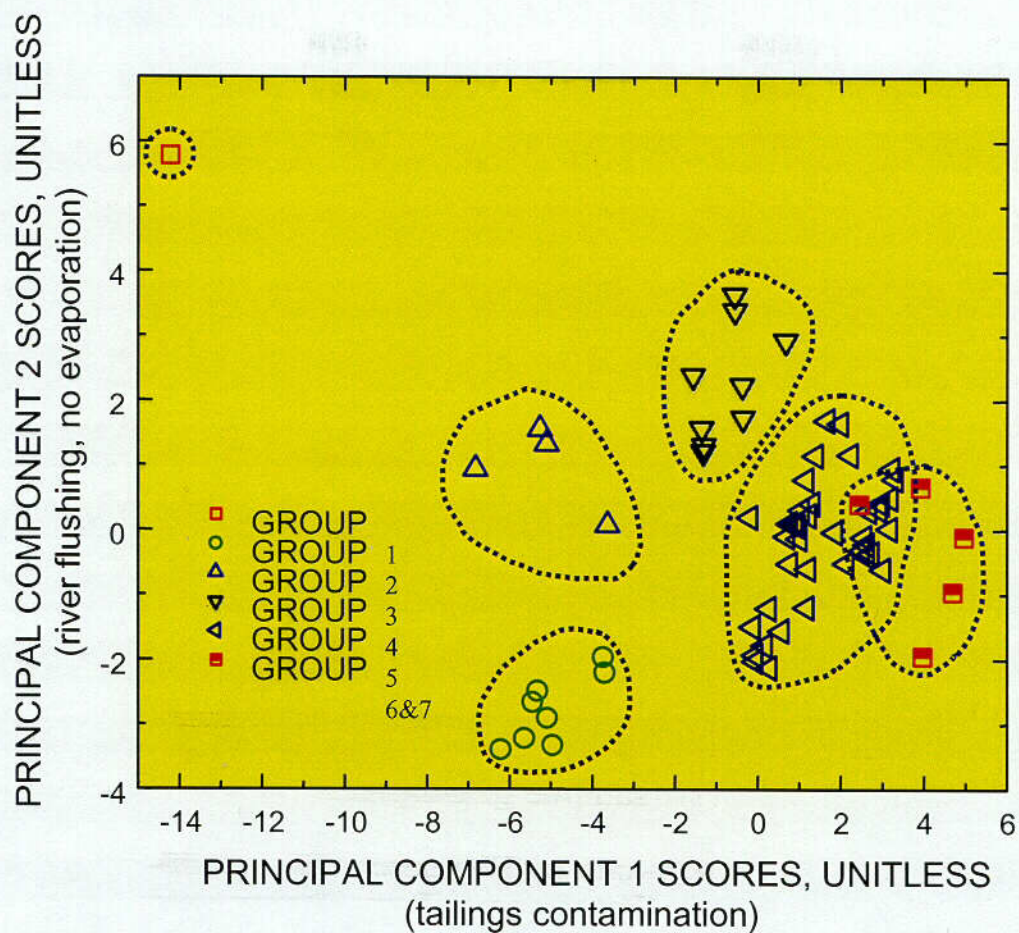


Figure 5-53. Principal Component 1 and 2 Scores for Ground and Surface Water Samples Collected at the Naturita Site

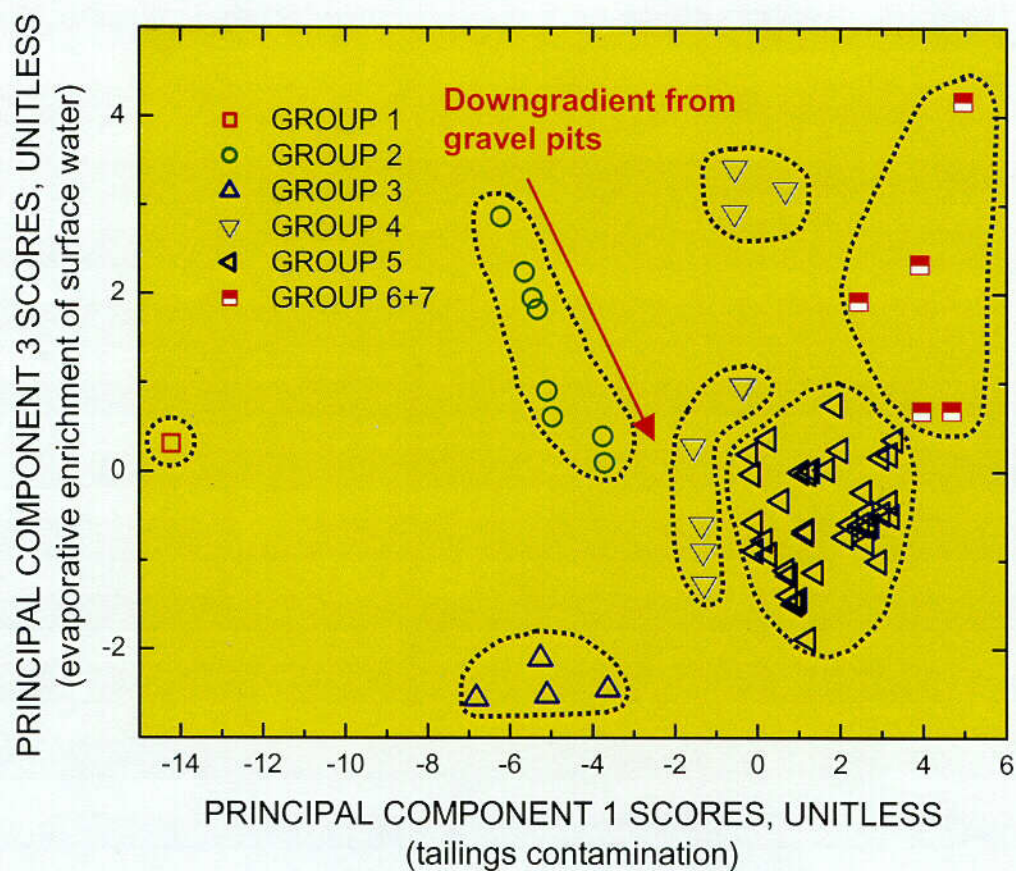


Figure 5-54. Principal Component 1 and 3 Scores for Ground and Surface Water Samples at the Naturita Site