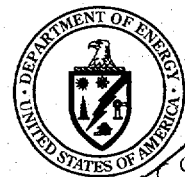




Site Observational Work Plan for the Durango, Colorado, UMTRA Project Site

January 2002

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



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UMTRA Ground Water Project

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Durango, Colorado, UMTRA Project Site**

January 2002

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

Project Number UGW-511-0006-10-000
Document Number U0143200

Work Performed Under DOE Contract Number DE-AC13-96GJ87335

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End of current text

Acronyms and Abbreviations

ACL	alternate concentration limit
AEC	U.S. Atomic Energy Commission
AGW	actual ground water
AWQC	ambient water quality criteria
BAF	bioaccumulation factor(s)
BCF	bioconcentration factor(s)
Bendix	Bendix Field Engineering Corporation
BLRA	Baseline Risk Assessment
BOR	U.S. Bureau of Reclamation
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
COPC	constituent/contaminant of potential concern
CRDL	contract required detection limit
DOE	U.S. Department of Energy
DQO	data quality objective
EA	environmental assessment
E-CPOC	ecological constituents of potential concern
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ESL	Environmental Sciences Laboratory
ft	foot (feet)
ft/day	foot (feet) per day
ft ² /day	square feet per day
ft ³	cubic feet
GCAP	Ground Water Compliance Action Plan
GJO	Grand Junction Office
HI	hazard index
HNO ₃	nitric acid
HQ	hazard quotient
IC	institutional control
ICP-AES	inductively coupled plasma-atomic emission spectrometry
ICP-MS	inductively coupled plasma-mass spectrometry
i.d.	inside diameter
IRIS	Integrated Risk Information System
K	hydraulic conductivity
K _d	distribution coefficient
LOAEL	lowest observed adverse effect level
LTMP	Long-Term Management Plan
LTSP	Long-Term Surveillance Plan
MAP	Management Action Process Document
MCL	maximum concentration limit
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
mL	milliliter(s)
mL/g	milliliter(s) per gram

mV	millivolt(s)
NEPA	National Environmental Policy Act
NIWQP	National Irrigation Water Quality Program
NOAEL	no observed adverse affect level
NRC	U.S. Nuclear Regulatory Commission
ORP	oxidation-reduction potential
pCi/L	picocuries per liter
Q	inflow
PEIS	Programmatic Environmental Impact Statement
PVC	polyvinyl chloride
RAP	Remedial Action Plan
RBC	risk-based concentration
REDC	Ranchers Exploration and Development Corporation
RfD	reference dose(s)
ROD	Record of Decision
RRM	residual radioactive material
SEE_PRO	Site Environmental Evaluation (database)
SOWP	Site Observational Work Plan
TAGR	Technical Approach to Groundwater Restoration
TDS	total dissolved solids
UCL ₉₅	95 percent upper confidence limit
UF	uncertainty factor(s)
UMTRA	Uranium Mill Tailings Remedial Action (Project)
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey
USV	United States Vanadium Corporation
VCA	Vanadium Corporation of America

Executive Summary

Uranium ore was processed from 1941 through 1963 at the Durango site, located 0.25 mile southwest of the city of Durango in La Plata County, Colorado. The former processing site consists of two geographically contiguous, but hydrogeologically separate, areas: the mill tailings area, which encompasses the northern portion of the site, and the raffinate ponds area, which encompasses the southern portion of the site. The site is bounded by Lightner Creek to the north, the Animas River to the east, South Creek to the south, and Smelter Mountain to the west. Contaminated materials were removed from both areas from 1986 through 1991 and stabilized in a disposal cell in Bodo Canyon, approximately 1.5 miles southwest of the processing site.

Mill Tailings Area

The mill tailings area is underlain by Mancos Shale, which has been truncated by the Smelter Mountain fault south of the mill tailings area. Along the base of Smelter Mountain, the Mancos Shale directly underlies a thick layer of colluvium; closer to Lightner Creek and the Animas River, deposits of river-laid sand and gravel occur over the shale bedrock and under the colluvium. Ground water at the mill tailings area is present in an unconfined alluvial aquifer, which is recharged by infiltration of precipitation and runoff, and by contact with the Animas River and Lightner Creek.

The primary sources of ground water contamination in the mill tailings area were the large and small tailings piles. The constituents of potential concern (COPC) identified in the 1995 Baseline Risk Assessment (BLRA) were reevaluated using data collected through August 2001. The more recent data indicate that uranium presents the greatest risk and is the COPC with concentrations that exceed the Uranium Mill Tailings Remedial Action (UMTRA) Project maximum concentration limit (MCL) in ground water in the greatest number of wells. Concentrations of selenium also exceed the MCL in several locations, and cadmium and molybdenum levels exceed their MCLs in only one location each.

To achieve compliance with Subpart B of Title 40 *Code of Federal Regulations* Part 192 (40 CFR 192), the U.S. Department of Energy's (DOE) proposed action is natural flushing in conjunction with institutional controls and continued monitoring. Ground water flow and transport modeling has predicted that site-related concentrations of uranium and molybdenum in the alluvial aquifer will decrease to levels below the MCL within 100 years. Modeling results also indicate manganese and sulfate concentrations will decrease below their risk-based and background levels, respectively. Selenium occurs naturally in background locations at the mill tailings area in concentrations above the MCL. Ground water flow and transport models indicate selenium concentrations will not decrease below the MCL within 100 years. Therefore DOE defers to the alternate concentration limit (ACL) value of 0.05 milligrams per liter (mg/L) for selenium from the U.S. Environmental Protection Agency's (EPA) Safe Drinking Water Act (the predicted concentration after 100 years is 0.0246 mg/L). Selenium concentrations are less than levels considered to be a risk to human health and the environment.

Cadmium concentration is elevated in only one well (0612) at the mill tailings area; all other on-site wells concentrations are at or near the detection limit. Cadmium accounts for only 6 percent of the risk at the mill tailings area using the worst-case residential drinking water scenario. Ground water flow and transport models indicate cadmium levels will not decrease below the MCL or risk-based concentrations within 100 years. Cadmium concentrations from well 0612

vary considerably, and since the completion of surface remediation, data indicate a downward trend greater than indicated by the model (because of the high estimated distribution coefficient used in modeling); the trend indicates that cadmium will decrease below the MCL. Cadmium will be monitored in well 0612 for the next 10 years to verify the downward trend in concentration.

The volume of water with cadmium concentrations above the MCL is considered to be small enough that it poses no unacceptable ecological risks. In addition, ground water at the mill tailings area is not a current or potential source of drinking water. Because of existing institutional controls and the availability of municipal water as a drinking water source, the most likely scenario for the mill tailings area is that no ground water exposures will occur.

Raffinate Ponds Area

Two bedrock units, both members of the Mesaverde Group, underlie the raffinate ponds area. The Point Lookout Sandstone underlies the northwestern two-thirds of the raffinate ponds area between Smelter Mountain and the Bodo Fault. The Bodo Fault is a northeast-southwest trending normal fault and dips to the southeast across the site. The Menefee Formation underlies the southeastern one-third of the raffinate ponds area, southeast of the fault. The Point Lookout Sandstone consists of siltstone with interbedded sandstone and shale. The Menefee Formation consists of massive sandstone with beds of carbonaceous shale and coal. Ground water at the raffinate ponds site is unconfined and is recharged by infiltration of precipitation and runoff, and by horizontal inflow from Smelter Mountain. Ground water flow at the raffinate ponds area is predominantly through joints, open bedding planes, and fractures.

Before surface remediation was completed, ground water in the raffinate ponds area occurred in both the surficial deposits and bedrock. At present, ground water in the raffinate ponds area occurs primarily in the bedrock. The primary sources of ground water contamination at the raffinate ponds area were spent raffinate liquids from the milling process that were pumped into a ditch and carried to the settling ponds. There the raffinate was disposed of through evaporation and seepage.

Since completion of surface remediation, uranium and selenium are the only constituents that have consistently exceeded the MCLs at the raffinate ponds area. The highest concentrations of selenium and uranium are detected in the central portion of the site east of the Bodo Fault, in the shallow wells of the Menefee Formation. With the exception of selenium, concentrations of all contaminants related to the uranium-ore processing (arsenic, molybdenum, sulfate, uranium, and vanadium) have decreased since the completion of surface remediation and continue to show downward trends in concentrations.

To achieve compliance with Subpart B of 40 CFR 192 at the raffinate ponds area, DOE's proposed compliance strategy is no remediation with the application of supplemental standards based on the criterion of limited use ground water due to widespread selenium contamination. The following facts indicate that selenium concentrations exceeding the MCL at the raffinate ponds area are a result of natural sources of selenium and not uranium-ore processing:

- The U.S. Department of Health, Education, and Welfare analyzed seepage from the tailings piles and the raffinate liquor while the mill was in operation. Selenium concentrations were below the detection limit in both sources. In addition, present-day pore water in the tailings at

the Bodo Canyon disposal cell shows that selenium is not the dominant contaminant in the mill tailings. The fact that selenium is the sole element of this group to increase in concentration, while concentrations of other constituents are decreasing, and historical selenium concentrations in the raffinate liquids are below the detection limit, indicate that the presence of selenium is not related to the uranium-ore processing.

- Concentrations of selenium vary; in most wells where selenium values are elevated, the wells are screened across coal deposits. The carbonaceous shales, coal deposits, and pyrite that are widespread across the raffinate ponds area are well documented to be enriched in selenium. The mobilization of selenium into ground water from these sources is related to the oxidation-reduction potential (ORP) in the ground water; selenium is mobilized with increasing oxidation. In most cases, increasing and decreasing selenium values at the raffinate ponds area show a definite correlation with ORP.
- Selenium concentration exceeds the MCL at background well 0599; most recently by nearly a factor of nine. The ORP is oxidizing in well 0599; in other background wells the ORP is negative (reducing conditions), preventing selenium from being mobilized into the ground water. Selenium concentrations in background surface water locations sampled by the U.S. Bureau of Reclamation exceed the MCL.

Ground water from the bedrock formations beneath the raffinate ponds area is not a current or potential source of drinking water. Potable water is readily available from the municipal water system in the vicinity of the site. Future use of ground water from the bedrock aquifer is unlikely based on the planned future development of a pumping plant on the raffinate ponds site. Therefore, the current and reasonably projected uses of site-affected ground water would be preserved with the application of supplemental standards.

In addition, ground water could not be reasonably treated for use as drinking water at the raffinate ponds area because the bedrock aquifer does not produce water in usable quantities except in the fault, joints, and fractured coal beds. Also, the poor quality of water in wells screened in these features would prevent anyone from wanting to drink the water. Ground water in some of the background wells (and many of the on-site wells) has a black discoloration and a strong odor of hydrogen sulfide gas; sulfide is detected in several background wells in concentrations above risk-based levels.

End of current text

1.0 Introduction

1.1 Purpose and Scope

The Durango Uranium Mill Tailings Remedial Action (UMTRA) Project site is a former uranium-ore processing site located near the city of Durango, Colorado. The former processing site consists of two geographically contiguous, but hydrogeologically separate, areas: the mill tailings area and the raffinate ponds area. Both areas are located on the west bank of the Animas River immediately southwest of the intersection of U.S. Highways 160 and 550, southwest of the city of Durango, in La Plata County, Colorado (Figure 1-1 and Plate 1).

The U.S. Department of Energy (DOE) completed surface remediation of abandoned uranium mill tailings and other contaminated surface residual radioactive material (RRM) associated with the former milling operation at the site by relocating the materials to the Bodo Canyon disposal cell, approximately 1.5 miles southwest of the Durango processing site. Surface remedial action began in November 1986 and was completed in May 1991. After the tailings piles and contaminated soils were removed, the mill tailings and the raffinate ponds surface areas were contoured and reseeded with native grasses.

DOE's goal is to implement a cost-effective ground water compliance strategy that is protective of human health and the environment. This Site Observational Work Plan (SOWP) documents the site-specific strategy that will allow DOE to comply with U.S. Environmental Protection Agency (EPA) ground water standards at the Durango site and provides a mechanism for stakeholder participation, review, and acceptance of the recommended remedial alternative. The SOWP is based on UMTRA Project programmatic documents mentioned in Section 1.2.

Compliance requirements for meeting the regulatory standards at the Durango 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, is reviewed in Section 3.0. Results of field investigations conducted at the site are presented in Section 4.0. Site-specific characterization of the geology, hydrology, and geochemistry 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 is presented in Section 7.0.

1.2 UMTRA Project Programmatic Documents

Programmatic documents that guide preparation of the SOWP include the *UMTRA Ground Water Management Action Process* (MAP) (DOE 2001a), 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 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.

Relationship to Site-Specific Documents

The surface Remedial Action Plan (RAP) (DOE 1991) provides early site characterization information. This information has been updated in developing this 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 be the concurrence document for compliance with Subpart B of 40 CFR 192 for the Durango uranium-ore processing site and will provide details of the required ground water monitoring program.

A baseline risk assessment (BLRA) (DOE 1995a) was prepared that identified 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., environmental assessment [EA]) will be prepared to evaluate any potential effects of implementing the proposed compliance strategy.

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

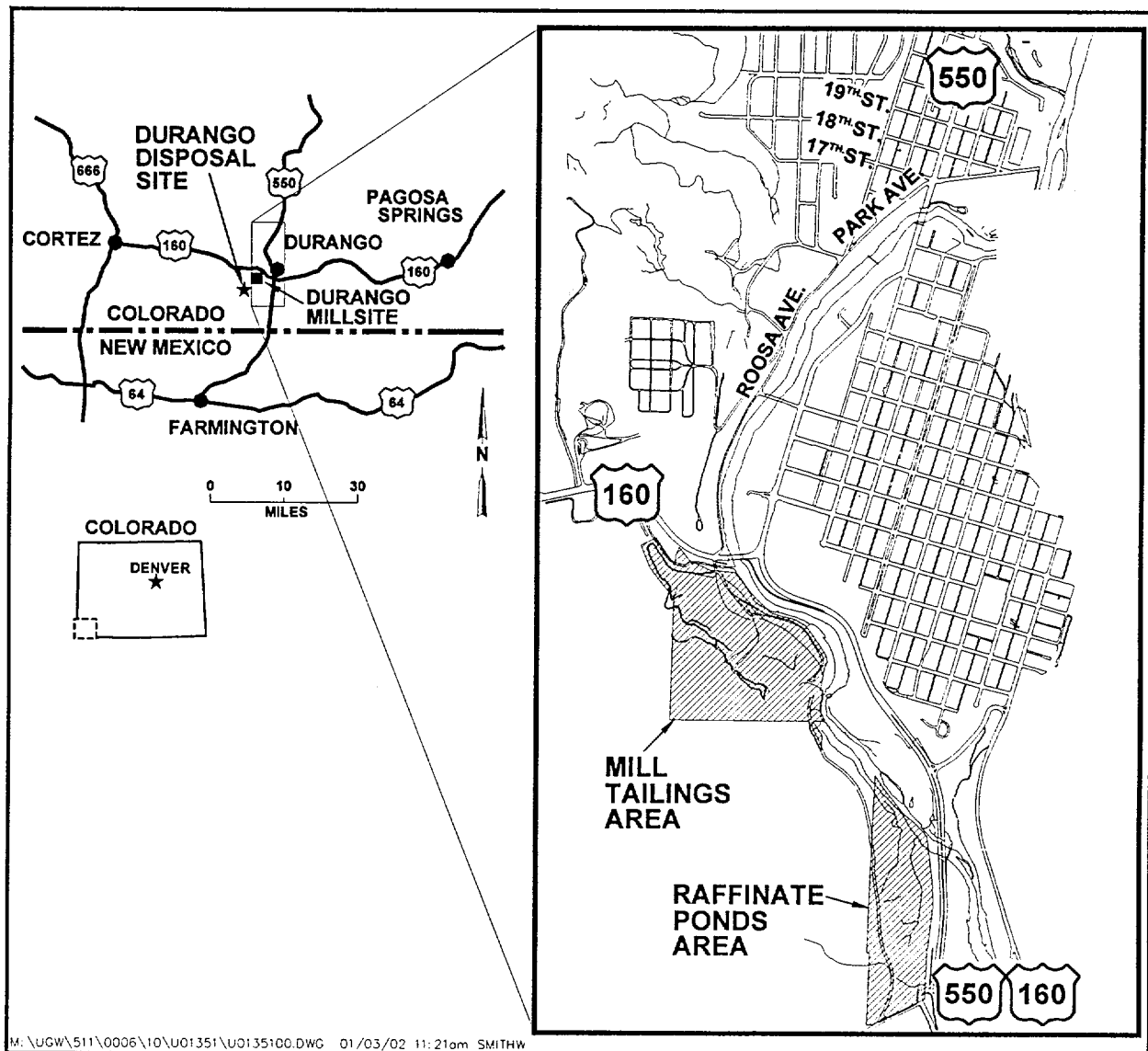


Figure 1-1. Site Location

End of current text

2.0 Regulatory Framework

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

2.1 Federal Regulations

2.1.1 Uranium Mill Tailings Radiation Control Act

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

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

In 1988, Congress passed the Uranium Mill Tailings Remedial Action Amendments Act (42 U.S.C. 7922 *et seq.*) authorizing DOE to extend, without limitation, the time needed to complete ground water remediation at the processing sites.

2.1.2 EPA Ground Water Standards

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

The standards in 40 CFR 192.02 (c)(1) require the Secretary of Energy to 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. Sections 4.6.2 and 4.6.3 of this document, ("Ground Water Quality at the Mill Tailings Area," and "Ground Water Quality at the Raffinate Ponds Area," respectively), comply with these requirements and identify the constituents of potential concern (COPCs) at the Durango site.

The standards for cleanup address two ground water contamination scenarios. The first scenario addresses ground water contaminated as a result of RRM associated with disposal cells. Future protection of ground water at the disposal site is being monitored as part of the Long-Term Surveillance and Maintenance Program. The second scenario addresses ground water

contaminated as a result of RRM in the uppermost aquifer at the former processing site. The UMTRA Ground Water Project addresses this ground water contamination and is regulated by Subparts B and C of 40 CFR 192.

2.1.2.1 Subpart B: Cleanup Standards

The regulations allow the option of complying with 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 are specific to the UMTRA Project. The MCLs for inorganic constituents that apply to UMTRA Project sites are given in Table 1 to Subpart A of 40 CFR 192.

Alternate Concentration Limit (ACL)—An 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.

Natural Flushing Standards

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

2.1.2.2 Subpart C: Implementation

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

Supplemental Standards

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

- (a) Remedial action necessary to implement Subpart A or B would pose a significant risk to workers or members of the public.
- (b) Remedial action to meet the standards would directly produce harm to human health and the environment that is clearly excessive when compared to the health and environmental benefits, now or in the future.

- (c) The estimated cost of remedial action is unreasonably high relative to long-term benefits, and the RRM does not pose a clear present or future hazard.
- (d) The cost of remedial action for cleanup of a building is clearly unreasonably high relative to the benefits.
- (e) There is no known remedial action.
- (f) The restoration of ground water quality is technically impracticable from an engineering perspective.
- (g) The ground water is considered limited use ground water and is not a current or potential source of drinking water because:
 - Concentrations of total dissolved solids (TDS) exceed 10,000 milligrams per liter (mg/L).
 - Widespread ambient contamination is present that cannot be cleaned up using treatment methods reasonably employed in public water systems.
 - The quantity of water available for sustained continuous use at a well is less than 150 gallons per day.

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

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

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

One of the four cleanup standards (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 4.0, “Summary of Recent Field Investigations,” presents a summary of the geology and ground water quality of the site; Section 5.0, “Conceptual Site Model,” presents a summary of the hydrology and geochemistry of the site; and Section 6.0, “Summary of Human Health and Ecological Risk,” evaluates potential risks at the site. This information provides the basis to select the compliance strategies to be applied to the COPCs. Section 7.0, “Ground Water Compliance Strategy,” presents a discussion of the proposed compliance strategy that is specific to the two areas and includes a justification for selecting natural flushing for the mill tailings area and supplemental standards for the raffinate ponds area. Ground water at the raffinate ponds area can be designated limited use due to widespread ambient selenium contamination.

2.1.3 Cooperative Agreements

UMTRCA requires that compliance with ground water standards be accomplished with the full participation of the states and Indian tribes on whose lands uranium mill tailings are located.

Section 103 (a) of UMTRCA directs DOE to enter into cooperative agreements for remedial actions with the states and tribes. A cooperative agreement is currently in place with the State of Colorado.

2.1.4 National Environmental Policy Act

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

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

- Active ground water remediation
- Natural flushing (passive remediation)
- No ground water remediation

A Durango site-specific EA will be prepared to recommend the preferred remediation alternative and to address all environmental issues associated with the proposed alternative.

2.1.5 Other Federal Regulations

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

2.2 DOE Orders

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

2.3 State Regulations

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

3.0 Site Background

The Durango UMTRA Project site lies outside the city limits, about 0.25 mile from the central business district of Durango (Figure 3-1). The mill was constructed in 1941 to produce vanadium; uranium production began in 1943. Ore was delivered to the mill from various mines in the Uravan mineral belt. An overview of the site's physical setting and climate, a history of the former milling operation, a summary of surface remediation, land use and water use is presented in the following sections.

3.1 Physical Setting and Climate

The former Durango processing site consists of two separate areas: the mill tailings area, which included two tailings piles and the mill infrastructure, and the raffinate ponds area, about 1,500 feet (ft) south of the mill tailings area. The two site areas are connected by an impassable service road cut along the base of Smelter Mountain.

The mill tailings area encompasses approximately 40 acres. It is on a bedrock-supported river terrace between Smelter Mountain to the west, the Animas River to the east and south, and Lightner Creek to the north (Figure 3-2). A lead smelter near the south end of the mill tailings area operated from 1880 to 1930. Slag from the smelter operation was deposited at the southeast corner of the area along the edge of the Animas River.

A gauging station maintained by the U.S. Geological Survey (USGS) is approximately 4,500 ft upstream from the confluence of the Animas River and Lightner Creek. The annual mean flow from 1970 to 2000 was 847 cubic feet per second (cfs), and the record 7-day low flow was 100 cfs in December 1971 (DOE 1995a).

Lightner Creek flows along the northern edge of the mill tailings area. Historically, the average flow is 22.6 cfs; minimum daily flows are 1.0 cfs or less (USGS 1993).

The raffinate ponds area occupies approximately 20 acres on another river terrace approximately 1,500 ft south of the mill tailings area along the west bank of the Animas River (Figure 3-3). A narrow terrace above the Animas River connects the two areas. A small intermittent creek (South Creek) forms the southern boundary of the raffinate ponds area. Raffinates from the processing of uranium and vanadium were discharged into a series of ponds on the terraced slope of the raffinate ponds area. The topography of the mill tailings area was modified during removal of the tailings and contaminated soils. The property slopes steeply down from Smelter Mountain but becomes relatively level near Lightner Creek and the Animas River.

The Animas River flows south along the eastern edge of the northern half of the raffinate ponds area downstream of the mill tailings area. No tributaries enter the Animas River between the two sites, but the outfall from the Durango municipal wastewater treatment plant is at the north end of the raffinate ponds area on the other side of the Animas River. This plant discharges approximately 2 million gallons per day (DOE 1995b).

South Creek, along the southern edge of the raffinate ponds area, is at the lower end of the arroyo along the north side of the Bodo Canyon disposal site. This creek is dry except during heavy rainfall events, wet periods, and when treated water is released from the toe drain collection pond at the disposal cell. South Creek joins the Animas River approximately 1,000 ft east of the raffinate ponds area.

The semiarid climate of the Durango area is characterized by severe winters and moderate summers. The annual mean temperature is 50 °F; monthly averages vary from 19 °F in January to 70 °F in July. Precipitation is predominantly from heavy rainstorms (May through October) and winter snowfall. Precipitation averages approximately 20 inches per year. Meteorological data from the Durango weather station from 1971 to 2000 is summarized in Table 3–1. Annual potential evapotranspiration exceeds precipitation by about 30 inches (DOE 1995a). However, during December, January, and February, precipitation is twice the potential evapotranspiration, resulting in ample moisture available for infiltration (Tsivoglou and others 1960). The prevailing wind direction is west-northwest down the river valley.

Table 3–1. Summary of Meteorological Data for Durango, Colorado

Month	Air Temperature °F		Precipitation (inches)	Snowfall (inches)
	Average Maximum	Average Minimum		
January	39.5	11.0	1.72	17.6
February	46.1	16.8	1.55	15.0
March	53.2	23.1	1.72	10.5
April	62.2	29.3	1.35	3.5
May	71.1	35.8	1.12	0.5
June	82.3	43.1	0.69	0.0
July	86.8	50.2	1.68	0.0
August	84.1	49.0	2.24	0.0
September	76.5	41.2	2.08	0.0
October	65.9	31.3	2.35	1.0
November	50.0	20.9	1.77	5.3
December	41.3	13.3	1.68	15.4
Annual	63.4	30.5	19.94	68.8

3.2 Site History

In 1941 the United States Vanadium Corporation (USV) built a mill on the site of the old lead smelter (Figure 3–4) to furnish vanadium to the Metals Reserve Company, a company established by the federal government to purchase strategic materials needed during World War II. Starting in 1943, USV also reprocessed the vanadium tailings to recover uranium for the Manhattan Project. The mill was closed in 1946.

In 1949, the USV mill was reopened by the Vanadium Corporation of America (VCA) and operated until March 1963 (Figure 3–5) under a contract to sell uranium to the U.S. Atomic Energy Commission (AEC). VCA retained ownership of the millsite and adjoining property until 1967, when VCA merged into Foote Mineral Company. In 1976 and 1977, the site was purchased by Ranchers Exploration and Development Corporation (REDC); REDC was subsequently acquired by Hecla Mining Company in 1984.

Prior to surface remediation, the State of Colorado acquired the site. The State has subsequently deeded the mill tailings area property to the City of Durango, and the raffinate ponds area was deeded to the Animas-La Plata Water Conservancy District.



Figure 3-1. Durango UMTRA Project Site

C01



Figure 3-2. Mill Tailings Area

CO2

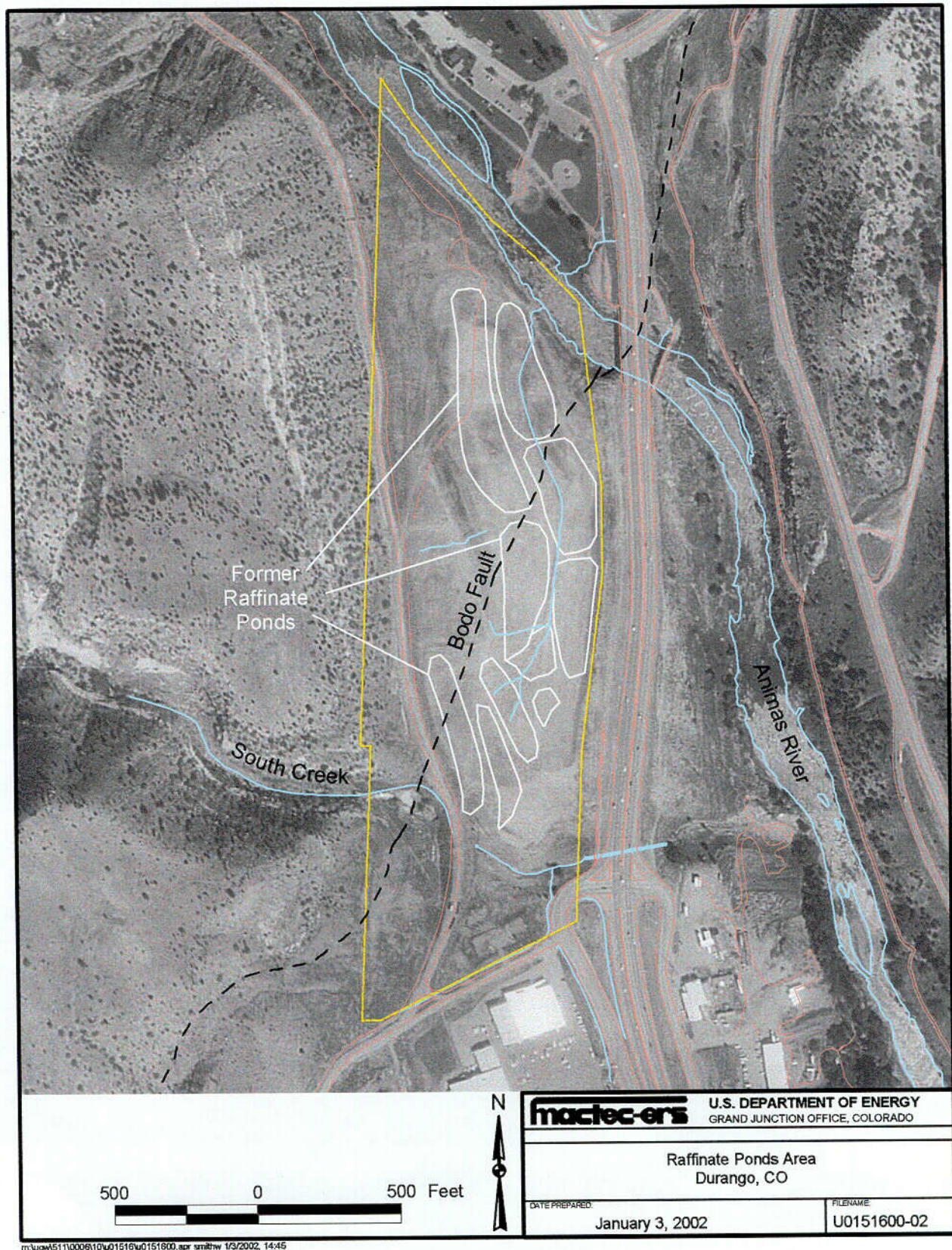


Figure 3-3. Raffinate Ponds Area

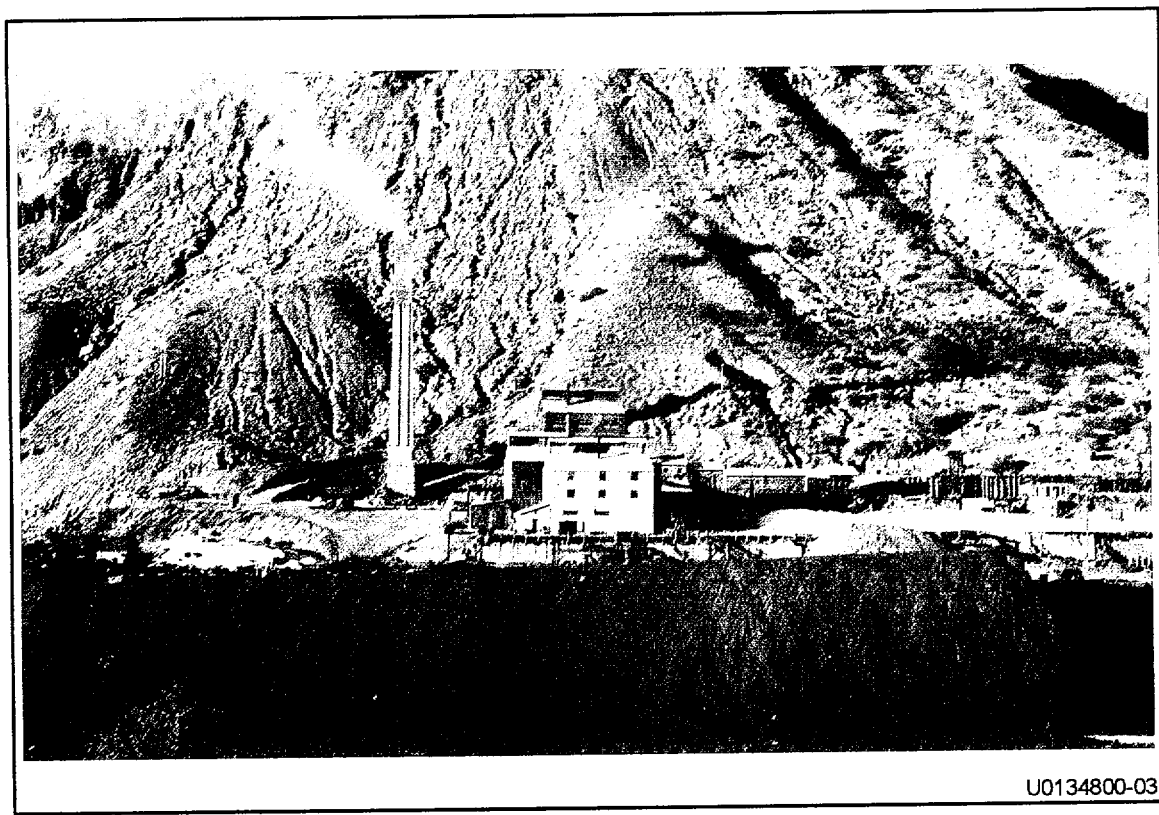


Figure 3-4. Former Durango Processing Site 1941

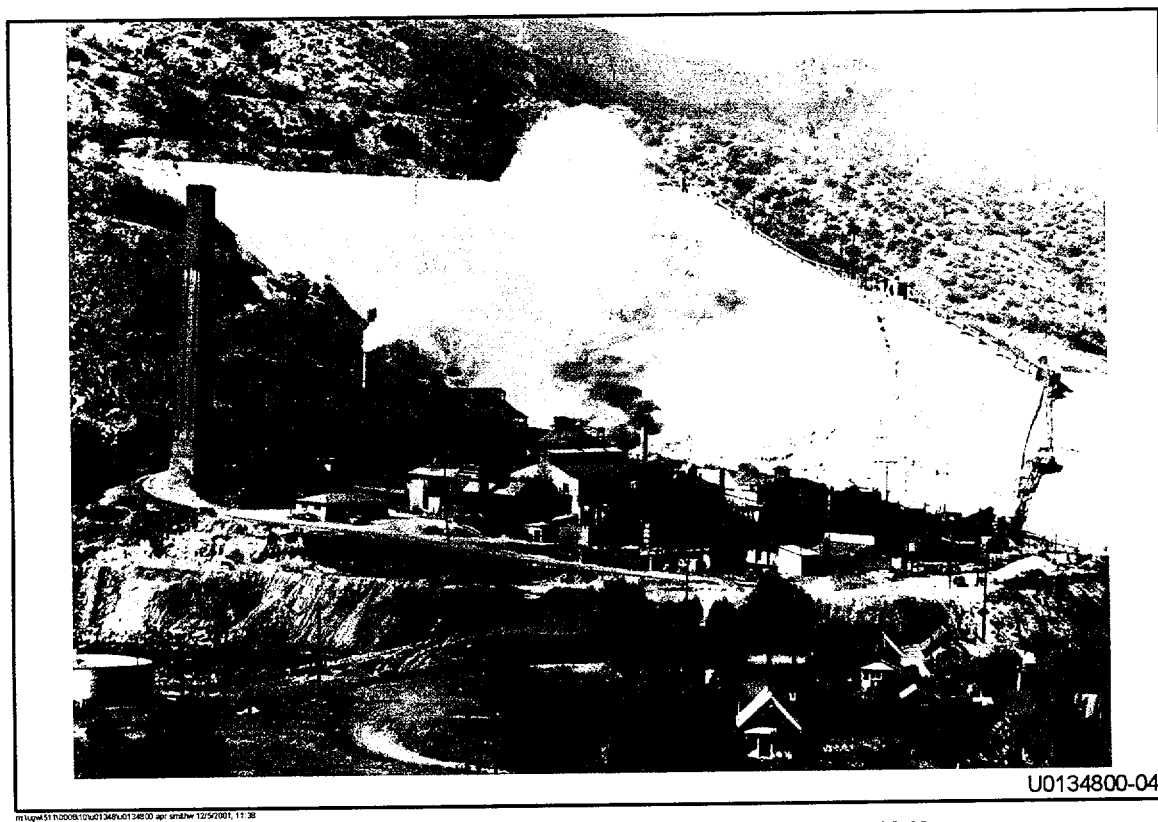


Figure 3-5. Former Durango Processing Site, Circa 1949

The milling process involved two separate stages. In the first stage, ores were roasted with sodium chloride, then treated with a sodium carbonate solution to produce an alkaline solution containing both uranium and vanadium. This solution was filtered to separate the solution from the tailings, then treated to remove uranium and vanadium. The alkaline-leach tailings were washed with water and stored for use in the second stage of processing (Tame and others 1961; Merritt 1971).

The second stage of processing used the tailings from the first stage. The tailings were leached using an acid solution containing both hydrochloric and sulfuric acids. The leachate was then separated from the acid-leach tailings and oxidized using potassium permanganate. Uranium and vanadium were removed from this solution by solvent extraction using an immiscible organic solvent. The spent solution (raffinate) was disposed of after the uranium and vanadium were removed from the aqueous solution (Tame and others 1961).

Before 1959, all aqueous solutions and acid-leach tailings were discharged into the Animas River (Tsivoglou and others 1960). Beginning in 1959, overflow water from the stored alkaline leach tailings and slurried acid-leach tailings were mixed in a settling pond atop the former large tailings pile adjacent to the mill. Overflow from this pond was treated and settled in a second pond atop the former small tailings pile at the mill tailings area. Overflow from this pond and spent alkaline-leach solutions from the first stage of uranium-vanadium recovery were discharged directly into the Animas River (Tsivoglou and others 1960).

Raffinates from the second stage of processing contained most of the radioactivity. This waste solution was pumped to a tank above the mill which discharged into a 3,000-ft-long ditch that carried the waste to the raffinate ponds area. An additional 3,000 ft of ditch carried the raffinate through a series of ponds on the terraced slope of the raffinate ponds area. The raffinate evaporated and percolated into the underlying alluvium, colluvium, and sandstone bedrock. The ponds and tailings were removed during surface remedial action completed in 1991.

3.3 Surface Remediation

DOE began relocating the tailings piles, mill debris, and contaminated soils from the mill tailings area and raffinate ponds area to the Bodo Canyon disposal site in November 1986; remedial action was completed in May 1991. A total of 2.5 million cubic yards of contaminated materials were relocated to the Bodo Canyon disposal cell. Following removal of the contaminated material at the site, approximately 230,000 cubic yards of uncontaminated soil was backfilled and contoured for site drainage and seeded with native vegetation.

The remaining lead smelter stack was demolished and hauled to the disposal cell for burial. The haul road between the processing site and the disposal site was scanned during and after remedial action to ensure that the roadway had not become contaminated. Figure 3-6 through Figure 3-9 show the mill tailings area and raffinate ponds area prior to surface remediation and after completion of remediation, respectively.

Supplemental standards were applied to contamination left in place in two regions along the banks of the Animas River, to unreachable areas of windblown contamination on the slope of Smelter Mountain, and to soils contaminated with thorium-230 in the raffinate ponds area (Figures 3-10 and 3-11). In addition, a small lens of uranium ore was left in place at the mill tailings area below the layers of lead slag along portions of the river bank (DOE 1994b).

3.4 Land Use

The region's primary landowner, the federal government, controls the San Juan National Forest north of Durango and holds in trust large Indian reservation lands south and west of Durango. Privately owned lands are second in extent, followed by state, county, and municipal lands. The City of Durango is owner of the former mill tailings area, and the former raffinate ponds area is owned by the Animas-La Plata Water Conservancy District. Land use in the vicinity of the Durango site is primarily commercial, residential (in the city of Durango), and open space. The City operates a nearby sewage treatment plant and a city park on the east side of the Animas River. The Colorado Department of Natural Resources controls the Bodo Canyon Wildlife Area west of the raffinate ponds site.

Land in downtown Durango, northeast of the site, has been developed since the late 1800s. The major land use changes near the site have occurred in the Animas River valley. This land has been converted to urban uses by the construction of the sewage treatment plant across the Animas River, south of the mill tailings area, and the construction of a commercial center, south of the raffinate ponds area. In the early 1970s land use within the Bodo Canyon Wildlife Area changed from livestock grazing to resource conservation and recreation.

Potential development plans for the former mill tailings area include construction of a park, visitor's center, parking lots, and a museum or other type of public building (DOE 1995a). There are no plans to develop either portion of the site for residential use (Rogers 2001).

As part of the Animas-La Plata water project, there are plans to construct a pumping plant in the former raffinate ponds area of the site (Figure 3–12). This federal project would supply municipal, industrial, and drinking water to Durango, and Farmington and Aztec, New Mexico; and water to the Navajo Nation, Southern Ute, and Mountain Ute tribes. Development of additional water resources is a concern because the city's water supply is not sufficient to meet future needs. The Animas-La Plata Water Conservancy District, the U.S. Bureau of Reclamation (BOR), and the Colorado Department of Public Health and Environment (CDPHE) are in the process of developing a *Restricted Use Plan* for the raffinate ponds area. The BOR is presently planning to have the State of Colorado convey a 50-year renewable easement to the BOR for the land needed for the pumping plant. Although the land-use plan is not yet completed, residential use will not be considered, and permanent building of any type at the raffinate ponds area will not be allowed without prior approval from CDPHE and the DOE.

3.5 Water Use

Approximately 13,000 people live within the Durango city limits (DOE 1994a). There are no known wells in use within the city limits. Development and utility policies for the city of Durango prohibit the drilling of private wells within the city limits. However, wells can be drilled on county lands (DOE 1995a).

The water supply system for the city of Durango is the largest in the county, not only serving city residents, but also selling water to neighboring water districts and companies serving surrounding developed areas. The city's primary water source is the Florida River; additional water is taken from the Animas River during high-demand periods (generally during the summer). The water pumping station from the Animas River is approximately 2 miles upstream from the northern boundary of the former mill tailings area.

A survey of water use in the area surrounding the Durango site was conducted using information from the Colorado Division of Water Resources database and field investigations (DOE 1994a). Although the city is considering developing additional water resources to supplement the existing water supply, ground water has not been considered as a water source for the municipal system (DOE 1995a). Ground water in the area is considered of poor quality due to elevated levels of hardness, iron, and manganese (DOE 1995a).

The nearest known downgradient well is east of U.S. Highway 550, approximately 0.2 mile southeast of the site, and on the west side of the Animas River. However, this well is under a building and has never been used because of a black discoloration of the water (DOE 1994a). Additional wells are on the east side of the Animas River and are at distances ranging from 0.8 to 1.5 miles from the site. All other known wells are north of Lightner Creek, and none of these wells would be affected by contaminated ground water from the site.

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Figure 3-6. Mill Tailings Area Prior to Surface Remediation



Figure 3-7. Mill Tailings Area After Completion of Remediation



Figure 3-8. Raffinate Ponds Area Prior to Surface Remediation

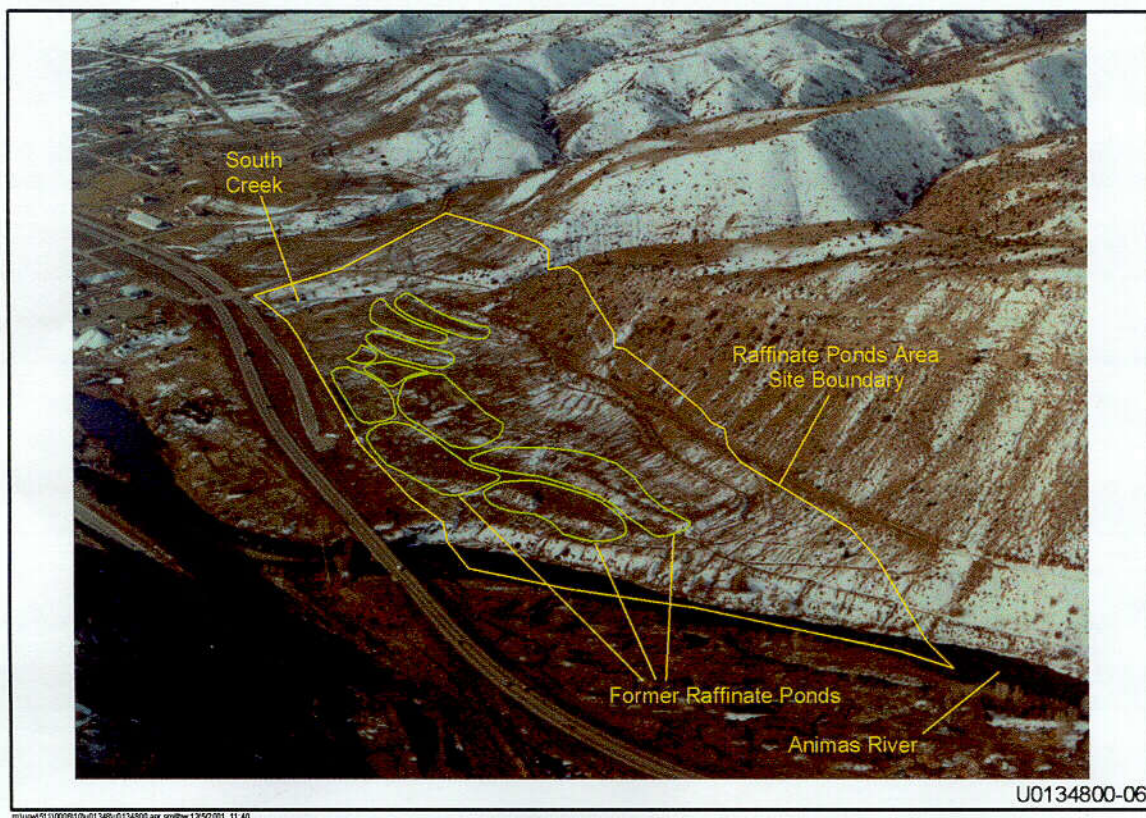


Figure 3-9. Raffinate Ponds Area After Completion of Remediation

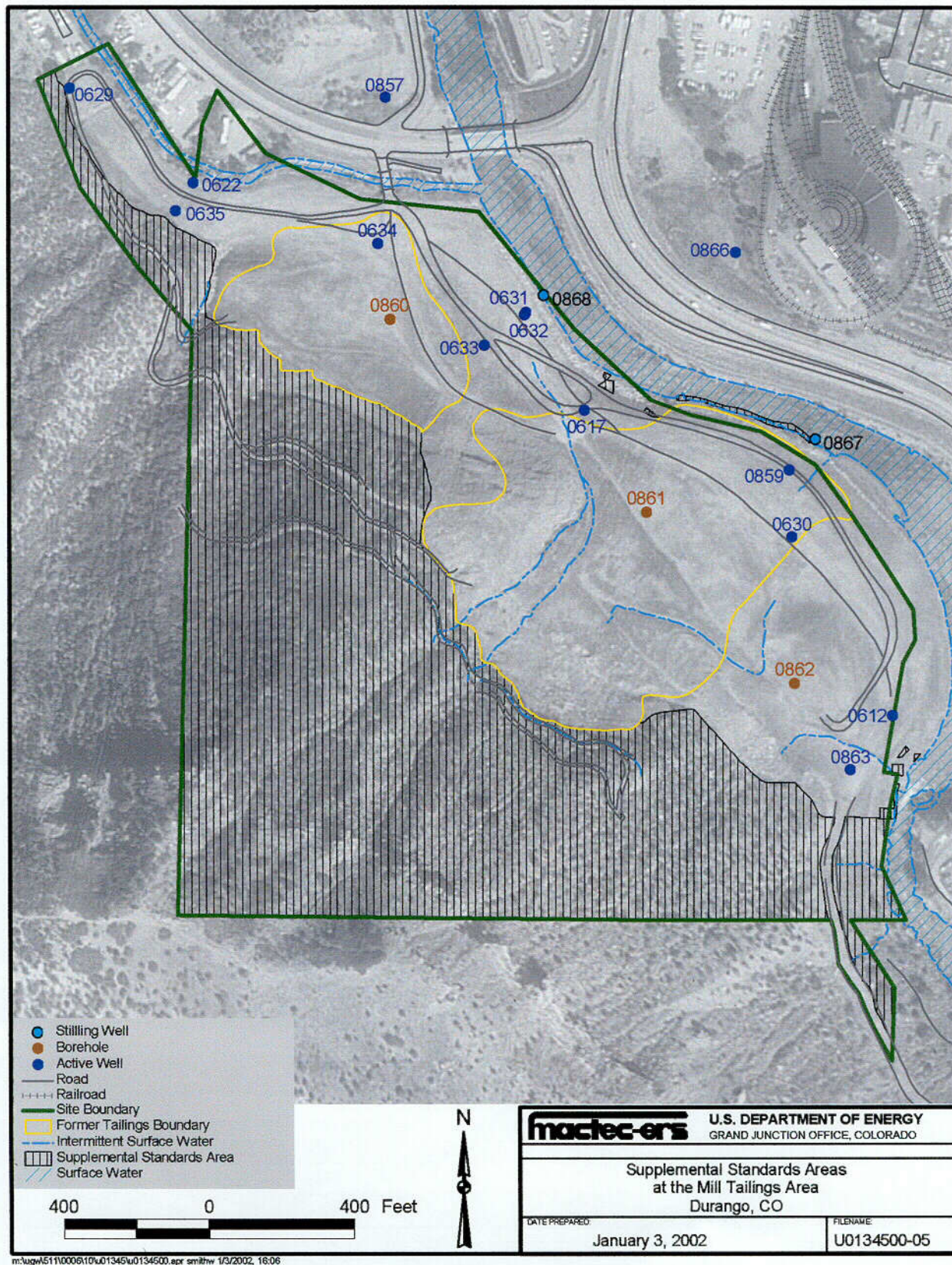


Figure 3-10. Supplemental Standards Area within the Mill Tailings Area

01/30/02		Leadership Level - Monthly		NRR OPERATING PLAN REPORTING						
			2001	2002	Monthly Performance				FY02	
FY 01	FY 02		Actual	Target	Oct	Nov	Dec	1Q02	YTD	
PA Num	PA Num									
		Expired/Potential Contract Closeouts (#JCNs)	50	65	na	na	69	69	69	
		Labor Effectiveness								
		Programs to Products Ratio								
		OR PM / Licensing	13.1%	12%	12.1%	12.7%	12.2%	12.4%	12.4%	
		NPR PM / Licensing	17.5%	45%	4.5%	2.0%	5.4%	4.5%	4.5%	
		Decom PM / Licensing	21.2%	25%	18.8%	20.3%	14.4%	17.6%	17.6%	
		Renewal PM / Licensing	8.1%	5%	6.0%	7.7%	11.6%	8.2%	8.2%	
		OG Program / Total	11.7%	12%	12.1%	21.0%	17.0%	15.6%	15.6%	
		Allegation Program / Total	45.2%	45%	60.7%	63.4%	62.3%	61.9%	61.9%	
		Renewal Program / Total	35.1%	50%	16.3%	19.8%	13.4%	16.3%	16.3%	
		Event Review Program / Total	43.6%	35%	32.2%	39.9%	35.0%	34.9%	34.9%	
		iSTS Program / Total	36.8%	45%	44.5%	36.8%	53.3%	45.4%	45.4%	
		Decom Program / Total	38.3%	45%	24.7%	24.3%	30.5%	25.7%	25.7%	
		Comp PM Reviews / Total	19.0%	25%	15.0%	13.3%	9.5%	12.9%	12.9%	
		Open PM Reviews / Total	10.1%	10%	9.9%	lost	15.2%	15.2%	15.2%	
		OL Program / Total	15.2%	20%	25.1%	38.7%	22.1%	27.3%	27.3%	
		FTE Productivity								
		Technical (Direct Hours)	1392	1460	1418	1326	1284	1325	1325	
		Supervisory (9A1B Hours)	1500	1585	1741	1493	1363	1476	1476	
		Clerical (9A1D Hours)	1614	1640	1684	1459	1444	1520	1520	
		Quality								
		Measures Under Development	TBD	TBD	TBD	TBD	TBD	TBD	TBD	New

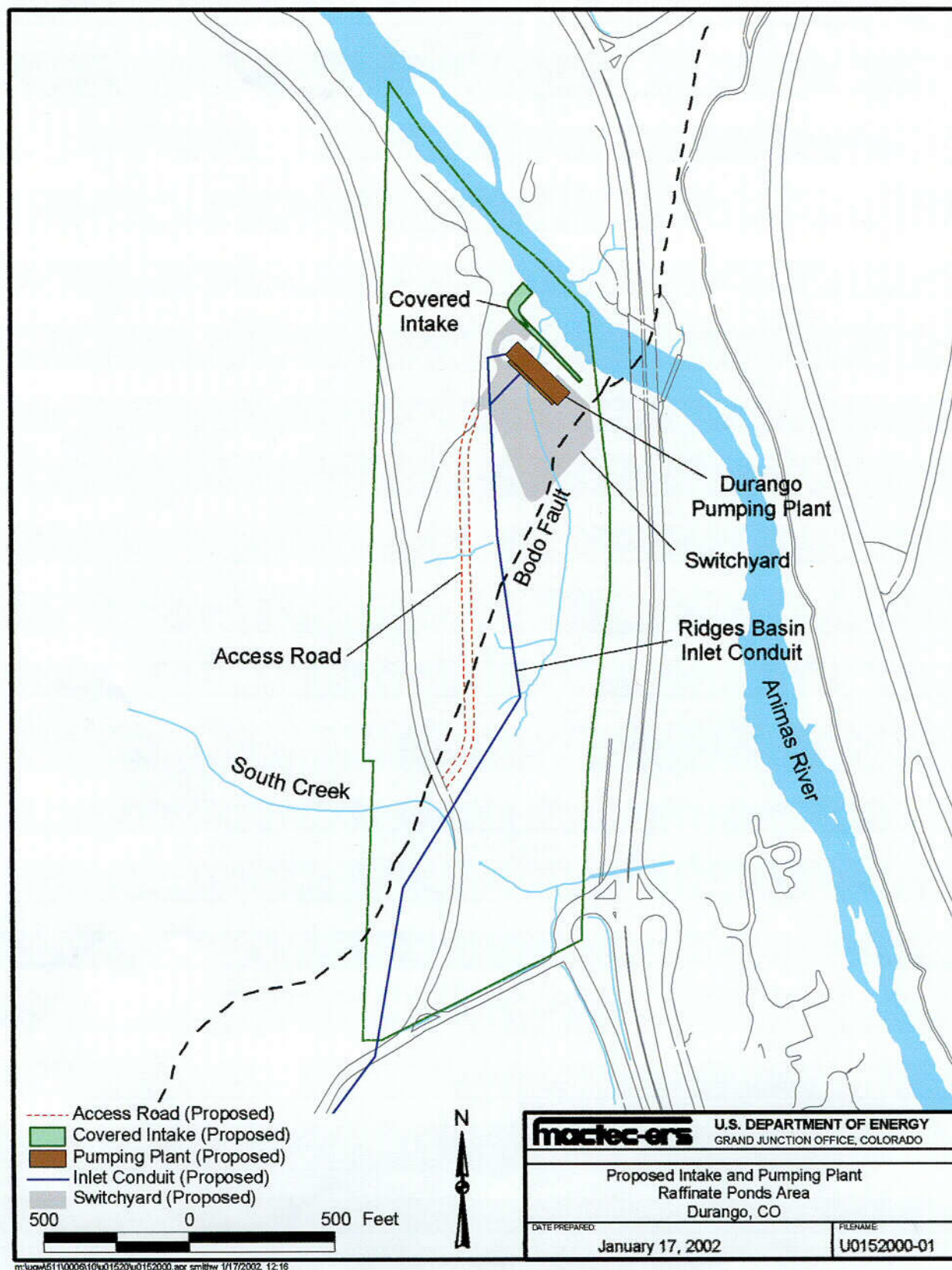


Figure 3-12. Proposed Animas-La Plata Pumping Plant Location at the Raffinate Ponds Area

C08

4.0 Summary of Recent Field Investigations

Historical characterization data for the Durango processing site are presented in the RAP (DOE 1991) and the BLRA (DOE 1995a). An evaluation of this data at the Durango processing site indicated additional investigations were needed to complete the SOWP and select the strategy for compliance with EPA ground water protection standards in 40 CFR 192. Additional investigations were needed to (1) further define hydraulic properties of the alluvial and bedrock aquifers for use in ground water flow and transport modeling, (2) determine the extent of contamination in the ground water, and (3) determine whether the ground water constituents in the alluvial and bedrock aquifers will flush naturally within 100 years. The fieldwork included installing monitor wells for ground water sampling and aquifer testing (slug tests) and installing stilling wells to determine Animas River water elevations. Other work included subpile soil sampling and analysis to evaluate potential residual source term beneath the site, determination of distribution coefficients, collection and analysis of ground water and surface water from locations on site and downgradient from the site, and sediment sampling from surface water locations. Results of these investigations, along with more recent water quality analytical data, are presented in this section.

4.1 Ground Water Monitor Well Installation

Monitor wells were installed to collect water samples for the characterization of ground water quality and to provide a means to determine hydraulic properties of the alluvial and bedrock aquifers. Wells were drilled using the SONIC drilling method, which enabled collection of continuous samples through the entire interval drilled. Installation procedures, construction details, and locations for the wells are described in this section. The following procedures from the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998) were used for monitoring well installation.

- GN-13 (P), "Standard Practice for Equipment Decontamination"
- LQ-14(P), "Technical Comments on ASTM D 5092—Standard Practice for Design and Installation of Ground Water Monitor Wells in Aquifers"

After installation of the monitor wells, the top of each casing was surveyed for elevation and location coordinates. Completion diagrams and lithologic descriptions for each well installed during the 2000 field investigation are provided in Appendix A and summarized in Table 4-1. Figure 4-1 shows a construction diagram of a typical monitor well installed during the Durango field investigation.

4.1.1 Mill Tailings Area

Four monitor wells and two stilling wells were installed at the mill tailings area during the field investigation (Figure 4-2). In addition, five locations were drilled and soil samples were collected, but wells were not installed. All alluvial wells were completed using 2-inch inside diameter (i.d.), flush-joint, threaded, poly vinyl chloride (PVC) casing and wire-wrapped screen (0.02-inch slot size). All the alluvial monitor wells were screened over the entire saturated thickness, which was 20 ft or less. Two wells (0859 and 0863) were installed on site to characterize the nature and extent of ground water contamination and to determine the hydrologic properties of the aquifers.

Table 4–1. Durango Field Investigation Monitor Well Installation Summary

Well Number	Site	Formation/Location	Well Depth (ft)	Screened Interval (ft)	Purpose
0857	Mill tailings	Alluvium/Background	19	12–17	Background water quality
0859	Mill tailings	Alluvium/On site	32	21.5–31.5	Water quality/water level
0863	Mill tailings	Colluvium/On site	68	58–67.5	Water quality/water level
0866	Mill tailings	Alluvium/Background	22	12–21.5	Background water quality
0867	Mill tailings	Alluvium/Animas River	NA	NA	Animas River stilling well
0868	Mill tailings	Alluvium/Animas River	NA	NA	Animas River stilling well
0875	Raffinate ponds	Point Lookout/Background	122.5	82–122	Background water quality
0876	Raffinate ponds	Fault/On site	75	54.5–74.5	Water quality/water level
0878	Raffinate ponds	Menefee/On site	47	37–46.5	Water quality/water level
0879	Raffinate ponds	Menefee/On site	37	27–36.9	Water quality/water level
0880	Raffinate ponds	Menefee/ On site	37	27–36.9	Water quality/water level
0881	Raffinate ponds	Point Lookout/On site	37	27–36.9	Water quality/water level
0882	Raffinate ponds	Menefee/Downgradient	35	24.5–34.5	Water quality/water level
0883	Raffinate ponds	Menefee/Downgradient	55	45–55	Water quality/water level
0884	Raffinate ponds	Menefee/Downgradient	47	36.5–46.5	Water quality/water level
0886	Raffinate ponds	Cliff House and Alluvium/Downgradient	30	19.5–29.5	Water quality/water level
0887	Raffinate ponds	Fault/On site	93.2	82.7–92.7	Water quality/water level
0888	Raffinate ponds	Fault/On site	148	133–147.5	Water quality/water level
0889	Raffinate ponds	Point Lookout/Downgradient	90.5	80–90	Water quality/water level
0890	Raffinate ponds	Menefee/On site	73	63.0–72.5	Water quality/water level
0891	Raffinate ponds	Menefee/On site	75	64.5–74.5	Water quality/water level
0892	Raffinate ponds	Fault/On site	80	69.5–79.5	Water quality/water level
0893	Raffinate ponds	Point Lookout/On site	75	64.5–74.5	Water quality/water level
0902	Raffinate ponds	Menefee/On site	148	128–148	Water quality/water level
0903	Raffinate ponds	Menefee/Background	65.4	34.9–64.9	Background water quality
0905	Raffinate ponds	Point Lookout/Off site	172	161.5–172	Water quality/water level
0906	Raffinate ponds	Alluvium/Animas River	NA	NA	Animas River stilling well

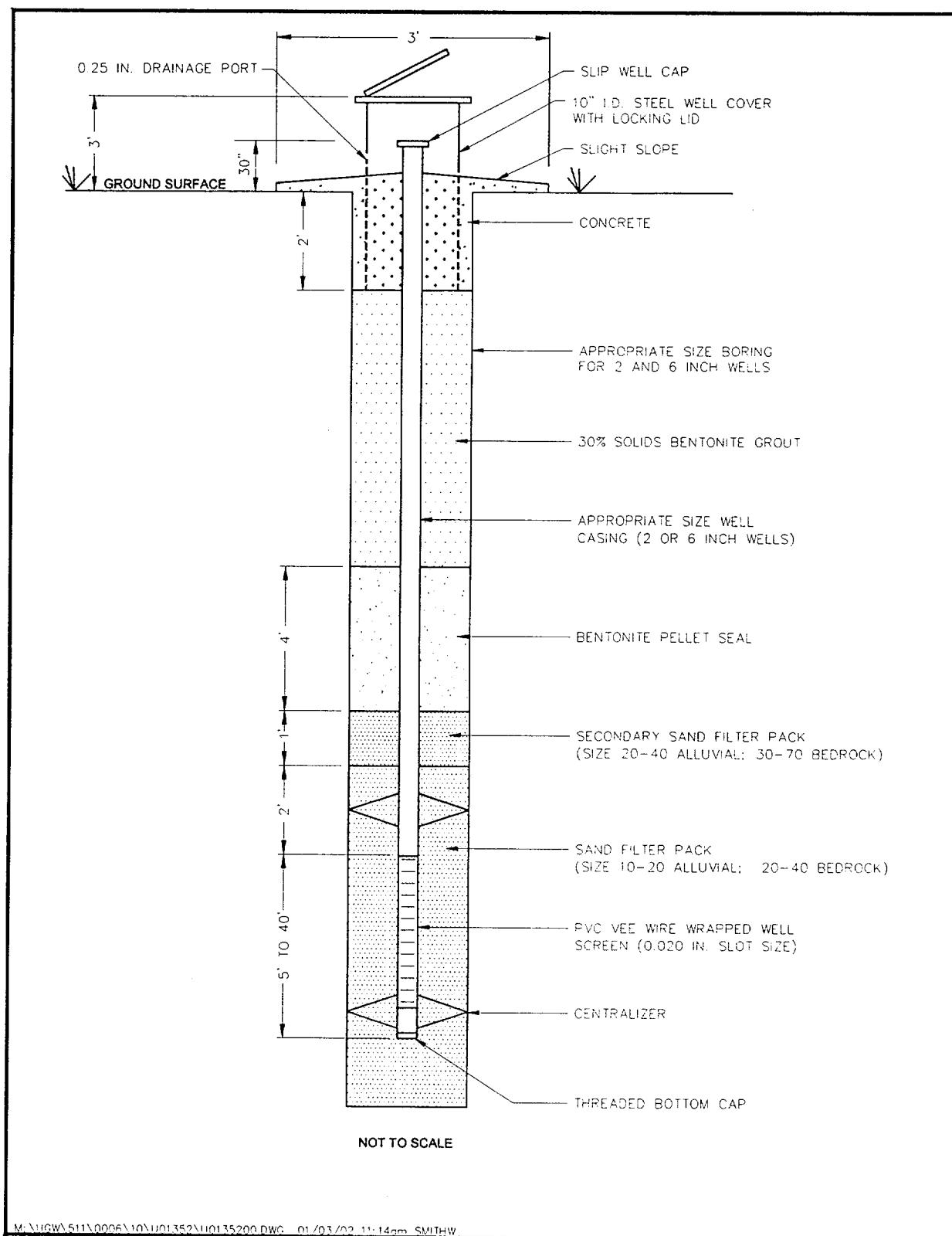


Figure 4–1. Typical Well Completion Diagram

Prior to the field investigation, two background wells (0629 and 0658) had been established for determining background water quality at the mill tailings area. Well 0658 is a privately owned well in a campground approximately 0.75 mile west of the mill tailings area and is screened in the Lightner Creek alluvium. Because this well is in use it cannot be purged before sampling; the well is periodically treated with chlorine. Well 0629 is on site, upgradient from the former small tailings pile and is completed in colluvium overlying the Mancos Shale bedrock. Because this monitor well is completed in clay-rich colluvial material, it contains very little water and tends to pump dry during sampling events. In addition, although well 0629 is upgradient on the site, it is within the area where surface remediation activities were performed.

Because of uncertainties about these existing background locations, and because neither well was completed in the Animas River alluvium (where most of the ground water at the mill tailings area occurs), two additional background wells were installed at the mill tailings area. Wells 0857 and 0866 were installed in background areas that were not affected by site processes and were both screened in Animas River alluvium (Figure 4–2). A slight petroleum odor was noted during the drilling of well 0857, indicating it may have been affected by an anthropogenic source other than the previous milling operations; although this location was outside the influence of the millsite operations, it may not represent true background conditions.

Two wells were completed as stilling wells for the Animas River. These wells were completed by installing data loggers into 2-inch PVC casing. The PVC casings for these wells were left with the bottom ends uncapped, approximately 1 ft below the low-flow water level elevation of the Animas River.

Boreholes at two off-site locations and three on-site locations (Figure 4–2) did not intersect any alluvial ground water above the top of the Mancos Shale bedrock. The off-site boreholes (0864 and 0865) were drilled east of the Animas River. The on-site boreholes (0860, 0861, and 0862) were drilled along the western edge of the mill tailings area near the base of Smelter Mountain.

4.1.2 Raffinate Ponds Area

Twenty monitor wells and one stilling well were installed in the raffinate ponds area (Figure 4–3). Alluvial ground water does not occur in the raffinate ponds area (except at well 0607) therefore, all the wells installed were screened in bedrock formations. All bedrock wells were completed using 2-inch i.d., flush-joint, threaded, PVC casing and wire-wrapped screen (0.02-inch slot size).

Two of the wells (0875 and 0903) were installed in background areas west of the site to characterize the upgradient bedrock ground water that is unaffected by the former processing operations. Wells 0875 and 0903 were screened in the Point Lookout Sandstone and Menefee Formations, respectively.

Eleven wells were installed on site, and seven wells were installed off site to characterize the nature and extent of ground water contamination and to determine the hydrologic properties of the aquifers. Twelve wells were completed in the Menefee Formation, three wells were completed in the Point Lookout Sandstone, and three wells were screened across the Bodo Fault zone, which traverses the raffinate ponds area (Figure 4–3).



Figure 4-2. Mill Tailings Area Wells and Boreholes

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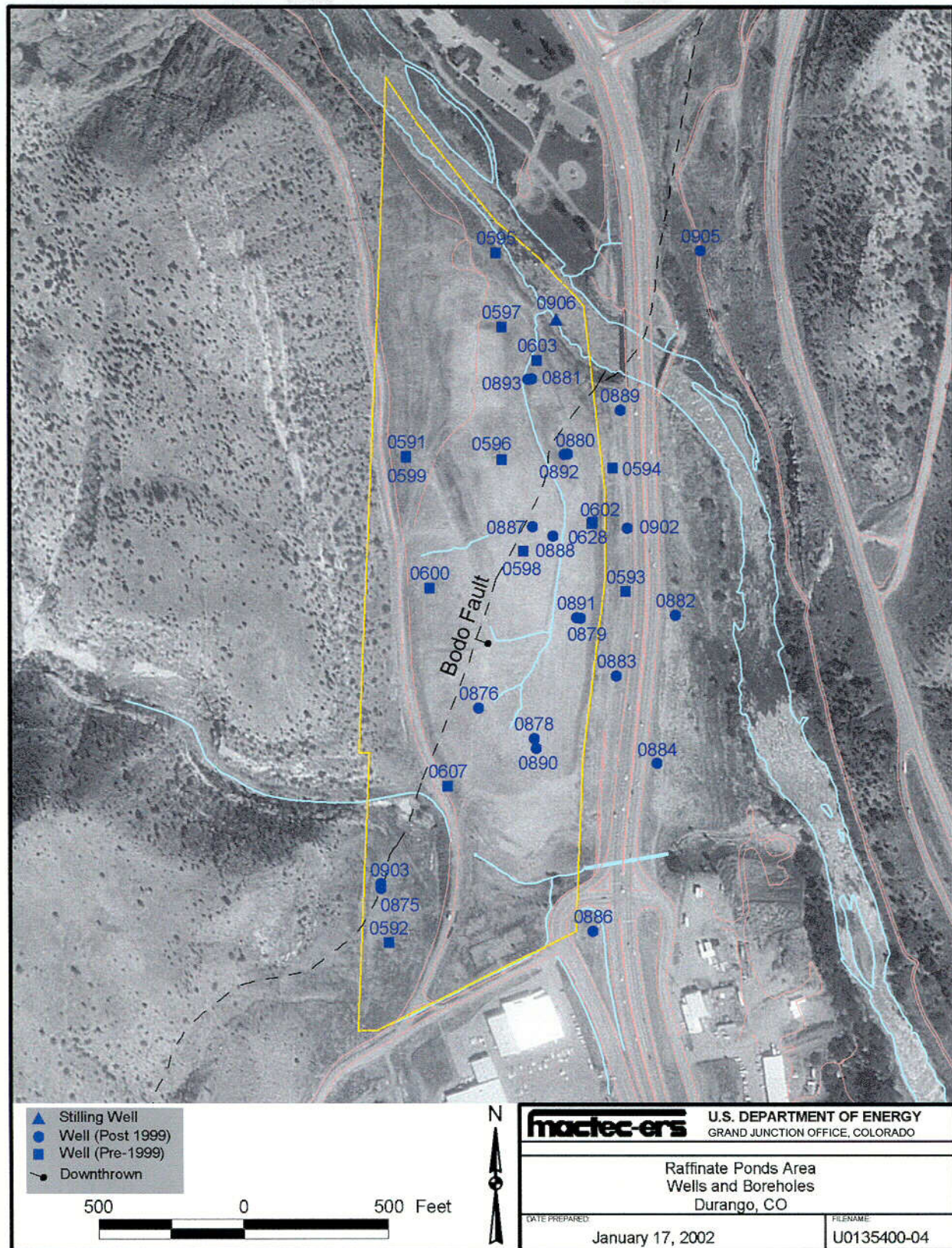


Figure 4-3. Raffinate Ponds Area Wells and Boreholes

C/O

4.1.2.1 Status of Existing Monitor Wells at the Raffinate Ponds Area

The U.S. Bureau of Reclamation (BOR) performs sampling at the raffinate ponds area (for purposes related to the proposed Animas-La Plata project) and has installed wells 0599 and 0600 as upgradient background wells. However, it was determined that because of the cross-gradient proximity of well 0600 to the former location of the southernmost raffinate pond, this well would not be considered a background location for this site investigation.

In the *Preliminary Hydrogeochemical Characterization of the Durango, Colorado, Tailings and Raffinate Ponds Areas* (DOE 1983), monitor well 0607 was identified as a background well (based on statements of individuals who worked at the mill during its operation, only the northern raffinate ponds ever contained any effluent from the mill). Because of its proximity to the former location of the southernmost raffinate ponds, well 0607 was not considered a background location for this site investigation.

Monitor well 0602 was installed in the Menefee Formation in the central portion of the raffinate ponds area prior to site remediation. This well was completed with two separate screened intervals, and an inflatable packer was installed to separate the screened areas. The upper section of the well has a 10-ft screen within a massive sandstone of the Menefee Formation. The lower section of the well has a 5-ft screen across a coal bed below the sandstone unit. Appendix A presents the monitor well logs and lithologic descriptions. It is not known when the packer was installed (sometime prior to 1995), but the supply lines to the surface have deteriorated and fallen down the well annulus. Attempts to retrieve the lines have been unsuccessful, resulting in the lines breaking farther down the well. Attempts to insert a down-hole camera into the well were also unsuccessful. It is not known if the packer is still inflated or to what degree the packer itself may have deteriorated over time. Results from this well are included in the following sections with the caveat that the source of water sampled from this well cannot be clearly determined.

Monitor well 0628 is adjacent to well 0602. The original lithologic log for this well identifies it as being completed in the Cliff House Sandstone. However, the Cliff House Sandstone is not present within the boundaries of the raffinate ponds area. This well is actually completed within the Menefee Formation in what is believed to be massive, fine-grained sandstone. The well is screened continuously from its total depth of 32 ft to the surface. A visual investigation of the well using the down-hole camera showed the screened interval begins 2 ft below the surface. The protective concrete surface pad shown in the well completion log is no longer intact. Below the concrete pad the completion log indicates 3 ft of bentonite pellets were installed, extending down into the upper portion of the screen. The screened interval beginning only 2 ft below the surface adversely affects the integrity of analytical results from the well. Concentrations detected in samples from well 0628 may not be indicative of actual ground water conditions at depth, but may reflect the transport of surface or near surface materials into the well by precipitation or snowmelt. Results from well 0628 are not considered to be a valid representation of the constituent concentrations actually present or the geochemical conditions of ground water at this location.

The GCAP will be prepared to document the remediation decision. It is anticipated that this document will recommend abandoning wells 0602 and 0628 and replacing them with a well that will yield valid and technically defensible ground water analyses.

4.1.3 Soil and Rock Sampling

Soil and rock samples were collected during the installation of the monitor wells for lithologic logging and chemical analysis. Soil and rock samples were collected for chemical analysis to determine distribution coefficients (K_d) and mobile fractions of site-related constituents in the subpile soils to aid in characterizing subsurface contaminant transport.

Continuous core samples of the alluvium at the mill tailings area and of the bedrock formations at the raffinate ponds area were collected. Samples were collected in 10-ft intervals within the SONIC drill stem as the drill pipe was advanced through the formation. Clean water was used as needed to cool the advancing drill stem. Recovered core was vibrated out of the drill stem and placed in plastic bags within longitudinal separators. The uppermost portion of the sample was inspected, and all slough was discarded. After the site geologist described the cores, samples of selected intervals were placed in clean bags and labeled for analysis in the Grand Junction Office (GJO) Environmental Sciences Laboratory (ESL).

All soil and rock sampling was performed in accordance with the following procedures from the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998):

- GN-8(P), "Standard Practice for Sample Labeling"
- GN-9(P), "Standard Practice for Chain-of-Sample-Custody Control and Physical Security of Samples"
- GN-13(P), "Standard Practice for Equipment Decontamination"
- SL-9(P), "Technical Comments on ASTM D 2113-83(93)—Standard Practice for Diamond Core Drilling for Site Investigation"

4.1.4 Lithologic Logging

Lithologic descriptions of the alluvium and bedrock formations were recorded by the site geologist and are presented in the borehole summaries in Appendix A. All lithologic logging was performed in accordance with the following procedures from the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998):

- SL-19(P), "Technical Comments on ASTM D 2488-93—Standard Practice for Description and Identification of Soils"
- SL-24(P), "Technical Comments on ASTM D 2487-93—Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)"

4.2 Geology Investigation

The *Summary of Site Conditions and Work Plan, Durango Colorado* (DOE 2000b) presents geologic information as it was known from the preliminary hydrogeochemical characterization conducted by Bendix Field Engineering Corporation (Bendix) (DOE 1983), a hydrogeochemical site characterization by the BOR (1990), and the baseline risk assessment (DOE 1995a). Additional geologic characterization in fall 2000 was conducted mainly in the raffinate ponds area in conjunction with borehole drilling for monitor well installations. Recent geologic mapping by the Colorado Geological Survey for the Durango West and Durango East 7.5 minute quadrangles (Kirkham and others 1999, and Carroll and others 1999, respectively) covered the site areas, which are mostly on the Durango West quadrangle, and provided additional

information on stratigraphic and structural characteristics. The recent doctoral dissertation by Gillam (1998) on the late Cenozoic geology and soils of the lower Animas River valley also provided information in the recognition and description of Quaternary terrace deposits in the site areas.

4.2.1 Mill Tailings Area

Figure 4-4 is a geologic map of the mill tailings area. This map, compiled mainly from Kirkham and others (1999), shows the area to be underlain by the upper part of the gray, marine Mancos Shale. The presence of scattered gypsum crystals in the calcareous Mancos Shale verifies its high content of sulfate; the shale is also widely known for its high selenium content. Several hundred feet up the north slope of Smelter Mountain above the site is the gradational contact of the overlying Point Lookout Sandstone, in the lower part of which thin sandstone beds are interbedded with shale. The Mancos and Point Lookout are covered in most places in the mill tailings area by recent (active) and old (inactive) colluvial deposits emplaced by gravity and sheetwash. Drilling of boreholes in this site area for monitor wells in fall 2000 confirmed earlier interpretation of geologic conditions.

4.2.2 Raffinate Ponds Area

Figure 4-5 is a geologic map of the more stratigraphically varied and structurally complex raffinate ponds area. Bedrock units slightly younger than those at the mill tailings area are exposed at the raffinate ponds area. These units are part of the Mesaverde Group and include, in ascending order, the Point Lookout Sandstone, the Menefee Formation, and the Cliff House Sandstone. Just southwest of the area, along the Bodo Fault in Bodo Canyon, a small area of Lewis Shale (overlying the Cliff House Sandstone) outcrops. The Bodo Fault, named on the map by Kirkham and others (1999), cuts diagonally through the raffinate ponds area and has a displacement of about 200 ft. Generally, in this area the Point Lookout Sandstone is in the footwall (west, or upthrown, side) of the fault, and the Menefee Formation is in the hanging wall (east, or downthrown, side) of the fault. Except for bedrock outcrops along the steep east flank of Smelter Mountain and along some of the west bank of the Animas River, most of the area is covered by Quaternary colluvial material or fill material emplaced during reclamation.

Stratigraphic descriptions of bedrock formations in the site area are provided in the Bendix (DOE 1983) and BOR (1990) reports. Bedrock mapping units used in preparation of the geologic map (Figure 4-5) were adopted mainly from the new Colorado Geological Survey maps by Kirkham and others (1999) and Carroll and others (1999). A large-scale (1 inch = 200 ft), more detailed geologic map of the area shown in Figure 4-5 is provided as Plate 2.

The Point Lookout Sandstone represents an eastward prograding shoreline between the sea in which the Mancos Shale was deposited and the coastal plain where the Menefee Formation was accumulating (Kirkham and others 1999). The Point Lookout is subdivided into two units, a lower part and an upper massive part. The lower part is 250 to 300 ft thick and consists of interbedded thin sandstone and shale beds. Sandstone beds are less than 1 ft thick and are more frequent in the upper part of the unit; shale beds are gray, fossiliferous, bioturbated, and slightly carbonaceous, and become more predominant in the lower part of the unit. The few exposures of the lower Point Lookout in the area are west of the Bodo Fault along the bank of the Animas River and in a small north-flowing tributary drainage (Figure 4-5).

The upper massive part of the Point Lookout Sandstone is mainly composed of two thick, light gray to yellowish gray, fine- to medium-grained sandstone beds, each about 35 ft thick. A carbonaceous shale and siltstone bed several feet thick with limonite concretions separates the two sandstone beds. Total thickness of the upper Point Lookout is 75 to 80 ft, and it forms two distinctive cliffs along the east side of Smelter Mountain. Other exposures in the site area are just west of the Bodo Fault in the canyon of South Creek where several old quarries mined the sandstone, on the south abutment of the U.S. Highways 160 and 550 bridge just east of the Bodo Fault, and east of the Animas River on the slope above well 0905 (Plate 2). The topmost sandstone is typically bleached nearly white because of the reducing environment of the basal coal bed of the Menefee Formation lying immediately above. The relationship of the Point Lookout Sandstone to the Bodo Fault and the overlying Menefee Formation is shown in the 1,700-ft-long, north-south cross section (Plate 3) along the east side of the raffinate ponds area. The location of this cross section A–A' is shown in Figure 4–5.

The Menefee Formation is present in the raffinate ponds area east of the Bodo Fault. It is approximately 200 to 250 ft thick and consists of interbedded gray, brown, and black carbonaceous shale, fine-grained sandstone, and coal. Sandstone beds in many places contain abundant carbonaceous debris. Coal beds may be up to 5 ft thick, and one several feet thick occurs at the base of the formation. The coal and carbonaceous shale beds typically contain naturally high concentrations of selenium.

The Menefee Formation is exposed in only a few places in the raffinate ponds area. Exposures are of sandstone in the north part of the area just west of the highway, along the Animas River bank, and a distinctive basal coal bed just west of the highway bridge. Other Menefee outcrops are along the south flank of Smelter Mountain and on the hill south of South Creek where there is an old coal prospect. East of the highway across from the south part of the site area is another Menefee coal and sandstone outcrop area near an old slag pile. An excellent section of Menefee Formation is exposed east of the site area and east of the Animas River on the slope above the old railroad grade. Visible on this slope is an approximate division of the formation into four coal-carbonaceous shale layers and four sandstone layers. Even though these layers are somewhat lenticular and cannot be traced over distances of miles, they appear to be roughly correlated along strike to the west in the subsurface of the raffinate ponds area.

Numerous boreholes and wells penetrate parts of the Menefee Formation in the raffinate ponds area east of the Bodo Fault. From this abundant subsurface data and nearby exposures of the formation just east of the Animas River, a north-south cross section (Plate 3) was prepared showing an approximate stratigraphic framework of the Menefee. Correlations in this section were based heavily on the presence of coal and carbonaceous shale zones in the boreholes. The dip of strata in the cross section is approximately 12 degrees to the south; and strike of the beds is approximately due east; these strike and dip approximations were derived from those shown in the geologic maps of Kirkham and others (1999) and Carroll and others (1999). Individual borehole stratigraphic data were projected from various distances onto the line of the cross section. Although several approximations were made in constructing the cross section, it provides a relative thickness and stratigraphic framework for the Menefee Formation in the site area south and east of the Bodo Fault. Screened intervals in the Menefee wells indicate that ground water occurs both in the thick coal and carbonaceous shale units (that are probably well fractured) as well as in the thick permeable sandstone units.

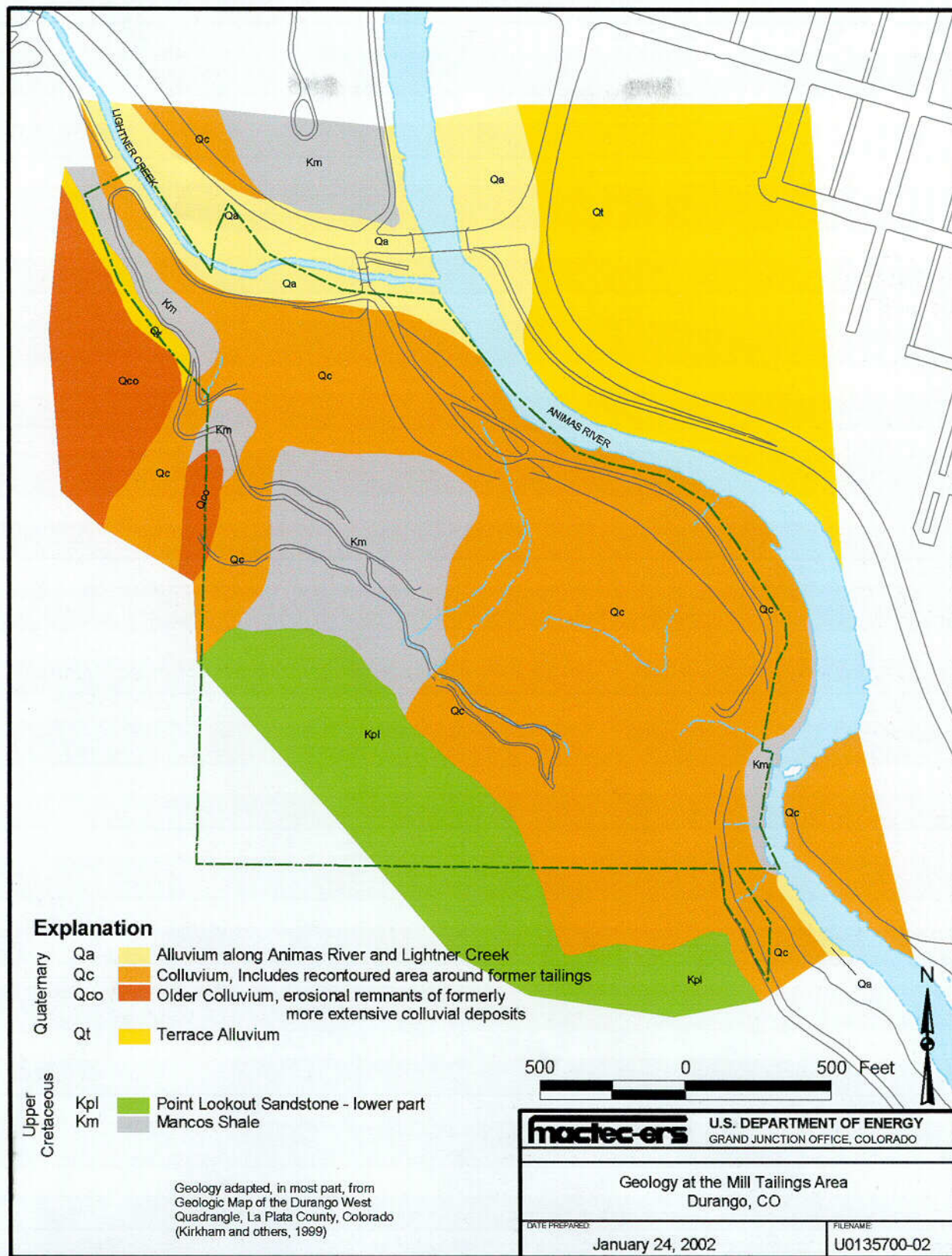


Figure 4-4. Geology at the Mill Tailings Area

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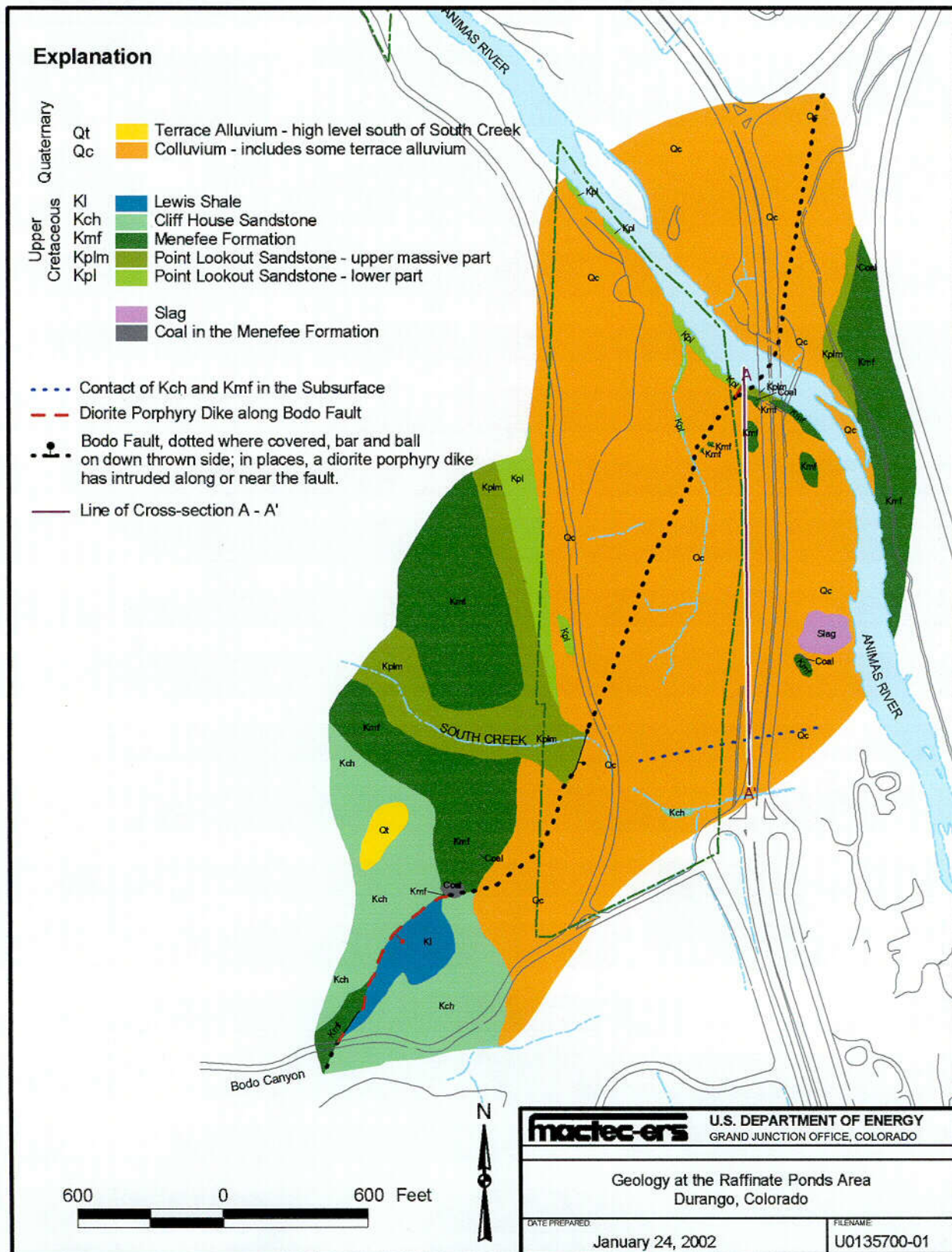


Figure 4-5. Geology at the Raffinate Ponds Area

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The lower Cliff House Sandstone consists of red brown (rust-colored) fine- to medium-grained sandstone beds with abundant fossil burrows. This formation represents a transgressive shallow marine barrier island beach front environment (Kirkham and others 1999). The contact between the Cliff House Sandstone and Menefee Formation is covered; its approximate position is about 200 ft north of South Creek (Figure 4-5).

Quaternary material mapped as colluvium covers much of the site area. Included with the colluvium are sheetwash deposits, alluvium along the Animas River, fill material and soil associated with surface re-contouring during remediation, glacial outwash, and terrace gravels 20 to 100 ft above the Animas River. These various Quaternary materials may be as much as 30 ft thick in the site area.

The Bodo Fault cuts through the site area but is exposed only at the north end of the area (just west of the U.S. Highways 160 and 550 bridge) and just southwest of the area for several hundred feet north of County Road 211 up Bodo Canyon. Also, the fault is obvious in the bottom of South Creek where massive sandstone of the Point Lookout Sandstone abruptly ends and colluvial material is present downstream (Figure 4-5). The buried location of the fault across the site was fairly well established from magnetometer surveys conducted by Bendix (DOE 1983). Good descriptions of the fault and associated alteration and intrusive dike rock are given in the BOR 1990 report from several boreholes drilled through the fault. North of the Animas River, the fault position is less certain. During this investigation, evidence for the fault was sought in the deep borehole for well 0905, but none was found, indicating the fault is farther to the west. From field locations and subsurface borehole penetrations of the fault across the site, its dip ranges from 45 to 65 degrees and it trends from due north to nearly due east.

Dikes of diorite porphyry have intruded the Bodo Fault along much of its length; they are probably associated with early Laramide intrusive rocks of the La Plata Mountains to the west. Up to several feet thick, the dikes may occur alone or branch into several dikes along the fault zone. Where exposed north of the Bodo Canyon road, the dikes are red brown, well oxidized, and moderately to highly weathered. Gray siltstone and shale adjacent to a dike in the fault zone west of the U.S. Highways 160 and 550 bridge has been altered to resistant hornfels by contact metamorphism.

Cored material from boreholes during the investigation in fall 2000 displayed subsurface characteristics of the fault zone and the diorite porphyry intrusions. Where fresh, the diorite porphyry was resistant and medium brown to medium gray. In most cases, the diorite showed propylitic alteration with hornblende altering to chlorite. Effects of the fault and diorite porphyry dikes on the adjacent sedimentary rocks include baking of gray shales to hornfels and, in some cases, to light-colored porcelaneous material. Sandstone near the fault was usually well fractured with limonite, pyrite, and calcite present along fractures. Black sooty material and soft gray gouge material was present near the fault. Pyrite occurred in vugs in some sandstone, which was metamorphosed to quartzite-like material. Also, pyrite occurred in unaltered sandstone and shales in segregations as large as 2 inches in diameter and as finely disseminated material. The pyrite likely contains a significant amount of selenium as is commonly associated with igneous intrusive rock. Effects of the fault zone and associated diorite porphyry dikes in the form of increased fracturing and alteration extend up to an estimated 50 ft or more from the fault.

Joint directions in bedrock in the raffinate ponds area were measured by Kirkham and others (1999). They found an orthogonal pattern with the oldest and most prevalent joint set trending north-northeast and a younger, secondary joint set trending east-northeast.

4.3 Aquifer and Slug Tests

Aquifer tests at the Durango site were performed by Bendix in 1983 (DOE 1983), BOR in 1990 (BOR 1990), and MACTEC-ERS in 2001. Appendix F presents the details of the MACTEC-ERS tests and summarizes the results from the Bendix and BOR tests.

Aquifer testing at the former mill tailings area is hampered by thin saturated zones and depths to water that exceed 25 ft. These conditions prevent conventional pumping tests because where the saturated alluvium is thin, multiple well testing is impractical because of limited available drawdown. If the depth to water exceeds 25 ft, a centrifugal pump cannot be used because the required lift exceeds the capability of the pump. In consequence, only slug tests were conducted at the former mill tailings area by MACTEC-ERS and previous investigators. MACTEC-ERS performed slug tests in the mill tailings area at wells shown in Figure 4-6.

At the raffinate ponds area, ground water occurs in bedrock units of the Menefee Formation and the Point Lookout Sandstone. Except where the Bodo Fault crosses the raffinate ponds area, the well yields in the bedrock formations are so low that it would be impractical to conduct conventional aquifer tests. Along the Bodo Fault, Bendix (DOE 1983) performed a pumping test; results from that test are presented in Appendix F. Because the bedrock formations were anticipated to have low yields, slug tests were recommended for characterizing the hydraulic conductivity at the raffinate ponds area. Slug tests were performed at wells 0602, 0876, 0878, 0879, 0881, 0882, 0883, 0888, 0889, 0890, and 0902 (Figure 4-6) at the raffinate ponds area.

In November 1990, BOR performed slug tests and packer tests at the former raffinate ponds area as part of the design of the pumping plant for the Animas-La Plata water project. Results of the BOR tests are presented in Appendix F.

Table 4-2 presents the results of the MACTEC-ERS slug tests for the former mill tailings area and the raffinate ponds area. As shown in Table 4-2, the hydraulic conductivity ranged from 1 to 28 ft/day for the Animas River alluvium and was 66 ft/day for the Lightner Creek alluvium. Table 4-2 also shows that the hydraulic conductivity of the Menefee Formation ranges from a minimum of 0.003 ft/day at well 0902 to 5.3 ft/day for the duplicate test at well 0882. Hydraulic conductivity of the Point Lookout Sandstone was low at locations 0881 and 0889 where it was measured by MACTEC-ERS. Slug test and packer test results described by BOR (Appendix F) indicate that the Point Lookout Sandstone has a uniformly low hydraulic conductivity.

Within the Bodo Fault, the slug test for well 0888 indicates a hydraulic conductivity of 6.4 ft/day. This result for the Bodo Fault confirms earlier tests by Bendix (DOE 1983) when a value of 4.4 ft/day was determined. The slug test results indicate that the Bodo Fault is a potential conduit for ground water flow at the site.

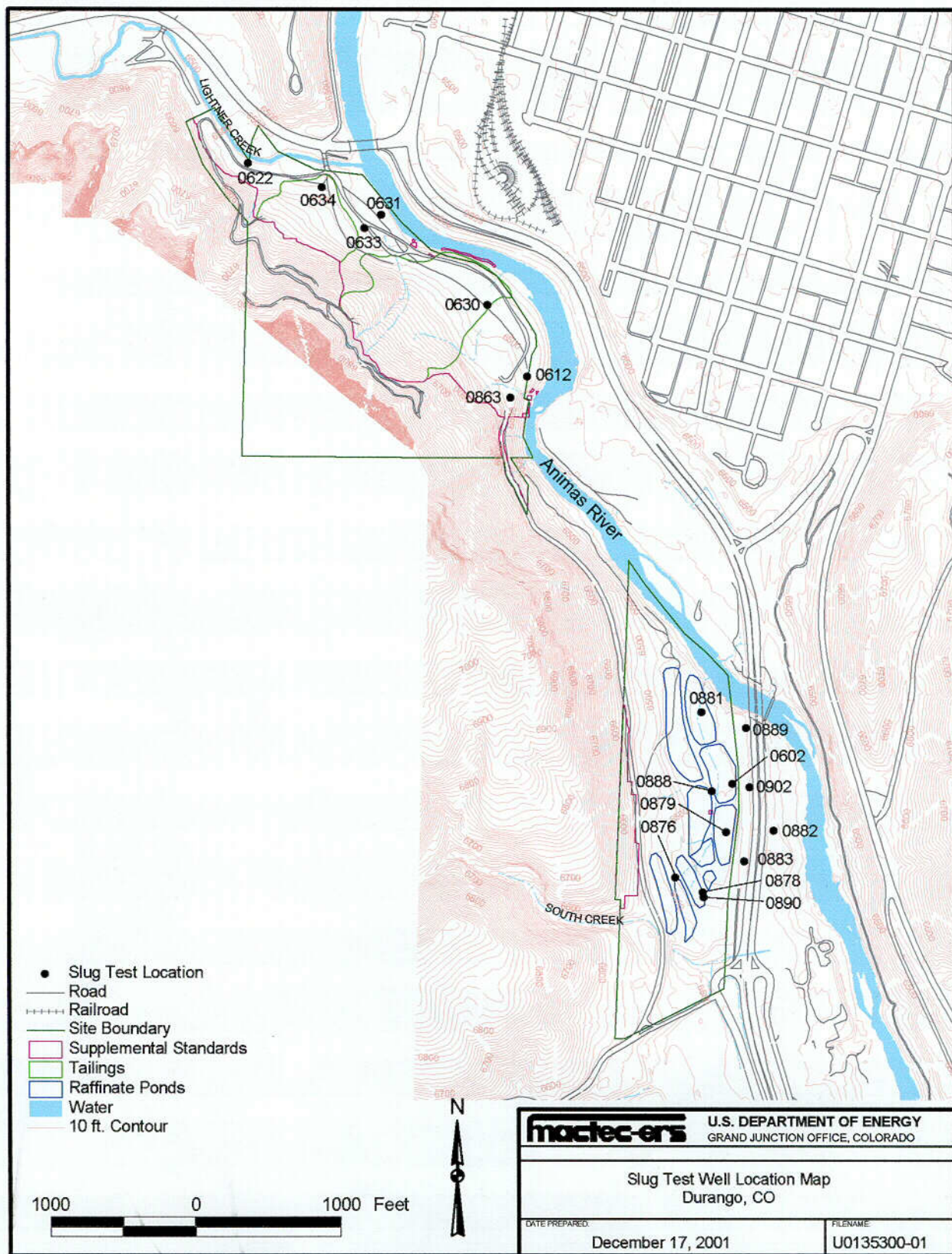


Figure 4-6. Slug Test Well Location Map

Table 4-2. Summary of Slug Tests Performed at the Durango Sites by MACTEC-ERS

DUR-01 Mill Tailings Area	Well	Hydraulic Conductivity (ft/day)	Formation	DUR-02 Raffinate Ponds Area	Well	Hydraulic Conductivity (ft/day)	Formation
	0612	10	Alluvium		0602	0.26	Menefee
	0612-dup	13	Alluvium		0876	0.09	Menefee
	0622	66	Lightner Cr. Alluvium		0878	1	Menefee
	0630	13	Alluvium		0879	0.043	Menefee
	0631	27	Alluvium		0881	0.016	Point Lookout
	0631-dup	26	Alluvium		0882	4.7	Menefee (coal)
	0633	1	Alluvium		0882-dup	5.3	Menefee (coal)
	0634	8	Alluvium		0883	0.017	Menefee
	0863	26	Alluvium		0888	6.4	Menefee (fault)
	0863-dup	28	Alluvium		0889	0.014	Point Lookout
					0890	0.3	Menefee
					0902	0.003	Menefee

Note: All alluvium is derived from the Animas River unless noted otherwise.
dup = duplicate sample

4.4 Subpile Soil Sampling

A study of subpile soils was done to determine if cadmium, lead, molybdenum, selenium, or uranium are present in soils in sufficient concentrations to be a source of contamination to the ground water at the Durango site. Thirty-nine soil samples were analyzed. Nineteen samples were obtained from the mill tailings area, including three background samples (Figure 4-7). Twenty samples were collected from the raffinate ponds area, including four background samples (Figure 4-8).

4.4.1 Subpile Soil Sampling Methods

Soil samples were collected as individual grab samples by backhoe from locations most likely to be contaminated. Two samples were collected above the water table at each location. Samples were taken from the backhoe bucket at depths ranging from 2 to 6 ft. Samples 0913 from 3.5 ft deep and 0914 from 3 ft deep were rock samples obtained from the Menefee Formation and Point Lookout Sandstone, respectively. The two rock samples were crushed to obtain leachable samples.

Background samples were collected from areas off site. Two samples of colluvium (0931-COL and 0932-COL) were collected upgradient from the site along the base of Smelter Mountain. One sample of alluvium (0930-AL) was collected about 1,500 ft upstream from the site along the Animas River.

4.4.2 Subpile Soil Sampling Chemical Extraction Methods

Concentrations of constituents in soil are determined through sample digestion, separation of the liquid phase by centrifuging or filtering, analysis of liquid phase constituent concentrations, and calculation of the concentrations in the solid phase. The most suitable digestion methods are those that remove only the loosely bound constituents because they have the highest potential for contaminating ground water and being accessible to plants and animals. The choice of extraction

method and leaching fluid determines which specific constituents can be extracted. The kinds of liquid media used to digest samples range from deionized water to strong acids combined with hot fluxing agents. Numerous digestions with different solutions would be needed to provide a complete picture of constituent distribution in a soil.

This project was intended to provide data for a screening-level assessment of soil accessible to plants and animals. A five percent solution of nitric acid (HNO_3) was used for digestion. This acidic solution should release the adsorbed cations and dissolve the carbonate minerals. Although anions adsorb more strongly at low pH, they should also be released because the acid dissolves most of the amorphous oxyhydroxide adsorbent phases. Five-percent HNO_3 will not dissolve most silicate minerals, which is desirable because the constituents in silicate minerals are not readily available to ground water. Analytical methods for the soil sampling are discussed in greater detail in the *Contaminants in Subpile Soils* report (Appendix J).

4.4.3 Mill Tailings Area Subpile Soil Sampling Results

Nineteen samples were collected from 11 locations (Figure 4–7). Two samples from different depths were collected from each location, except samples from locations 0930, 0931, and 0932, where each is a single surface sample. All sample pairs have similar lithology. One sample, 0918–5 ft, contains slag, which is solid waste material left from the operation of the lead smelter.

Mill tailings area subpile soil data are listed in Table 4–3. Three surface soil samples, 0930–AL, 0931–COL, and 0932–COL, are background samples. Cadmium concentrations in these three samples are greater than the mean crustal concentration of 0.2 milligrams per kilogram (mg/kg). Selenium concentrations in background samples exceed both the detection limit of 0.35 mg/kg and the mean crustal concentration of 0.05 mg/kg. Lead concentrations in background samples 0931–COL and 0930–AL also are greater than the crustal mean. The presence of lead in concentrations greater than the crustal mean in background samples indicates that lead is available in the environment and the soils are able to adsorb it. The elevated cadmium, lead, and selenium concentrations in background samples suggests these constituents are natural components of the rocks and soil. Concentrations of molybdenum and uranium in background samples are less than the mean crustal concentrations, which indicates that these constituents are not natural rock and soil components. Significantly elevated concentrations of cadmium, lead, and selenium and elevated concentrations (greater than the crustal mean) of molybdenum and uranium indicate an anthropogenic source.

Nine of the 16 nonbackground samples have cadmium concentrations greater than the crustal mean of 0.2 mg/kg. Lead concentrations in five nonbackground samples are greater than the mean crustal composition of 13 mg/kg. All 16 nonbackground samples have selenium concentrations greater than the crustal mean of 0.05 mg/kg and the detection limit 0.35 mg/kg. Only two samples have molybdenum concentrations that are greater than the mean crustal concentration of 1.5 mg/kg. Five samples have uranium concentrations greater than the mean crustal concentration of 1.80 mg/kg. Elevated molybdenum and uranium concentrations may be attributable to milling activity.

Slag was collected with soil in sample 0918–5 ft, and no slag was collected in sample 0918–3 ft. The slag is associated with the operation of the lead smelter and could be expected to contain high concentrations of lead. Therefore, the source of lead contamination cannot be solely attributable to uranium milling activity.

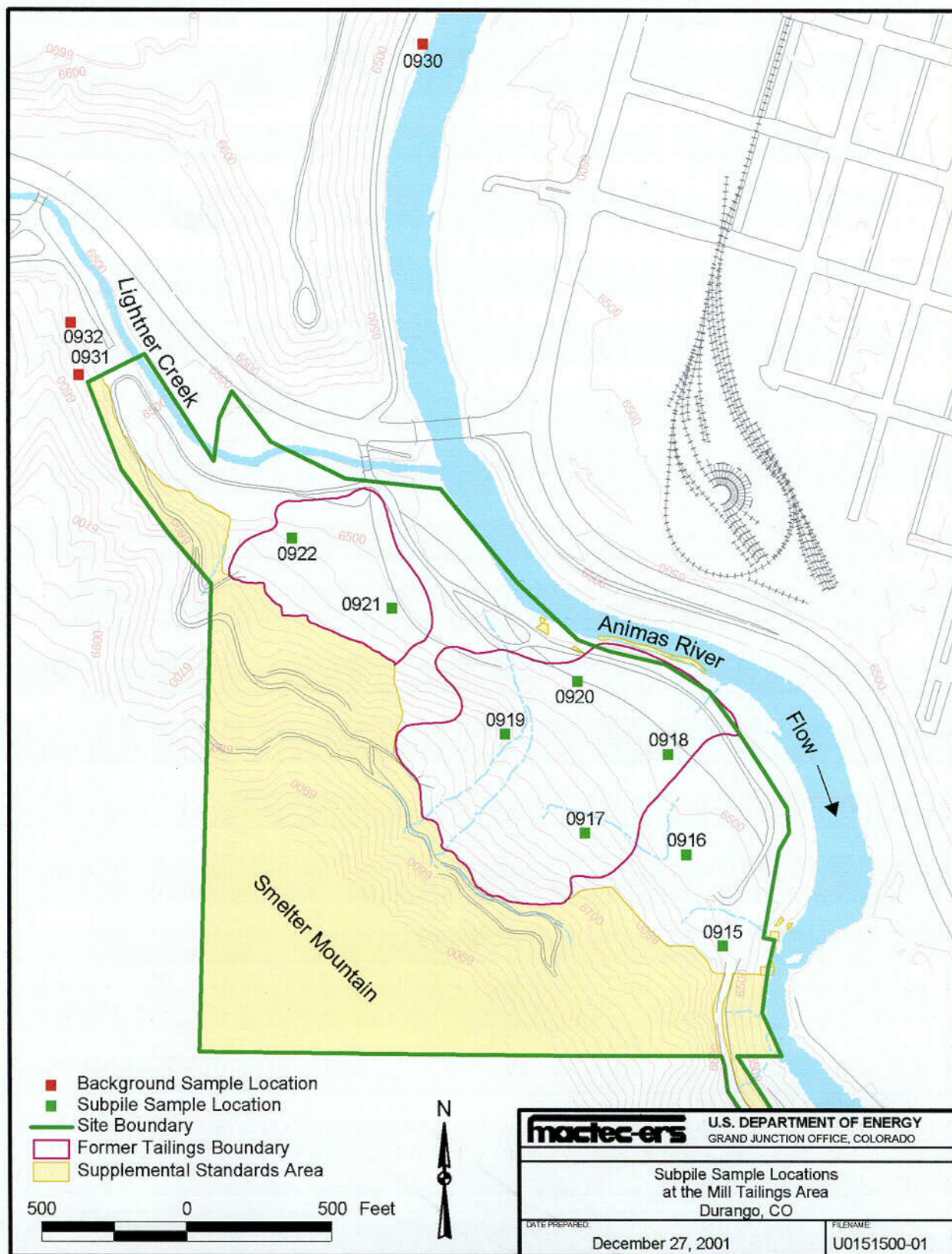


Figure 4-7. Subpile Soil Sample Locations at the Mill Tailings Area

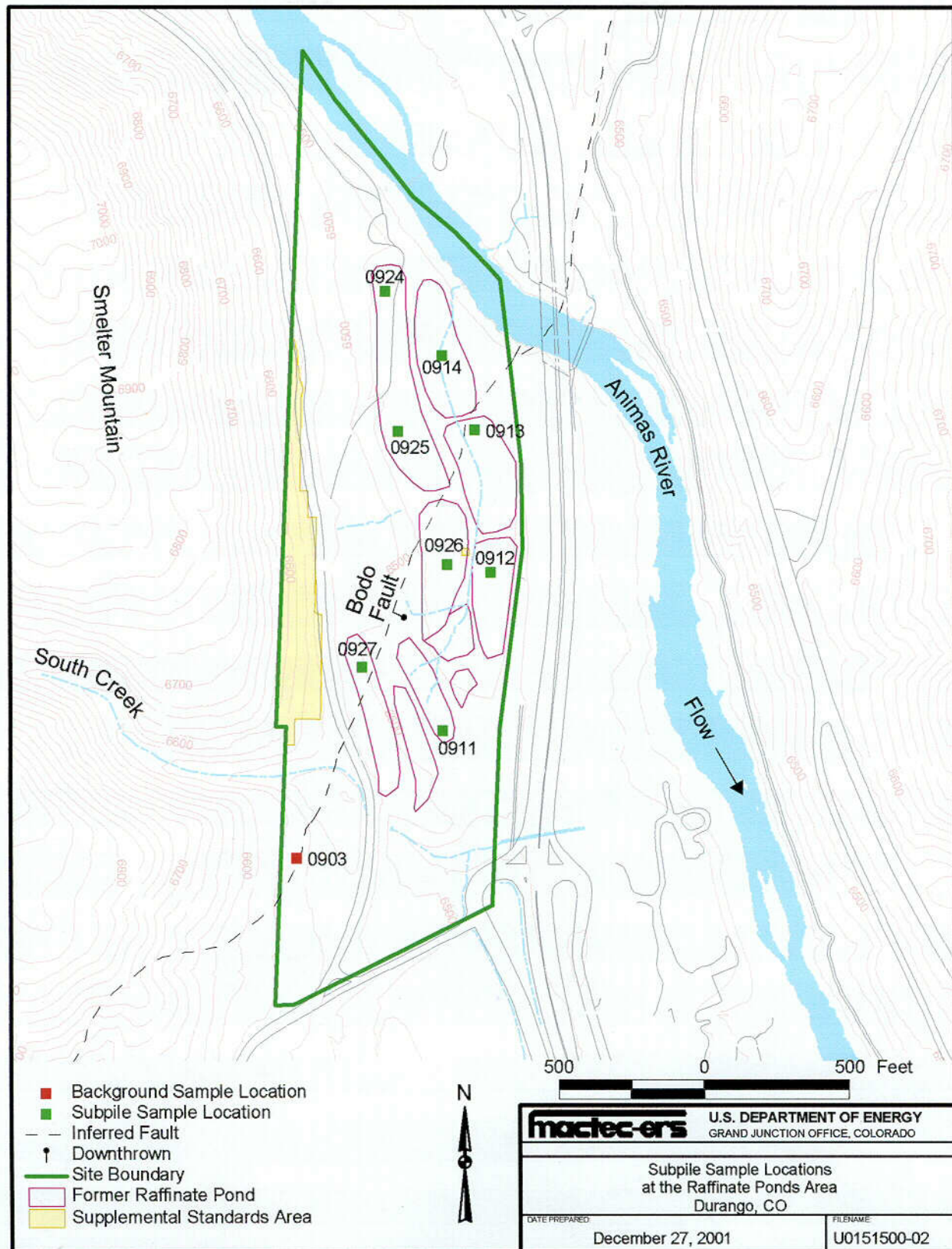


Figure 4-8. Subpile Soil Sample Locations at the Raffinate Ponds Area

Table 4-3. Constituent Concentrations in Durango Mill Tailings Area Subpile Soil Samples

Sample		Cadmium		Lead	Molybdenum		Selenium		Uranium
Well	Depth (ft)	(mg/kg)	DQ ^a	(mg/kg)	(mg/kg)	DQ	(mg/kg)	DQ	(mg/kg)
0915	-3 ^b	0.14		8.58	0.08	U	0.41	B	0.36
0915	-5	0.10		6.98	0.08	U	0.49	B	0.34
0916	-3	0.25^c		13.8	0.08	U	0.35	U	0.48
0916	-5	0.21		12.7	0.08	U	0.35	U	0.49
0917	-2	7.20		79.6	0.88	B	1.31		21.8
0917	-4	4.17		42.5	2.18		1.29		10.7
0918	-3	0.096	B	5.67	0.096	B	0.68		0.35
0918	-5	5.15		6660	10.8		2.00		42.4
0919	-2	0.76		9.23	0.087	B	0.56		6.90
0919	-4	0.18		7.37	0.08	U	0.47	B	3.24
0920	-2	0.25		14.7	0.08	U	0.35	U	0.50
0920	-5	0.17		6.47	0.08	U	0.92		0.30
0921	-2	0.22		9.35	0.091	B	0.64		1.72
0921	-4	0.17		9.10	0.08	U	0.86		0.72
0922	-2	0.20		11.4	0.08	U	0.37	B	0.76
0922	-3	0.28		11.7	0.08	U	0.35	U	0.75
0930	-AL	1.27		141	0.50	B	0.60		0.77
0931	-COL	0.85		13.6	0.66	B	0.88		1.22
0932	-COL	0.57		6.95	0.13	B	0.72		0.54
Crustal average ^d		0.2		13	1.5		0.05		1.8

^aData Qualifiers: B signifies that the reported value is less than the required detection limit but is greater than or equal to the actual instrument detection limit. U signifies that the value is less than the detection limit.

^bSample collection depth (ft) below ground surface. Depths labeled as -AL and -COL are surface samples. AL is from the alluvium and COL is from the colluvium.

^c**Bold type** indicates that concentrations are greater than the average crustal value.

^dFrom Mason and Moore 1982.

Elevated constituent concentrations at some locations, (such as 0917), indicate milling processes may have influenced soil chemistry. Although concentrations of cadmium, lead, and selenium appear to be naturally greater than the crustal mean, significantly elevated constituent concentrations, such as those in sample 0918-5 ft, appear to be limited to small, separate areas. Likewise, elevated concentrations of molybdenum and uranium appear to be limited in area. Samples with elevated concentrations are sufficiently few and separated that the concentrations may not be a significant, continuing source of contamination.

4.4.4 Raffinate Ponds Area Subpile Soil Sampling Results

Twenty samples were collected from nine locations (Figure 4-8). Two samples were collected from each location except location 0903, where four background samples were collected at depths of 4 ft, 14 ft, 23 ft, and 28 ft. Two samples, 0913-4 ft and 0914-3 ft, were rock core samples and were crushed to obtain the required less than 2- millimeter (mm) fraction. The lithology of the samples is similar, except in samples 0913-4 ft and 0914-3 ft. Sample 0913-4 ft was collected as a consolidated core sample of unweathered, medium-grained, light-gray sandstone from the Menefee Formation. Sample 0914-3 ft was collected as a consolidated sample of shale from the Point Lookout Sandstone. The remaining samples have similar

lithology with minor variations in the amount of silt, degree of rounding, and type of rock material present.

Raffinate ponds area subpile soil data are listed in Table 4–4. The selenium concentrations of all samples are greater than the mean crustal concentration. Background concentrations of cadmium, lead, molybdenum, and uranium are less than the mean crustal concentrations. The higher concentrations of cadmium and lead in samples from the mill tailings area are not present in samples from the raffinate ponds area.

Table 4–4. Constituent Concentration in Durango Raffinate Ponds Area Subpile Soil Samples

Sample		Cadmium		Lead	Molybdenum		Selenium		Uranium
Well	Depth (ft)	(mg/kg)	DQ ^a	(mg/kg)	(mg/kg)	DQ	(mg/kg)	DQ	(mg/kg)
0903	-4 ^b	0.041	B	4.40	0.12	B	0.35	U	0.18
0903	-14	0.057	B	4.81	0.11	B	0.35	U	0.18
0903	-23	2.17^c		4.50	0.13	B	0.35	U	0.29
0903	-28	0.11		10.0	0.12	B	0.35	U	0.21
0911	-2	0.19		8.45	0.08	U	0.35	U	0.41
0911	-6	0.38		6.62	0.08	U	0.39	B	0.90
0912	-2	3.39		5.21	0.23	B	1.51		2.30
0912	-5	1.79		5.96	0.31	B	1.50		2.09
0913	-2	1.31		12.6	0.093	B	1.00		2.03
0913	-4	0.081	B	6.14	0.33	B	0.53		0.29
0914	-2	13.4		7.63	0.08	U	2.77		15.1
0914	-3	0.21		13.6	0.39	B	0.89		0.61
0924	-2	0.84		10.7	0.096	B	0.66		2.05
0924	-5	2.03		9.34	0.12	B	1.19		6.50
0925	-2	0.42		10.6	0.18	B	1.10		1.27
0925	-5	0.60		9.95	0.15	B	0.47	B	1.17
0926	-2	7.85		5.96	0.11	B	1.22		19.5
0926	-4	6.98		7.71	0.16	B	1.16		4.60
0927	-3	0.51		6.46	0.08	U	0.59		6.07
0927	-5	0.74		7.16	0.08	U	0.52		4.79
Crustal average ^d		0.2		13	1.5		0.05		1.8

^aData Qualifiers: B signifies that the reported value is less than the required detection limit but is greater than or equal to the actual instrument detection limit. U signifies that the value is less than the detection limit.

^bSample collection depth (ft) below ground surface. Depths labeled as –AL and –COL are surface samples. AL is from the alluvium and COL is from the colluvium.

^c**Bold type** indicates that concentrations are greater than the average crustal value.

^dFrom Mason and Moore 1982.

Both samples from locations 0912, 0924, 0926, and 0927 have cadmium and uranium concentrations greater than the mean crustal concentrations. Both samples from locations 0914 and 0925 have cadmium concentrations greater than the crustal mean. The uranium concentration in samples 0914–2 ft and 0913–2 ft, and the lead concentration of 0914–3 ft are greater than the mean crustal concentrations. Cadmium concentration in samples 0903–23 ft, 0911–6 ft, and 0913–2 ft are greater than the crustal mean.

Elevated concentrations of cadmium, lead, molybdenum, and uranium suggest that milling processes influenced soil chemistry. As in the mill tailings area, high constituent concentrations

are limited to small, separate areas. Overall, the concentrations may not be significant enough to be a continuing source of contamination.

4.5 Distribution Coefficient

As contaminated ground water migrates through soil and rock, contamination is distributed between the solid and liquid phases. This phenomenon causes the contamination to travel at a slower rate than the average ground water velocity. Chemical processes that retard the migration rate of the contaminant plume can include adsorption, absorption, mineral precipitation, diffusion into immobile porosity, attachment to microbes, and transfer to vapor phases. It is generally not possible to differentiate among these processes. However, a bulk parameter (K_d) has been used with some success to model the retardation of contaminant movement for many aquifer systems. Most numerical ground water models use the K_d concept in simulations of contaminant transport. Site-specific K_d values are approximated from R_d values that are empirically determined. This laboratory study was conducted to determine R_d values for four stratigraphic units at the Durango site.

4.5.1 Definitions and Calculations

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

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

R_d values are calculated from experimental data as

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

where

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

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

At elevated concentrations of a constituent, R_d often varies with the aqueous concentration. In this case, the isotherm is said to be nonlinear and cannot be accurately represented by K_d .

4.5.2 Methods

Surface samples were collected by shovel and bedrock samples were collected with a rotasonic drill rig. Samples were collected from background areas to avoid the complication of contamination in the solid phases before analyses. If contamination is present in the solids, it must be accounted for by measuring concentrations in both the solid and aqueous phases. If no contamination is present in the solid phase, only the aqueous solution requires analysis, making the procedure less complicated and less prone to analytical error. It is believed the lithology and mineralogy in the background areas are similar to those in contact with the contaminant plume.

R_d data were collected using ESL Procedure CB($R_d - 1$) (DOE 1999b). Surface water was collected from the Animas River to use for leaching the mill tailings area samples, and ground water was collected from well 0592 to use for leaching the raffinate ponds area samples. The collected waters were spiked with known amounts of cadmium, lead, molybdenum, selenium, and uranium concentrates to produce a target concentration of each constituent; these waters are called control samples.

Several rounds of determinations, changes in the target solution concentrations, and the use of synthetic ground water for Round 3 of the raffinate ponds area determinations were necessary because of the instability of the control solutions. Table 4–5 through Table 4–7 list the constituent concentrations of the control samples and the target concentrations for each study area and for each round of analyses. Due to the number of samples, the concentrations of the control solutions were measured for each batch of samples in Round 1 of the raffinate ponds area determinations. As a result, there are five control solutions in Round 1 of the raffinate ponds area determinations. As listed in Round 1 determinations, the target concentrations were 1 mg/L for cadmium, lead, molybdenum, selenium, and uranium. In Round 2, the target concentration of uranium changed to 0.5 mg/L and lead was not included. In Round 3, determinations were conducted on raffinate ponds area samples using synthetic ground water, and the target concentrations of cadmium and molybdenum changed to 0.5 mg/L and the selenium and uranium concentrations did not change.

A six-point isotherm was determined for each sample in Round 1. Samples in Rounds 2 and 3 were single-point determinations. Samples were analyzed for cadmium, lead, molybdenum, and uranium by inductively coupled plasma-mass spectrometry (ICP-MS), and selenium was determined by inductively coupled plasma-atomic emission spectrometer (ICP-AES) by the GJO Analytical Laboratory.

Table 4–5. Control Solution Stability for Mill Tailings Area Samples

Listed are target concentrations, control solution compositions, and percent of the target concentration recovered for mill tailings area determinations.

Analyte	Units	Animas River Water					
		Round 1			Round 2		
		Target ^a	Control	% of Target	Target	Control	% of Target
Cadmium	mg/L	1.0	0.985	98.5^b	1.0	0.999	99.9
Lead	mg/L	1.0	0.151	15.1	NA ^c	NA ^c	NA ^c
Molybdenum	mg/L	1.0	0.609	60.9	1.0	1.01	101
Selenium	mg/L	1.0	1.15	115	1.0	1.04	104
Uranium	mg/L	1.0	0.485	48.5	0.5	0.456	91.2

^aCalculated desired concentration.

^bBold type indicates control concentration is within 15 percent of target concentration.

^cNA = Constituent not added

Table 4–6. Control Solution Stability for Raffinate Ponds Area Samples, Round 1.

Listed are control solution compositions, which used water from well 0592, for Round 1. The mean concentrations are calculated from these data and are listed.

Analyte	Units	Target ^a	Round 1: Water from Well 0592					
			Control 1	% of Target	Control 2	% of Target	Control 3	% of Target
Cadmium	mg/L	1.0	0.945	94.5^b	0.936	93.6	0.899	89.9
Lead	mg/L	1.0	0.0443	4.43	0.026	2.62	0.0076	0.76
Molybdenum	mg/L	1.0	0.633	63.3	0.595	59.5	0.604	60.4
Selenium	mg/L	1.0	0.451	45.1	0.736	73.6	1.10	110
Uranium	mg/L	1.0	0.0061	0.61	0.0061	0.61	0.0058	0.58

^aCalculated desired concentration.

^bBold type indicates control concentration is within 15 percent of target concentration.

Table 4–7. Control Solution Stability for Raffinate Ponds Area Samples, Rounds 2 and 3

The control solution compositions of Round 2, which used water from well 0592, and of Round 3, which used synthetic ground water, are listed.

Analyte	Units	Round 2: Well 0592			Round 3: Synthetic		
		Target ^a	Control	% of Target	Target ^a	Control	% of Target
Cadmium	mg/L	1.0	0.0084	0.84	0.5	0.358	71.6
Lead	mg/L	NA ^c	NA ^c	NA ^c	NA ^c	NA ^c	NA ^c
Molybdenum	mg/L	1.0	0.104	10.4	0.5	0.525	105
Selenium	mg/L	1.0	0.0038	0.38	1.0	1.150	115
Uranium	mg/L	0.5	0.465	93^b	0.5	0.466	93.2

^aCalculated desired concentration.

^bBold type indicates control concentration is within 15 percent of target concentration.

^cNA = Constituent not added

4.5.3 Solution Stability of Lead

All control solutions created from surface and ground waters were unstable with regard to lead. Sufficient lead was added to produce a lead concentration of 1 mg/L. The measured concentration in the spiked Animas River sample, which was used to leach mill tailings area samples, was 0.151 mg/L. The concentration of lead in water from well 0592, which was used to leach raffinate ponds area samples, ranged from 0.0076 to 0.0443 mg/L. The low concentrations may be due to solubility constraints; lead may have reached its solubility limit in solution. For example, it is possible that interaction with sulfate in the water and/or interaction with iron in the water resulted in the precipitation of lead. If so, the filtration of the water prior to submitting the samples to the GJO Analytical Laboratory may have removed the lead from the water and produced the data results shown.

4.5.4 Solution Stability - Mill Tailings Area

Water collected from the Animas River was used to leach samples from the mill tailings area. Sample locations are shown in Figure 4–9. As listed in Table 4–5, the control solutions used in Round 1 of the R_d determinations were stable with regard to cadmium and selenium. A constituent is considered stable if the measured concentration in the control sample is within 15 percent of the target concentration. The stable constituents are shown in bold type. In Round 2, the solutions were stable with regard to cadmium, molybdenum, selenium, and uranium. The results obtained from stable constituent concentrations are used to determine the R_d values.

4.5.5 Solution Stability Raffinate Ponds Area

In Rounds 1 and 2, solid samples from the raffinate ponds area were leached with water from well 0592 (Figure 4–10). In Round 3, the samples were leached with laboratory prepared synthetic ground water. The pH and oxidation-reduction potential (ORP) of the water from well 0592 when it arrived at the ESL was 7.55 and –322 millivolts (mV), respectively, and it had a very strong sulfur odor. By the end of the Round 1 determinations, the pH was 7.00, the ORP was –135 mV, and the sulfur odor had decreased. These changes indicate a change in redox conditions in the water affected the stability of the control solutions. As a result, the final round of determinations, Round 3, were conducted using synthetic ground water to ensure stable redox conditions.

In Round 1, the constituent concentrations of the control solutions were measured for each batch of samples. For the raffinate ponds area, there are five control solutions and the constituent concentrations vary in each solution (Table 4–6). A constituent is considered stable if the measured concentration in the control sample is within 15 percent of the target concentration. The stable constituents are shown in bold type. Control 1 is the solution used with the first batch of samples, which comprised seven samples, and control 5 is the composition of the solution when used with the last batch of samples, which comprised four samples. The changes in cadmium and selenium concentrations from control solution 1 through control solution 5 indicate the influence of redox conditions on constituent concentrations. Cadmium concentrations decreased with each successive control solution, and selenium concentrations increased with each successive control solution. The control solution concentrations of Round 1 were stable with regard to cadmium in controls 1 through 3 and were stable with regard to selenium in controls 3 and 4.

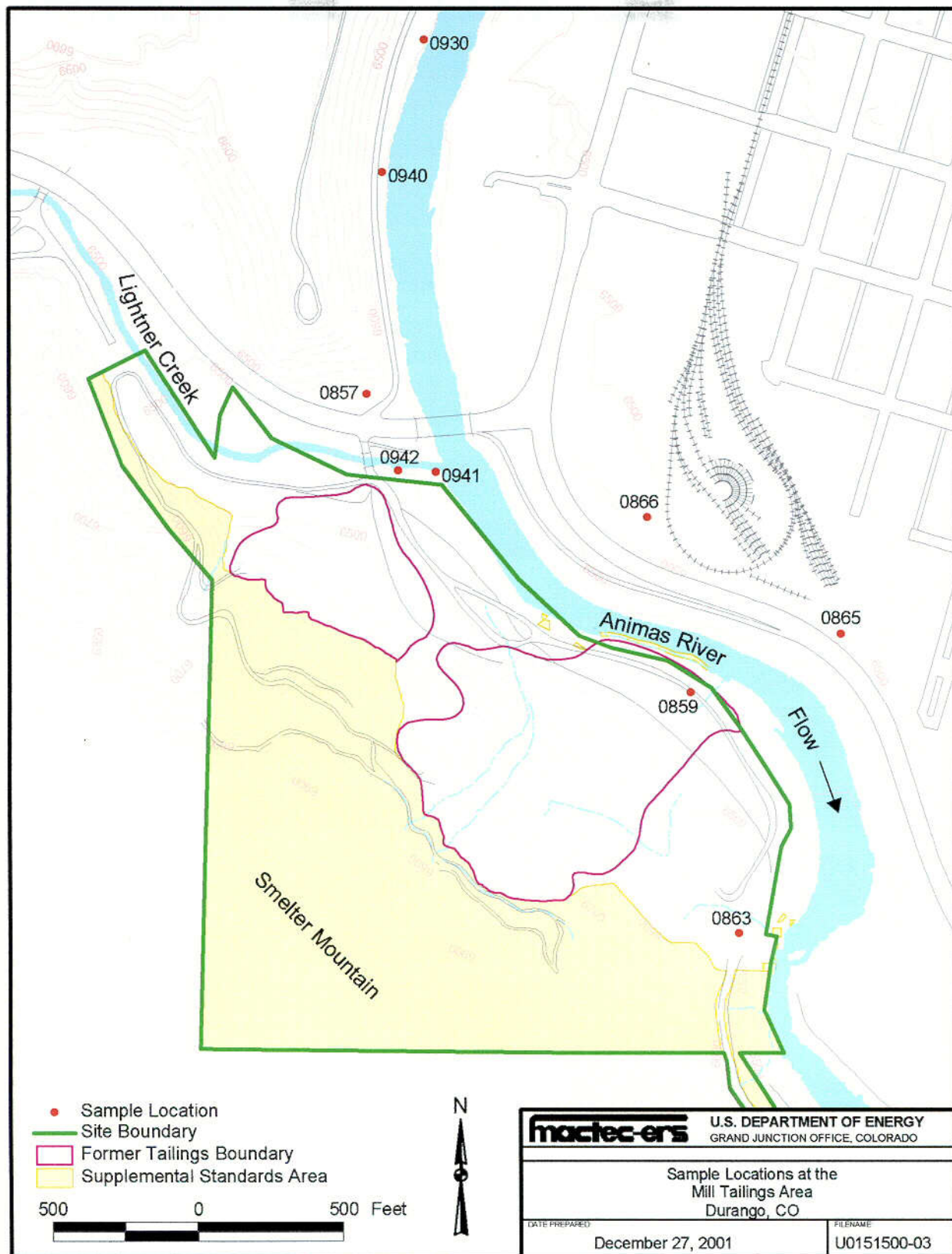


Figure 4-9. Distribution Coefficient Sample Locations at the Mill Tailings Area

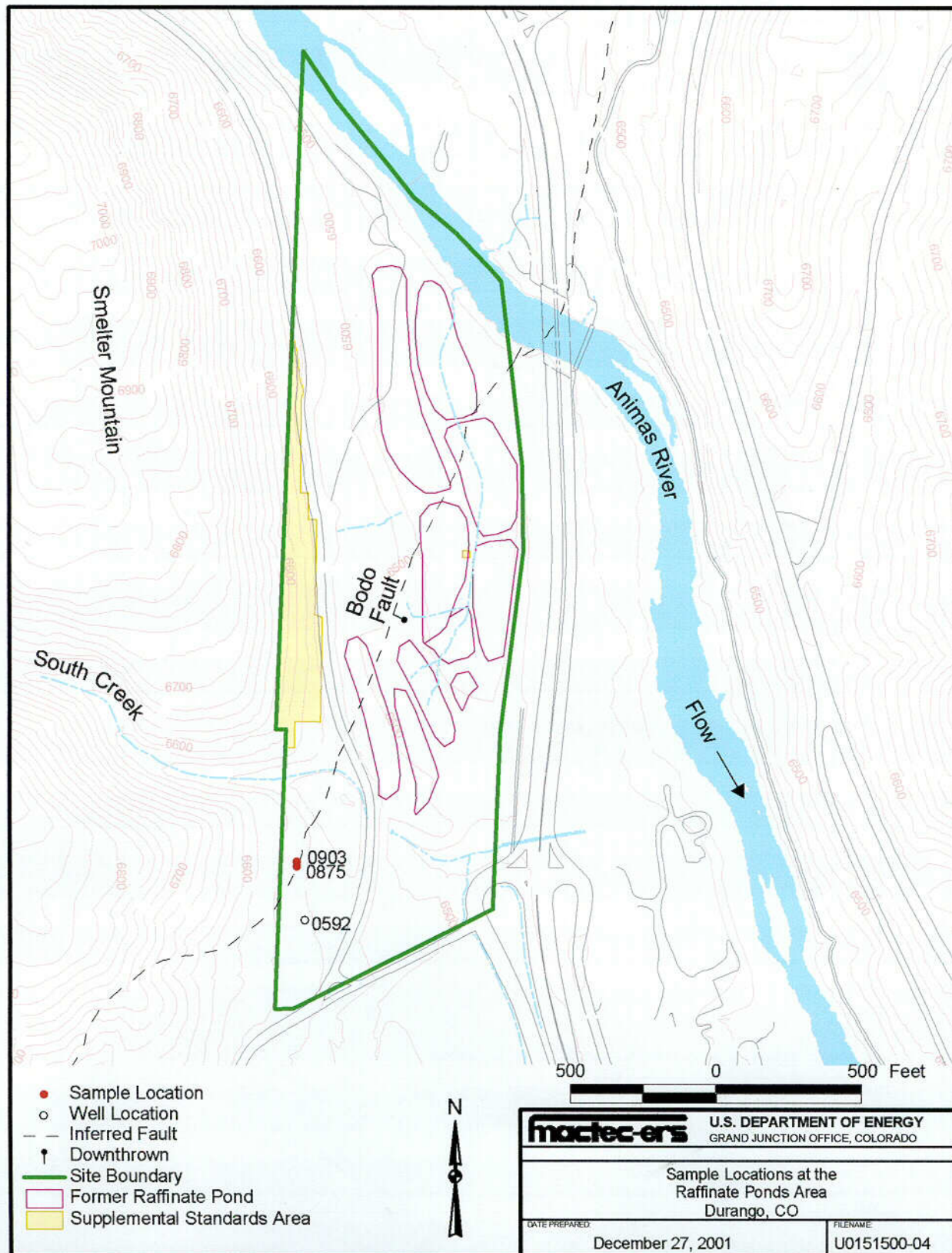


Figure 4-10. Distribution Coefficient Sample Locations at the Raffinate Ponds Area

The data for the raffinate ponds area control solutions for Rounds 2 and 3 are listed in Table 4–7. In Round 2, the control solution was stable with regard to uranium. In Round 3, the synthetic ground water control solution was stable with regard to molybdenum, selenium, and uranium.

4.5.6 Results

Sample locations are shown in Figure 4–7. Results of the R_d determinations are listed in Table 4–8. The data obtained from using solutions stable with regard to cadmium, molybdenum, selenium, and uranium are included in Table 4–8. In the table, R_d data show the range of values for each constituent and each stratigraphic unit. In addition, R_d values obtained from graphing the results of Round 1 determinations are provided. In the column labeled “Data from graphs,” each value derived from the graphs is the most linear of all the results with stable control solutions. The R_d values are compared to those measured at the Shiprock, New Mexico, UMTRA Project site.

Table 4–8. Results of R_d Determinations

Stratigraphic Unit	Analyte	R _d (mL/g) ^a				Data from graphs ^b		Comparison to Shiprock site ^c		
		Low	Mean	Median	High	R _d (mL/g)	Sample	Weathered	Unweathered	Floodplain
Durango Mill Tailings Area										
Mancos Shale	Cadmium	23.8	66.9	74.6	97.0	62.0	865–17 ft	214	132	
	Molybdenum	0.753	0.753	0.753	0.753					
	Selenium	15.5	23.1	23.6	26.0	24.3	865–17 ft	68	47	
	Uranium	3.90	3.90	3.90	3.90			1.13	1.97	
Quaternary alluvium	Cadmium	17.0	130	121	418	42	866–21 ft			23
	Molybdenum	0.190	1.90	1.28	6.21					
	Selenium	6.29	35.9	42.5	96.9	52.2	930–AL			11
	Uranium	0.685	4.21	2.89	10.0					2.15
Durango Raffinate Ponds Area										
Menefee Formation	Cadmium	8.36	82.8	64.7	292	8.86	875–64 ft			
	Molybdenum	-0.30	2.08	0.45	19.5					
	Selenium	2.98	35.9	23.4	104	22.8	903–53 ft			
	Uranium	0.30	1.44	1.14	5.20					
Point Lookout Sandstone	Cadmium	9.50	36.5	16.5	148	12	875–68 ft			
	Molybdenum	-0.34	0.07	0.15	0.39					
	Selenium	4.31	8.45	9.79	11.25					
	Uranium	0.00	1.59	1.88	2.35					

^aThe listed R_d values, in milliliters per gram (mL/g), have been adjusted for grain size, where appropriate.

^bThe R_d value is obtained from the most linear six-point isotherm stable control solution with regard to the constituent of interest.

^cDOE 1999a

4.5.6.1 Mill Tailings Area: Mancos Shale Results

The cadmium R_d results range from 23.8 to 97.0 mL/g. The result of the six-point isotherm is 62.0 mL/g, which is near the mean R_d of 66.9 mL/g. The R_d values are less than those measured in Mancos Shale at the Shiprock, New Mexico, UMTRA site.

The R_d result from a control solution stable with regard to molybdenum is 0.753 mL/g. R_d values for molybdenum were not measured at the Shiprock site.

R_d values for selenium range from 15.5 to 26.0 mL/g. The result of the six-point isotherm is 24.3 mL/g, which is near the mean and median values of 23.1 and 23.6 mL/g, respectively. This highest R_d value of 26.0 mL/g is less than all values for the Shiprock site.

The R_d value from a control solution stable with regard to uranium is 3.90 mL/g. This value is higher than those at the Shiprock site, which were 1.13 mL/g in the weathered Mancos Shale and 1.97 mL/g in the unweathered Mancos Shale.

4.5.6.2 Mill Tailings Area: Quaternary Alluvium

R_d values for cadmium range from 17.0 to 418 mL/g. The result of the six-point isotherm is 42.0 mL/g, which is less than the mean and median values of 130 and 121 mL/g, respectively. The R_d value for cadmium in floodplain alluvium at the Shiprock site is 23 mL/g.

The R_d results for molybdenum range from 0.190 to 6.21 mL/g. Determination of R_d values for molybdenum was not performed at the Shiprock site.

R_d values for selenium range from 6.29 to 96.9 mL/g. The R_d result obtained from the six-point isotherm is 52.2 mL/g, which is greater than the mean R_d value of 35.9 mL/g and the median R_d value of 42.5 mL/g. The R_d value for selenium in floodplain alluvium at the Shiprock site is 11 mL/g.

The R_d results for uranium range from 0.685 to 10.0 mL/g. The mean R_d value is 4.21 mL/g and the median R_d value is 2.89 mL/g. In comparison, R_d values obtained for the Quaternary alluvium at other UMTRA Project sites range from 0.5 to 11.4 mL/g (Table 4–9). The R_d value of 11.4 mL/g was an alluvium sample collected from a depth of 30 ft at Gunnison, Colorado, UMTRA Project site that was leached with actual ground water. The R_d value from the Grand Junction, Colorado, site is 2.15 mL/g, at the New Rifle, Colorado, site the value is 0.7 mL/g, and at the Old Rifle site the R_d value is 0.5 mL/g.

4.5.6.3 Raffinate Ponds Area: Menefee Formation

The cadmium R_d results range from 8.36 to 292 mL/g. The mean R_d value is 82.8 mL/g, and the median R_d value is 64.7 mL/g. The result of the six-point isotherm is 8.86 mL/g, which is near the lowest R_d value. R_d values for molybdenum range from -0.30 to 19.5 mL/g. The mean R_d value is 2.08 mL/g, and the median R_d value is 0.45 mL/g. The R_d values for selenium range from 2.98 to 104 mL/g. The R_d result obtained from the six-point isotherm is 22.8 mL/g; this value is near the median R_d value of 23.4 mL/g. R_d values for uranium range from 0.30 to 5.20 mL/g. The mean R_d value is 1.44 mL/g, and the median R_d value is 1.14 mL/g.

4.5.6.4 Raffinate Ponds Area: Point Lookout Sandstone

The R_d values for cadmium range from 9.50 to 148 mL/g. The R_d result obtained from the six-point isotherm is 12 mL/g and is less than the median value of 16.5 mL/g and the mean value of 36.5 mL/g. R_d values for molybdenum range from -0.34 to 0.39 mL/g. The mean R_d value is 0.07 mL/g, and the median R_d value is 0.15 mL/g. R_d values for selenium range from 4.31 mL/g to 11.2 mL/g. The mean R_d value is 8.45 mL/g, and the median value is 9.79 mL/g. The R_d values of uranium range from 0.00 to 2.35 mL/g. The mean R_d value is 1.59 mL/g, and the median R_d value is 1.88 mL/g.

Table 4-9. Quaternary Alluvium Uranium R_d Values from Other UMTRA Project Sites

Site	Sample ^a	R_d (mL/g)	Report
Durango Mill Tailings Area		< 10	DOE 2001b
Grand Junction, Colorado		2.15	DOE 1999e
Gunnison, Colorado	AGW-30 ft ^b	11.4	DOE 2000a
Gunnison, Colorado	AGW-54 ft	4.73	DOE 2000a
Old Rifle, Colorado		0.5	DOE 1999d
New Rifle, Colorado		0.7	DOE 1999c
Shiprock, New Mexico		2.15	DOE 1999a

^aA sample name is provided when there are R_d values for more than one sample. The value for the Durango Mill Tailings Area is a summary of all values.

^bAGW is actual ground water and the sample collection depth is listed.

4.6 Water Sampling and Analysis

Each newly completed monitor well was left undisturbed for at least 48 hours before it was developed. Development was performed according to the *Drilling Statement of Work* (DOE 2000c). After the wells were properly developed, monitor wells and surface water locations were sampled during four separate events. Samples were collected during November/December 2000, March/April 2001, June 2001, and August 2001 to represent the range of conditions from periods of low to high river flow. Additional sampling of background monitor wells and surface water locations was performed during the first week of May 2001 and the last week of June 2001. All samples collected during these sampling events were submitted to the GJO Analytical Laboratory for analyses. The following sections describe the sampling and analysis procedures and results.

4.6.1 Water Sampling Procedures and Quality Assurance

Ground water and surface water sampling was performed in accordance with the *Sampling and Analysis Plan for the UMTRA Ground Water Project* (DOE 1999f) and procedures in the *Grand Junction Office Environmental Procedures Catalog* (DOE 1998). The following procedures were used:

- GN-8(P), "Standard Practice for Sample Labeling"
- GN-9(P), "Standard Practice for Chain-of-Sample-Custody and Physical Security of Samples"
- GN-13(P), "Standard Practice for Equipment Decontamination"
- LQ-2(T), "Standard Test Method for the Measurement of Water Levels in Ground Water Monitor Wells"
- LQ-3(P), "Standard Practice for Purging Monitor Wells"
- LQ-4(T), "Standard Test Method for the Field Measurement of pH"
- LQ-5(T), "Standard Test Method for the Field Measurement of Specific Conductance"
- LQ-6(T), "Standard Test Method for the Field Measurement of the Oxidation-Reduction Potential (Eh)"
- LQ-7(T), "Standard Test Method for the Field Measurement of Alkalinity"
- LQ-8(T), "Standard Test Method for the Field Measurement of Temperature"
- LQ-9(T), "Standard Test Method for the Field Measurement of Dissolved Oxygen"

- LQ-10(T), “Standard Test Method for Turbidity in Water”
- LQ-11(P), “Standard Practice for Sampling Liquids”
- LQ-12(P), “Standard Practice for the Collection, Filtration, and Preservation of Liquid Samples”

Sample preservation consisted of storing the samples in an ice chest with ice to cool samples during field sampling, packaging, and shipping. Ground water and surface water samples were submitted to the GJO Analytical Laboratory. At least 10 percent of the samples collected and analyzed were field quality-control samples, which included equipment rinsate blanks and duplicates. These samples were submitted for the same analyses as other field samples.

Analyses of water samples submitted to the GJO Analytical Laboratory also were checked for accuracy through internal laboratory quality-control checks, such as blind duplicates, splits, and known standards as specified in relevant EPA guidelines or the *Handbook of Analytical and Sample Preparation Procedures*, Volumes I, II, and III (WASTREN, Inc., undated).

Final analytical results were entered into the SEE_PRO database, and an independent data validation assessment was performed on all results from each sampling event. Results of the ground water and surface water analyses are presented in Appendices D and E, respectively.

4.6.2 Ground Water Quality at the Mill Tailings Area

At the mill tailings area, samples were collected from the four alluvial background monitor wells 0629, 0658, 0857, and 0866 (Figure 4–11). Background location 0658 is an off-site privately owned domestic well. On-site samples were collected from ten locations: 0612, 0617, 0622, 0630, 0631, 0633, 0634, 0635, 0859, and 0863. Monitor well 0632 is completed in the Mancos Shale and is not sampled because it is dry. Surface water sampling results for the mill tailings area are presented in Section 4.6.4.

4.6.2.1 Background

Constituent concentrations in the new background wells (0857 and 0866) are within the range of concentrations from background wells 0629 and 0658 and support the 1995 BLRA assessment that two distinctly different water types and sources contribute to the ground water in the colluvium and gravel material at the mill tailings area. Selenium is the exception; selenium concentrations above the MCL (0.01 mg/L) have been detected in samples from the recently installed background wells; a maximum concentration of 0.011 mg/L was detected in well 0857, and a maximum concentration of 0.0148 mg/L was detected in well 0866.

It is expected that elevated selenium concentrations could occur naturally in wells not associated with the former uranium processing activities. Selenium is commonly found in high natural concentrations in the western United States. Most occurrences are related to Cretaceous sedimentary deposits (Seiler 1998), although elevated selenium levels are found in rocks from the Pennsylvanian to Quaternary in age (Stephens and others 1992). The river-laid sand and gravel deposits that compose both the mill tailings alluvium and the alluvium in the background locations occur over Mancos Shale bedrock. Concentrations, distribution, and sources of selenium in west-central Colorado have been studied extensively by the U.S. Geological Survey (USGS). The USGS found the highest concentrations of naturally occurring selenium (1.3 mg/L) were in shallow wells completed in alluvium overlying Mancos Shale (Wright and Butler 1993).



Figure 4-11. Mill Tailings Area Wells and Boreholes

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The key factors controlling mobilization of dissolved selenium are redox potential (measured as ORP) and pH (Masscheleyn and others 1990). At background well 0857 one selenium result (0.011 mg/L) exceeded the UMTRA standard of 0.01 mg/L. Because the pH did not change significantly, an increase in naturally occurring selenium in ground water would require an increase in the ORP. The elevated selenium concentration at this location occurred during the same period when the highest historical ORP and highest water levels were reported. The correlation between selenium concentrations, ORP, and water levels (Figure 4-12) demonstrates how naturally occurring selenium can be mobilized by oxidized water during periods of high flow. As the water table lowers, geochemical conditions become more reducing (by the action of naturally occurring microorganisms), which tends to remove selenium from solution in the ground water system (Butler and others 1994). Six samples have been collected from background well 0866 since November 2000, and selenium results from all of these samples (ranging from 0.0138 to 0.0148 mg/L) have exceeded the MCL. Selenium values and water levels in well 0866 do not show significant variation, and the ORP values are positive, reflecting oxidizing conditions.

4.6.2.2 Site-Related Contamination

Figure 4-13 through Figure 4-16 are spot plots of on-site and background alluvial wells showing concentrations of contaminants that exceed the MCL. These data are based on the sampling conducted in August 2001.

The primary sources of ground water contamination in the mill tailings area were the large and small tailings piles (Figure 4-17). Following completion of surface remediation, concentrations of arsenic, cadmium, lead, molybdenum, net alpha, radium-226+228, selenium, and uranium continued to exceed the MCL in on-site ground water. Results of ground water samples collected since November 2000 (four sampling events) show that arsenic, lead, and radium-226+228 are no longer detected in concentrations above the MCL, and net alpha has been detected only sporadically in a few wells. Locations where constituent levels still exceed the MCLs based on data from the August 2001 sampling event are presented in Table 4-10. As shown, concentrations of cadmium and molybdenum remain elevated in only one location (well 0612), and concentrations of selenium and uranium continue to exceed the standards in several locations.

In addition to the above constituents, antimony, manganese, sodium, sulfate, and vanadium were identified as COPCs in the BLRA (DOE 1995a). Since November 2000:

- All antimony results have been below the detection limit.
- With the exception of results from monitor wells 0612, 0630 and 0859, manganese results have been less than the maximum background ground water concentration of 1.05 mg/L. The highest concentration at well 0612 was 5.4 mg/L. The highest concentration at well 0630 was 2.68 mg/L. The highest concentration at well 0859 was 1.5 mg/L; however, the most recent value at well 0859 of 0.803 mg/L is below the background maximum of 1.05 mg/L.
- The highest concentration of sodium (765 mg/L) occurred in monitor well 0612.
- The highest concentration of sulfate (3,510 mg/L in August 2001) occurred in monitor well 0633. Monitor well 0633 is completed in the Mancos Shale, which commonly has ground water with elevated levels of sulfate.
- With the exception of one result of 0.0109 mg/L from well 0631, the only concentrations of vanadium above the detection limit occur in monitor wells 0612 and 0630; the highest (0.448 mg/L) is in well 0612.

Table 4–10. Ground Water Constituents with Concentrations that exceed the UMTRA Standards in August 2001 at the Durango Mill Tailings Area

Analyte	UMTRA Standard (mg/L)	Location (well)	Concentration in August 2001 (mg/L)
Cadmium	0.01	0612	0.0369
Molybdenum	0.1	0612	0.1160
Selenium	0.01	0617	0.0501
Selenium	0.01	0633	0.0445
Selenium	0.01	0635	0.0155
Selenium	0.01	0866 Background	0.0148
Uranium	0.044	0612	1.970
Uranium	0.044	0617	0.211
Uranium	0.044	0630	0.203
Uranium	0.044	0631	0.344
Uranium	0.044	0633	1.270
Uranium	0.044	0634	0.0585

Historically, monitor well 0612 has consistently shown the highest levels of contamination. This well is completed through the slag pile from the old lead smelter that remained in place following surface remediation. The slag in this area is 20 to 30 ft thick, and the occurrence of cadmium, molybdenum, and uranium (Table 4–10) in this well is believed to be associated with the alluvial material below the slag that remained in place following surface remediation. The Final Completion Report for the surface remediation project (DOE 1994b, Appendix K) documented that a thin lens of uranium precipitate identified below the slag was thought to be a result of an old spill on the slag pile that was slowly leaching through the slag. The material under the slag was sampled along the riverbank during surface remediation, and the volume-averaged concentrations were below NRC's unrestricted disposal guidelines (DOE 1994b, Appendix K). However, due to difficulties with excavating and drilling in the slag, the extent of potentially contaminated material beneath the slag was not fully characterized. Figure 4–18 shows the location of well 0612 and the slag pile as it was exposed during surface remediation.

Although some of the selenium concentrations at the mill tailings area may be a result of former processing activities, elevated concentrations can also be attributed to naturally occurring selenium, as evidenced by the concentrations above the MCL in background wells (Section 4.6.2.1).

4.6.3 Ground Water Quality at the Raffinate Ponds Area

At the raffinate ponds area, samples were collected from background bedrock well locations 0592, 0599, 0875, 0886, and 0903 (Figure 4–19). Eighteen on-site wells and seven off-site downgradient wells were sampled. Monitor wells 0891, 0893, and 0905 were not routinely sampled because these wells are either dry or purge dry and do not recover. Surface water sampling results for the raffinate ponds area is presented in Section 4.6.4.

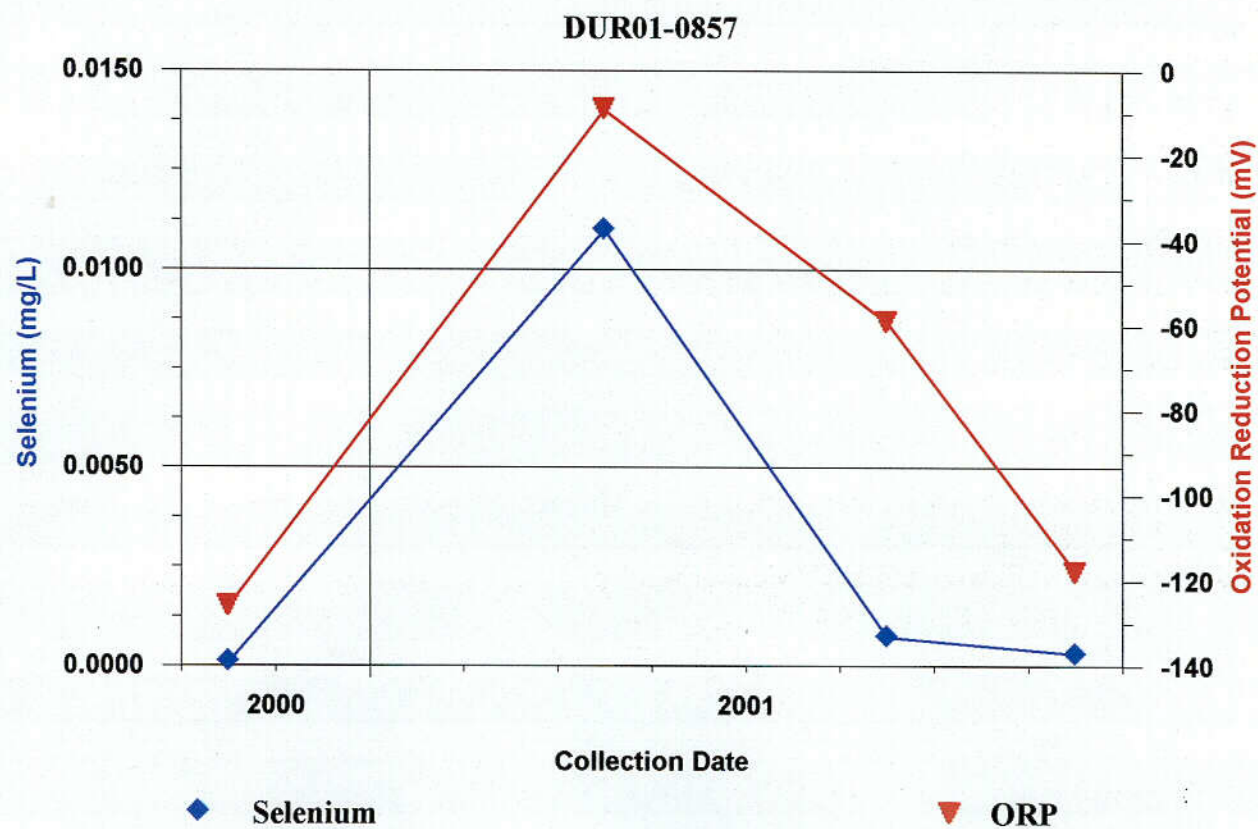


Figure 4-12. Selenium, ORP, and Water Levels at Durango Mill Tailings Area Background Well 857

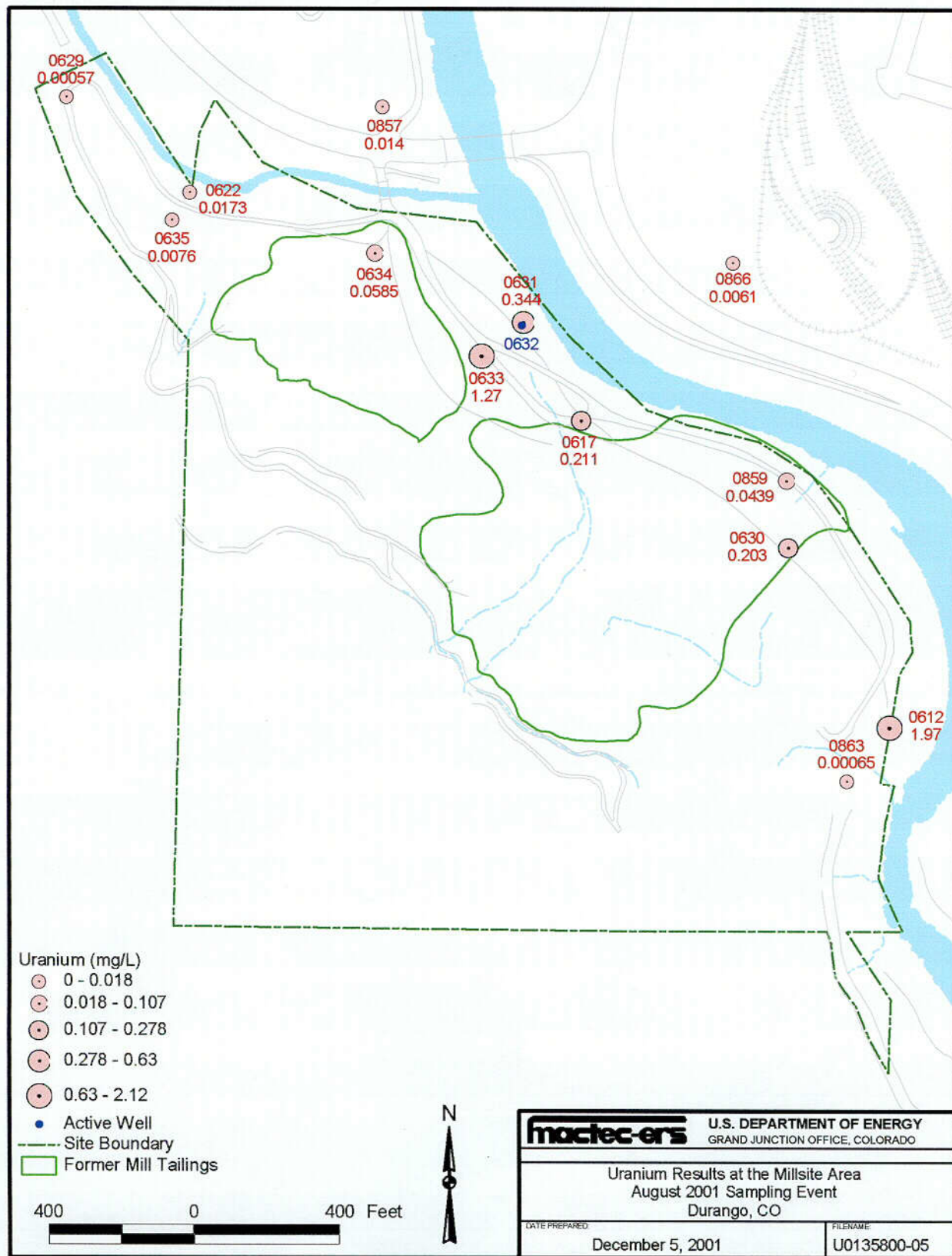


Figure 4-13. Uranium Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

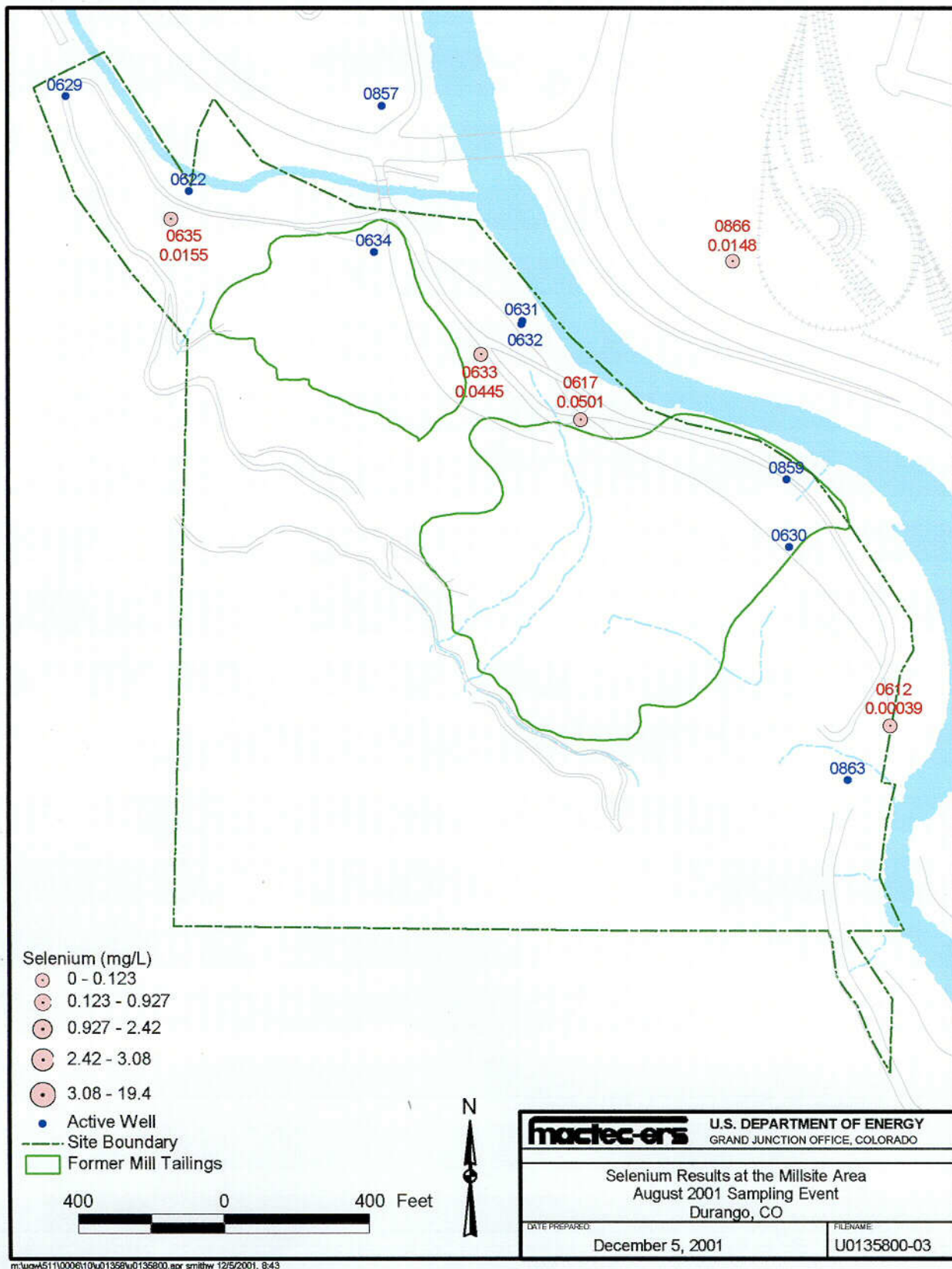


Figure 4-14. Selenium Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

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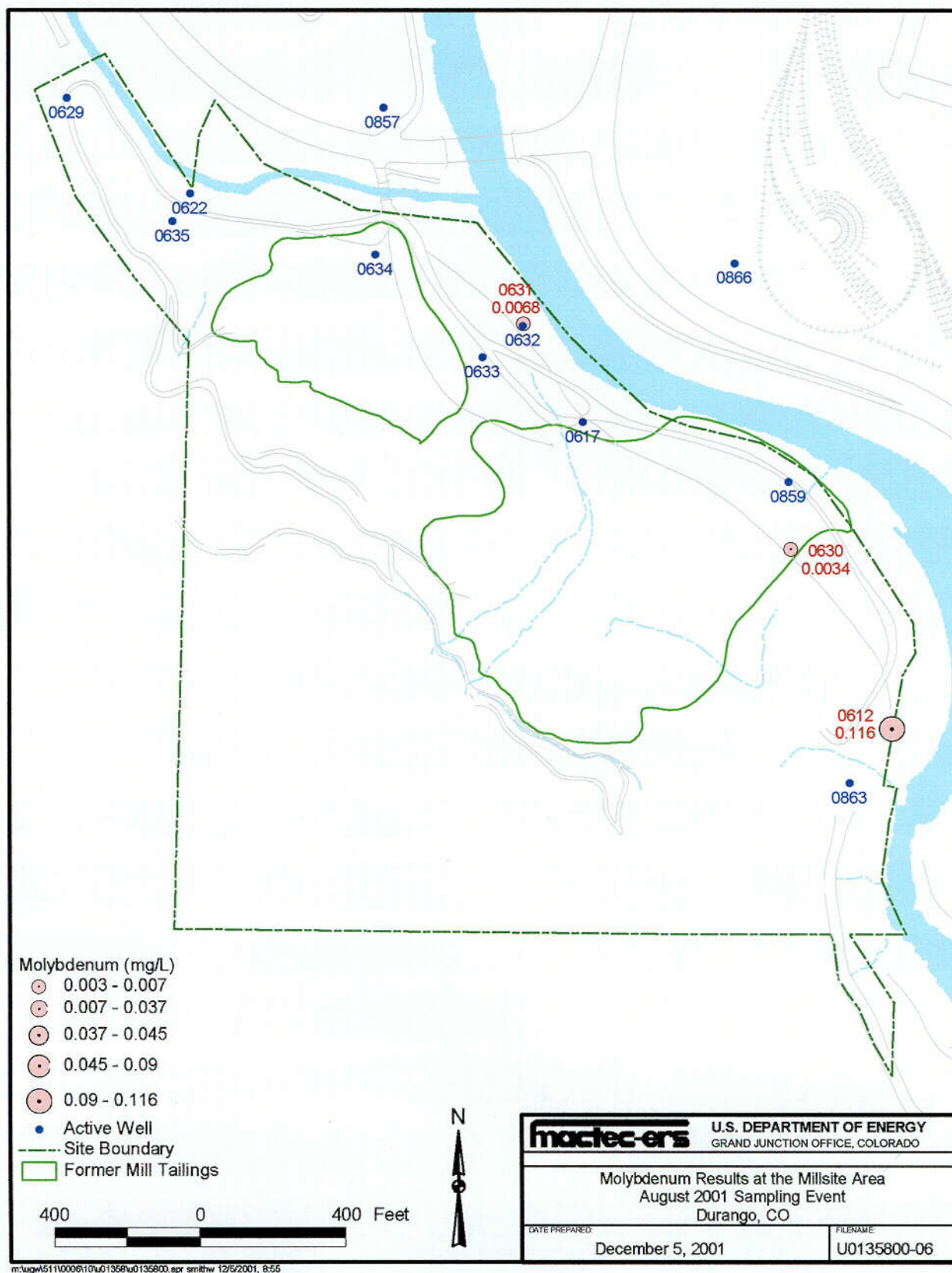


Figure 4-15. Molybdenum Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

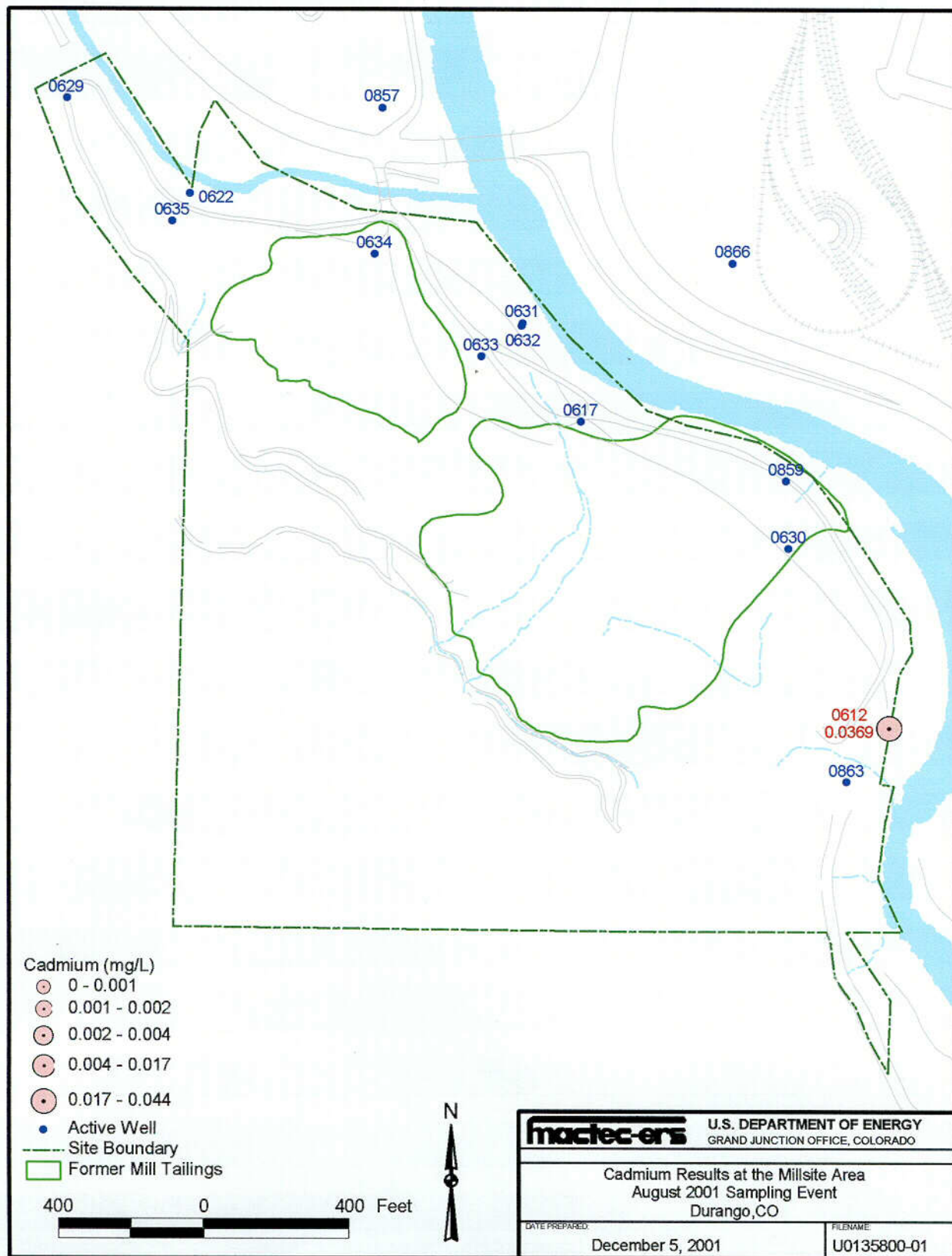


Figure 4-16. Cadmium Concentrations in Alluvial Ground Water at the Mill Tailings Area, August 2001

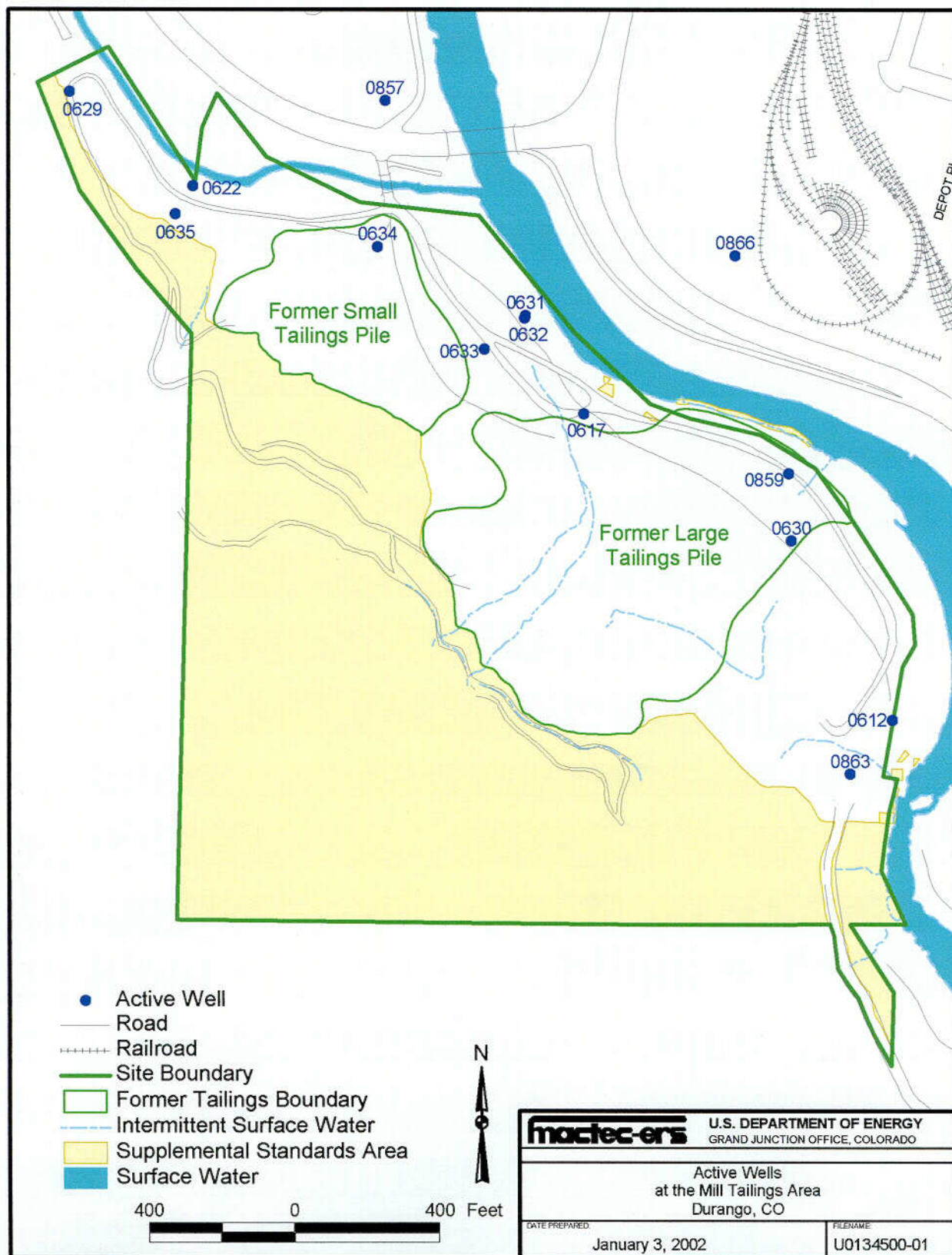


Figure 4-17. Active Wells at the Mill Tailings Area

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Figure 4-18. Occurrence of Lead Smelter Slag and Well 0612 Location at the Mill Tailings Area

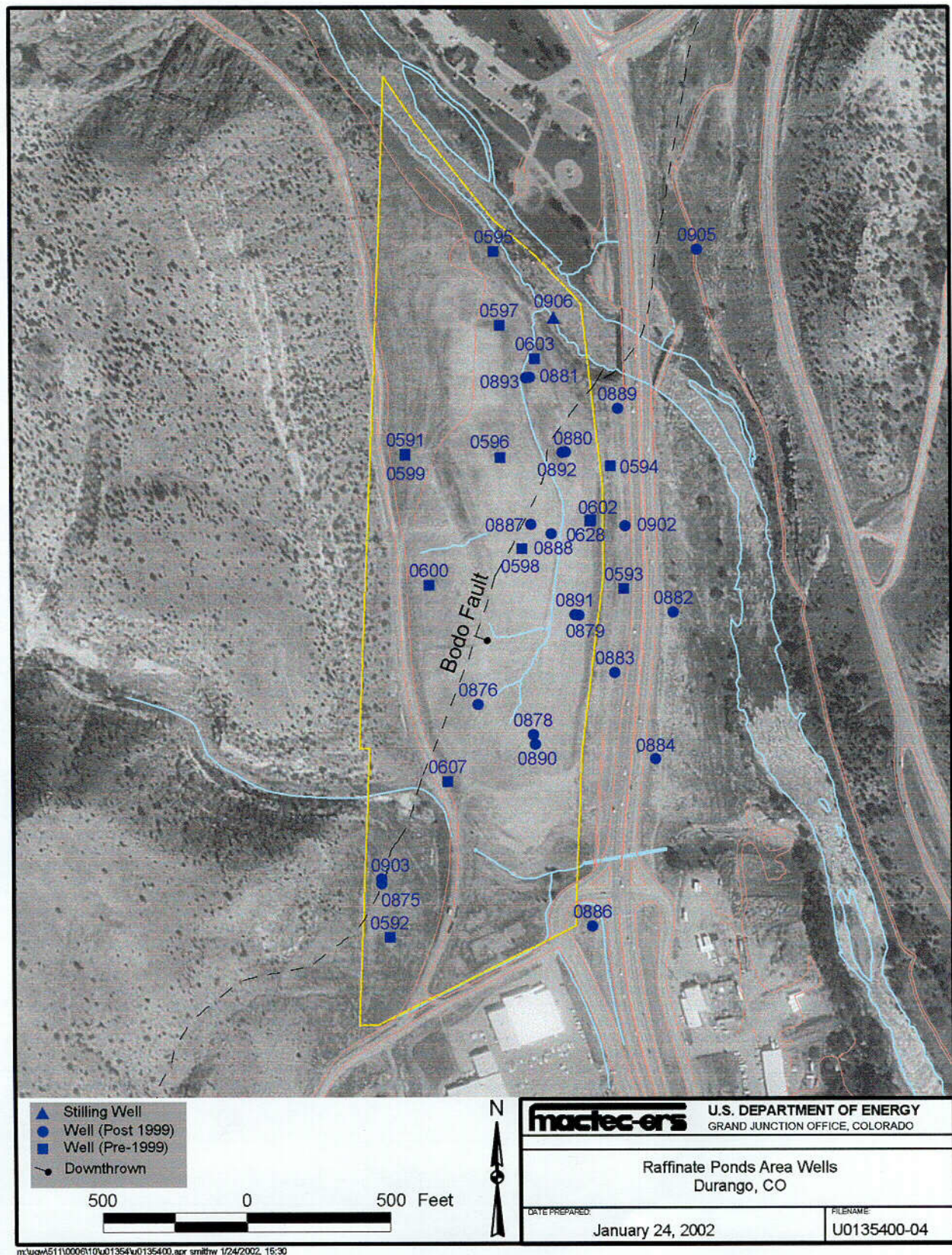


Figure 4-19. Raffinate Ponds Area Wells

4.6.3.1 Background

Prior to the field investigation, background water quality data for the raffinate ponds area was available from monitor well (0592) in the far southwest corner of the site and upgradient of the raffinate ponds area, and monitor well 0599 west of the former raffinate ponds (Figure 4-20). This well is screened across the Menefee Formation, Point Lookout Sandstone, and the Bodo Fault zone. A comparison of the water quality from this well to regional water quality in the Mesaverde Group indicates that ground water from well 0592 is within the range of regional ground water quality for all measured constituents (DOE 1995a). However, because the water from this well has a strong hydrogen sulfide odor and black discoloration, additional samples for sulfide were collected in November 2001.

Three additional wells were installed for determining background water quality as part of the field investigation and have been routinely sampled since November 2000. All of these wells are in areas unaffected by surface remediation and the former processing facility. Two of these monitor wells are near monitor well 0592 in the far southwest corner of the site. Well 0903 is completed in the Menefee Formation, and well 0875 is completed in the Point Lookout Sandstone. Well 0886 is completed in the Cliff House Sandstone outside the southeast corner of the site. A comparison of background water quality at these locations is presented in Section 5.3.1.

Background monitor well 0599 is completed in the Point Lookout Sandstone and, with the exception of selenium, the concentrations of constituents in well 0599 are comparable to concentrations in the other background well (0875) completed in the Point Lookout Sandstone. Selenium concentrations in background well 0599 ranged from 0.062 to 0.087 mg/L; all other constituents associated with the milling operations (arsenic, molybdenum, uranium, and vanadium) have had concentrations below the MCL at this location.

Selenium

Not unlike the mill tailings area, elevated selenium concentrations in background locations at the raffinate ponds area are not unexpected. Selenium concentrates in the pyrite-rich marine shales and sedimentary rocks of Late Cretaceous age (USGS 1999), which underlie the raffinate ponds area. In addition to the carbonaceous shales, numerous coal deposits are within the vicinity of the raffinate ponds area (Plate 3). Selenium concentrations in various coals are 10 to 20 times higher than the levels estimated for the earth's crust (Oldfield 1974). EPA and others reported selenium concentrations in coals of the United States in concentrations ranging from 0.4 to 10.65 mg/kg with an average concentration of 3.3 mg/kg (Oldfield 1974). Elevated selenium concentrations are not detected in background monitor wells locations, other than well 0599 at the raffinate ponds area. However, the ORP values are negative at the other background locations, indicating strongly reducing conditions. Therefore, even though selenium may be present in source rock, the geochemical conditions prevent it from being mobilized into the ground water in significant quantities at other background locations. Selenium at the raffinate ponds area is discussed in further detail in Section 5.4.

Sulfide

During the purging and sampling of wells, the field team noted the water had a black discoloration and an odor indicating the presence of hydrogen sulfide gas, most notably in background well 0592. Hydrogen sulfide gas is produced by the oxidation of organic matter through sulfide reduction. Sulfide sampling of selected wells was conducted in November 2001.

Samples were collected for analysis at the GJO Analytical Laboratory, and duplicate samples were analyzed on site.

Analyses of samples on site were performed using a colorimetric method (approved by EPA for waste water). Duplicate samples were analyzed in the field to achieve a lower detection limit (see Section 5.3.1.6). The detection limit for the Analytical Laboratory method is 1.0 mg/L, and the detection limit for the colorimetric field method is 0.01 mg/L. The lower detection limit was necessary because the risk-based default value for hydrogen sulfide as a contaminant in drinking water is 0.11 mg/L.

The concentration of sulfide in background well 0592 was 45.9 mg/L. Sulfide was also detected in background wells 0599 (0.02 mg/L), 0875 (0.1 mg/L), and 0886 (0.5 mg/L). Sulfide was not detected in well 0884. Although this was a limited sample set of data from background wells, the strong odor and black discoloration occur at many locations on site. It was also reported in the original BLRA (DOE 1995a) that when an attempt was made to collect a sample from the downgradient well nearest the site (0.2 mile), it was found to no longer be in use because of black discoloration of the water. The *Preliminary Hydrogeochemical Characterization of the Durango, Colorado, Tailings and Raffinate Ponds Areas* (DOE 1983) also reported the strong presence of hydrogen sulfide during the drilling of well 0601.

4.6.3.2 Site-Related Contamination

Before surface remediation was completed, ground water in the area of the raffinate ponds occurred in both the surficial deposits and the bedrock. At present, ground water in the raffinate ponds area occurs primarily in the bedrock units. The primary sources of ground water contamination at the raffinate ponds area were the spent raffinate liquids from the milling process that were pumped into a ditch and carried to the settling ponds (Figure 4–20) at the raffinate ponds area. There, the raffinate was disposed of through evaporation and seepage.

Since completion of surface remediation, uranium and selenium are the only constituents with concentrations that have consistently exceeded the UMTRA Project standards at the raffinate ponds area. Net alpha has been detected sporadically in only a few wells. The highest concentrations of selenium and uranium are detected in the central portion of the site east of the Bodo Fault, in the shallow wells screened in the Menefee Formation. Outside this central plume area, selenium concentrations above the MCL are also detected in wells 0607 and 0884; and uranium concentrations above the MCL are also detected in wells 0598 and 0884. With the exception of well 0628 (see Section 4.1.2), locations where constituent concentrations exceed the UMTRA Project standards, based on data from the sampling in August 2001, are presented in Table 4–11.

Figure 4–21 and Figure 4–22 are spot plots of on-site and downgradient bedrock well locations showing concentrations of selenium and uranium based on the sampling conducted in August 2001. As shown, uranium above the MCL occurs at well 0598, which is completed in the Bodo Fault zone. However, uranium concentrations in adjacent wells 0887 and 0888 are below background concentrations. Monitor well 0887 is completed in the Point Lookout Sandstone and screened at the same depth as well 0598. Monitor well 0888 is completed in the Bodo Fault zone and screened approximately 40 ft below the screened depth of well 0598 in the Bodo Fault. At monitor well 0598 (Figure 4–23) the concentration of uranium has been steadily decreasing since remediation was completed in 1991 and is nearing the MCL of 0.044 mg/L. Figure 4–23 and Figure 4–24 are time-concentration plots of uranium results at the raffinate ponds area.

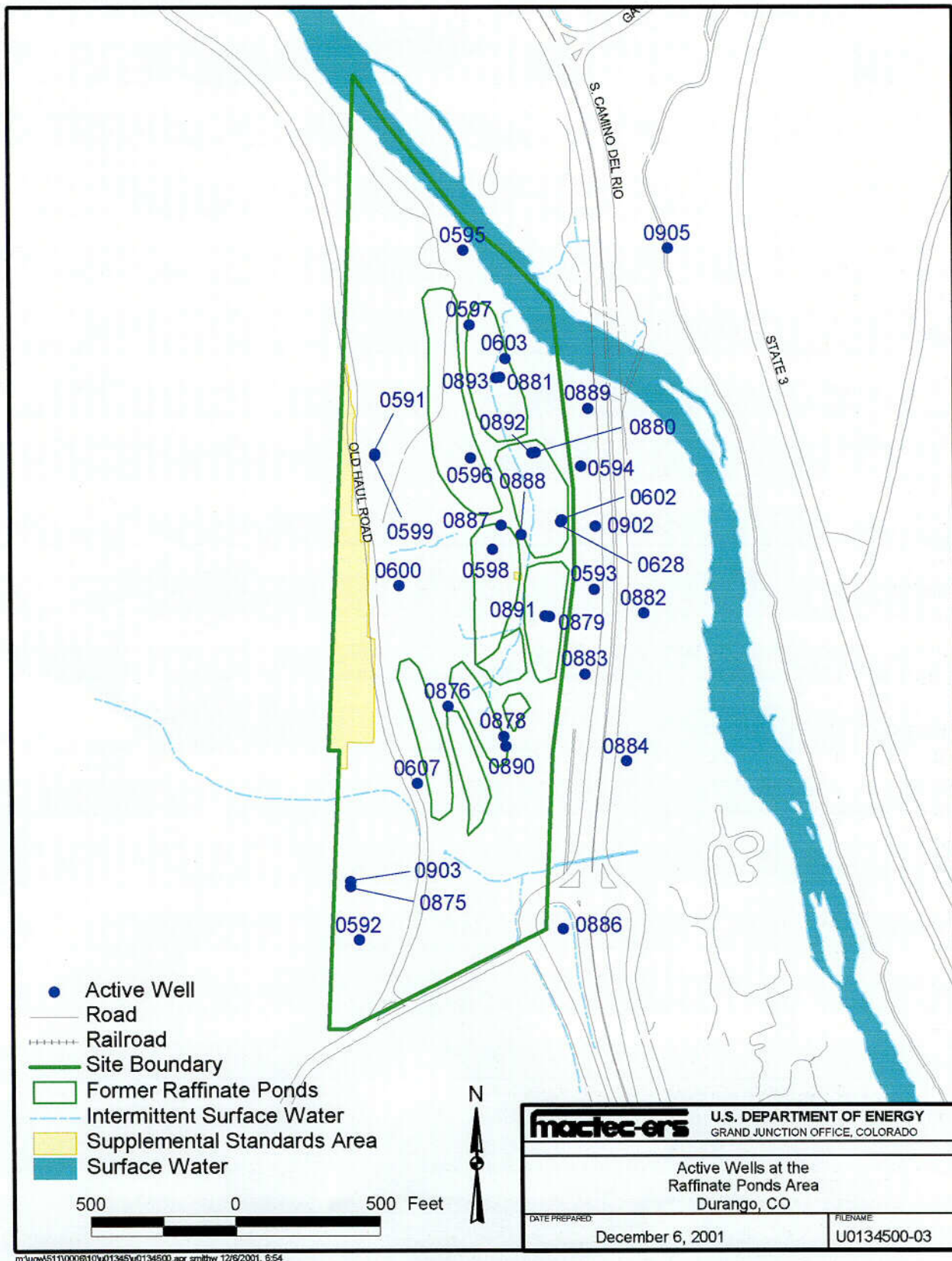


Figure 4-20. Active Wells at the Raffinate Ponds Area

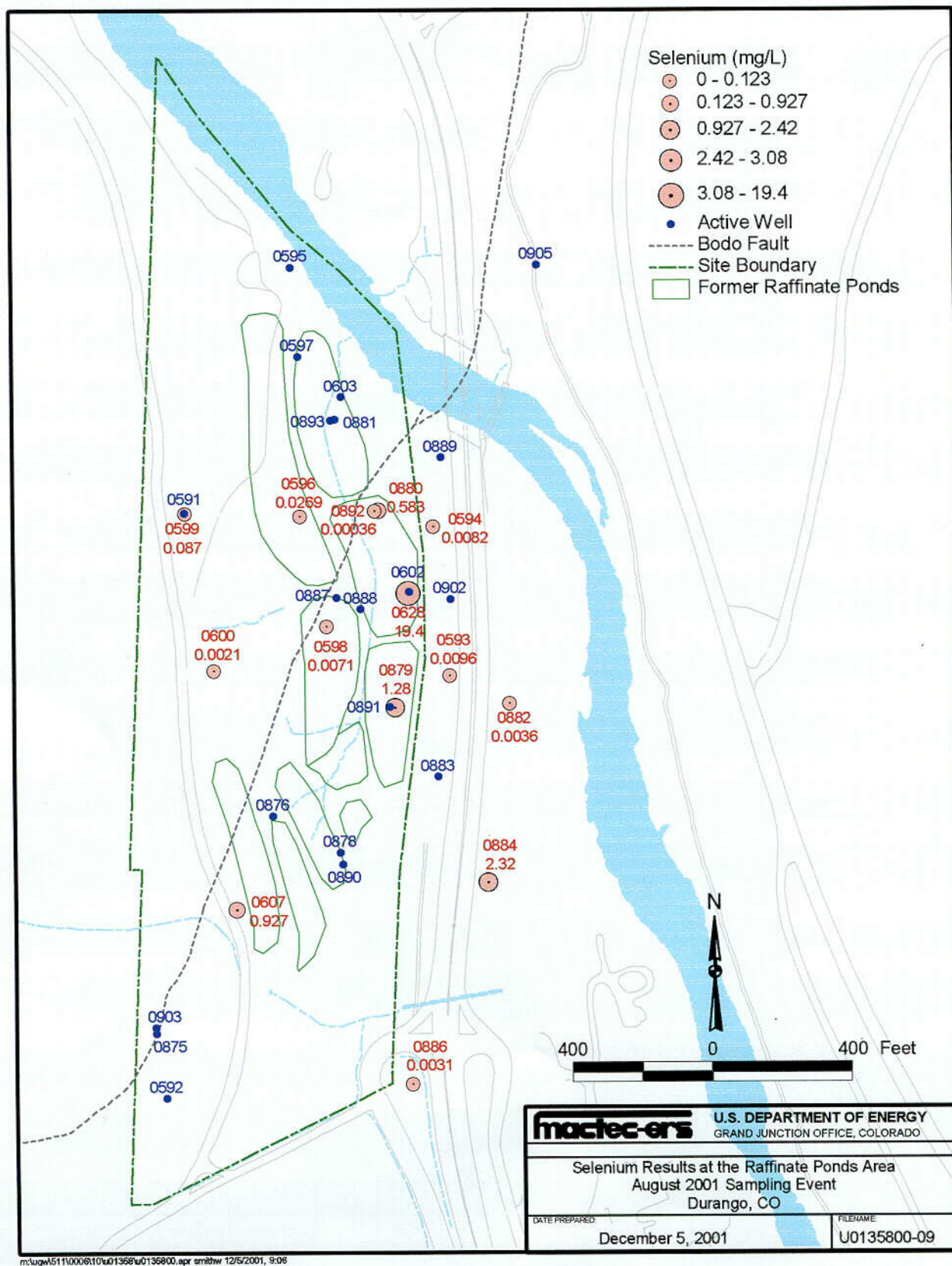


Figure 4-21. Selenium Concentrations in Ground Water at the Raffinate Ponds Area, August 2001

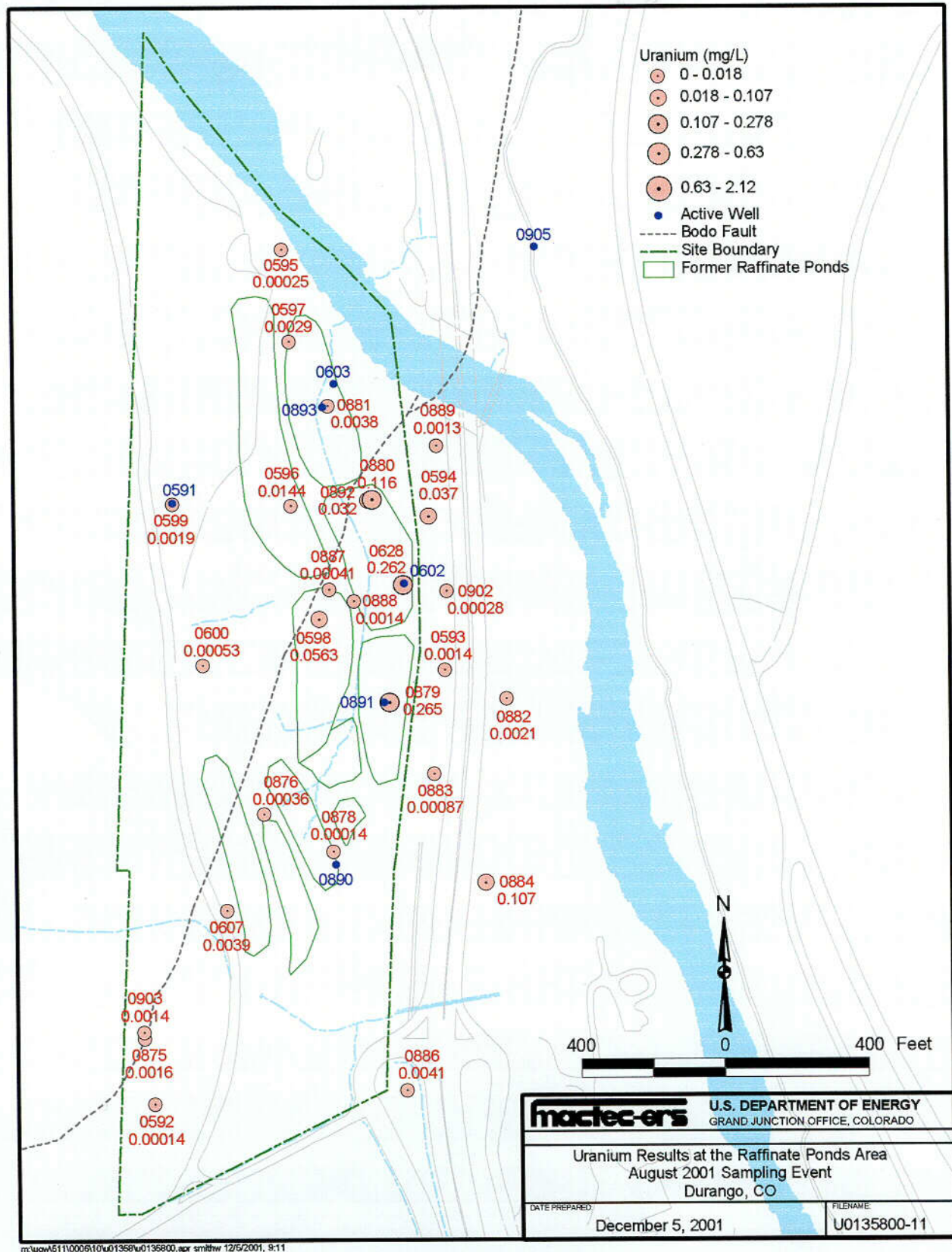


Figure 4-22. Uranium Concentrations in Ground Water at the Raffinate Ponds Area, August 2001

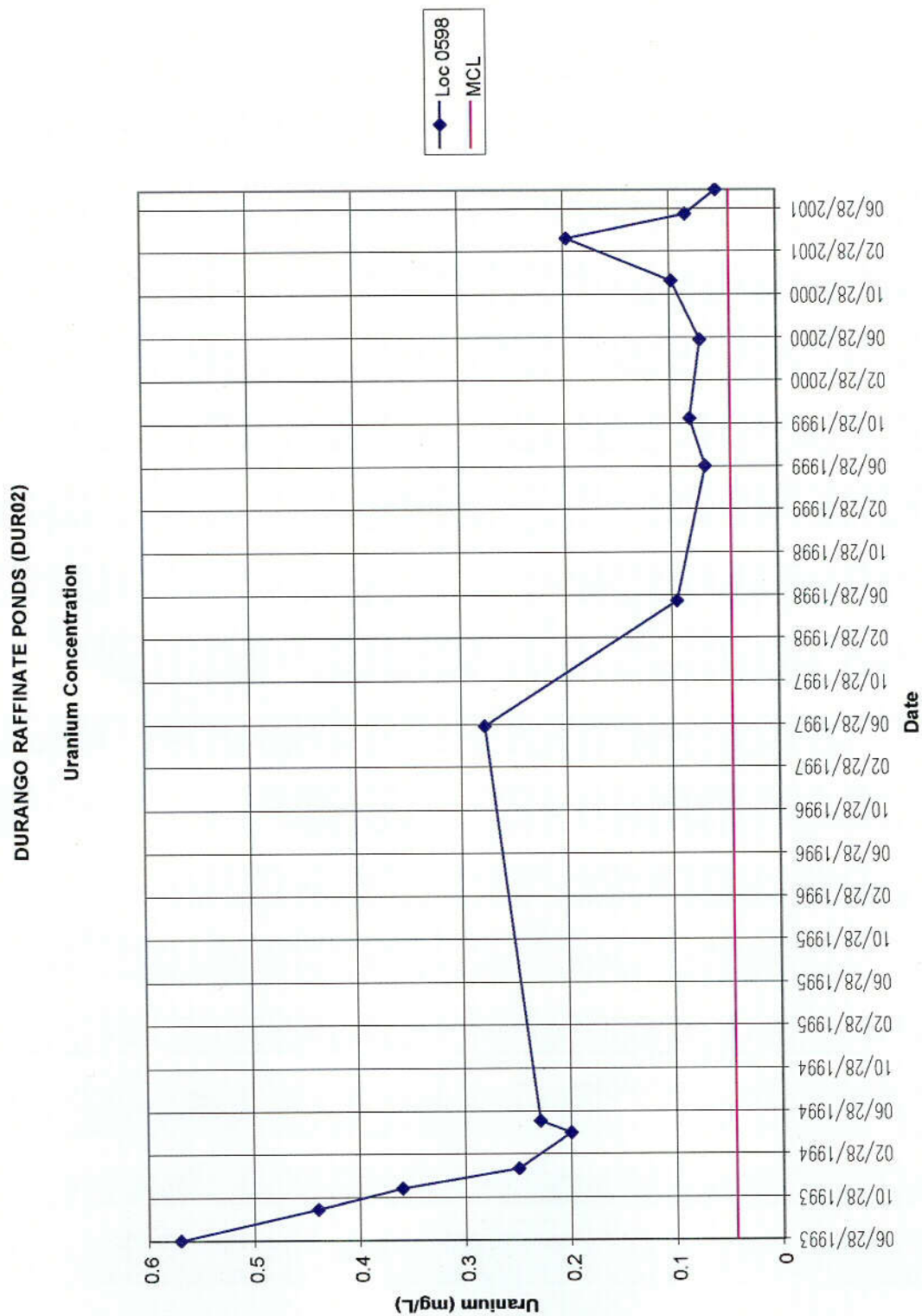


Figure 4-23. Uranium Concentration in Fault Well 598 at the Durango Raffinate Ponds Area

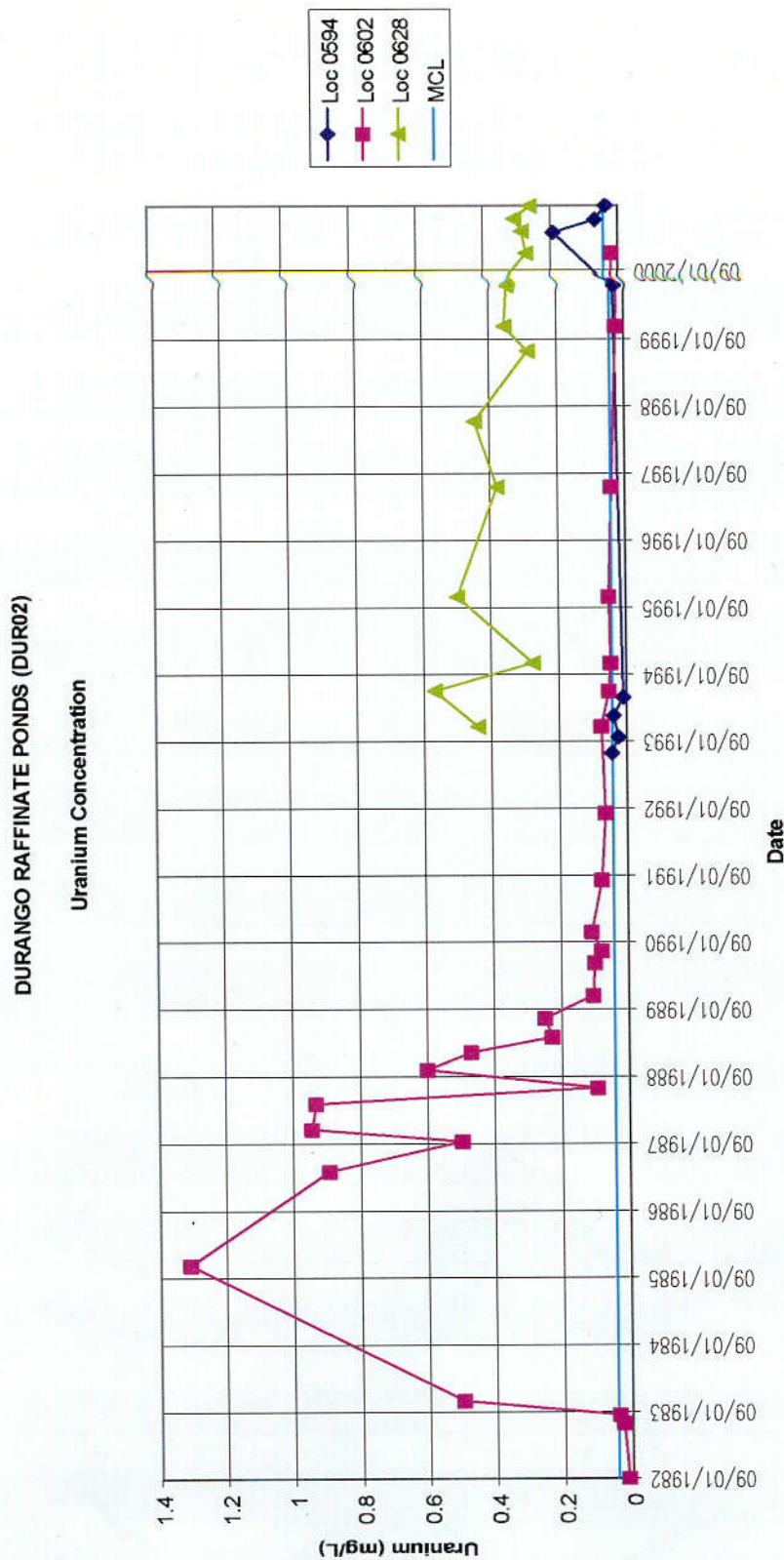


Figure 4-24. Uranium Concentration at the Durango Raffinate Ponds (DUR02)

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Table 4–11. Constituents with Concentrations That Exceeded the UMTRA Ground Water Standards in August 2001 at the Durango Raffinate Ponds Area

Analyte	UMTRA Standard (mg/L)	Location ^a (well)	Concentration in August 2001 (mg/L)
Selenium	0.01	0596	0.0269
Selenium	0.01	0598	0.010
Selenium	0.01	0599 ^b	0.087
Selenium	0.01	0607	0.927
Selenium	0.01	0879	1.280
Selenium	0.01	0880	0.583
Selenium	0.01	0884	2.320
Uranium	0.044	0598	0.0563
Uranium	0.044	0879	0.265
Uranium	0.044	0880	0.116
Uranium	0.044	0884	0.107

^a Monitor well 628 is not included because the results are not considered to be valid (see Section 4.1.2).

^b Monitor well 0599 is a background location.

With the exception of well 0598 in the Bodo Fault, all locations where uranium concentrations continue to exceed the MCL are completed at depths of 50 ft or less. Uranium above the MCL occurs in new monitor wells 0879, 0880, 0884, and in monitor well 0628. Immediately following remediation, uranium concentrations in monitor wells 0594 and 0602 consistently exceeded the MCL. However, results from the August 2001 sampling are below the MCL at both locations (0.037 mg/L and 0.0203 mg/L, respectively), as shown in Figure 4–24.

Concentrations of both selenium (2.32 mg/L) and uranium (0.107 mg/L) are above the MCLs at off-site well 0884, these elevated concentrations are isolated from the central on-site plume area. Monitor well 0884 is cross-gradient to downgradient from the former raffinate ponds (Figure 4–20), and between this well and the central plume area are monitor wells 0882, 0883, 0878, and 0890. Sample results have not shown any elevated concentrations of selenium or uranium in any of these in-between wells. Well 0884 is screened predominantly within a coal bed, and the fact that the well is isolated from the central on-site plume area suggests naturally occurring coal deposits may be a source of the elevated concentrations. In addition to selenium (see Section 5.4), various coal deposits have been well documented as containing high concentrations of uranium (IAEA 1974). No occurrences of other mill-related constituents (arsenic, cadmium, molybdenum, or vanadium) have concentrations exceeding MCLs at well 0884.

In addition to selenium and uranium, constituents identified as COPCs in the BLRA (DOE 1995a) included antimony, arsenic, cadmium, chloride, lead, manganese, molybdenum, sodium, sulfate, and thallium. Of these:

- Antimony concentrations have not exceeded the contract required detection limit (CRDL) at any location since 1995.
- Thallium concentrations have not exceeded the instrument detection limit (IDL) at any location since 1995.

- Arsenic, cadmium, lead, and molybdenum concentrations have not exceeded the MCLs at any location since 1995.
- Chloride concentrations have decreased (in wells that existed prior to 2000) from historical maximum concentrations. The highest chloride result from the sampling in August 2001 was 1,520 mg/L at well 0883.
- Manganese concentrations do not indicate any clear trends, either increasing or decreasing. The highest manganese result from the August 2001 sampling was 6.5 mg/L at well 0593.
- Sodium concentrations have decreased (in wells that existed prior to 2000) from historical maximum concentrations. The highest sodium result from the August 2001 sampling was 3,140 mg/L at well 0593.
- Sulfate concentrations have decreased (in wells that existed prior to 2000) from historical maximum concentrations. The most dramatic decrease in sulfate concentration has occurred at well 0602, where concentrations have decreased from a high of 17,000 mg/L (highest at the raffinate ponds area) in 1985 to a concentration of 4,570 mg/L during the sampling in August 2001.

4.6.4 Surface Water Quality

At the mill tailings area, surface water was sampled along Lightner Creek from two locations upgradient of the site (0506 and 0650) and from one location adjacent to the site (0651). The Animas River was sampled at two upgradient locations (0515 and 0652), at four locations adjacent to the site (0583, 0584, 0690 and 0691), and at one downgradient location (0586). Surface water sample locations are shown in Figure 4–25.

Manganese is the only constituent identified as a COPC for the mill tailings area in the BLRA (DOE 1995a) that was detected in concentrations statistically elevated above background concentrations (95 percent upper confidence limit [UCL_{95}]). Manganese concentrations exceeded the UCL_{95} sporadically during two sampling events; the maximum concentration was 0.158 mg/L at location 0583 during low-flow (November 2000). No manganese concentrations were greater than the maximum observed background value of 0.205 mg/L.

At the raffinate ponds area, surface water was sampled along South Creek, from one location upgradient of the site (0588). The Animas River was sampled at two locations adjacent to the site (0656 and 0657), and at one downgradient location (0654). Because of the proximity of the mill tailings area to the raffinate ponds area, the Animas River sample locations 0515 and 0652 were used to establish background for both sites. Raffinate ponds area surface water sample locations are shown in Figure 4–26.

Manganese was the only COPC identified for the raffinate ponds area that was detected in concentrations statistically elevated above background concentrations (UCL_{95}). Manganese concentrations exceeded the UCL_{95} sporadically during three sampling events; the maximum concentration was 0.139 mg/L at location 0657 during low-flow (November 2000). No manganese concentrations were greater than the maximum observed background value of 0.205 mg/L.

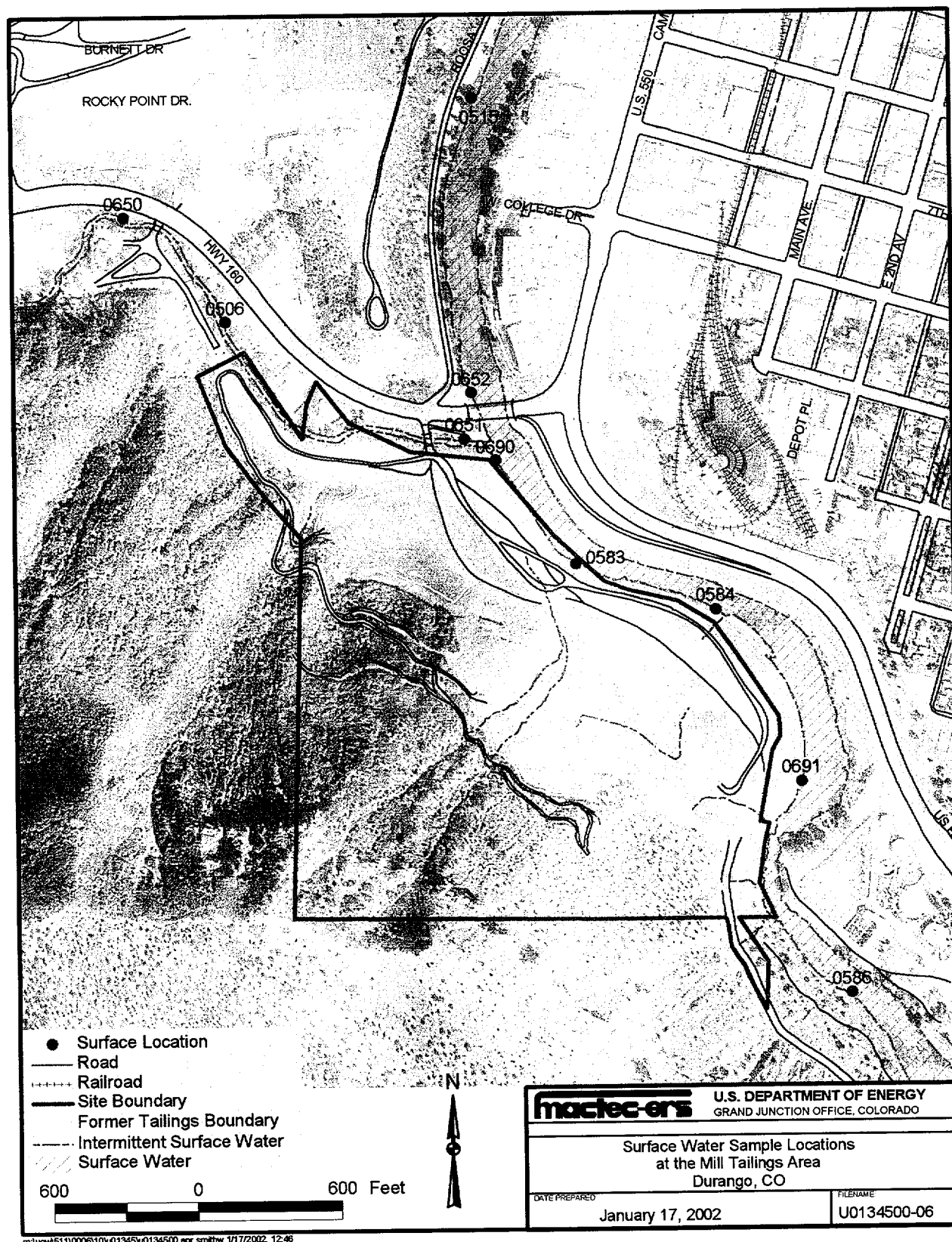


Figure 4-25. Surface Sample Locations at the Mill Tailings Area

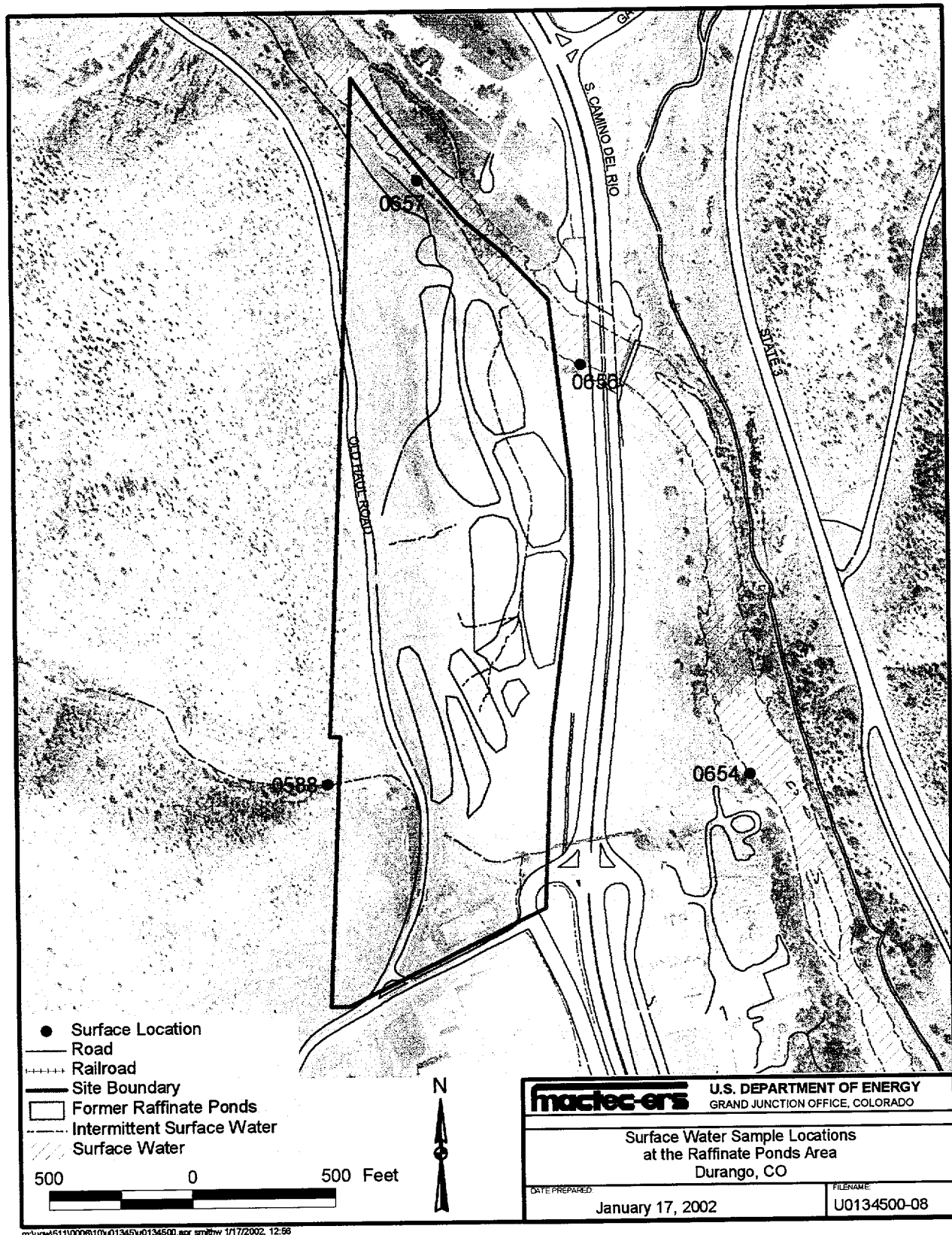


Figure 4-26. Surface Locations at the Raffinate Ponds Area

The South Creek samples serve as background samples for recharge entering the raffinate ponds area. Compared with other surface waters, these samples show a significant increase in TDS (1,700 mg/L) and sulfate. This is partly because South Creek is an intermittent drainage. The longer residence time for ground water contributing to surface flow, plus the drainage area composed of coal, shale, and sandstone units of the Menefee Formation, are responsible for the increase in TDS and sulfate concentrations in South Creek. Uranium concentration has also been relatively high (0.0333 mg/L) for a background source, especially for a surface drainage. The Menefee coal beds in the South Creek drainage appear to be the source of the higher uranium values. By way of comparison, the average trace element concentration of uranium in coal for the Rocky Mountain region ranges as high as 23.8 mg/kg (DOE 1983).

During the August 2001 sampling, both filtered and unfiltered samples were collected from all surface water locations. Results of the surface water sampling are discussed further in Section 6.0.

4.7 Ecological Investigation

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). To this end, surface waters and sediments were sampled for two primary reasons: (1) to determine if surface waters are being influenced by ground water contaminants, and (2) to determine if contaminants are present at concentrations that would result in a potential human health or ecological risk.

The BLRA (DOE 1995a) stated that South Creek was assumed not to be influenced by ground water from the raffinate ponds area. Because of this and the fact the creek is ephemeral, it was not sampled prior to June 2000. Lightner Creek and the Animas River have been sampled since 1982. In June 2000, a sampling location (0588) was established on South Creek above the raffinate ponds area, and an additional background surface water location (0515) was established on the Animas River. Both of these locations were included in the routine water sampling described in Section 4.6.4. Results of the surface water sampling indicate mill-related constituents have a negligible effect on surface waters and are discussed further in Section 6.2.

4.7.1 Sediment Sampling

The former Durango uranium-ore processing mill was next to the Animas River and Lightner Creek. Both bodies of water received contaminated fluids and sediments from the millsite while the mill was in operation. Sediment may contain contamination from three sources: (1) uptake from contaminated water in contact with it, (2) residual contamination (e.g., tailings) incorporated during milling, and (3) recently deposited contaminated sediments eroded from the millsite.

Sediment sampling was completed for the following 12 constituents along the Animas River, Lightner Creek, and South Creek adjacent to the surface water sampling locations:

Arsenic	Cadmium	Iron	Lead
Manganese	Mercury	Molybdenum	Nitrate
Selenium	Sulfate	Uranium	Zinc

However, the samples were analyzed by the laboratory without first being dried. As a consequence, the results represent concentrations of sediment and water together. The BLRA (DOE 1995a) identified cadmium, lead, and zinc as having elevated concentrations in downstream sample locations by a factor of 10. Some of this can be explained by the presence of naturally elevated levels of these constituents in lead-zinc ores, which are common in this area. The BLRA also concluded that most constituents are not anticipated to adversely affect the Animas River and Lightner Creek sediments. The results of sediment sampling are discussed further in Section 6.2.

4.7.2 EPA Investigation.

EPA conducted an ecological investigation at the former lead smelter in the mill tailings area under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1997. The site characterization included 10 surface water samples, 10 colocated sediment samples, 12 brown trout fillet samples, 12 rainbow trout fillet samples, and seven quality assurance/quality control samples. That EPA report is included as Appendix H.

Surface water and sediment analytical results of the EPA study indicated that aluminum was detected at concentrations significantly above background in surface water samples at seven locations along the Animas River below the mill tailings area. Within this same downstream area mercury was detected significantly above background in one sediment sample, and silver occurred above background in one sediment sample. The EPA study concluded that the mercury in the water sample was not related to the millsite and attributed the elevated concentration to a more widespread problem arising from elevated mercury concentrations in the southern Colorado mountains from area power plants. The occurrence of aluminum and silver were also determined not to be mill-related because these constituents were not detected on site as source contaminants.

The EPA site investigation also performed statistical analysis of the inorganic fish tissue data to determine the range of concentrations for each analyte in upstream and downstream tissue samples based on a 95 percent confidence level. The concentrations in upstream and downstream tissue samples were then compared to identify significant differences between upstream and downstream fish tissue. No elements were detected in fish tissue samples at statistically elevated levels.

The Colorado State Engineers Office has records of 90 household-use-only well permits for wells completed in the alluvium and bedrock within 4 miles of the mill tailings area. In trying to determine exposure pathways, EPA attempted to sample the closest of these wells and was unsuccessful. Although records for these wells exist, EPA discovered these residences are all now supplied by municipal water from the Florida and Animas Rivers. Development and utility policies for the city of Durango currently prohibit drilling of private wells within the city limits.

5.0 Conceptual Site Model

This section describes the main physical and chemical characteristics and features of the Durango site—the site geology, hydrogeology, and geochemistry—including a discussion of selenium at the raffinate ponds area, and provides results of the ground water flow and transport modeling.

5.1 Geologic Setting

The mill tailings and raffinate ponds areas of the Durango site lie on the north rim of the San Juan Basin, a large basin that is situated mainly south of the site in northwestern New Mexico. Bedrock in the site area is of Late Cretaceous age and dips south to south-southeast at approximately 7 to 15 degrees toward the center of the basin along a basin-rim structure known as the Hogback monocline. Two northeast-striking normal faults displace the bedrock in the site areas. Both faults are high angle and have down-to-the-southeast displacements. The northern of the two faults, the Smelter Mountain Fault, occurs between the two site areas and does not affect the hydrogeology of either area. The southern fault, the Bodo Fault, passes through the center of the raffinate ponds area. This fault affects the hydrogeology and presents additional complications by hosting a diorite porphyry dike along most of its length.

The south-flowing Animas River is along the east side of both site areas. Quaternary alluvium occurs in a few places in the site areas along the west side of the river and along Lightner Creek. Quaternary terrace deposits laid down by the ancestral river occur in several places in the raffinate ponds area, and terrace deposits along Lightner Creek are present in the northwest part of the mill tailings area. Quaternary colluvial deposits cover bedrock exposures in both site areas in many places along the east- and northeast-facing slopes of Smelter Mountain. Details of the stratigraphy and structure of the two site areas are described in Section 4.2.

5.2 Hydrogeology

Because the Durango site consists of two areas, the tailings area and the raffinate ponds area, and because both sites are hydraulically isolated from one another, separate site conceptual models were developed for each area.

5.2.1 Mill Tailings Area

Ground water at the mill tailings area is within an unconfined alluvial aquifer, which is recharged by infiltration of precipitation and runoff, and by contact with the Animas River and Lightner Creek. The lateral boundaries of the aquifer are constant head along the Animas River and Lightner Creek, no-flux where the aquifer contacts the Mancos Shale, and head-dependent flux where ground water of the Lightner Creek alluvium enters the site. Ground water exits the alluvial aquifer via flow into the Animas River. The base of the alluvial aquifer is in contact with Mancos Shale bedrock. Lateral inflow to the alluvial aquifer from the Mancos Shale and vertical leakage out of the alluvial aquifer are both assumed to be negligible. The alluvial aquifer is composed of sand, silt, and gravel derived from the Animas River and Lightner Creek. Saturated colluvial debris shed from Smelter Mountain occurs along the edges of the alluvial aquifer at some locations. Ground water occurs in the alluvial and colluvial deposits. The porosity of these deposits is assumed to be about 30 percent (Freeze and Cherry 1979).

5.2.1.1 Hydraulic Properties

Hydraulic conductivities of the alluvial deposits near the mill tailings area were measured by Bendix in 1983 (DOE 1983), BOR in 1990, and MACTEC-ERS in 2001. Table 5–1 presents a summary of the measurements.

Table 5–1. Summary of Hydraulic Conductivity for Alluvial Deposits at the Mill Tailings Area

	Qal^a Animas River	Qal^a Lightner Creek
No. of cases	11	2
Minimum	1	66
Maximum	28.6	260
Range	27.6	194
Sum	190.5	326
Median	20.6	163
Mean	17.3	163
Std. Error	2.9	97
Standard Dev	9.6	137
Variance	92.4	18818
Coefficient of Variation	0.55	0.84

^a Hydraulic conductivity is estimated in units of ft/day

Table 5–1 contains only two measured values for the Lightner Creek alluvium. The 260 ft/day result was obtained by Bendix (DOE 1983) using pneumatic pressure transducers that are insensitive to rapidly recovering water levels. The result of 66 ft/day obtained by MACTEC-ERS in 2001 is believed to be less biased and more precise because the equipment used — modern electronic pressure transducers and data loggers — are capable of capturing the rapidly changing water levels during a slug test. Therefore, the 66 ft/day value is used as the Lightner Creek alluvium hydraulic conductivity value.

For the Animas River alluvium, the median hydraulic conductivity value of 20.6 ft/day, rounded to 21 ft/day, is used to compute the water budget components.

5.2.1.2 Water Budget

The water budget for the mill tailings area is estimated from the hydraulic properties of the alluvial deposits, interpretations of alluvial thickness from borehole geologic logs, and projections of subcropping bedrock. Figure 5–1 presents a hydrogeologic map showing the water budget components for the mill tailings area. Components of the water budget are described in the following sections and summarized in Table 5–2.

Table 5–2. Water Budget for the Mill Tailings Area

Flow Component	Inflow (ft³/day)	Outflow (ft³/day)
Lightner Creek	990	840
Animas River	190	640
Areal Recharge	300	0
Total	1,480	1,480

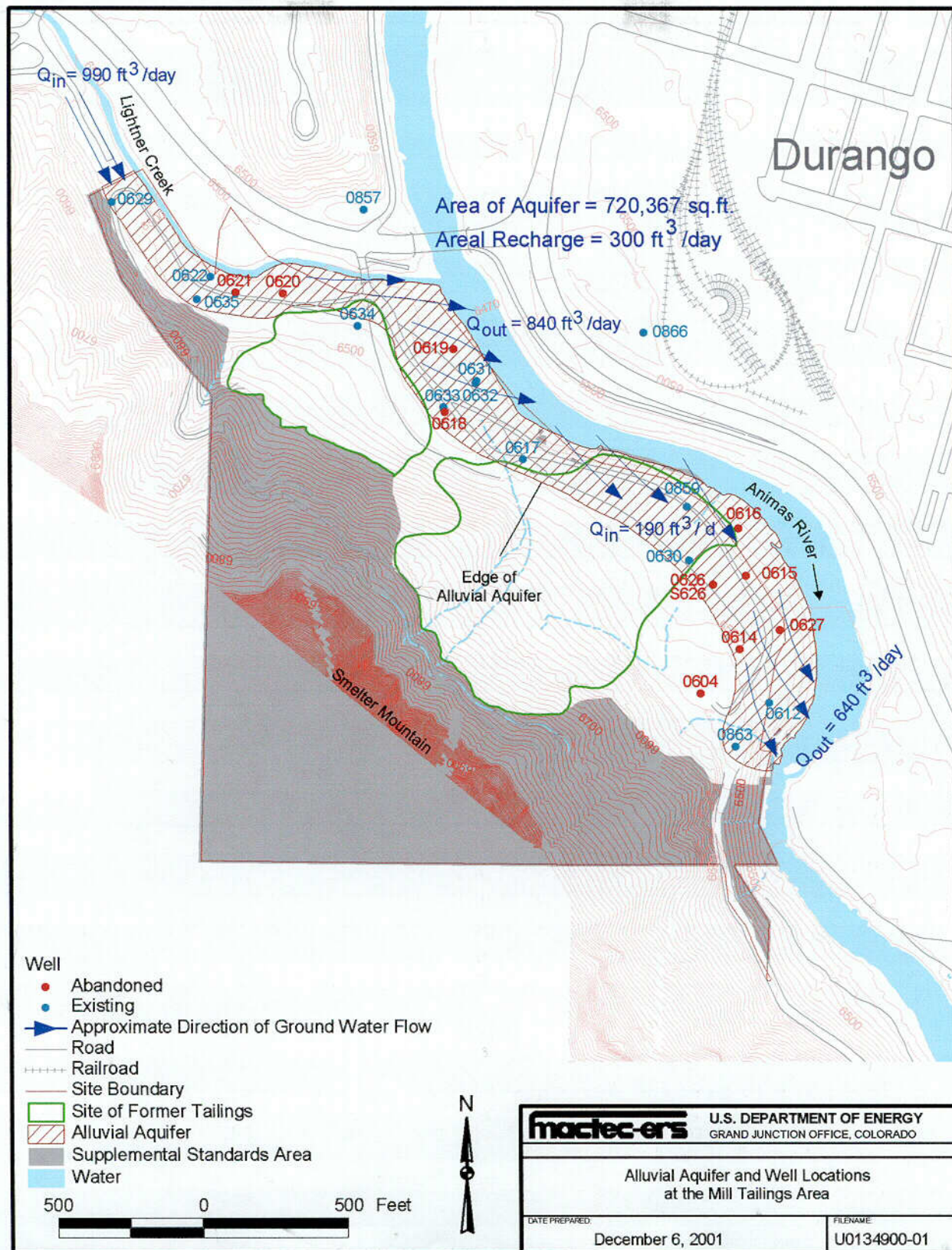


Figure 5-1. Alluvial Aquifer and Well Locations at the Mill Tailings Area

5.2.1.3 Areal Recharge

No explicit data exist to quantify the amount of areal recharge at the mill tailings area. In a past modeling study of the raffinate ponds area, the recharge from precipitation was determined through calibration to be 0.4 inch per year, or about 2 percent of the average annual precipitation (BOR 1990). The average annual precipitation for Durango from January 1, 1900, through March 31, 1991, is 19.1 inches (Colorado Climate Center 2001). In the absence of direct data, a value of about 10 percent of the annual precipitation would seem more reasonable for the water budget. Thus, 1.91 inches per year is distributed uniformly across the area (720,367 square feet [ft^2]) of the aquifer. The annual recharge rate for the aquifer is $1.91 \text{ inches/year} \times (1 \text{ ft}/12 \text{ inches}) \times (1 \text{ year}/365 \text{ days}) \times (720,367 \text{ ft}^2) = 300 \text{ cubic feet per day (ft}^3/\text{day)}$ (rounded).

5.2.1.4 Ground Water Inflow from Lightner Creek Drainage

This component of flow crosses the western site boundary along Lightner Creek and contains the ground water that originates as flow in Lightner Creek alluvium upgradient of the mill tailings area. The flow component cannot be determined with a high degree of certainty because the cross-sectional area and geometry of the saturated zone can only be extrapolated from limited data. The cross-sectional area of the alluvial aquifer was estimated by assuming it attains a maximum thickness of 8 ft at the axis of Lightner Creek; and thins to the south where it pinches out against the bedrock of Smelter Mountain. The contact is assumed to be a straight line. Consequently, the cross-sectional shape circumscribed by the aquifer is a triangle whose length and width is 120 ft by 8 ft, or approximately 500 ft^2 . Inflow (Q) to the tailings area through the Lightner Creek tributary is estimated as

$$Q = K (dh/dl) A$$

where

K = median hydraulic conductivity of the Lightner Creek alluvium (ft/day),
 dh/dl = hydraulic gradient (dimensionless), and
 A = cross-sectional area of the aquifer perpendicular to the flow direction.

$$Q = 66 \text{ ft/day} (0.03) 500 \text{ ft}^2 = 990 \text{ ft}^3/\text{day}$$

5.2.1.5 Outflow from Lightner Creek Alluvium

The Lightner Creek alluvial aquifer maintains a nearly constant width until it widens approximately 200 ft upstream of its confluence with the Animas River. The alluvial aquifer begins to widen just downstream of the bridge that provides access to the site. This region is where the alluvial characteristics of the aquifer change from those of predominantly Lightner Creek origin to those of Animas River origin, and the hydraulic conductivity in this region drops from 66 to 21 ft/day (Table 5-1). The reduction of hydraulic conductivity across this reach forces stream lines to diverge. Much of the flow from the Lightner Creek alluvium empties into the Animas River along a 750-ft reach extending from the Lightner Creek confluence to just east of well 0617. The outflow (Q) from this reach is estimated as

$$Q = K (dh/dl) A$$

where

$K = 21 \text{ ft/day}$ (Table 5-1, median value for Animas River alluvium),
 $dh/dl = 0.02$ (dimensionless), and
 $A = 2,000 \text{ ft}^2$ (approximate cross-sectional area of the aquifer perpendicular to the flow direction).

$$Q = 21 \text{ ft/day} (0.02) 2,000 \text{ ft}^2 = 840 \text{ ft}^3/\text{day}$$

5.2.1.6 Recharge from the Animas River

Downstream of the Lightner Creek discharge reach, the aquifer widens to more than twice its previous width. The reach over which the widening occurs is approximately 700 ft long. The aquifer gradually gains Animas River water along this stretch. The maximum width of the aquifer occurs near abandoned well 0616. The gain in the alluvial aquifer along this reach is estimated as

$$Q = K (dh/dl) A$$

where

$K = 21 \text{ ft/day}$ (Table 5-1, median value for Animas River alluvium),
 $dh/dl = 0.015$ (dimensionless), and
 $A = 600 \text{ ft}^2$ (approximate cross-sectional area of the aquifer perpendicular to the flow direction).

$$Q = 21 \text{ ft/day} (0.015) 600 \text{ ft}^2 = 190 \text{ ft}^3/\text{day}$$

5.2.1.7 Aquifer Discharge

The alluvial aquifer pinches out against a bedrock cliff of Mancos Shale near wells 0612 and 0863. All ground water in the alluvial aquifer empties into the Animas River at this point. Although discharge from this section could be estimated explicitly through flow-net construction, it is estimated here by the difference between the total inflows ($1,480 \text{ ft}^3/\text{day}$ from Table 5-2) and the Lightner Creek outflow component ($840 \text{ ft}^3/\text{day}$). The estimated flow from the aquifer is approximately $640 \text{ ft}^3/\text{day}$ in the discharge area.

5.2.1.8 Boundary Conditions

Lateral boundaries for the mill tailings area are as follows: (1) specified head along Lightner Creek and the Animas River, and (2) no-flux along the contact between the alluvium and the Mancos Shale bedrock.

5.2.1.9 Animas River/Aquifer Interaction

Wells 0863, 0859, and 0633 (completed in the colluvium, alluvium, and Mancos Shale, respectively) were equipped with dataloggers to monitor groundwater fluctuations between April and November, 2001. This data set is compared to the fluctuations of the Animas River stage in Figure 5-2. For comparison, the actual river elevation shown in Figure 5-2 is not as important as the fluctuation pattern shown, since the elevation is representative at only one point (stilling well 0876) along the Animas River.

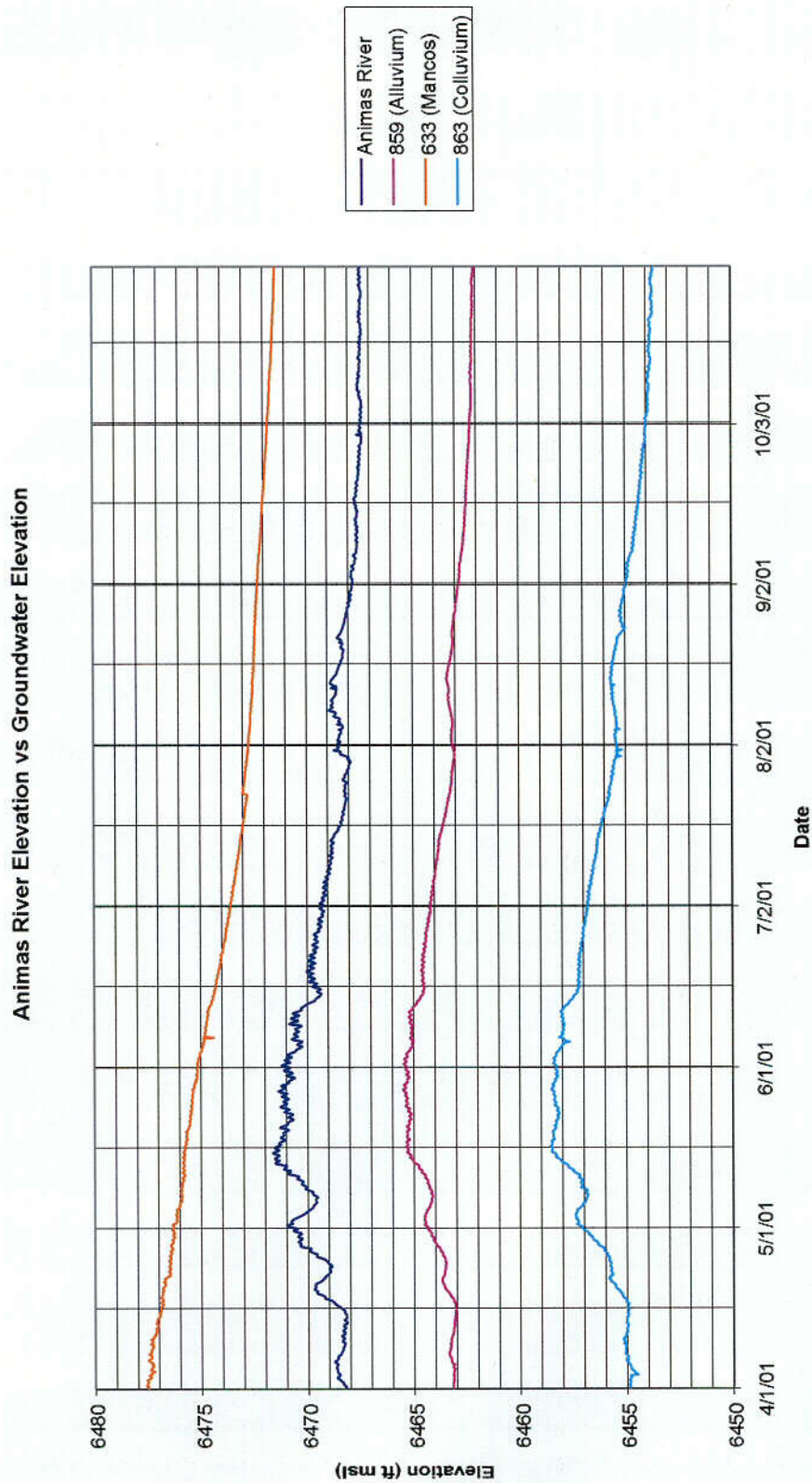


Figure 5-2. Animas River Elevation versus Ground Water Elevation

Ground water in the colluvium and alluvium exhibit the same fluctuation pattern as displayed by the Animas River stage, confirming that water in these two units are hydraulically connected to the river. Ground water in the Mancos Shale onsite does not exhibit the same pattern. As shown in Figure 5-2, the Mancos Shale ground water surface does not show a definite peak in mid-May like the colluvium and alluvium units, suggesting the Mancos shale ground water flow system is impacted by a source other than the Animas River.

5.2.2 Raffinate Ponds Area

Ground water at the raffinate ponds site is assumed to be unconfined. It is recharged by infiltration of precipitation and runoff and by horizontal inflow from Smelter Mountain. Water enters the flow system at the intersection of the Bodo Fault with South Creek. This influx is intermittent because South Creek is an ephemeral stream. Lateral boundaries to the raffinate ponds area ground water flow system consist of influx from Smelter Mountain and constant (or nearly constant) head along the Animas River. The southern margin of the raffinate ponds area has no physical boundary, but ground water is assumed to flow parallel to it; consequently, the southern boundary to the flow system is an assumed no-flux boundary.

The sandstone units of the Menefee Formation and the massive sandstone unit of the Point Lookout Sandstone are assumed to have a porosity of 33 percent (Morris and Johnson 1967). The basal member of the Point Lookout Sandstone is assumed to have a maximum porosity of 5 percent (Freeze and Cherry 1979; Morris and Johnson 1967).

5.2.2.1 Hydraulic Conductivity

Hydraulic conductivity of the bedrock units was measured by Bendix (DOE 1983), BOR (1990), and MACTEC-ERS in 2001. Table 5-3 presents a statistical summary of the measurements. The hydraulic conductivity data for each hydrostratigraphic unit indicate that the Point Lookout Sandstone is the least conductive material. In addition, the lower member (predominantly shale and siltstone) of the Point Lookout Sandstone is apparently an aquitard. The lower member is present in the subsurface beneath the raffinate ponds area.

The Menefee Formation consists mostly of low-conductivity sandstone, but is relatively permeable where fractures or lenticular coal beds are present. The hydraulic conductivity of the fractured zones and the coal beds is comparable to the conductivity of the Bodo Fault. In Table 5-3, the maximum conductivity listed for the Menefee Formation of 5.3 ft/day was measured at well 0882 (Appendix F, MACTEC-ERS Calculation U0133300), which was completed in a coal bed. This measurement singularly skews the mean hydraulic conductivity considerably above the median value. The median value is more representative of the sandstone beds in the Menefee Formation.

Table 5-3. Basic Statistics of Hydraulic Conductivity by Geologic Formation at the Durango Site

	Point Lookout Sandstone	Menefee Formation	Bodo Fault
No. of cases	16	12	10
Minimum	0.006	0.003	0.120
Maximum	0.304	5.3	6.98
Range	0.298	5.297	6.86
Sum	1.089	12.73	23.394
Median	0.050	0.175	0.623
Mean	0.068	1.061	2.339
Std. Error	0.018	0.541	0.866
Standard Dev.	0.074	1.874	2.738
Variance	0.005	3.513	7.498
Coefficient of Variation	1.083	1.767	1.170

Hydraulic conductivity is in units of feet per day

5.2.2.2 Water Budget

The water budget for the raffinate ponds area is estimated from the hydraulic properties of the bedrock units and interpretations of geologic logs. Figure 5-3 presents a hydrogeologic map showing the water budget components for the raffinate ponds area. Components of the water budget are described in the following sections and summarized in Table 5-4.

Table 5-4. Water Budget for the Raffinate Ponds Area

Flow Component	Inflow (ft ³ /day)	Outflow (ft ³ /day)
Areal recharge	890	
Smelter Mountain	420	
South Creek	600	
Point Lookout Sandstone		260
Menefee Formation		1,780
Total ^a	1,910	2,070

^a ± 10 percent

5.2.2.3 Lateral Inflow from Smelter Mountain

Lateral inflow from the Smelter Mountain area is inferred because the Point Lookout Sandstone is contiguous and underlies both the raffinate pond terrace and Smelter Mountain. Infiltration of snowmelt and runoff, together with vertical leakage, probably sustains a water table in the sandstone units beneath Smelter Mountain. Ground water is assumed to occur in the massive member of the Point Lookout Sandstone, and some component of flow is believed to migrate eastward to the raffinate pond terrace area. Discharge from Smelter Mountain is approximated as follows:

Hydraulic gradient (dh/dl) ≈ 0.01 ,
 Hydraulic conductivity (K) ≈ 0.050 ft/day,
 Width perpendicular to flow is 2,800 ft (the length), and
 Saturated thickness of the bedrock is assumed to be 300 ft.

$$Q = K (dh/dl) A = (0.050 \text{ ft/day}) \times (0.01) \times (2,800 \text{ ft}) \times (300 \text{ ft}) = 420 \text{ ft}^3/\text{day}$$

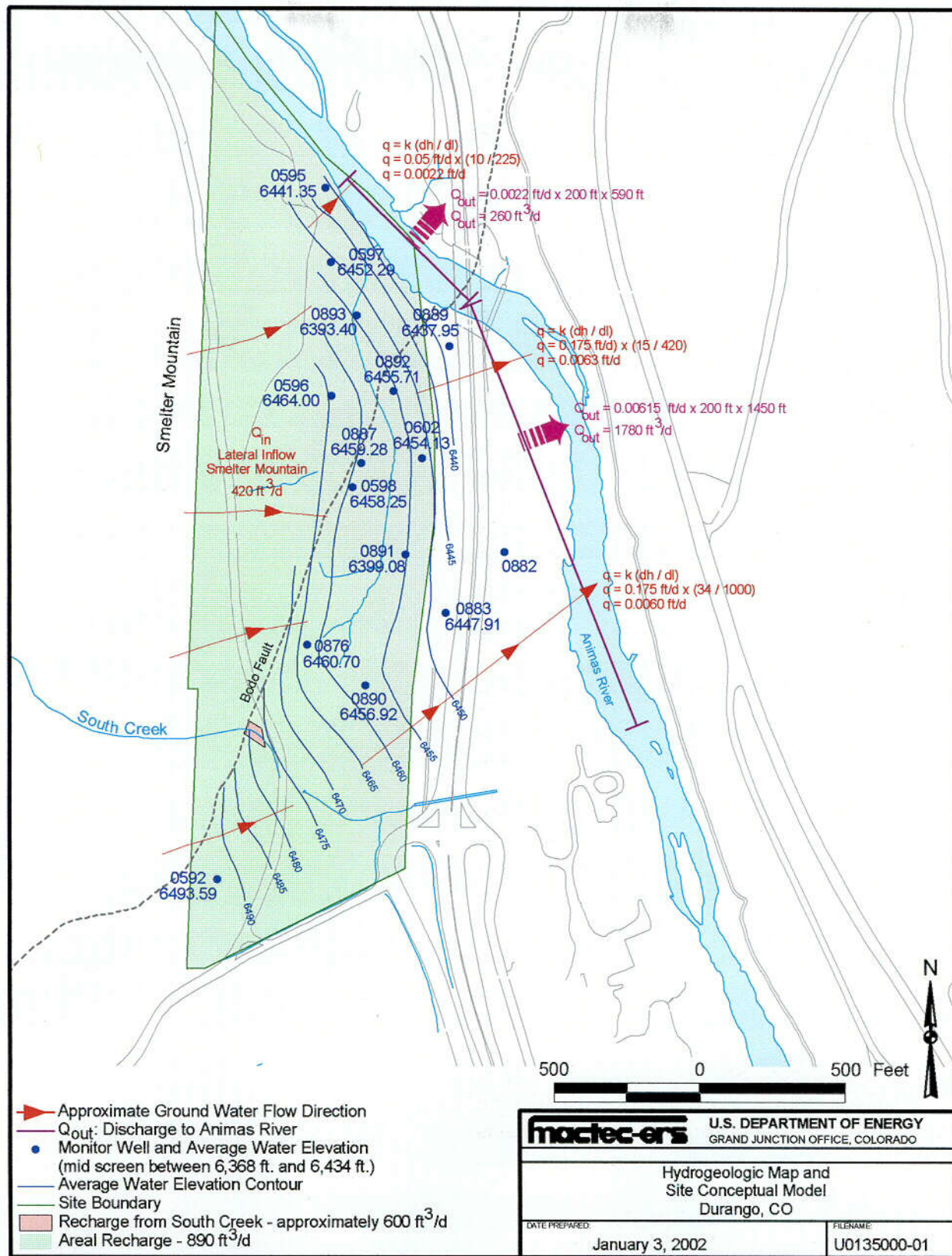


Figure 5-3. Hydrogeologic Map and Site Conceptual Model of the Raffinate Ponds Area

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5.2.2.4 Areal Recharge

Data were not collected to quantify the amount of areal recharge. In a past modeling study of the raffinate ponds area, the recharge from precipitation was estimated by model calibration to be 0.4 inch per year, or about 2 percent of the average annual precipitation (BOR 1990). The average annual precipitation at Durango from January 1, 1900, through March 31, 1991, is 19.1 inches (Colorado Climate Center 2001). In the absence of direct data, a value of about 10 percent of the annual precipitation would seem reasonable as a starting point for the water budget. The surface of the raffinate ponds area is approximately 2,040,000 ft² (46.8 acres). Based on 10 percent of average annual precipitation, the areal recharge would be 1.91 inches/year (1 ft/12 inches) (1 yr/365 days) (2,040,000 ft²) = 890 ft³/day.

Recharge from South Creek

South Creek is an ephemeral stream that enters the raffinate ponds area near the southwest corner of the property where it crosses the Bodo Fault. Table 5-3 shows the median hydraulic conductivity of the bedrock to be approximately 4 times higher along the fault. In addition, the maximum hydraulic conductivity in the fault zone is about 7 ft/day. The locally elevated hydraulic conductivity along the fault is believed to provide a conduit for recharge when South Creek contains water. The average recharge rate is estimated using Darcy's Law:

$$Q = K (dh/dz) A$$

where

Q is the total recharge in ft³/day,

K is the median hydraulic conductivity (ft/day),

dh/dz is the vertical hydraulic gradient, assumed unity (dimensionless), and

A is the cross-sectional area where the recharge enters the aquifer (1,000 ft²).

$$Q = 0.6 \text{ ft/day} \times (1) \times (1,000 \text{ ft}^2) = 600 \text{ ft}^3/\text{day}$$

Discharge to the Animas River

The thickness of the bedrock flow system is assumed to be approximately 200 ft. Wells screened in the middle elevations of the bedrock were used to estimate the ground water discharge to the Animas River. As shown on Figure 5-3, the hydraulic gradient through the Point Lookout Sandstone sections is approximately 0.044 (10/225). The width perpendicular to flow through the Point Lookout Sandstone is approximately 590 ft. Hydraulic conductivity of the Point Lookout Sandstone is 0.05 ft/day (Appendix F, MACTEC-ERS Calculation U0133300). Ground water discharge through the Point Lookout Sandstone from the site is estimated as

$$Q = K (dh/dl) A = 0.05 \text{ ft/day} (0.044) (590 \text{ ft}) (200 \text{ ft}) = 260 \text{ ft}^3/\text{day}.$$

The specific discharge is estimated at two locations in Figure 5-3 based on a hydraulic gradient through the Menefee Formation of between 0.034 and 0.036. The total discharge through the Menefee Formation is then estimated based on a width perpendicular-to-flow of approximately 1,450 ft. Median hydraulic conductivity of the Menefee Formation is 0.175 ft/day (Appendix F,

MACTEC-ERS Calculation U0133300). Ground water discharge through the Menefee Formation from the site is estimated as

$$Q = K (dh/dl) A = 0.175 \text{ ft/day} (0.035) (1,450 \text{ ft}) (200 \text{ ft}) = 1,780 \text{ ft}^3/\text{day}.$$

Ground water exiting the site flows toward the Animas River. The course of the ground water flow eastward appears to approximately follow the strike direction of the bedrock.

5.2.2.5 Boundary Conditions

Lateral boundary conditions for the raffinate ponds area are assumed to be (1) specified head along the Animas River, (2) limited flux to account for ground water inflow from Smelter Mountain, and (3) no-flux along the southern boundary (assuming that the southern boundary of the model is parallel to a stream line).

5.2.2.6 Animas River/Aquifer Interaction

Figure 5-4 shows the comparison of the ground water fluctuations of the various aquifers at the raffinate ponds area to the Animas River. Dataloggers installed in wells 0889, 0882, and 0887 provided ground water surface elevations from wells completed in the Point Lookout Sandstone, Menefee Formation, and the Bodo Fault, respectively. The data presented for the Animas River were collected from stilling well 0906.

The data presented in Figure 5-4 suggests ground water flow in the Point Lookout Sandstone and Menefee Formation is hydraulically connected to the Animas River. The ground water fluctuation pattern provided by the well completed in the Bodo Fault zone does not match the pattern provided by the Animas River, suggesting the ground water flow system associated with the fault zone is impacted by a source other than the Animas River.

5.3 Geochemistry

DOE collected ground water data from the former processing site and vicinity from September 1982 through August 2001. The data from 1999 through August 2001 were used to assess surface water and ground water quality. The nature and extent of site-related constituents occurring above natural background concentrations are evaluated, and the fate and transport of the site-related constituents in the ground water are summarized in the following sections.

5.3.1 Natural Background

The water quality prior to milling operations is inferred by characterizing the water quality in areas upgradient of the site that are unaffected by process contamination. Surface waters, soils, and ground water from the alluvium, colluvium, Menefee Formation, Mancos Shale, and Point Lookout Sandstone were evaluated. Data used in this assessment are derived from background surface and ground water samples from both the mill tailings area and the raffinate ponds area. Mean analyte concentration data are reported in Table 5-5. The total number of samples analyzed and the number of samples that produced values greater than the detection limit are listed. The low, mean, and high concentrations of analytes with concentrations greater than the detection limit are also reported. The mean concentrations are derived only from the samples that have concentrations greater than the detection limit. The maximum concentration of an analyte is listed for those analytes that were not detected.

Animas River Elevation vs Groundwater Elevation

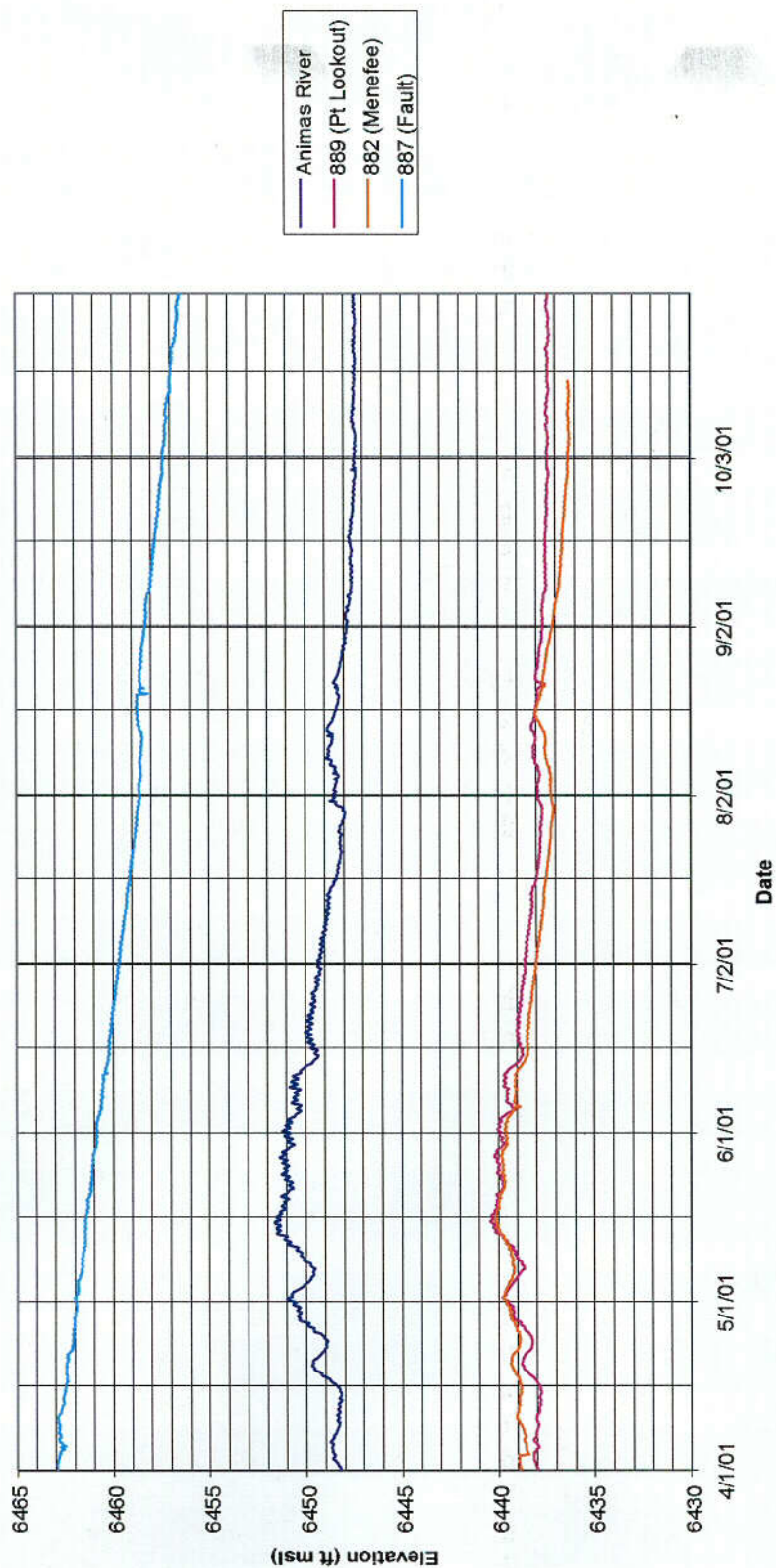


Figure 5-4. Animas River Elevation versus Ground Water Elevation

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Table 5-5. Background Mean Water Composition for Surface and Ground Waters from the Mill Tailings Area and the Raffinate Ponds Area
Samples were collected from June 1999 through August 2001. Samples were filtered unless otherwise noted.

Analyte	Unit	SURFACE WATER ^a			DURANGO MILL TAILINGS AREA ^b			Alluvial Aquifer ^c			Menefee Aquifer ^d			Point Lookout Aquifer ^e		
		FOD ^f	Mean	Range	FOD ^f	Mean	Range	FOD ^f	Mean	Range	FOD ^f	Mean	Range	FOD ^f	Mean	Range
DURANGO RAFFINATE PONDS AREA																
Major Ions																
Ammonium	mg/L	0/27	U	0.046	11/18	1.20	0.135 - 2.28	3/4	0.36	0.116 - 0.767	12/13	0.935	0.036 - 1.41	6/11	1.01	0.468 - 1.39
Calcium	mg/L	31/31	57.5	21.0 - 89.8	20/20	267	126 - 583	4/4	141	78.2 - 170	15/15	148	95 - 242	11/11	158	7.34 - 371
Chloride	mg/L	31/31	8.50	1.44 - 20.9	20/20	64.2	9.90 - 265	4/4	59.0	22.1 - 82.4	15/15	50.8	42.8 - 83.6	11/11	42.7	15.9 - 73
Magnesium	mg/L	31/31	14.7	2.68 - 30.3	20/20	151	40.7 - 254	4/4	104	51.1 - 134	15/15	161	130 - 216	11/11	5.16	2.68 - 7.57
Nitrate	mg/L	12/31	1.36	0.503 - 3.15	9/20	8.32	0.257 - 11.2	4/4	9.36	0.926 - 18.9	5/15	2.27	0.508 - 4.99	11/11	62.0	2.32 - 140
Potassium	mg/L	31/31	1.83	0.677 - 3.40	20/20	4.36	2.38 - 8.17	4/4	5.43	5.24 - 5.65	15/15	6.56	5.65 - 8.85	5/11	8.17	7.87 - 8.41
Sodium	mg/L	31/31	12.6	2.53 - 20.6	20/20	246	35.3 - 488	4/4	208	99.1 - 367	15/15	242	186 - 270	11/11	481	299 - 722
Sulfate	mg/L	31/31	90.3	23.8 - 160	20/20	1255	114 - 2190	4/4	553	154 - 744	15/15	781	441 - 1330	10/11	826	4.13 - 1750
Metals																
Antimony	mg/L	0/31	U ^g	0.0029 ^h	0/20	U ^g	0.0012 ^h	0/4	U ^g	0.0008 ^h	0/15	U ^g	0.0012 ^h	0/11	U ^g	0.0014 ^h
Arsenic	mg/L	0/31	U ^g	0.0010	0/20	U ^g	0.0013	0/4	U ^g	0.0005	0/15	U ^g	0.001	0/11	U	0.0034
Cadmium	mg/L	0/31	U ^g	0.0009	0/20	U ^g	0.0007	0/4	U ^g	0.00069	0/15	U ^g	0.00071	0/11	U	0.0011
Chromium	mg/L	1/31	0.011	0.011 - 0.011	0/20	U ^g	0.0059	0/4	U ^g	0.0059	0/15	U ^g	0.0059	0/11	U	0.0063
Copper	mg/L	0/27	U ^g	0.0063	0/18	U ^g	0.0090	0/4	U ^g	0.0034	0/13	U ^g	0.0069	0/11	U	0.004
Iron	mg/L	12/27	0.285	0.033 - 1.03	15/18	3.38	0.120 - 14.7	4/4	1.13	0.161 - 2.95	2/13	0.131	0.095 - 0.166	7/11	0.0346	0.035 - 1.71
Lead	mg/L	0/31	U ^g	0.0048	0/20	U ^g	0.0023	0/4	U ^g	0.00028	0/15	U ^g	0.00051	0/11	U	0.0017
Manganese	mg/L	21/31	0.068	0.010 - 0.205	20/20	0.601	0.073 - 1.05	4/4	0.274	0.09 - 0.605	15/15	0.141	0.052 - 0.58	6/11	0.382	0.289 - 0.49
Molybdenum	mg/L	0/31	U ^g	0.0033	0/20	U ^g	0.0057	0/4	U ^g	0.0031	0/15	U ^g	0.0035	2/11	0.013	0.011 - 0.0155
Selenium	mg/L	0/31	U ^g	0.0015	8/20	0.014	0.011 - 0.0148	2/4	0.0069	0.006 - 0.0078	1/15	0.008	0.008 - 0.0077	5/11	0.075	0.062 - 0.087
Thallium	mg/L	0/31	U ^g	0.0004	0/20	U ^g	0.0004	0/4	U ^g	0.00033	0/15	U ^g	0.00037	0/11	U	0.00032
Uranium	mg/L	8/31	0.001	0.001 - 0.0013	11/20	0.012	0.005 - 0.035	4/4	0.0048	0.0041 - 0.0056	6/15	0.004	0.001 - 0.0093	11/11	0.005	0.002 - 0.0321
Vanadium	mg/L	0/31	U ^g	0.0042	0/20	U ^g	0.0020	0/4	U ^g	0.0015	0/15	U ^g	0.0023	0/11	U	0.0015
Zinc	mg/L	9/27	0.062	0.052 - 0.079	0/18	U ^g	0.023	0/4	U ^g	0.0148	2/13	0.178	0.126 - 0.23	0/11	U	0.0416
Other																
Alkalinity as CaCO ₃ ⁱ	mg/L	40/40	133	37.0 - 214	34/34	413	334 - 499	8/8	534	356 - 876	26/26	638	387 - 794	20/20	778	325 - 1522
pH ^j	s.u.	25/25	7.95	6.82 - 8.53	19/19	6.98	6.41 - 8.24	4/4	7.30	7.08 - 7.75	14/14	7.10	6.61 - 7.64	11/11	7.44	7.03 - 7.86
Redox Potential ^j	mV	25/25	75.8	-107 - 198	19/19	-8.21	-126 - 230	4/4	-85.8	-147 - -20	12/12	-198	-380 - 83	10/10	-49	-187 - 173
Specific Conductance ^j	umhos/cm	25/25	697	169 - 2550	19/19	2641	1003 - 4080	4/4	2118	1439 - 2580	14/14	2554	2280 - 3020	11/11	2436	1147 - 3340
Temperature ^j	C	25/25	11.0	2.10 - 19.3	19/19	12.0	9.40 - 15.8	4/4	14.6	12.5 - 18.9	12/12	14.55	9.5 - 17.6	11/11	14.75	12 - 16.6
Total Dissolved Solids	mg/L	31/31	294	93.0 - 452	20/20	2528	623 - 3860	4/4	1545	1300 - 1920	15/15	1948	1620 - 2740	11/11	2175	1010 - 3140
Radiologic																
Lead-210	pCi/L	0/27	U ^g	1.50	0/18	U ^g	1.47	0/4	U ^g	1.30	0/13	U ^g	1.46	0/11	U	1.32
Polonium-210	pCi/L	5/27	0.078	0.060 - 0.110	2/18	0.075	0.060 - 0.090	0/4	U ^g	0.350	0/13	U ^g	0.420	2/11	0.105	0.09 - 0.12
Radium-226	pCi/L	9/27	0.144	0.100 - 0.230	9/17	0.160	0.120 - 0.220	4/4	0.328	0.16 - 0.65	10/13	0.258	0.16 - 0.61	8/11	0.46	0.1 - 0.7
Radium-228	pCi/L	0/27	U ^g	1.53	0/17	U ^g	1.39	1/4	0.73	0.73 - 0.73	0/13	U ^g	1.31	3/11	1.04	0.5 - 1.56
Thorium-230	pCi/L	0/27	U ^g	12.0	0/18	U ^g	2.60	0/4	U ^g	1.70	1/13	3.1	3.1 - 3.1	0/11	U	3.2

^a Samples collected from locations 0506, 0515, 0650, and 0652. Data includes four unfiltered duplicate samples collected in August 2001, unless otherwise noted.

^b Samples collected from wells 0629, 0857, and 0866.

^c Samples collected from well 0886.

^d Samples collected from wells 0592 and 0903.

^e Samples collected from wells 0599 and 0875.

^f Frequency of detection: number of samples above detection limit/number of samples analyzed.

^g Values are less than the detection limit and are not reported.

^h Maximum value (in *italics*) is less than the detection limit; reported to provide scale of the detection limit.

ⁱ Half of the samples were filtered and half were not filtered.

^j All samples unfiltered.

5.3.1.1 Background Surface Water

Surface water of the Durango site includes Lightner Creek, which flows along the northern edge of the mill tailings area, and the Animas River, which flows along the eastern and southern boundaries of the mill tailings area and along the eastern edge of the northern half of the raffinate ponds area. South Creek, which is along the southern edge of the raffinate ponds area, is dry except during heavy rainfall and when water is released from the toe drain collection pond at the disposal cell. South Creek joins the Animas River approximately 1,000 ft east of the raffinate ponds area.

The average major ion concentrations of Animas River water are plotted on the Piper diagram presented in Figure 5-5. Surface water samples were collected from locations 0506, 0515, 0652, and 0650. Surface water is a calcium-bicarbonate type with concentrations ranging from 93 to 440 mg/L. The mean pH is 7.96 and the water has a mean iron concentration of 0.0486 mg/L, which indicates the water is oxidizing. Concentrations of the following 13 analytes were less than or equal to the detection limit: ammonium, antimony, arsenic, cadmium, copper, lead, molybdenum, selenium, thallium, vanadium, lead-210, radium-228, and thorium-230 (Table 5-5).

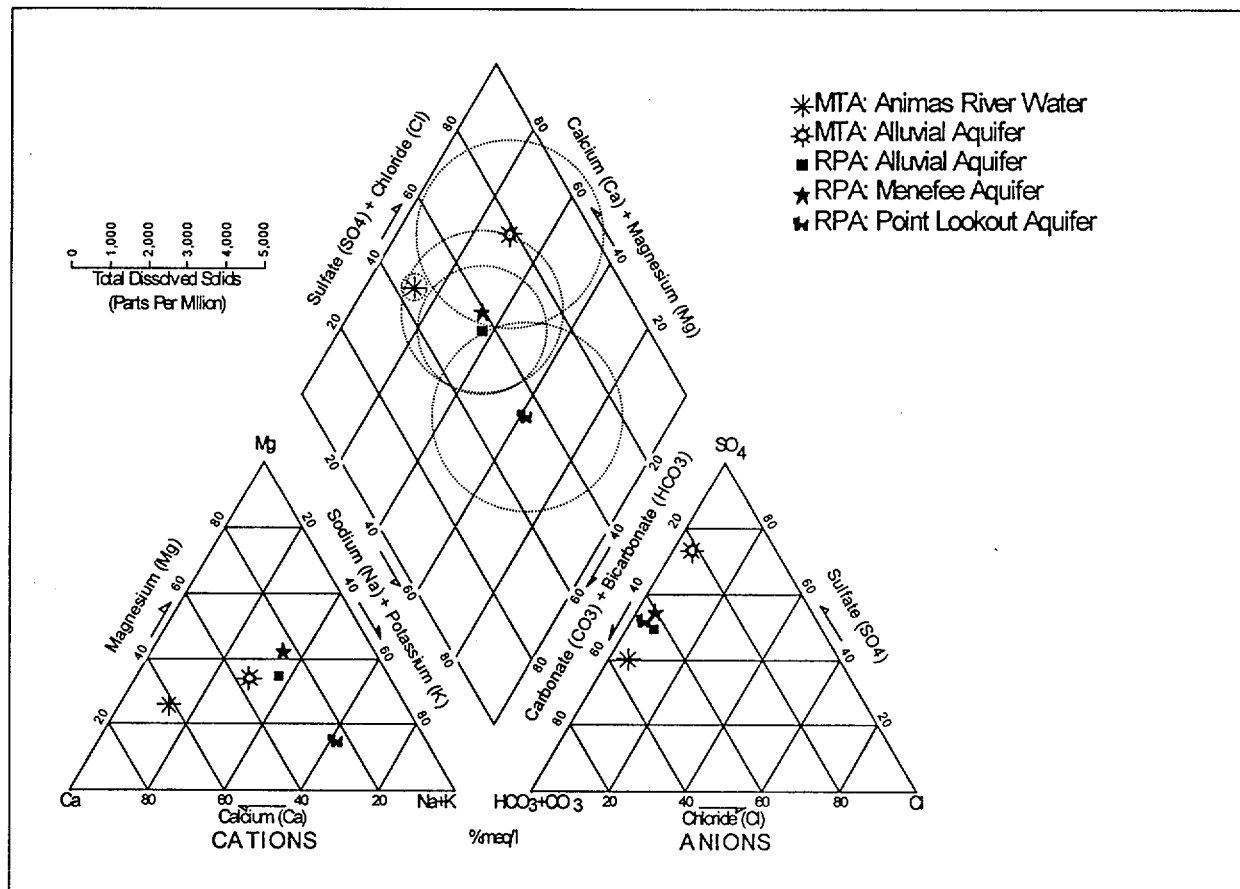


Figure 5-5. Piper Diagram for Mill Tailings Area (MTA) and Raffinate Ponds Area (RDA) Background Ground Water and Animas River Water using Mean Concentrations

5.3.1.2 Mill Tailings Area Background Ground Water

Background ground water data were obtained from monitor wells 0629, 0857, and 0866. Mean analyte concentrations are reported in Table 5–5. Concentrations of 13 analytes were below their detection limits: antimony, arsenic, cadmium, chromium, copper, lead, molybdenum, thallium, vanadium, zinc, lead-210, radium-228, and thorium-230.

The mean major ion concentrations are plotted on the Piper diagram presented in Figure 5–5. According to the Piper diagram, no cation dominates. The mean pH is 6.99, and the TDS concentrations range from 623 to 3,820 mg/L. Selenium concentrations range from 0.011 to 0.0148 mg/L; the MCL for selenium is 0.010 mg/L. Iron concentrations range from 0.120 to 14.7 mg/L, and the mean concentration is 3.38 mg/L.

5.3.1.3 Raffinate Ponds Area Background Alluvial Ground Water

Background ground water data for the alluvial aquifer of the raffinate ponds area were obtained from well 0886. Mean analyte concentrations are reported in Table 5–5. Concentrations of the following thirteen analytes were below their detection limits: antimony, arsenic, cadmium, chromium, copper, lead, molybdenum, thallium, vanadium, zinc, lead-210, polonium-210, and thorium-230.

Figure 5–5 shows the mean major ion concentrations. According to the Piper diagram, there is neither a dominant cation nor a dominant anion. No constituent exceeds its MCL. The mean pH is 7.30, and the measured TDS concentrations range from 1,300 to 1,920 mg/L. The iron concentration ranges from 0.161 to 2.95 mg/L; the mean iron concentration is 1.13 mg/L.

5.3.1.4 Raffinate Ponds Area Background Ground Water from the Menefee Formation

Background ground water data for the Menefee Formation of the raffinate ponds area were obtained from sampling wells 0592 and 0903. Analyte concentration data are reported in Table 5–5. Concentrations of the following twelve analytes were below their detection limits: antimony, arsenic, cadmium, chromium, copper, lead, molybdenum, thallium, vanadium, lead-210, polonium-210, and radium-228.

The mean major ion concentrations are interpreted using the Piper diagram presented in Figure 5–5. According to the Piper diagram, there is no dominant cation or anion. No constituent exceeds its MCL. The mean pH is 7.10, and measured TDS concentrations range from 1,620 to 2,740 mg/L. Iron concentrations range from 0.095 to 0.166 mg/L, and the mean iron concentration is 0.131 mg/L.

5.3.1.5 Raffinate Ponds Area Background Ground Water from the Point Lookout Sandstone

Background ground water data for the Point Lookout Sandstone of the raffinate ponds area were obtained from sampling wells 0599 and 0875. Analyte concentration data are reported in Table 5–5. Concentrations of the following eleven analytes were below their detection limits: antimony, arsenic, cadmium, chromium, copper, lead, thallium, vanadium, zinc, lead-210, and thorium-230.

The mean major ion concentrations are interpreted using the Piper diagram presented in Figure 5-5. Ground water is a sodium-sulfate type with TDS concentrations ranging from 1,010 to 3,140 mg/L. The mean pH is 7.44. Sodium concentrations range from 299 to 722 mg/L, and sulfate concentrations range from 4.13 to 1,750 mg/L. Iron concentrations range from 0.035 to 1.71 mg/L.

5.3.1.6 Raffinate Ponds Area Background Ground Water and Sulfide

A rotten-egg odor is strongly present at several locations in the raffinate ponds area, which indicates the presence of reduced sulfur. Sulfur occurs in oxidation states ranging from S^{2-} to S^{6+} ; consequently, the chemical behavior of sulfur is related strongly to redox properties of aqueous systems. The geochemical cycle of sulfur is characterized by a rather rapid recycling of solute forms in water and of gases and aerosols in the atmosphere. Sulfide species are the final reduction product, and if the pH is above 7, $HS^-_{(aq)}$ will form rather than $H_2S_{(aq)}$.

Reduced sulfur, such as H_2S and $HS^-_{(aq)}$, are highly toxic to most organisms, so biota are strongly affected. Most people can detect the rotten-egg odor of hydrogen sulfide in waters that have only a few tenths of a milligram per liter of this material in solution. The risk-based value for $H_2S_{(aq)}$ as a contaminant in drinking water is 0.11 mg/L, assuming the contaminated water is the primary source of drinking water over a period of 30 years for adults. Natural waters subjected to unusual conditions may attain high concentrations of hydrogen sulfide.

Ground water samples were collected from nine wells to measure the sulfide concentration in order to fully assess the health risks. The sample collected from well 0592 has a hydrogen sulfide, $H_2S_{(aq)}$, concentration of 45.9 mg/L. The remaining eight wells had concentrations less than the GJO Analytical Laboratory detection limit of 1 mg/L. The GJO Analytical Laboratory method, G-3 R05, is based upon EPA method 376.1. A field method with a lower detection limit was used to better determine sulfide concentrations. Hach method 8131 is a colorimetric method that measures sulfide, S^{2-} , concentrations in the field (Hach 1998). The range of reliable detection is from 0.08 to 0.70 mg/L. Concentrations of $H_2S_{(aq)}$ in ground water samples from wells 0598 and 0875 were 0.15 and 0.11 mg/L, respectively; the risk-based value is 0.11 mg/L. The presence of sulfide was indicated by the slightly blue color of the samples from wells 0599, 0884, and 0886 after the addition of the reagents. However, the concentrations were less than 0.08 mg/L and could not be estimated reliably.

If any reactive iron compounds are present, the sulfide species will react to form solid sulfides. The reduced sulfur ion, S^{2-} , forms sulfides of low solubility with most metals. Sulfur that occurs in reduced form in the sulfide minerals is relatively immobile. Species, such as heavy metals, adsorbed onto ferric oxyhydroxides will be released to solution. Many of the heavy metals, such as copper, zinc, molybdenum, lead, and mercury, that are relatively soluble in oxidizing waters (provided that the pH is not too high), are highly insoluble in the presence of dissolved sulfide species. Because iron is common and widely distributed, the iron sulfides have a substantial influence on sulfur geochemistry. There are many consequences of ferric iron and sulfate reduction. When sulfide minerals undergo weathering in contact with aerated water, the sulfur is oxidized to yield sulfate ions that go into solution in the water. Hydrogen ions are produced in considerable quantity in this oxidation process and can decrease the pH. Pyrite crystals occur in many sedimentary rocks and constitute a source of both ferrous iron and sulfate in ground water. Pyrite, particularly, is commonly associated with biogenic deposits such as coal, which form under strongly reducing conditions.

5.3.1.7 Stiff Diagrams and Background Waters

Mean major ion concentrations are also plotted on a Stiff diagram (Figure 5–6). Stiff diagrams are a way of plotting the major ion composition of a water to produce a symbol whose shape indicates the relative proportions of the different ions, and whose size indicates total concentrations (Drever 1997). Similarities and differences can be quickly identified. The three major anions plot on the right side of the center axis, and the major cations plot on the left side.

As shown in Figure 5–6, Animas River water contains the lowest concentrations of major ions. The shape of the Animas River water Stiff diagram is hexagonal and is a calcium-bicarbonate-type water, as indicated by the Piper diagram (Figure 5–5). The major ion concentrations of the background ground waters of the mill tailings area vary. The diagram is not symmetric. The background ground water has higher concentrations of all major ions and a higher mean concentration of sulfate than of any other anion.

In the raffinate ponds area, the Stiff diagrams are similar for the alluvial aquifer and for the Menefee aquifer and indicate that concentrations of the major cations and anions are similar. The Point Lookout aquifer has higher concentrations of sodium and potassium and lower concentrations of magnesium.

5.3.1.8 Mill Tailings Area Background Soil Chemistry

Data for the background soils are presented in Table 5–6. Section 4 presents a full description of the subpile soil sampling methods and results. Background surface soil samples were collected from subpile soil sample locations 0930, 0931, and 0932 (Figure 5–7).

Cadmium concentrations in the background soils were greater than the crustal mean concentration of 0.2 mg/kg. Two soil samples had lead concentrations greater than the crustal mean concentration of 13 mg/kg. Molybdenum concentrations were greater than the detection limit and were less than the crustal mean concentration of 1.5 mg/kg. Selenium concentrations of all three samples were greater than the detection limit of 0.35 mg/kg and the crustal mean of 0.05 mg/kg. Uranium concentrations were greater than the detection limit and less than the crustal mean.

Table 5–6. Constituent Concentrations in Durango Background Soil Samples

Sample	Cadmium	Lead	Molybdenum	Selenium	Uranium
Mill Tailings Area (mg/kg)					
930-AL	1.27 ^a	141	<i>0.5</i> ^b	0.60	0.77
931-COL	0.85	13.6	<i>0.66</i>	0.88	1.22
932-COL	0.57	6.95	<i>0.13</i>	0.72	0.54
Raffinate Ponds Area (mg/kg)					
903-04	<i>0.041</i>	4.40	<i>0.12</i>	<i>0.35</i>	0.18
903-14	<i>0.057</i>	4.81	<i>0.11</i>	<i>0.35</i>	0.18
903-23	2.17	4.50	<i>0.13</i>	<i>0.35</i>	0.29
903-28	0.11	10.0	<i>0.12</i>	<i>0.35</i>	0.21
Crustal mean ^c	0.2	13	1.5	0.05	1.8

^a **Bold:** Value is greater than the crustal mean.

^b *Italic:* Value is less than the detection limit.

^c Mason and Moore (1982).

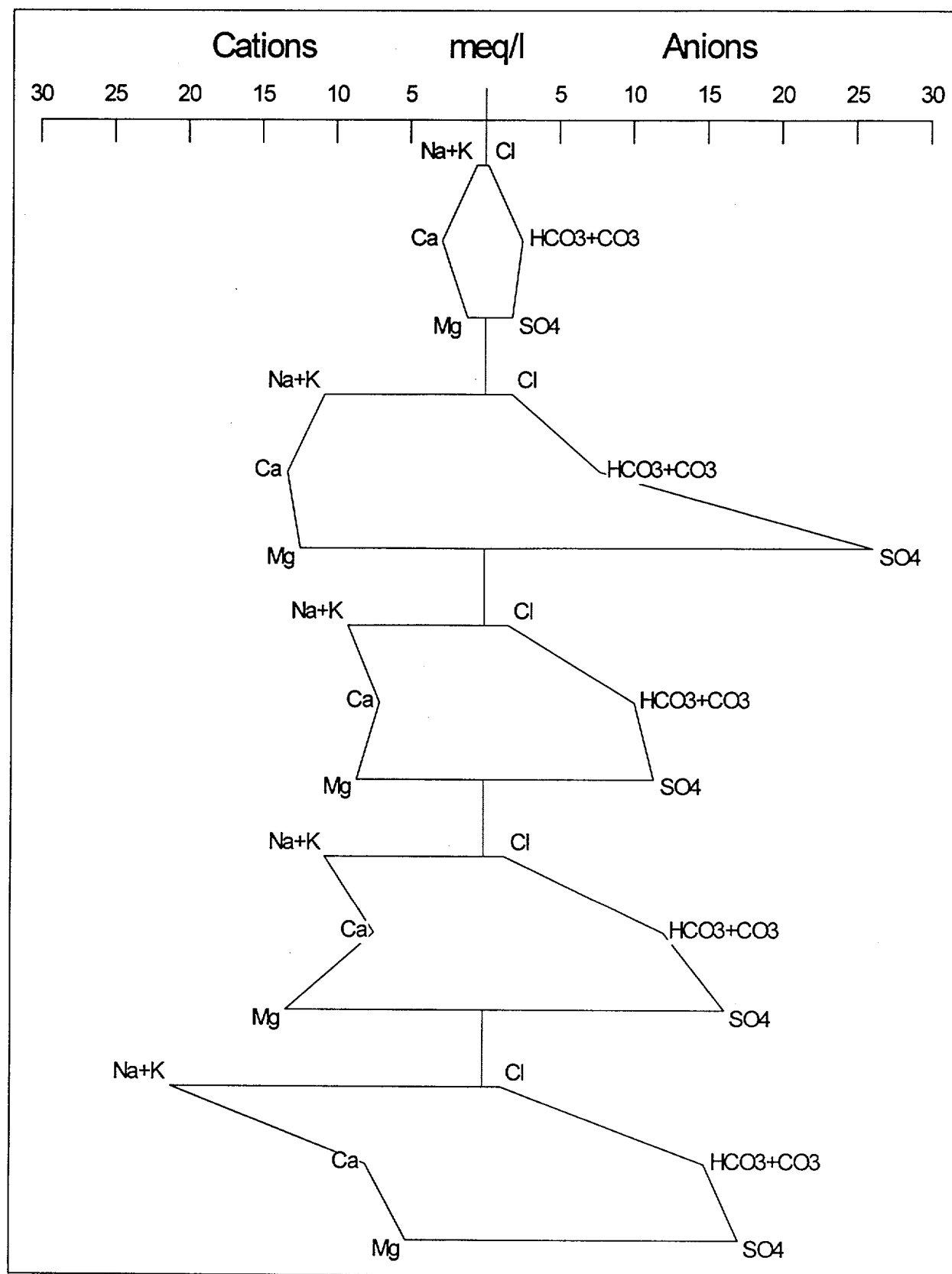


Figure 5-6. Stiff Diagram for Mill Tailings Area (MTA) and Raffinate Ponds Area (RPA) Background Ground Waters and Animas River Water using Mean Concentrations

5.3.1.9 Raffinate Ponds Area Background Sediment and Soil Chemistry

Data for the raffinate ponds area background soils are presented in Table 5–6. Section 4 presents a full description of the subpile soil sampling methods. Background samples were collected at depths of 4 ft, 14 ft, 23 ft, and 28 ft at location 0903 (Figure 5–8).

The cadmium concentrations in one sample exceeded the crustal mean of 0.2 mg/kg. None of the other mean crustal concentrations were exceeded. Lead and uranium concentrations were greater than the detection limits but less than the crustal mean. Molybdenum and selenium concentrations were less than the detection limits.

5.3.2 Mill Tailings Area: Areal Extent of Ground Water Contamination

Maximum constituent concentrations in background ground waters are listed in Table 5–7. The highest background concentration of manganese was less than the human health risk-based level for manganese. The highest background concentration of selenium is greater than the MCL. The highest background concentration of uranium was less than the MCL. The areal extent of ground water contamination is discussed in terms of those samples and well locations that have constituent concentrations greater than the MCL.

Table 5–7. Maximum Constituent Concentrations in Background Ground Waters

Water	Constituent Concentration (mg/L)					
	Cadmium	Lead	Manganese	Molybdenum	Selenium	Uranium
UMTRA MCL ^a	0.01	0.05	1.7	0.1	0.01	0.044
Mill Tailings Area						
Alluvial Aquifer	0.00034	0.007	1.050	0.0057	0.0148	0.0354
Raffinate Ponds Area						
Alluvial Aquifer	U	U	0.605	0.0031	0.0078	0.0056
Menefee Aquifer	U	U	0.58	0.0035	0.0077	0.0093
Point Lookout Aquifer	0.0003	0.005	0.49	0.0155	0.087	0.0321

^aThe human health risk-based value is listed for manganese.

U = less than detection.

Cadmium concentrations in well 0612 exceeded the 0.01 mg/L MCL; the highest value was in the November 2000 sample (Figure 5–9). From 1999 through August 2000 concentrations ranged from 0.0258 to 0.0435 mg/L. The only other location where cadmium concentration has exceeded the MCL is at well 0630, where the concentration of 0.0167 mg/L, was detected in a sample from the November 2000 sampling. The lead concentrations in all samples from June 1999 through August 2001 were below the 0.05 mg/L MCL and were below the detection limit (Figure 5–10). Concentrations of manganese have exceeded the human health risk-based level of 1.7 mg/L seven times at 0612 and two times at location 0630 from June 1999 through August 2001 (Figure 5–11). The 0.1 mg/L MCL for molybdenum was exceeded five times at well location 0612 (Figure 5–12). Molybdenum concentrations ranged from 0.116 to 0.150 mg/L. Selenium concentrations exceeded the MCL at well locations 0612, 0617, 0622, 0630, 0633, 0635, 0857, and 0866, which is the background well (Figure 5–13). Uranium concentrations exceed the MCL of 0.044 mg/L at seven locations: 0612, 0617, 0630, 0631, 0633, 0634, and 0859 (Figure 5–14).

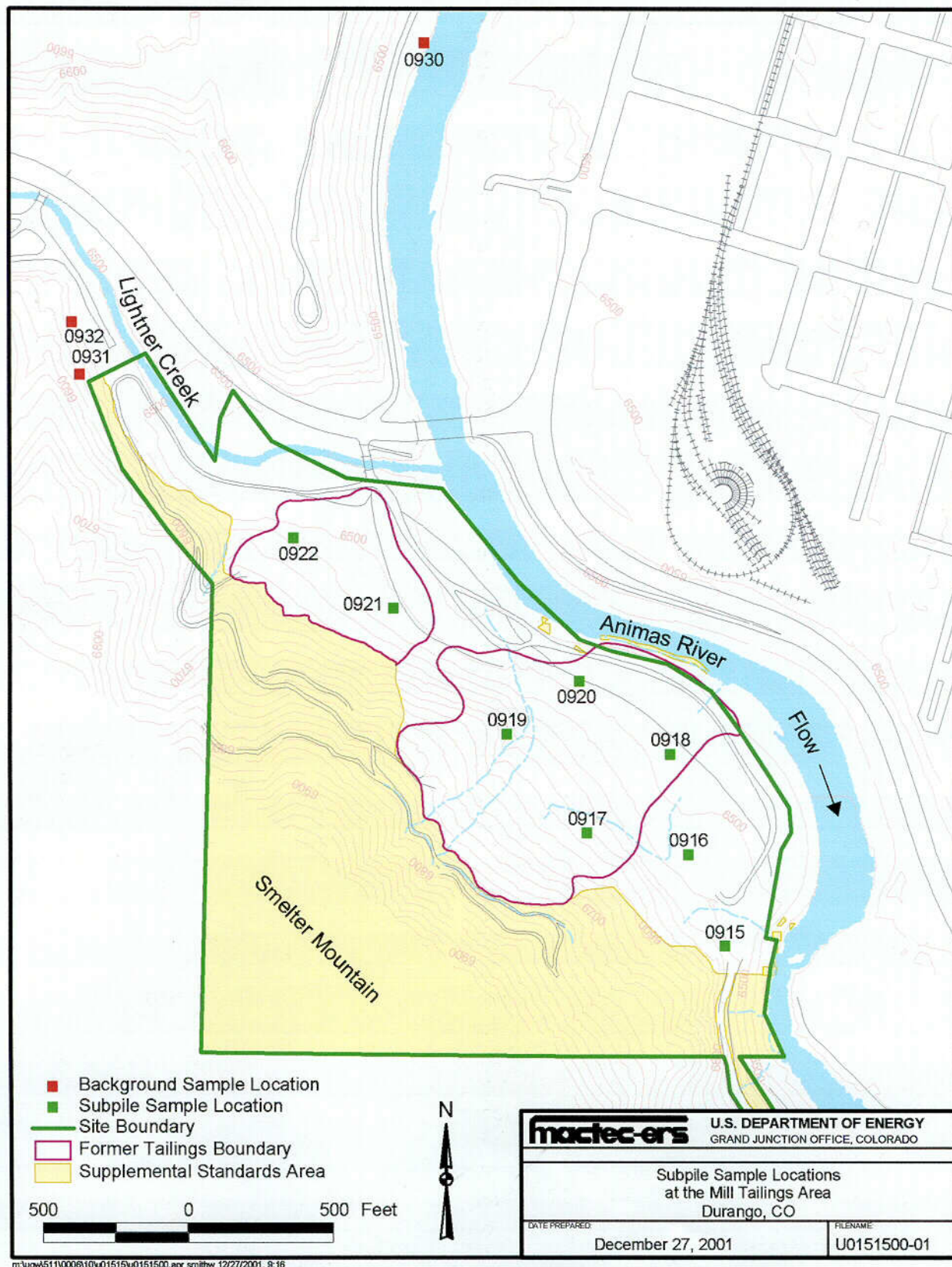


Figure 5-7. Subpile Soil Sample Locations at the Mill Tailings Area

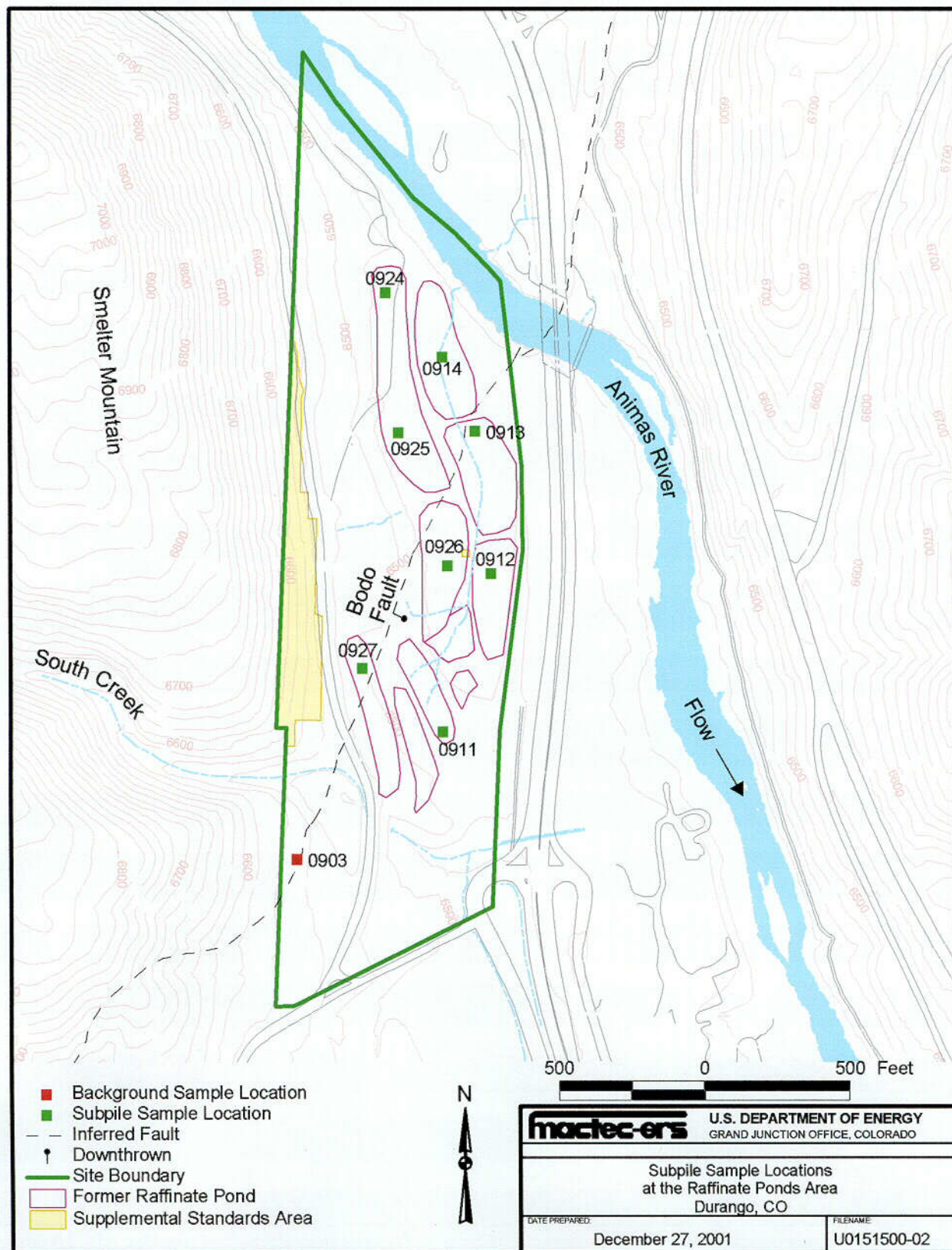


Figure 5-8. Subpile Soil Sample Locations at the Raffinate Ponds Area

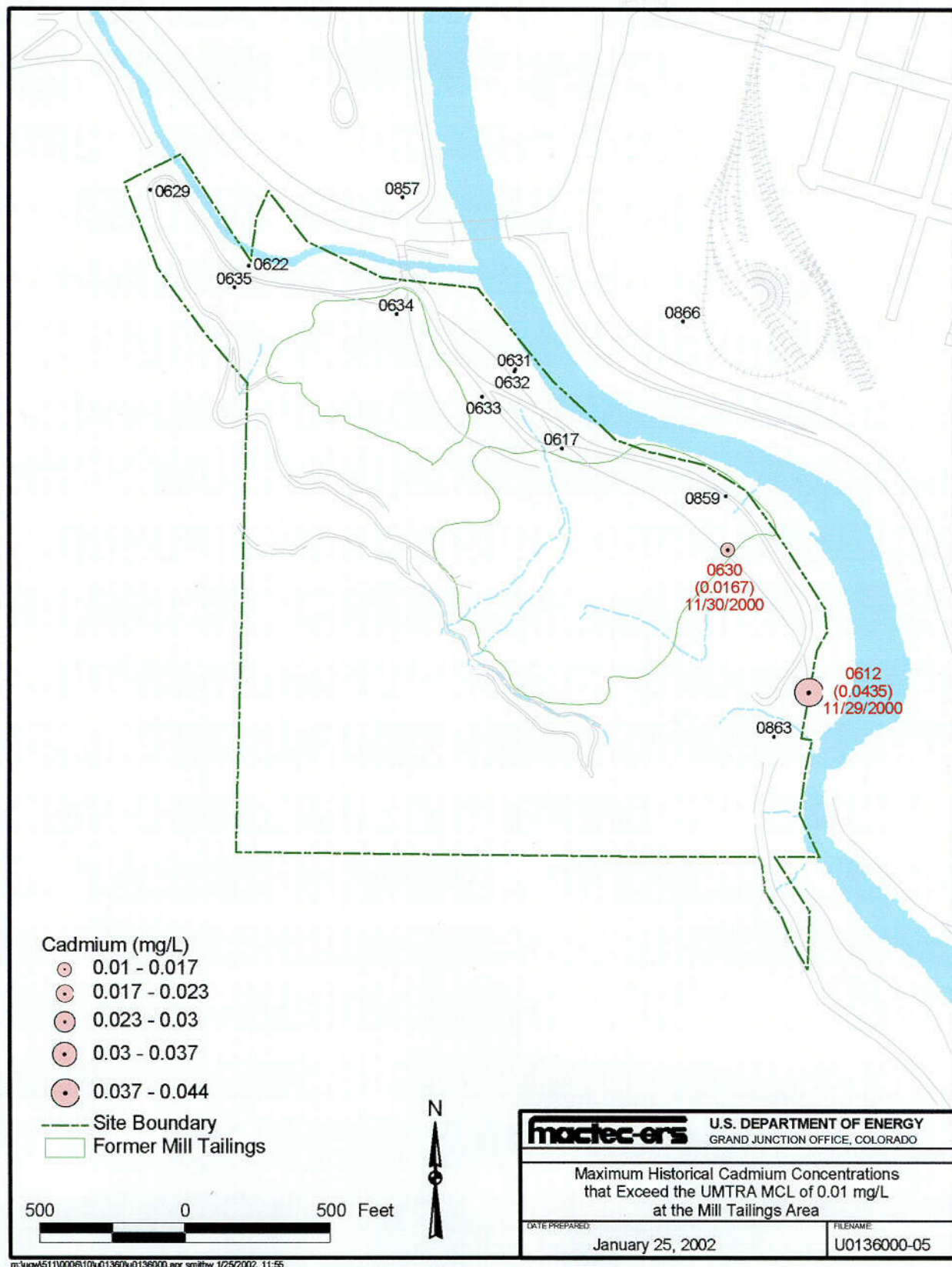


Figure 5-9. Maximum Historical Concentrations of Cadmium at the Mill Tailings Area

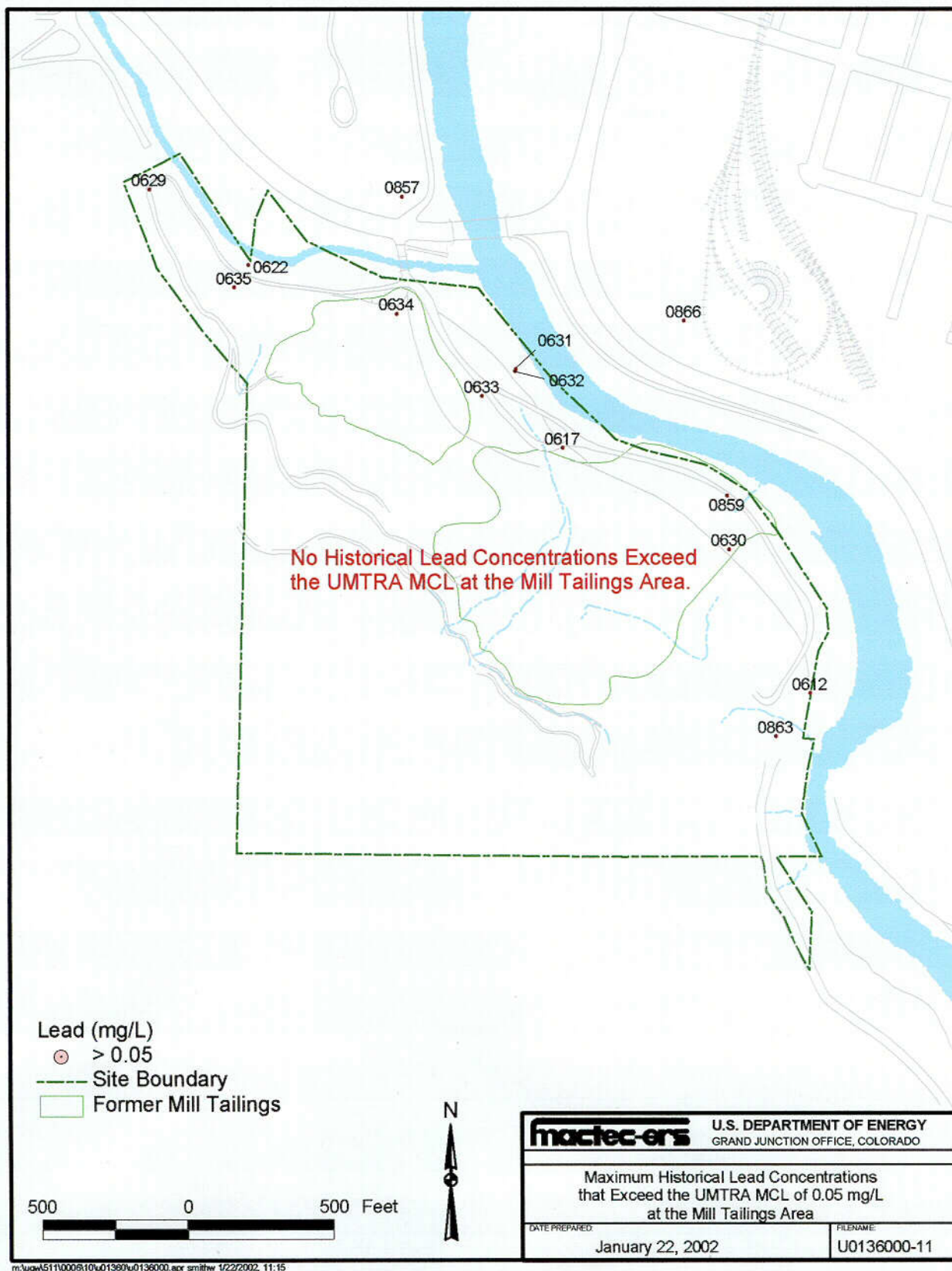


Figure 5-10. Maximum Historical Concentrations of Lead at the Mill Tailings Area

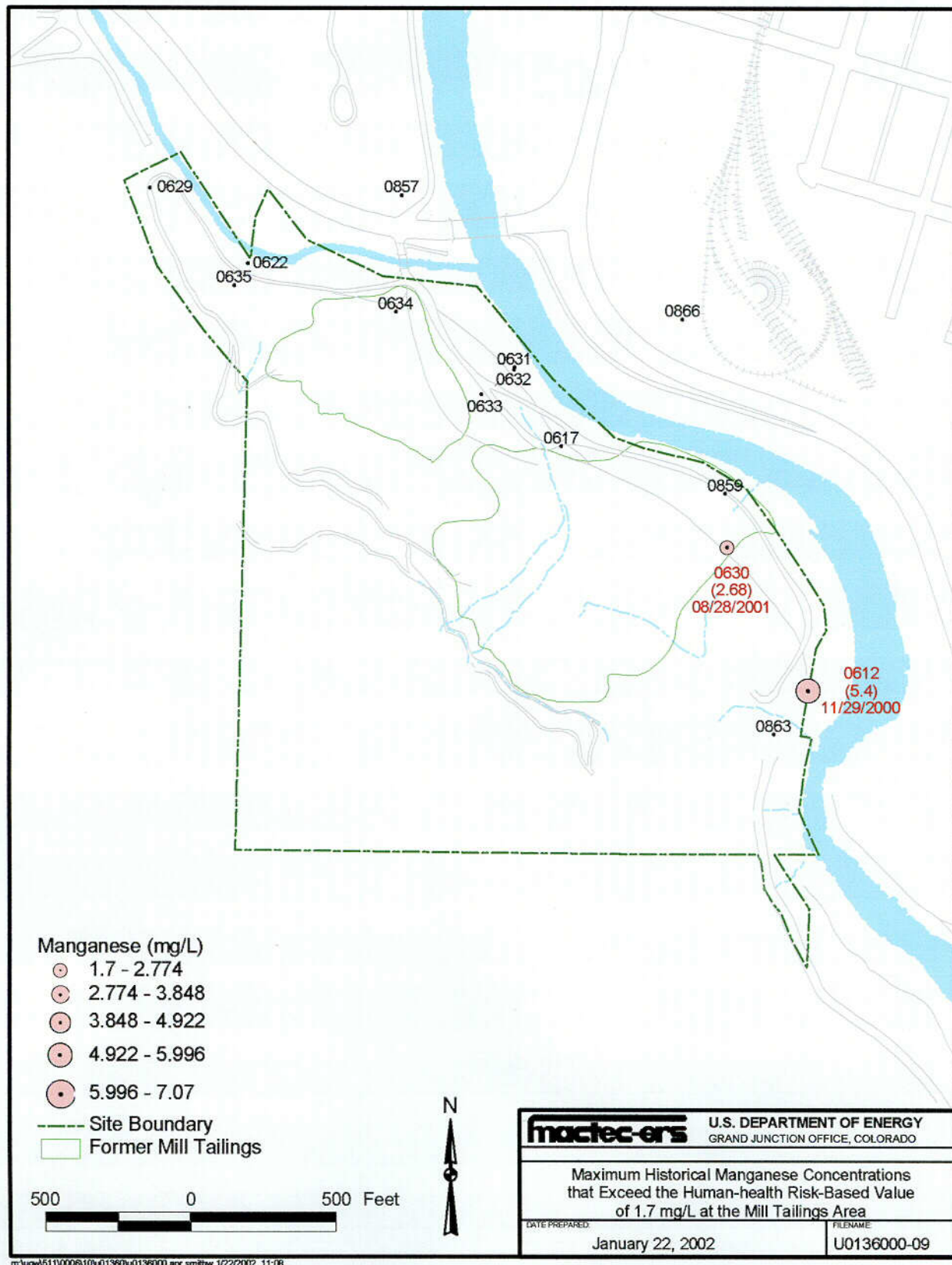


Figure 5-11. Maximum Historical Concentrations of Manganese at the Mill Tailings Area

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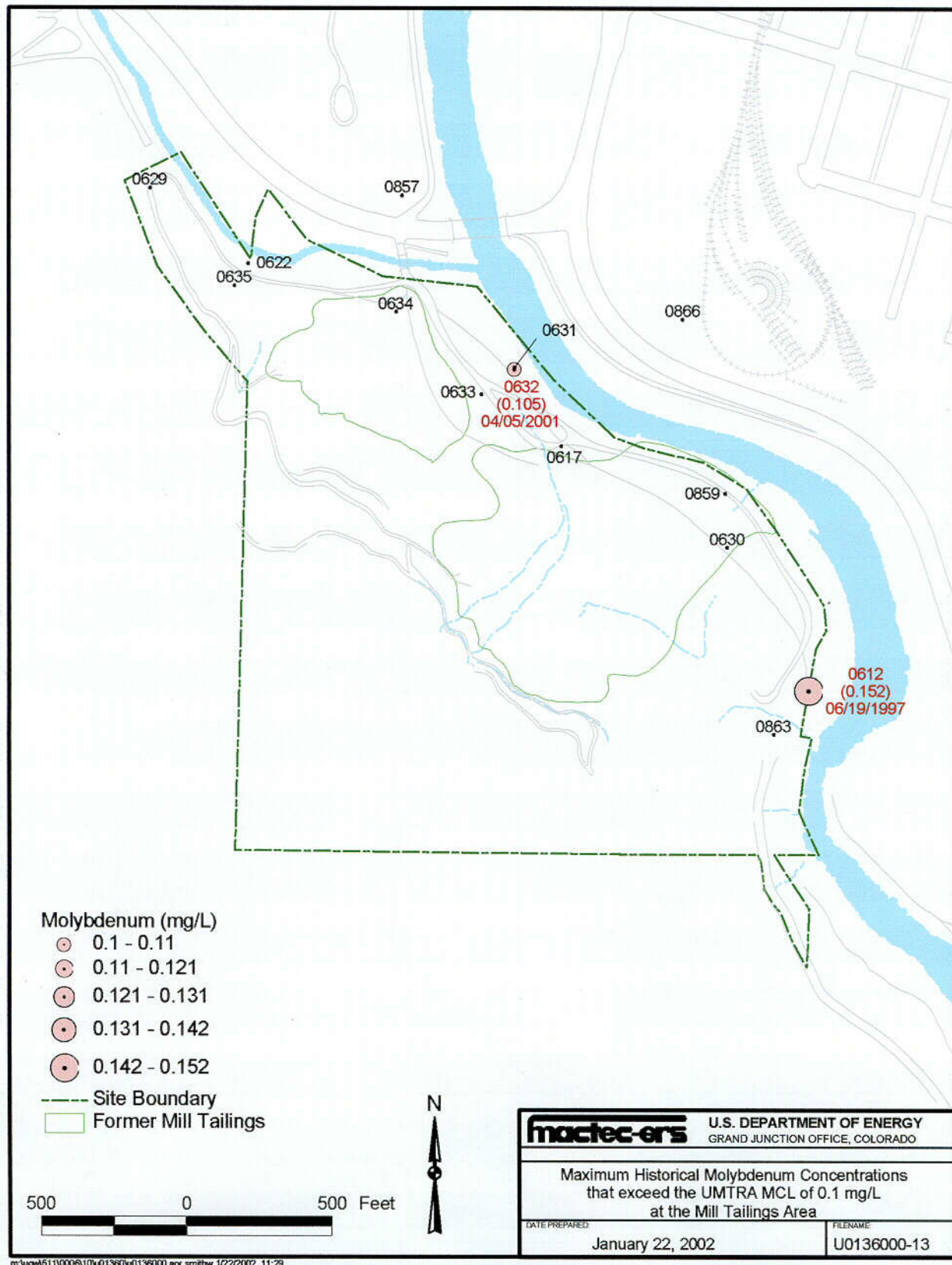


Figure 5-12. Maximum Historical Concentrations of Molybdenum at the Mill Tailings Area

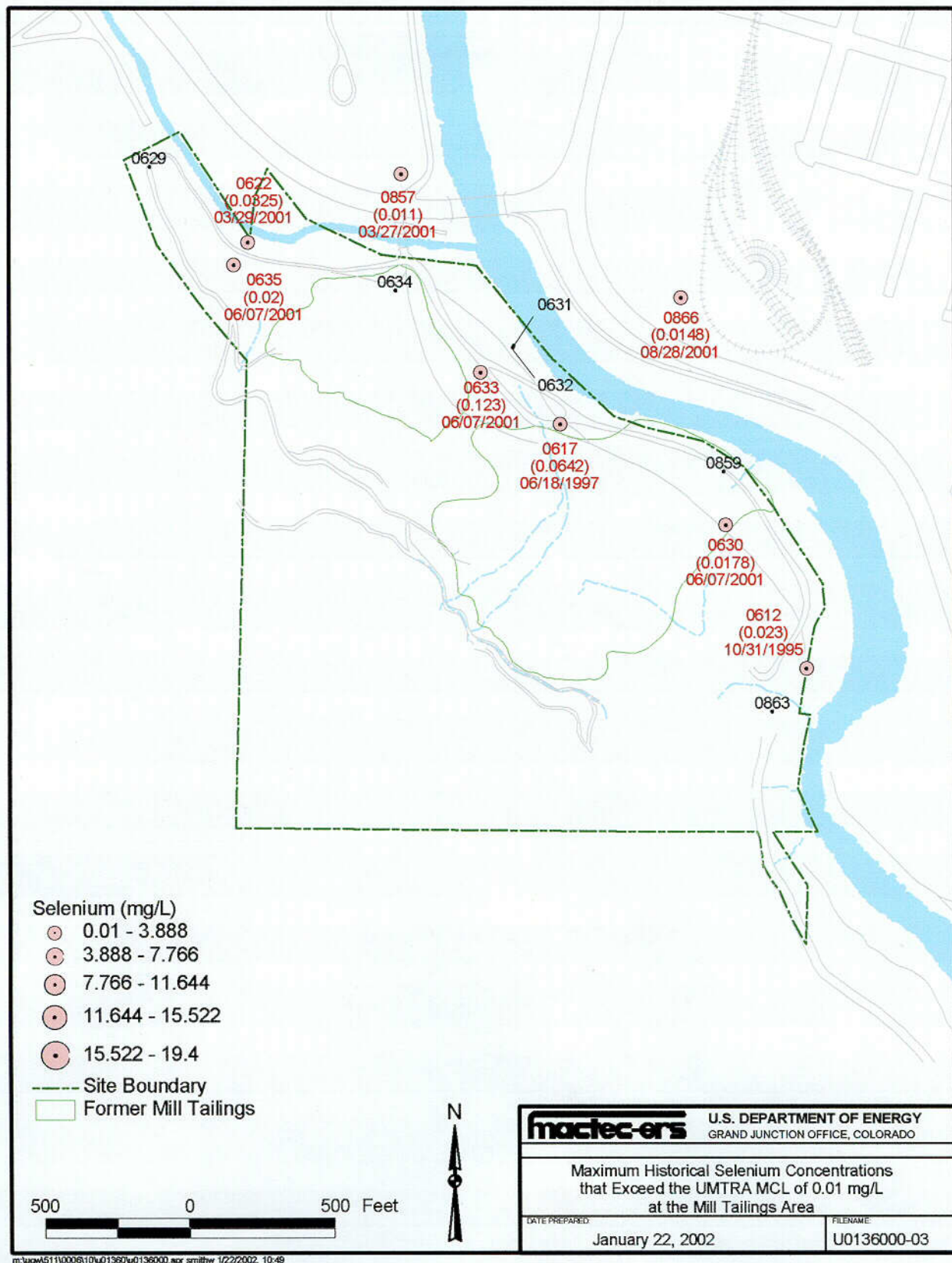


Figure 5-13. Maximum Historical Concentrations of Selenium at the Mill Tailings Area

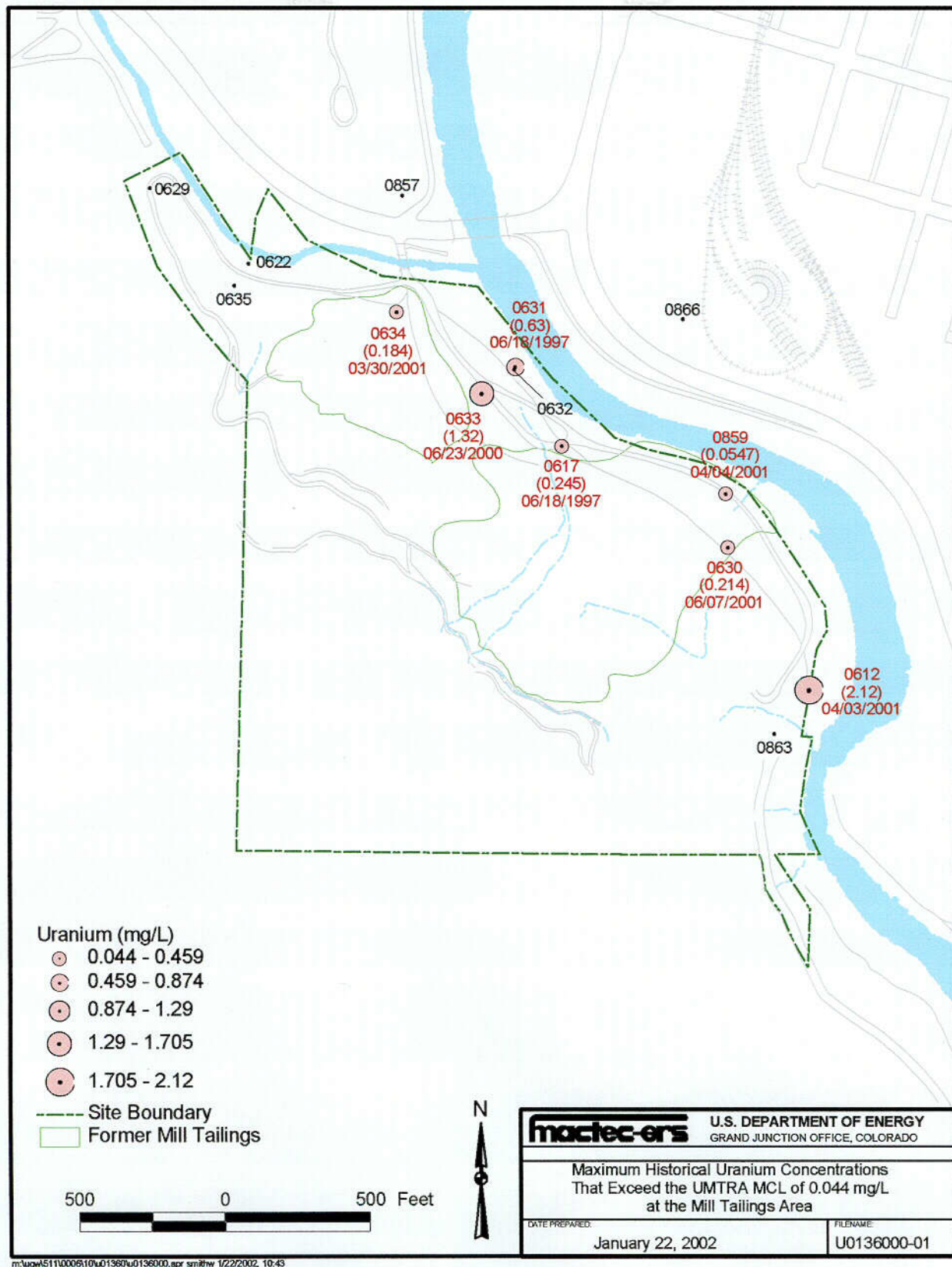


Figure 5-14. Maximum Historical Concentrations of Uranium at the Mill Tailings Area

5.3.3 Raffinate Ponds Area: Areal Extent of Ground Water Contamination

Constituents that exceeded their MCL or human health risk-based standard (manganese), at the raffinate ponds area are displayed in Figure 5-15 through Figure 5-20. The concentrations shown are the maximum historical values for each well location from June 1999 through August 2001; where no historical value has exceeded an MCL or the human health risk-based standard, the constituent concentrations are not listed.

No sample from any well has exceeded the MCL for cadmium (Figure 5-15) or lead (Figure 5-16). Manganese concentrations have exceeded the human health risk-based levels at six wells: 0593, 0598, 0628, 0879, 0880, and 0882 (Figure 5-17). The molybdenum MCL was exceeded in December 2000 at well 0905 (Figure 5-18). Selenium concentrations exceeded the MCL at 10 wells in 2001: 0594, 0596, 0598, 0599, 0600, 0607, 0628, 0879, 0880, and 0884 (Figure 5-19). Uranium concentrations have exceeded the MCL at six wells: 0594, 0598, 0628, 0879, 0880, and 0884 (Figure 5-20).

5.3.3.1 Alluvial Aquifer

Well 0886 is the only background location where alluvium is present. Maximum constituent concentrations in alluvial background ground water from this well are listed in Table 5-7. Concentrations of cadmium, lead, and molybdenum were at or below their detection limits in background alluvial ground water. Concentrations of manganese were less than the human health risk-based level, and concentrations of selenium and uranium were less than their respective MCLs in background alluvial ground water.

Alluvial ground water occurs on site in only one isolated location, at well 0607. Table 5-8 lists the constituents in alluvial ground water at the raffinate ponds area with concentrations that exceed an MCL or the human health risk-based level for manganese. Selenium is the only constituent in alluvial ground water (i.e., in well 0607) with concentrations that exceed its MCL. Concentrations of cadmium, lead, manganese, molybdenum, and uranium were all below both background and their MCLs.

5.3.3.2 Menefee Aquifer

Maximum constituent concentrations in background water in the Menefee Formation are listed in Table 5-7. Cadmium, lead, and molybdenum were not detected in Menefee Formation background waters. The highest background concentration of manganese was less than the human health risk-based level and the highest background concentrations of selenium and uranium were less than their MCLs.

Table 5-8 shows the constituents with concentrations in Menefee Formation ground water that exceeded an MCL or the human health risk-based level. In samples from on-site Menefee Formation wells, concentrations of cadmium, lead, and molybdenum were less than their MCLs. Cadmium concentrations exceeded the background concentration and the detection limit at wells 0594, 0598, 0628, 0879, 0884, and 0891. Lead concentrations exceeded the background concentration and the detection limit at wells 0603, 0879, and 0880. Molybdenum concentrations exceeded the background concentration and the detection limit at wells 0603, 0876, and 0891.

Manganese concentrations were greater than the human health risk-based value at wells 0593, 0598, 0879, 0880 and 0882. Manganese concentrations were greater than the maximum

background concentration and greater than the detection limit at wells 0593, 0598, 0602, 0628, 0879, 0880, 0888, and 0892.

Table 5–8. Raffinate Ponds Area Sample Concentrations Greater Than an UMTRA MCL or the Human Health Risk-Based Value for Manganese

Well	1999		2000			2001				
	June	November	June	November	December	March	April	May	June	August
Alluvial Aquifer										
0607	Se	Se	Se		Se		Se		Se	Se
0886 ^a										
Menefee Aquifer										
0592 ^a										
0593			Mn			Mn			Mn	Mn
0594						Se, U			Se, U	
0598	U	U	U		U		Mn, Se, U		Mn, Se, U	Se, U
0602										
0603										
0628	Se, U	Se, U	Se, U		Se, U		Se, U		Se, U	Se, U
0876										
0878										
0879					U	Mn, Se, U			Mn, Se, U	Mn, Se, U
0880					Mn	Se, U			Se, U	Se, U
0882					Mn		Mn		Mn	Mn
0883										
0884					Se, U		Se, U		Se, U	Se, U
0888										
0890										
0891										
0892										
0902										
0903 ^a										
Point Lookout Aquifer										
0595										
0596									Se	Se
0597										
0599 ^a			Se		Se		Se		Se	Se
0600							Se			
0875 ^a										
0881										
0887										
0889										
0893										

NOTE: Listed is the ground water sampling schedule from June 1999 through August 2001. The listed constituent exceeded its UMTRA MCL or the human health risk-based value for manganese.

^a Background well

	Well was sampled.
	Well not sampled.

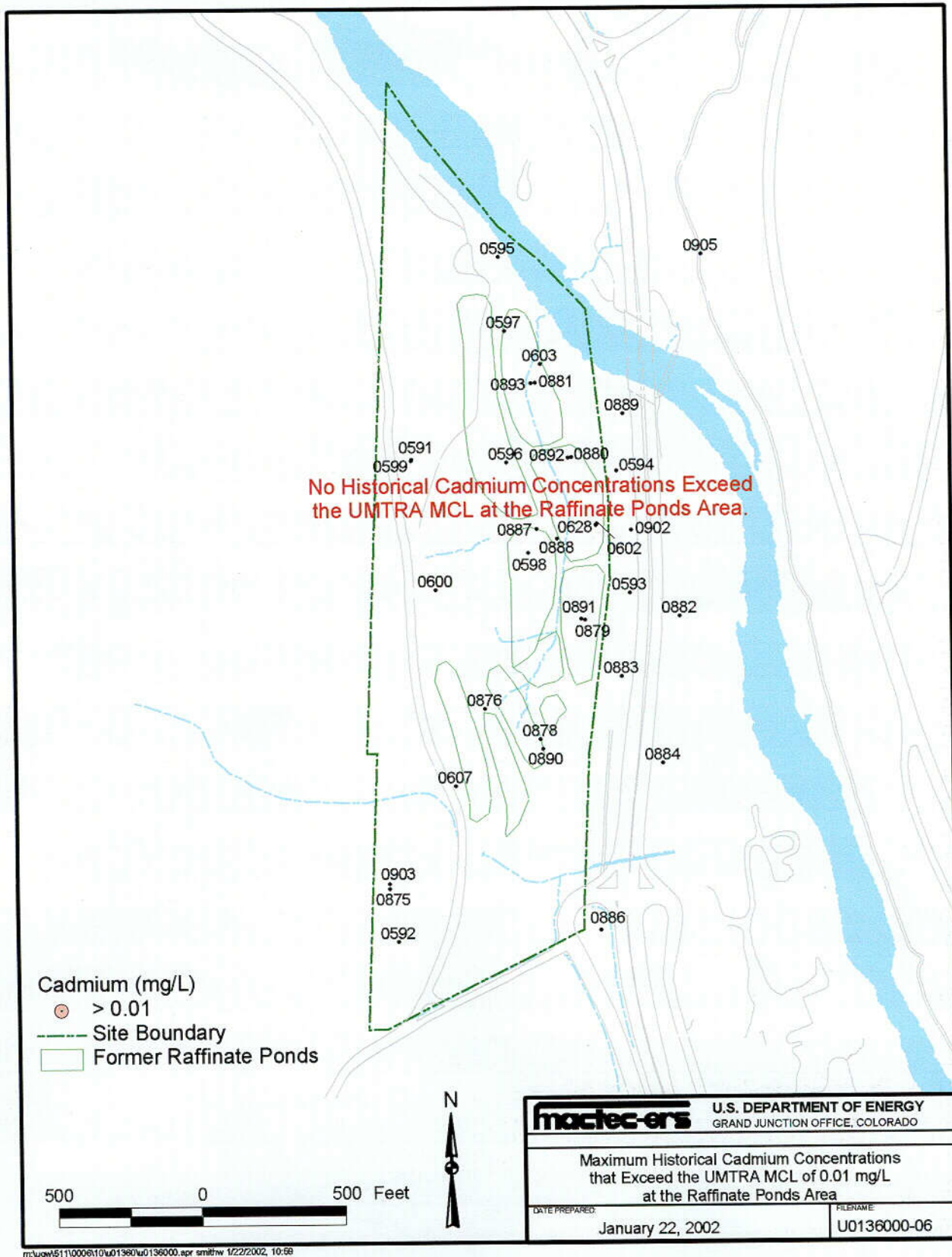


Figure 5-15. Maximum Historical Concentrations of Cadmium at the Raffinate Ponds Area

C 44

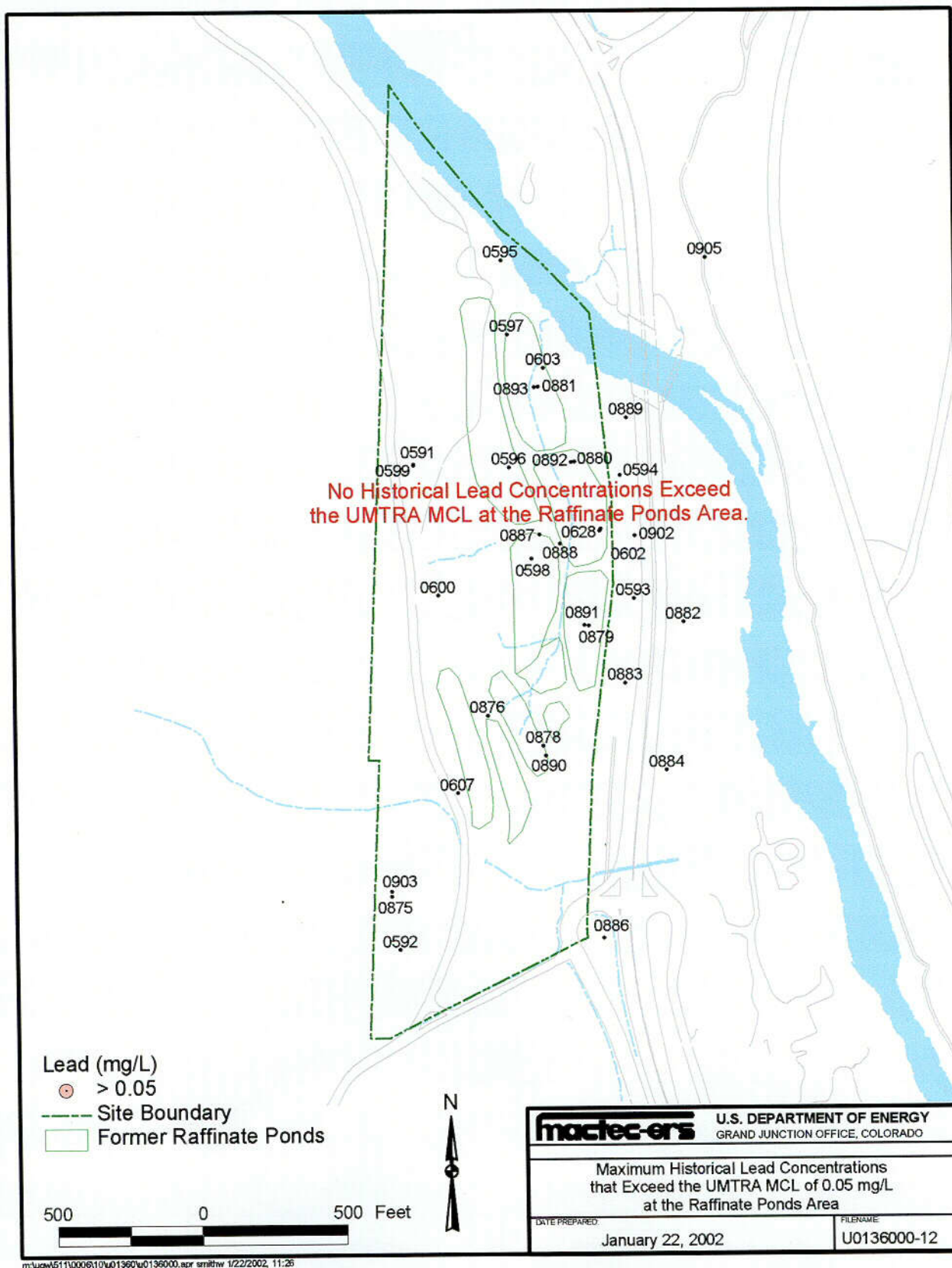
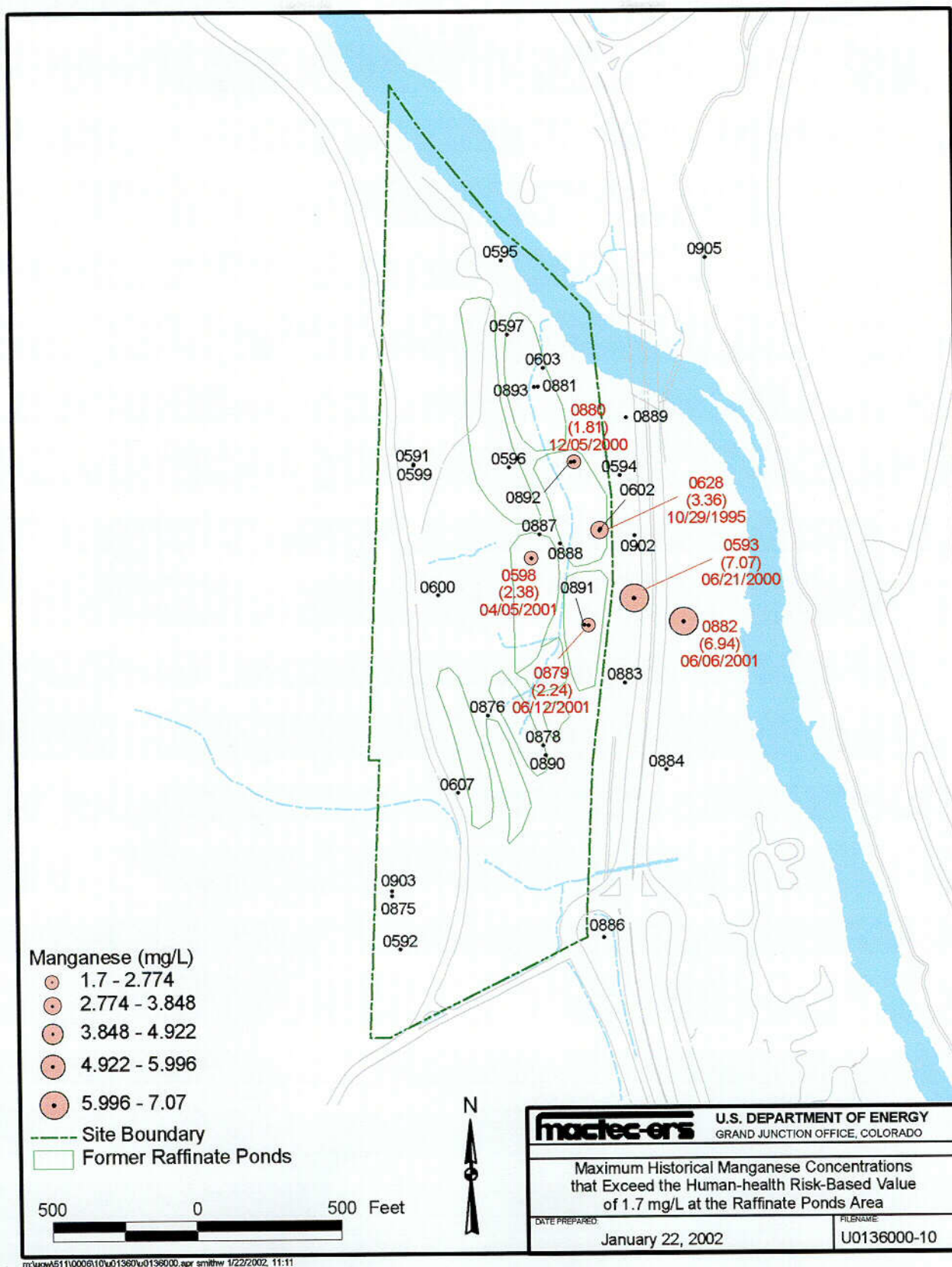


Figure 5-16. Maximum Historical Concentrations of Lead at the Raffinate Ponds Area



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Figure 5-17. Maximum Historical Concentrations of Manganese at the Raffinate Ponds Area

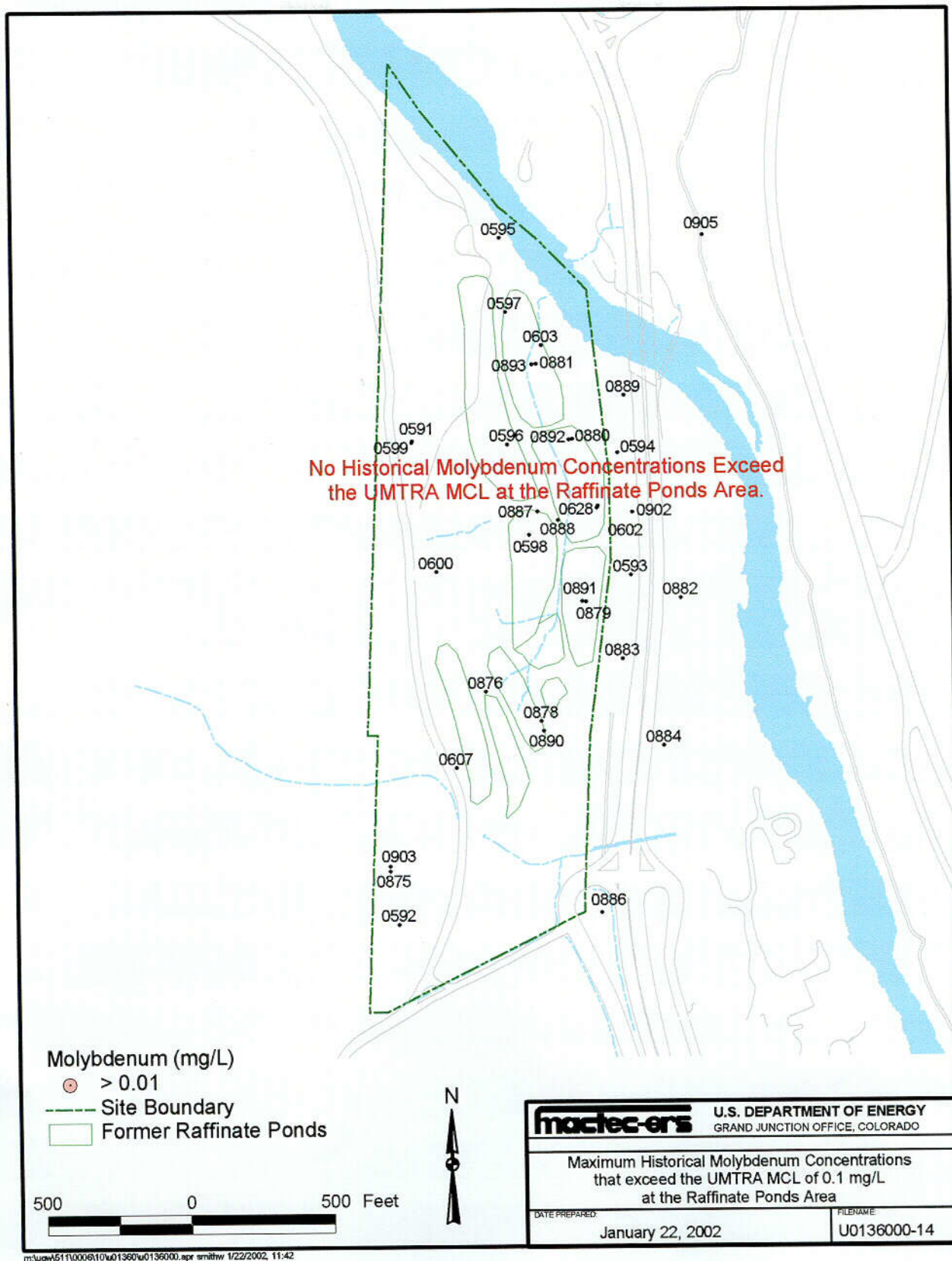
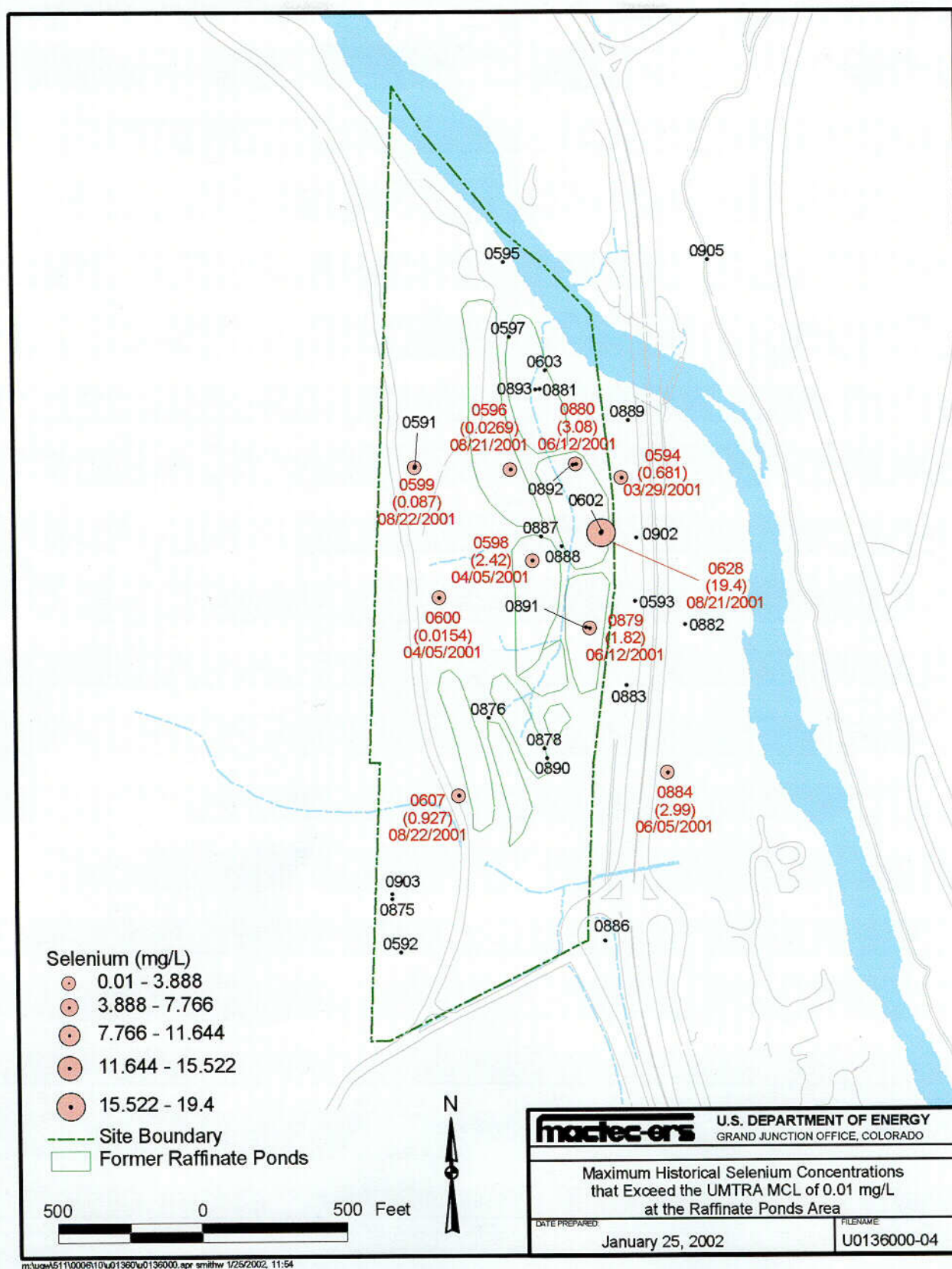


Figure 5-18. Maximum Historical Concentrations of Molybdenum at the Raffinate Ponds Area

C47



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Figure 5-19. Maximum Historical Concentrations of Selenium at the Raffinate Ponds Area

C48

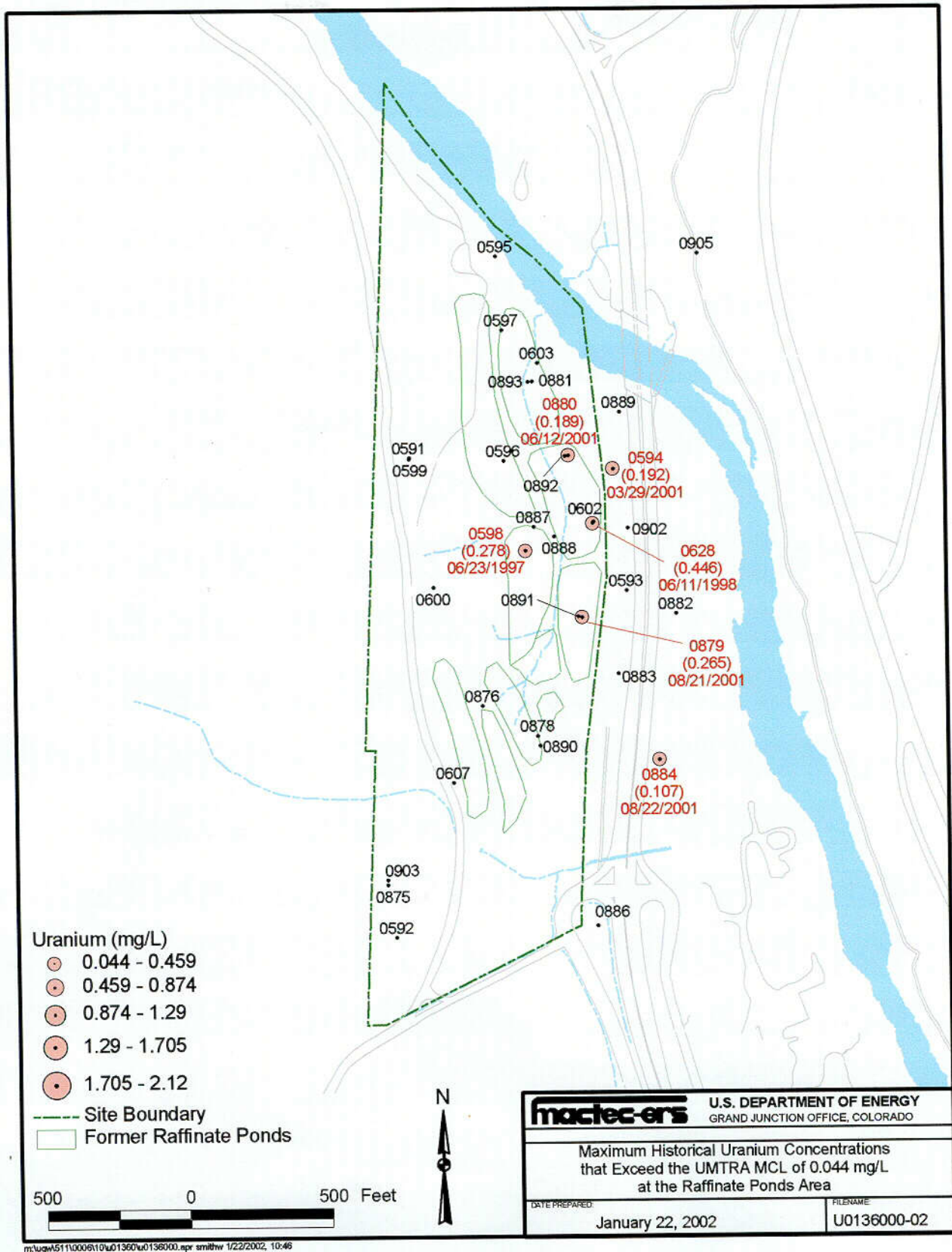


Figure 5-20. Maximum Historical Concentrations of Uranium at the Raffinate Ponds Area

Selenium and uranium concentrations were greater than their MCLs at wells 0594, 0598, 0628, 0879, 0880, and 0884. At well 0593, the selenium concentration in the sample from August 2001 was greater than the background concentration and the detection limit. Uranium concentrations were greater than the highest background concentration and the detection limit at wells 0602, 0891, and 0892.

5.3.3.3 Point Lookout Aquifer

Table 5-7 lists the maximum background concentrations in Point Lookout Sandstone ground water. Cadmium and lead were not detected. The highest background concentration of manganese was less than the human health risk-based level and the highest concentrations of molybdenum, selenium, and uranium were less than their MCLs.

Table 5-8 lists the Point Lookout Sandstone wells where selenium concentrations exceeded the MCL. In on-site Point Lookout Sandstone wells, concentrations of cadmium, lead, molybdenum, and uranium were less than their MCLs. Cadmium concentration exceeded both the background and the detection limit at one location in December 2000. The lead concentration exceeded background and the detection limit at well 0893 in December 2000. Manganese concentrations were less than the human health risk-based level. Molybdenum concentrations exceeded background and the detection limit at well 0887 in November 2000 and at well 0893 in December 2000 and March 2001. All uranium concentrations were above the detection limit but were less than the highest background concentration. Selenium concentrations exceeded the MCL at wells 0596 and 0600, and background well 0599. Selenium concentrations in the remaining samples were below the detection limit.

5.3.4 Fate and Transport of COPCs

In the mill tailings area, antimony, cadmium, iron, lead, lead-210, manganese, molybdenum, polonium-210, radium-226+228, selenium, sodium, sulfate, thorium-230, uranium, and vanadium were identified as COPCs in the Baseline Risk Assessment (BLRA) (DOE 1995a). In the raffinate ponds area, antimony, arsenic, cadmium, chloride, iron, lead, lead-210, manganese, molybdenum, polonium-210, radium-226+228, selenium, sodium, sulfate, thallium, thorium-230, and uranium were identified as COPCs in the BLRA. Analysis of ground water data resulted in the reduction of the number of COPCs to five: cadmium, lead, molybdenum, selenium, and uranium. These five analytes were the only constituents with concentrations that regularly exceeded the MCLs. Although manganese does not have an MCL, it was retained as a COPC because its concentrations were above the human health risk-based level of 1.7 mg/L. Mobility of the COPCs in the subsurface environment is a function of the types of solution complexes formed, the affinity and capacity of the solid-phase adsorption sites for the contaminant, and the solubilities of the reactive minerals containing the contaminant. The dominant solution species are summarized for all aquifers in Table 5-9.

Table 5–9. Dominant Aqueous Species in the Background Ground Waters

Ion	Mill Tailings Area	Raffinate Ponds Area		
	Alluvium	Alluvium	Menefee Formation	Point Lookout Sandstone
Cadmium	Cd^{2+} CdSO_4	CdCO_3 Cd^{2+}	Cd^{2+} CdCO_3	CdCO_3 Cd^{2+}
Manganese(II)	Mn^{2+} MnSO_4	Mn^{2+} MnSO_4	Mn^{2+} MnSO_4	Mn^{2+} MnSO_4
Molybdenum	CaMoO_4 MoO_4^{2-}	MoO_4^{2-} CaMoO_4	MoO_4^{2-} CaMoO_4	MoO_4^{2-} CaMoO_4
Lead	PbCO_3 PbHCO_3^+	PbCO_3 PbHCO_3^+	PbCO_3 PbHCO_3^+	PbCO_3 $\text{Pb}(\text{CO}_3)_2^{2-}$
Selenium(IV)	HSeO_3^- SeO_3^{2-}	HSeO_3^- SeO_3^{2-}	HSeO_3^- SeO_3^{2-}	HSeO_3^- SeO_3^{2-}
Uranium(VI)	$\text{UO}_2(\text{CO}_3)_3^{4-}$ $\text{UO}_2(\text{CO}_3)_2^{2-}$	$\text{UO}_2(\text{CO}_3)_3^{4-}$ $\text{UO}_2(\text{CO}_3)_2^{2-}$	$\text{UO}_2(\text{CO}_3)_3^{4-}$ $\text{UO}_2(\text{CO}_3)_2^{2-}$	$\text{UO}_2(\text{CO}_3)_3^{4-}$ $\text{UO}_2(\text{CO}_3)_2^{2-}$

Note: Species were predicted using the geochemical computer code PHREEQC2.2 (Parkhurst and Appelo 1999). These species do not take into account changes in redox potential because an average redox potential was used.

5.3.4.1 Cadmium

Cadmium contamination at the mill tailings area is limited to wells 0612 and 0630 (Figure 5–9). Cadmium concentrations at well 0612 range from 0.0258 to 0.0435 mg/L and have exceeded the MCL in seven samples collected from June 1999 through August 2001. With the exception of a single sample in which cadmium concentration exceeded the MCL at well 0630, the zone of contamination is limited to well 0612.

According to geochemical models generated using the computer code PHREEQC2.2 (Parkhurst and Appelo 1999), the dominant aqueous cadmium species in the alluvial ground water are Cd^{2+} and CdSO_4 (Table 5–9). The ground water has a mean pH of 6.99, and the conditions are oxidizing. Under these conditions cadmium is soluble and mobile; however, the data do not indicate that cadmium concentrations are increasing in neighboring wells. This may be due to ground water flow direction or to the adsorption of cadmium onto iron and manganese oxyhydroxides. According to the geochemical modeling, ground water is supersaturated in iron hydroxides and iron oxyhydroxides (Table 5–10). Supersaturation indicates sufficient concentrations of ions are present for precipitation of a solid, such as iron hydroxides. Modeling cannot predict when or at what rate precipitation will occur.

Cadmium concentrations in all samples from the raffinate ponds area are below the MCL (Figure 5–15), although concentrations are increasing at wells 0879 and 0884. Alluvial ground water has a mean pH of 7.30; water in the Menefee Formation has a mean pH of 7.10, and Point Lookout Sandstone ground water has a mean pH of 7.44. Redox conditions of the ground waters range from strongly reducing, where the $\text{H}_2\text{S}_{(\text{aq})}$ concentration is 45.9 mg/L, to oxidizing. Cadmium itself does not respond readily to changes in redox conditions. However, it does respond to redox changes in sulfur species and iron and manganese. If sulfur is present, cadmium will precipitate as a sulfide. Under oxidizing conditions cadmium may precipitate with manganese oxide and adsorb onto iron and manganese oxyhydroxides, which are important substrates for adsorption. According to the geochemical model, ground water from the alluvium and the Point Lookout Sandstone is supersaturated in iron hydroxides and iron oxyhydroxides (Table 5–10).

Table 5-10. Calculated Saturation Indices in the Background Ground Waters

Phase	Mill Tailings Area	Raffinate Ponds Area			
	Alluvium	Alluvium	Menefee Formation	Point Lookout Sandstone	Chemical Formula
Aragonite	0.14	0.40	0.25	0.68	CaCO ₃
Calcite	0.29	0.55	0.4	0.83	CaCO ₃
Dolomite	0.66	1.30	1.17	1.58	CaMg(CO ₃) ₂
Fe(OH) _{2.7} Cl _{0.3}	7.02	6.02	2.59	6.52	Fe(OH) _{2.7} Cl _{0.3}
Fe(OH) ₃ (a)	2.04	1.14	-2.33	1.72	Fe(OH) ₃
Goethite	7.93	7.03	3.56	7.61	FeOOH
Hematite	17.9	16.1	9.13	17.2	Fe ₂ O ₃
Jarosite-K	0.26	-3.86	-13.38	-2.21	KFe ₃ (SO ₄) ₂ (OH) ₆
Magnetite	19.3	17.7	9.37	18.6	Fe ₃ O ₄
Fe ₃ (OH) ₈	2.78	1.19	-7.11	2.13	Fe ₃ (OH) ₈
Rhodochrosite	0.06	0.16	-0.28	0.47	MnCO ₃
Se(metal)	-5.7	-1.89	6.76	-4.26	Se
Siderite	0.54	0.56	-0.54	0.35	FeCO ₃
Aragonite	0.14	0.40	0.25	0.68	CaCO ₃
Calcite	0.29	0.55	0.4	0.83	CaCO ₃
Dolomite	0.66	1.30	1.17	1.58	CaMg(CO ₃) ₂
Fe(OH) _{2.7} Cl _{0.3}	7.02	6.02	2.59	6.52	Fe(OH) _{2.7} Cl _{0.3}

Note: Saturation indices were calculated using the geochemical code PHREEQC2.2 (Parkhurst and Appelo 1999). Phases that are super saturated (positive value) are listed in the table.

5.3.4.2 Lead

Lead concentrations in ground water samples from the mill tailings area are all below the MCL (Figure 5-10). Mobility of lead is naturally low because of its low solubility under both oxidizing and reducing conditions. Lead concentrations may be low because of solubility constraints, adsorption, or precipitation. Under oxidizing conditions, lead may coprecipitate with manganese oxide and adsorb onto organic matter and inorganic surfaces, such as manganese and iron oxides. Iron or manganese solids present in sufficient amounts may scavenge lead from solution. According to the geochemical model, ground water is supersaturated in iron hydroxides and iron oxyhydroxides (Table 5-10). Supersaturation indicates sufficient concentrations of ions are present for precipitation of a solid, such as iron hydroxides. Modeling cannot predict when or at what rate precipitation will occur.

In ground water samples from the raffinate ponds area, lead concentrations are all below the MCL (Figure 5-16). Lead concentrations exceeded background in samples from wells 0603, 0879, 0880, and 0893. Lead levels are not increasing within the raffinate ponds area. Concentrations may be low because of solubility constraints, adsorption, or precipitation. According to the geochemical model, ground water from the alluvium and the Point Lookout Sandstone is supersaturated in iron hydroxides and iron oxyhydroxides (Table 5-10).

5.3.4.3 Manganese

At the mill tailings area, manganese concentrations in ground water have exceeded the risk-based value seven times at well 0612 and two times at well 0630 from June 1999 through August 2001 (Figure 5–11). Manganese mobility is related to redox conditions of the subsurface, and its chemistry is similar to that of iron. Manganese forms oxide minerals under oxidizing conditions and is soluble under reducing conditions. Manganese can substitute for calcium in calcite. According to the geochemical model, the dominant manganese species are Mn^{2+} and MnSO_4 (Table 5–9). The geochemical model shows that background ground waters are supersaturated with respect to calcite and various iron minerals (Table 5–10). Supersaturation indicates sufficient concentrations of ions are present for precipitation of a solid, such as iron hydroxides. Modeling cannot predict when or at what rate precipitation will occur.

In the raffinate ponds area, manganese concentrations exceeded the detection limit, background, and the human health risk-based value in samples from wells 0598 and 0880, and the well cluster 0593, 0879, and 0882 (Table 5–8). Concentrations do not appear to be increasing in those wells but are increasing in well 0892, which is near well 0880. Redox conditions of the ground waters range from strongly reducing, where the $\text{H}_2\text{S}_{(\text{aq})}$ concentration is 45.9 mg/L, to oxidizing. Under reducing conditions, manganese is dissolved and present in aqueous form. Under oxidized conditions, manganese may be in both aqueous form and precipitated as manganese oxide. Speciation is dependent upon redox conditions. Manganese behavior is similar to that of iron and generally takes longer to precipitate from solution than iron. The geochemical models for water from the alluvium and the Point Lookout Sandstone indicate that background ground waters are supersaturated with respect to calcite and various iron minerals (Table 5–10). Ground water from the Menefee Formation is supersaturated with respect to calcite and is undersaturated for some iron minerals. Undersaturation indicates precipitation of a solid is unlikely.

5.3.4.4 Molybdenum

At the mill tailings area, molybdenum contamination is limited to wells 0612 and 0630 (Figure 5–12). Concentrations do not appear to be increasing at any location, and the data do not indicate molybdenum is migrating. Dominant species include $\text{CaMoO}_4(\text{aq})$ and MoO_4^{2-} (Table 5–9). Molybdenum has a relatively high geochemical mobility that allows it to enter into solution in water under oxidizing conditions. Molybdenum will precipitate in reduced waters. Solubility controls include precipitation with common metals as metal molybdates. The effectiveness of this control depends on the solubility of the metal. Molybdenum can be adsorbed by amorphous ferric oxyhydroxides. Geochemical modeling indicates that iron minerals are supersaturated in the background ground water (Table 5–10). Supersaturation indicates sufficient concentrations of ions are present for precipitation of a solid, such as iron hydroxides. Modeling cannot predict when or at what rate precipitation will occur.

In ground water samples from the raffinate ponds area, molybdenum concentrations are all below the MCL (Figure 5–18). Two samples from well 0891 indicate concentrations at this location are increasing slightly; levels have increased to values above the detection limit from concentrations that were less than the detection limit. In all other locations, concentrations are not increasing. Dominant species include MoO_4^{2-} and $\text{CaMoO}_4(\text{aq})$ (Table 5–9). Ground water from the alluvium and from the Point Lookout Sandstone is supersaturated with respect to iron minerals. Ground water from the Menefee Formation is undersaturated with respect to these minerals (Table 5–10).

Table 5–11. Mill Tailings Area Sample Concentrations Greater Than an UMTRA MCL or the Human Health Risk-Based Value for Manganese.

Well	1999		2000			2001				
	June	November	June	November	December	March	April	May	June	August
0612	Cd, Mn, U	Cd, Mn, Mo, U	Cd, Mn, Mo, U	Cd, Mn, Mo, U			Cd, Mn, Mo, U		Cd, Mn, U	Cd, Mn, Mo, U
0617	Se, U	Se, U	Se, U	Se, U			Se, U		Se, U	Se, U
0622						Se				
0629										
0630	Se, U	U	Se	U			Mn, U		U	Mn, U
0631	U	U	U	U			U		U	U
0632							Mo			
0633	Se, U	Se, U	Se, U	Se, U			Se, U		Se, U	Se, U
0634						U			U	U
0635						Se			Se	Se
0658										
0857 ^a						Se				
0859				U			U			
0863										
0866 ^a				Se		Se		Se	Se	Se

NOTE: Listed is the Ground Water Sampling Schedule from June 1999 Through August 2001. The Listed Constituent Exceeded its UMTRA MCL or the Human Health Risk-Based Value for Manganese.

^a Background well locations

	Well was sampled.
	Well not sampled.

5.3.4.5 Uranium

Uranium concentrations exceed the MCL and are greater than background concentrations in samples from seven locations (Figure 5–14). Concentrations are increasing in wells 0630 and 0633. In the remaining five wells, concentrations are fluctuating but do not give a steady indication of increasing or decreasing. Uranium concentrations at well 0612 are greater than 1 mg/L. Because there are no wells between well 0612 and the Animas River, the extent and direction of uranium migration is difficult to determine. However, well 0612 is in an area where a lens of uranium was left in place beneath the lead slag following remediation; concentrations may continue to remain elevated (see Section 4.6.2.2). Uranium concentrations at well 0633 have been greater than 1 mg/L in five sampling events. Uranium concentrations have not increased at wells 0617, 0631, and 0632 and may indicate the uranium migration has not extended to these locations or that concentrations have attenuated. According to the geochemical model, the dominant aqueous uranium species are $\text{UO}_2(\text{CO}_3)_3^{4-}$ and $\text{UO}_2(\text{CO}_3)_2^{2-}$ (Table 5–9). The background ground water is supersaturated with respect to calcite, $\text{Fe}(\text{OH})_{2.7}\text{Cl}_{0.3}$, goethite, hematite, and magnetite (Table 5–10). Under oxidizing conditions, uranium is soluble in ground water and mobile due to the presence of aqueous carbonate, a strong complexing agent. Uranium is often sequestered by adsorption to iron oxyhydroxides in soil or through the precipitation of calcite.

In the raffinate ponds area, uranium concentration in ground water samples from the one alluvial well (0607) and the Point Lookout Sandstone are below the MCL (Figure 5–20). Concentration in samples from the Menefee Formation exceeded the MCL at six wells (0594, 0598, 0628, 0879, 0880, and 0884). Of these locations, well 0598 is along the Bodo Fault. At well 0592, the uranium concentrations are less than the MCL; the screen depth of well 0592 is 42.5 ft, below that of well 0880, where concentrations exceed the MCL. Similarly, uranium concentrations at well 0891 are less than the MCL, and the screen depth of well 0891 is 37.5 ft below that of well 0879, where concentrations are greater than the MCL. In both cases, the well pairs are close to each other. These data suggest uranium concentrations are not increasing with depth. Wells that neighbor the six contaminated wells do not show the influence of contamination and may indicate the uranium migration has not extended to these locations or that uranium concentrations have attenuated. Redox conditions range from reducing to oxidizing. According to the geochemical model, the dominant aqueous uranium species under oxidizing conditions are $\text{UO}_2(\text{CO}_3)_3^{4-}$ and $\text{UO}_2(\text{CO}_3)_2^{2-}$ (Table 5–9). Under reducing conditions, it is likely that uranium is present in solid form, as U(IV). Saturation indices for iron phases depend upon the redox conditions. Under reducing conditions, iron is present in aqueous form; oxidizing conditions produce solid iron phases. Regardless of the redox conditions, all waters are supersaturated with respect to calcite (Table 5–10). Under oxidizing conditions, uranium is soluble in ground water and mobile due to the presence of aqueous carbonate, a strong complexing agent. This mobility is limited under reducing conditions. Uranium mobility can be limited by adsorption to iron oxyhydroxides in soil under oxidizing conditions or through the precipitation of calcite.

5.3.4.6 Selenium

At the mill tailings area, selenium concentrations have exceeded the MCL at eight locations in samples of both background ground water and site ground water (Figure 5–13). Concentrations have increased at wells 0617, 0630, 0633, 0635, and 0866. The mobility of selenium is low. In the presence of iron, selenium may form the mineral FeSe_2 and may coprecipitate with pyrite under reducing conditions. Under oxidizing conditions, selenium may be adsorbed on or interact with ferric oxyhydroxides. The geochemical model indicates selenium is present as Se(VI), and the dominant species are HSeO_3^- and $\text{H}_2\text{SeO}_{3(\text{aq})}$ (Table 5–9). Iron hydroxides and oxyhydroxides are supersaturated in the water (Table 5–10). Supersaturation indicates sufficient concentrations of ions are present for precipitation of a solid, such as iron hydroxides. Modeling cannot predict when or at what rate precipitation will occur.

In the raffinate ponds area, selenium concentrations exceed the MCL in samples from 10 wells (Figure 5–19). Selenium levels in each of these wells have exceeded the MCL at least twice, and the concentration in well 0607 has exceeded the MCL seven times from June 1999 through August 2001. According to the data, selenium concentrations are not increasing in wells downgradient from well 0607. The mean background concentrations range from 0.0069 mg/L in alluvial ground water to 0.075 mg/L in ground water of the Point Lookout Sandstone. Selenium concentrations have been greater than 1 mg/L in five wells (0598, 0628, 0879, 0880, and 0884), all of which are completed in the Menefee Formation. These higher concentrations appear to be limited in location and not part of a continuous plume. Concentration is increasing at well 0628 but is below the detection limit in well 0602, approximately 5 ft downgradient. Selenium concentration in well 0598 is decreasing from its highest value of 2.42 mg/L in April 2001. Yet, adjacent wells 0888 and 0892 have concentrations below the detection limit. Selenium concentrations above the MCL in well 0884 occur in an isolated location downgradient and off

site. Selenium migration may be limited by adsorption and precipitation and is discussed in the following section.

5.4 Selenium at the Raffinate Ponds Area

Selenium is the constituent present at relatively high concentrations in the greatest number of wells at the raffinate ponds area. Selenium concentration has exceeded the MCL on at least one occasion at wells 0593, 0594, 0596, 0598, 0600, 0602, 0603, 0607, 0628, 0879, 0880, and 0884. In wells 0593 and 0600, selenium levels have exceeded the MCL on only one occasion. Concentrations in well 0607 have been increasing since the completion of surface remediation. In the remainder of the wells, historical concentrations of selenium have fluctuated from below detection limits to orders of magnitude above the MCL, often over short periods of time. With the exception of well 0598 screened in the Bodo Fault, the locations where selenium levels are above the MCL are shallow wells (screened 50 ft or less below ground surface). With the exception of wells 0596 and 0600, all wells with elevated selenium concentrations are screened within or below coal or carbonaceous shale units (no concentrations are above the MCL in any of the wells screened solely within the massive sandstone units). Results of the field investigation (along with historical data) indicate that selenium in the ground water is derived from naturally occurring sources (coal, carbonaceous shale, and pyrite), and is not related to raffinate from the ore processing.

Selenium concentrations in all samples from background well 0599 have exceeded the 0.01 mg/L MCL; concentrations have ranged from 0.62 to 0.87 mg/L. Although elevated selenium concentrations are not detected in other background wells at the raffinate ponds area, the ground water in all other background wells is reducing and under reducing conditions selenium is not mobilized into the ground water (in background wells at the mill tailings area where the conditions are oxidizing selenium concentrations exceed the MCL).

As an indication of the abundance of naturally occurring selenium in the area, a hazard rating method was developed to determine whether surface waters would have sufficient selenium to be toxic to aquatic life. This method has been applied to the proposed Animas-La Plata water project. That review indicated the proposed reservoir will cause selenium toxicity in sensitive aquatic life (Lemly 1997). Selenium concentrations in background surface waters, collected by the BOR for the Animas-La Plata project have exceeded the UMTRA MCL (BOR 1996).

5.4.1 Literature Review

It is well known that selenium occurs naturally in high concentrations in the western United States. Most occurrences are related to Cretaceous sedimentary deposits (Seiler 1998), although elevated concentrations are found in rocks from Pennsylvanian to Quaternary age (Stephens and others 1992). Selenium occurrences are usually associated with sulfur because the two elements are closely related in ionic size, permitting selenium to commonly substitute for sulfur in sulfide minerals.

Evaporite deposits from the Mancos Shale are often implicated for degrading water quality in irrigated regions in the Intermountain West (Stephens and others 1992). However, coals can also be sources of selenium. For example, Naftz and Rice (1989) reported total selenium values of 0.5 to 2 mg/kg for early Tertiary sandstones associated with coal seams from the Powder River Basin. Selenium may be the most enriched trace element in coal (Valkovic 1983). The

occurrence of selenium in conjunction with coal has relevance to the Durango site because the Menefee Formation is coal bearing and thus may be a source for the naturally occurring selenium.

Coleman and Delevaux (1957) performed an extensive review of selenium occurrences on the Colorado Plateau. These investigators found the following sulfides contained selenium in decreasing amounts: galena, chalcopyrite, arsenopyrite, sphalerite, pyrite, and pyrrhotite. Selenium was also found to be associated with pyrite and coalified wood in Emery County, Utah. Samples of pyrite and marcasite collected from the Mancos Shale near Slick Rock, Colorado, had an average of 140 mg/kg of selenium. The highest selenium level in Colorado Plateau pyrites or marcasites reported in their study was 300 mg/kg. Chalcocite (Cu_2S) in the Slick Rock district contained as much as 1.2 percent (12,000 mg/kg) selenium. However, of particular importance to the circumstances at Durango is the selenium content of pyrite, which is abundant in the bedrock units underlying the site (Section 4.2).

5.4.2 Durango Site Historical Data

Historical data indicate selenium was not unusually abundant in the Durango processing operations and was not detected at all in the effluent (raffinate) that flowed to the raffinate ponds area (Tsivoglou and others 1960). This suggests that highly variable and increasing selenium concentrations at the raffinate ponds area are not a result of contamination associated with uranium processing operations.

In 1958 and 1959, the U.S. Department of Health, Education, and Welfare conducted an intensive field study of interstate pollution of the Animas River, with special emphasis on the contributions from the Durango processing site while the mill was in operation. The studies were a cooperative effort of the Public Health Service, the New Mexico and Colorado State Departments of Health, the San Juan County Health Department, and the AEC (Tsivoglou and others 1960). The studies included extensive sampling (over a period of several months in 1958) of the main plant discharges, the tailings pond discharges, and the organic raffinate effluents (acid liquor from solvent extraction) (Tsivoglou and others 1960). Additional samples were collected through the first half of 1959 by State of Colorado and local health agencies.

The studies concluded seepage from both the tailings piles and the raffinate ponds contained a similar suite of contaminants derived from the processing reagents. The analyses indicated the tailings seepage was more diluted, with a pH of 4.1 and total dissolved solids (TDS) of 8,450 mg/L. By contrast, seepage from the raffinate ponds had a pH of 0.8 and a TDS of 116,000 mg/L. (Tsivoglou and others 1960). However, dissolved selenium was not detected in either contaminant source (it was present in the main plant effluent). Chemical analyses of the raffinate ponds liquor as reported by Tsivoglou and others (1960) is shown in Table 5-12.

Table 5-12. Chemical Analyses of Mill Discharge to the Raffinate Ponds

Chemical	Concentration (mg/L)
Arsenic	16
Selenium	<0.01
Beryllium	30
Vanadium	250
Copper	23
Manganese	200
Iron	370
Sodium	16,000
Fluoride	12
Sulfate	66,000
Chloride	6,500
Total Hardness	20,000
Total Dissolved Solids	116,000
PH	0.8

Historical data and the occurrence of selenium in background well 0599 (Section 4.6.3.1) indicate variable and increasing selenium concentrations in ground water at the raffinate ponds are related to naturally occurring sources of selenium, and not the former mill operations.

5.4.3 Data Review of Selenium in Well 0628

Because of the screen length and current condition of well 0628, analytical results from this well are not considered to be a valid and reliable assessment of ground water conditions at this location. However, results from this well are included in the discussion because of anomalously high selenium concentrations detected from 1993 to the present (Table 5-13). Selenium concentrations in well 0628 have historically demonstrated a large degree of fluctuation, with values ranging from 0.14 mg/L to a most recent value of 19.4 mg/L. Well 0628 is screened continuously from its total depth of 32 ft to 2 ft below the surface, and the protective concrete surface pad is no longer intact. Analytical results from this well may reflect the transport of surface or near-surface materials into the well by precipitation, runoff from storm events, or snowmelt.

As shown in Plate 3, the screened interval nearly to the surface in well 0628 is near a subcropping zone of coal beds in the Menefee Formation. The screened interval is not shown at the ground surface in the cross section because it was projected to identify lithology. These nearby subcropping coal beds are a likely source for selenium to be mobilized by increasing contact with oxidizing water. This interpretation is supported by the correlation between water levels and selenium concentrations in this well. As shown in Figure 5-21, with the exception of the most recent value, there is a direct correlation between water levels and selenium concentrations.

Well 0602 is downgradient within 5 ft of well 0628, but with a screened interval from 32 to 57 ft. Selenium concentrations in well 0602, although variable (the well is screened in a coal bed), have been below the detection limit since 1990, indicating that elevated selenium concentrations are not derived from ground water flow below the water table. Sampling events for well 0602 since 1993 are listed in Table 5-13.

Table 5–13. Selenium Concentration in Well 0628 at the Durango Raffinate Ponds Area

Date Sampled	Concentration (mg/L)
11/21/1993	1.11
06/03/1994	0.14
11/03/1994	1.70
10/29/1995	0.33
06/19/1997	6.54
06/11/1998	1.85
06/29/1999	0.70
11/11/1999	2.66
06/21/2000	4.01
12/06/2000	1.77
04/04/2001	12.3
06/12/2001	10.9
08/21/2001	19.4

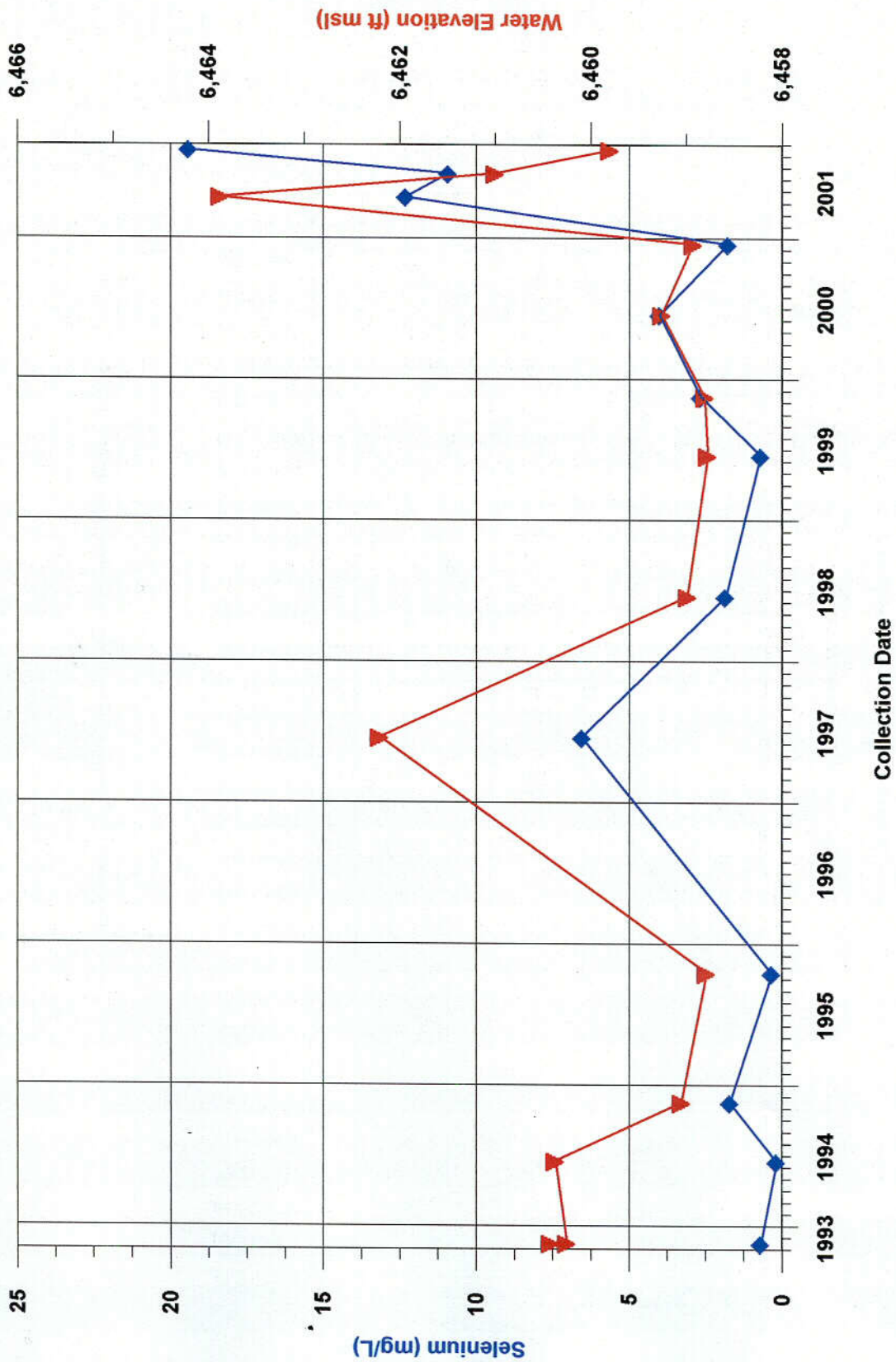
The values for iron in well 0628 have also decreased dramatically since 1995 (Figure 5–22), indicating the ORP has likely increased, which enhances the mobilization of naturally occurring selenium.

Well 0628 was installed in 1993, and since that time concentrations of uranium, sulfate, and TDS have all shown a clear downward trend. The decrease in levels of millsite-related constituents in well 0628, the absence of selenium in deeper adjacent well 0602, and the increasing oxidation (decreasing iron concentrations) indicate geochemical conditions are mobilizing naturally occurring selenium in the nearby subcropping coal beds.

5.4.4 Data Review of Selenium in Well 0607

At the raffinate ponds area, only well 0607 has data before and after surface remediation (from 1982 to present). Other wells in place before remediation were lost because of the on-site activities associated with remediation (except well 0602, see Section 4.1.2). Post-remediation (1991) well 0607 has had an increase in selenium from near the detection limit to nearly 1 mg/L. The increase in concentration is not correlated with increases in other uranium-ore related contaminants.

DUR02-0628



◆ Selenium
▼ Water Elevation
 Figure 5-21. Selenium Concentrations and Ground Water Elevations at Well 0628

C 50

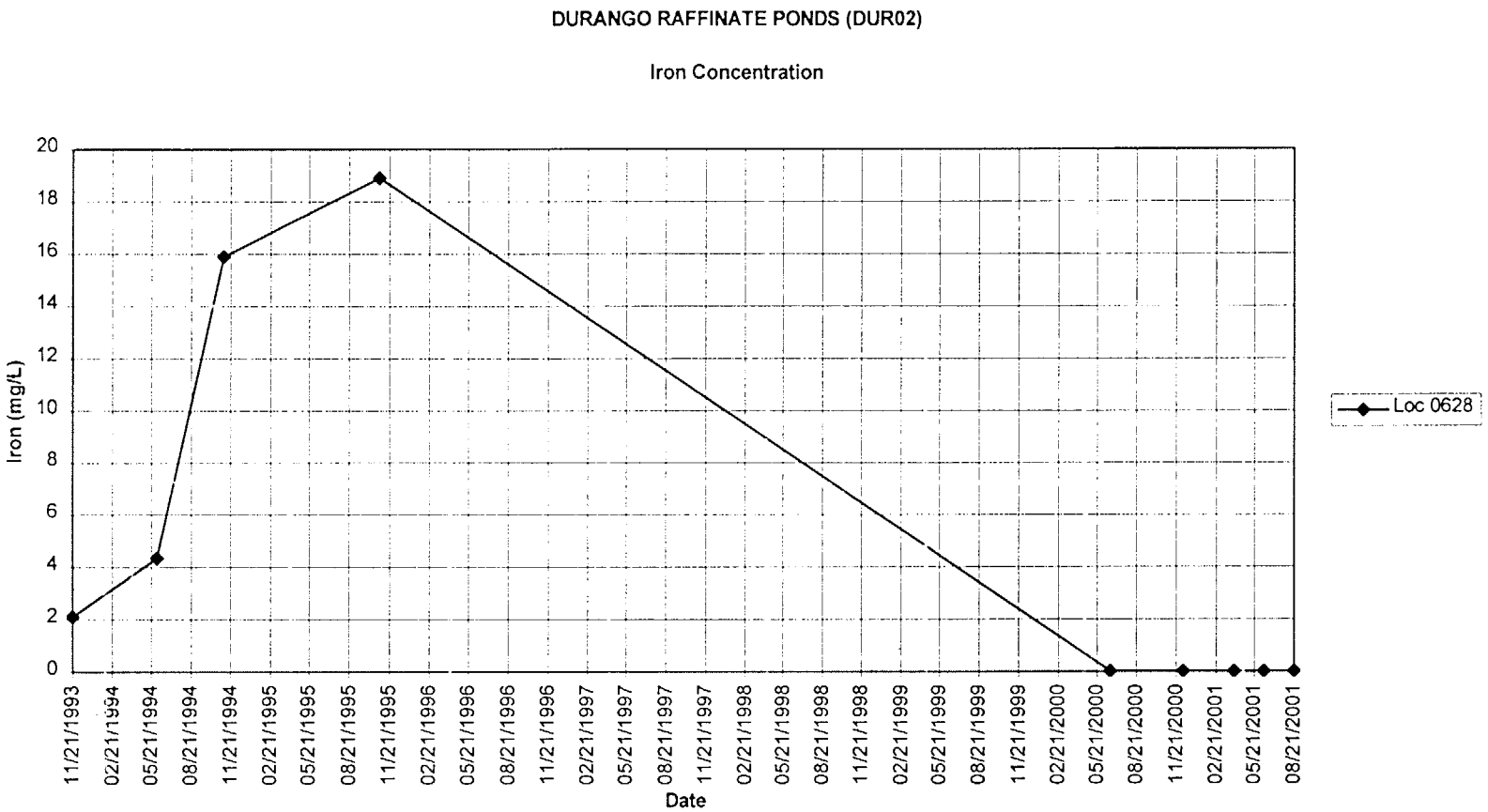


Figure 5-22. Time-Concentration Plot of Iron in Well 0628

A review of the data for well 0607 indicates that increased selenium is not due to the former processing operations. The reasons are as follows

- Well 0607 is hydraulically upgradient from the former raffinate ponds. Ground water in the area of well 0607 receives surface recharge from South Creek (Section 5.2.2). Because ground water flows past the well toward the former ponds, the former ponds are not a source for the increasing selenium concentrations in well 0607.
- All available data regarding contamination at the site, historical evidence regarding selenium occurrence, and geochemical principles that explain selenium mobility indicate that if selenium were from the uranium operations, concentrations of other contaminants (e.g., uranium, molybdenum) would increase in the same manner. The fact that only selenium levels are increasing indicates its source is not the former uranium operations.
- Geochemical changes in ground water from pre-to post-remediation explain the dissolution of selenium from the Menefee Formation. As noted by Masscheleyn and others (1990), "Redox potential and pH are key factors in the biogeochemistry of selenium." Little change in pH has been observed; thus, an increase in naturally occurring selenium would require an increase in the redox potential. Plots of iron and ORP versus time (Figure 5-23 through Figure 5-25) demonstrate redox potential has increased. Iron precipitates when the pH is near neutral and conditions are oxidizing. The plot of iron versus time shows a significant decrease from pre- to post-remediation, indicating an increase in redox potential. Similarly, although there is not a large ORP database, the data available indicate an increase in ORP. Collecting valid ORP measurements is difficult and the results are often unreliable, or at best usable to compare general redox conditions and very general trends. Processes associated with the precipitation of iron under oxidizing conditions are well understood and are probably the more reliable indicators of redox conditions.
- Except for the levels of selenium (Figure 5-26), ground water quality has improved. For the selenium increase to be caused by site-related activities, the overall water quality of the aquifer should be degraded further as well. At other millsites, water contaminated by past uranium-ore processing activities has high a concentration of dissolved solids, a high alkalinity, and a high conductance. The ions chiefly responsible for TDS, alkalinity, and conductance (e.g., sodium, calcium, sulfate, carbonate) are highly mobile in ground water. There is no explanation for how these could decrease while an associated contaminant could increase. As shown in Figure 5-27 through Figure 5-29, TDS, alkalinity, and conductance have all decreased since remediation. In other words, with respect to general water quality, the water in well 0607 has been diluted with cleaner water since remediation. Hence, the only explanation for the increase in selenium is that an influx of water with greater oxidation potential is causing the release of naturally occurring selenium from the aquifer solids.

Figure 5-23 shows all historical iron concentrations for well 0607, and Figure 5-24 shows more recent concentrations in detail. The results are notable because of the time frame when redox conditions began to change. As shown in the figures, the increase of ORP and the resulting decrease in iron concentrations began in 1983, approximately 4 years before surface remediation began. This indicates surface remediation activities were not a factor in changing the oxidizing conditions at this location.

5.4.5 Selenium Concentrations Before Surface Remediation

Before surface remediation, ground water in the raffinate ponds area occurred in both the surficial deposits and the bedrock (DOE 1995a). At present, ground water occurs primarily in the

bedrock units. Prior to the start of surface remediation in 1987, selenium concentrations exceeded the MCL in seven raffinate ponds area wells, all of which were subsequently abandoned during remediation. Figure 5-30 shows the maximum selenium concentrations in wells sampled from 1982 to 1986 (prior to remediation) where the MCL was exceeded. Tables 5-14 through 5-16 show pre-remediation selenium and uranium concentrations at these locations.

Table 5-14. Selenium and Uranium Concentrations in Alluvial Wells from 1982 to 1985 at the Raffinate Ponds Area

Well	Date Sampled	Selenium (mg/L)	Uranium (mg/L)
0606	09/01/1982	6.80	1.10
0606	07/01/1983	2.40	0.76
0606	08/15/1983	3.00	1.00
0606	11/10/1983	3.70	2.00
0606	03/14/1985	2.64	-
0623	09/01/1982	0.929	0.80
0623	07/01/1983	1.60	0.71
0623	08/15/1983	1.80	0.50
0623	11/01/1983	2.20	0.60
0625	09/01/1982	0.34	1.20
0625	07/01/1983	2.00	2.90
0625	08/15/1983	0.96	2.00
0625	11/01/1983	0.43	2.40

Table 5-15. Selenium and Uranium Concentrations in Bedrock Wells from 1982 to 1985 at the Raffinate Ponds Area

Well	Date Sampled	Selenium (mg/L)	Uranium (mg/L)
0602	09/01/1982	ND	0.01
0602	07/01/1983	ND	0.02
0602	08/15/1983	ND	0.03
0602	11/01/1983	0.02	0.50
0602	03/14/1985	0.06	-
0602	11/10/1985	ND	1.31
0603	09/01/1982	ND	0.002
0603	07/01/1983	ND	0.004
0603	08/15/1983	ND	0.002
0603	11/01/1983	ND	0.003
0603	03/15/1985	0.01	-
0603	11/10/1985	ND	0.004

ND = Not Detected

Table 5-16. Selenium and Uranium Concentrations in Bodo Fault Wells from 1982 to 1985 at the Raffinate Ponds Area

Well	Date Sampled	Selenium (mg/L)	Uranium (mg/L)
0610	09/01/1982	0.014	0.026
0610	07/01/1983	0.03	0.083
0624	09/01/1982	0.042	0.70
0624	07/01/1983	0.03	0.58
0624	08/15/1983	0.02	1.00
0624	11/01/1983	0.03	0.40
0624	03/15/1985	2.56	-

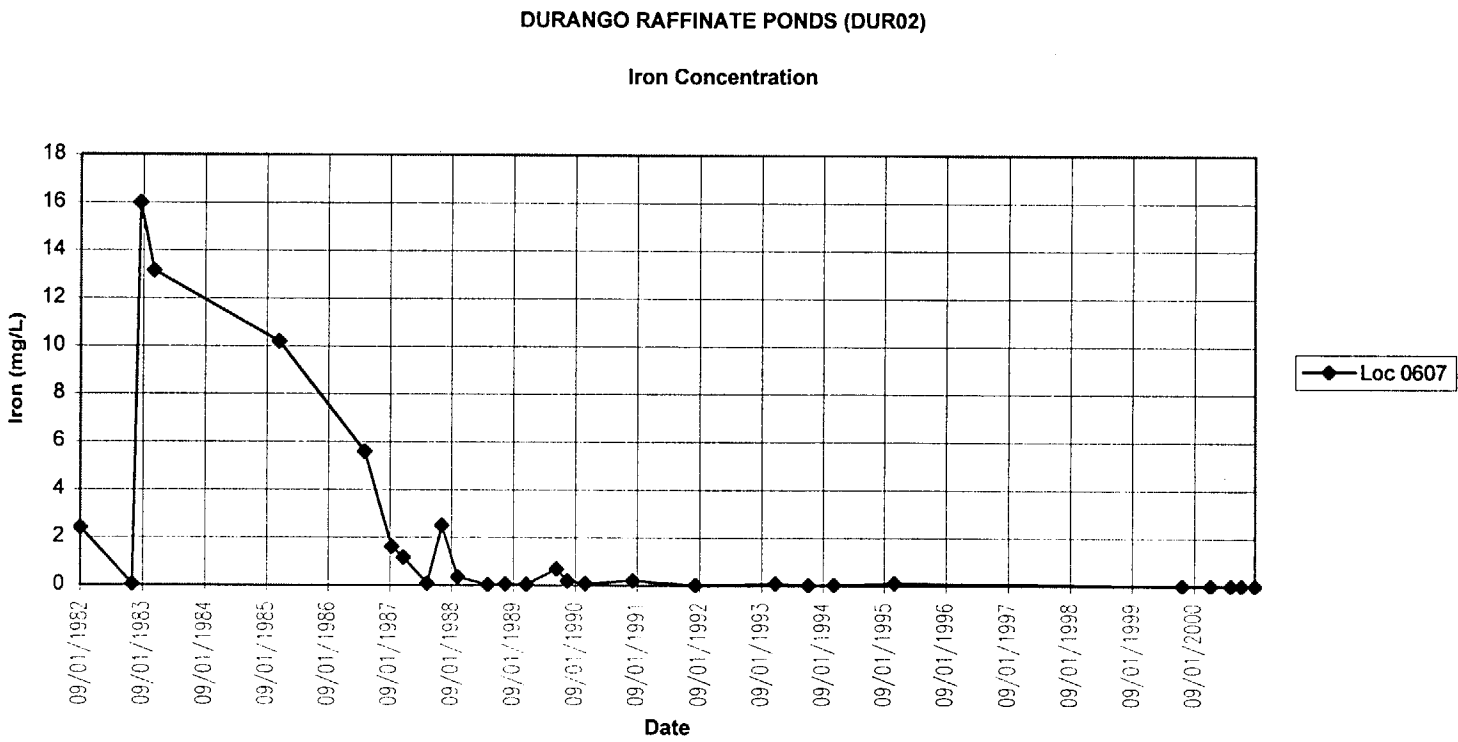


Figure 5-23. Time-Concentration Plot of Iron in Well 0607

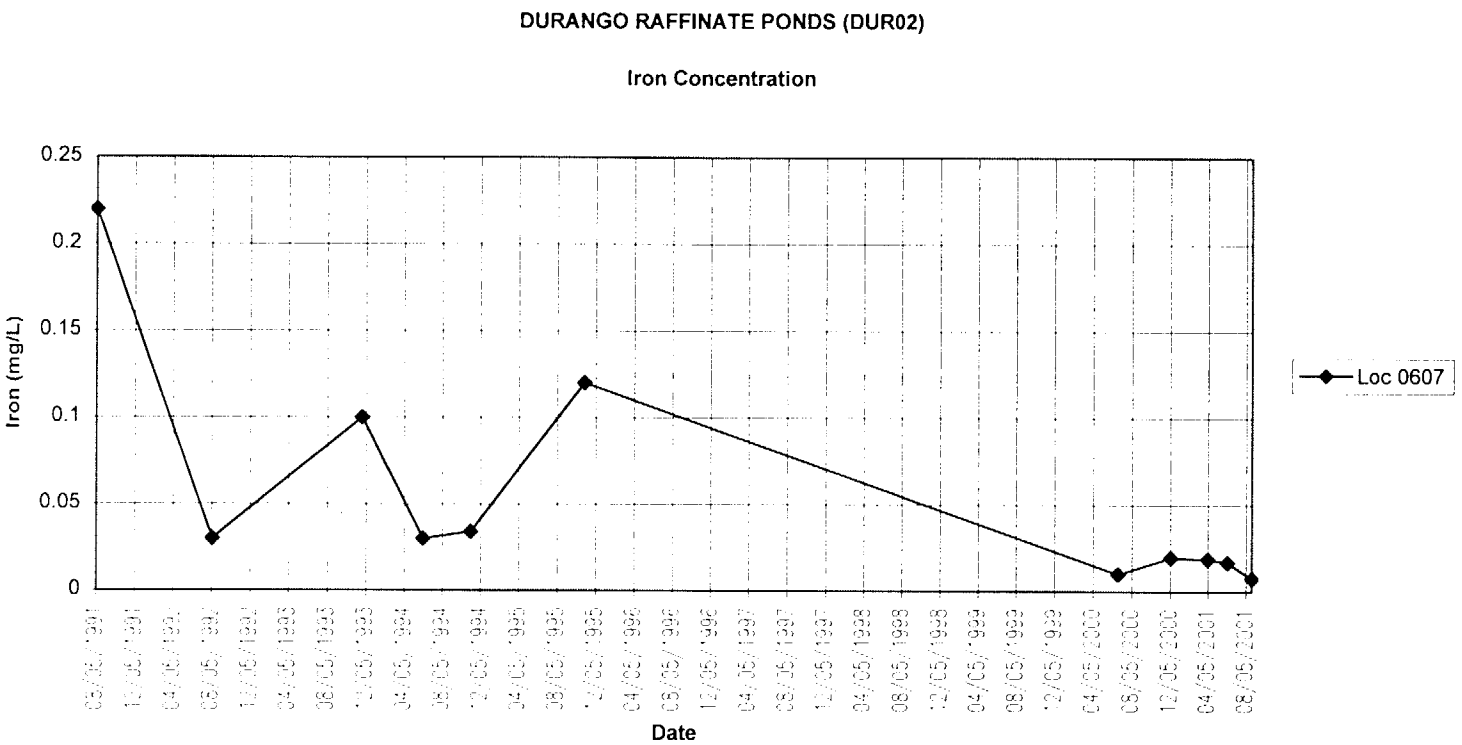


Figure 5-24. Time-Concentration Plot Detail of Iron in Well 0607

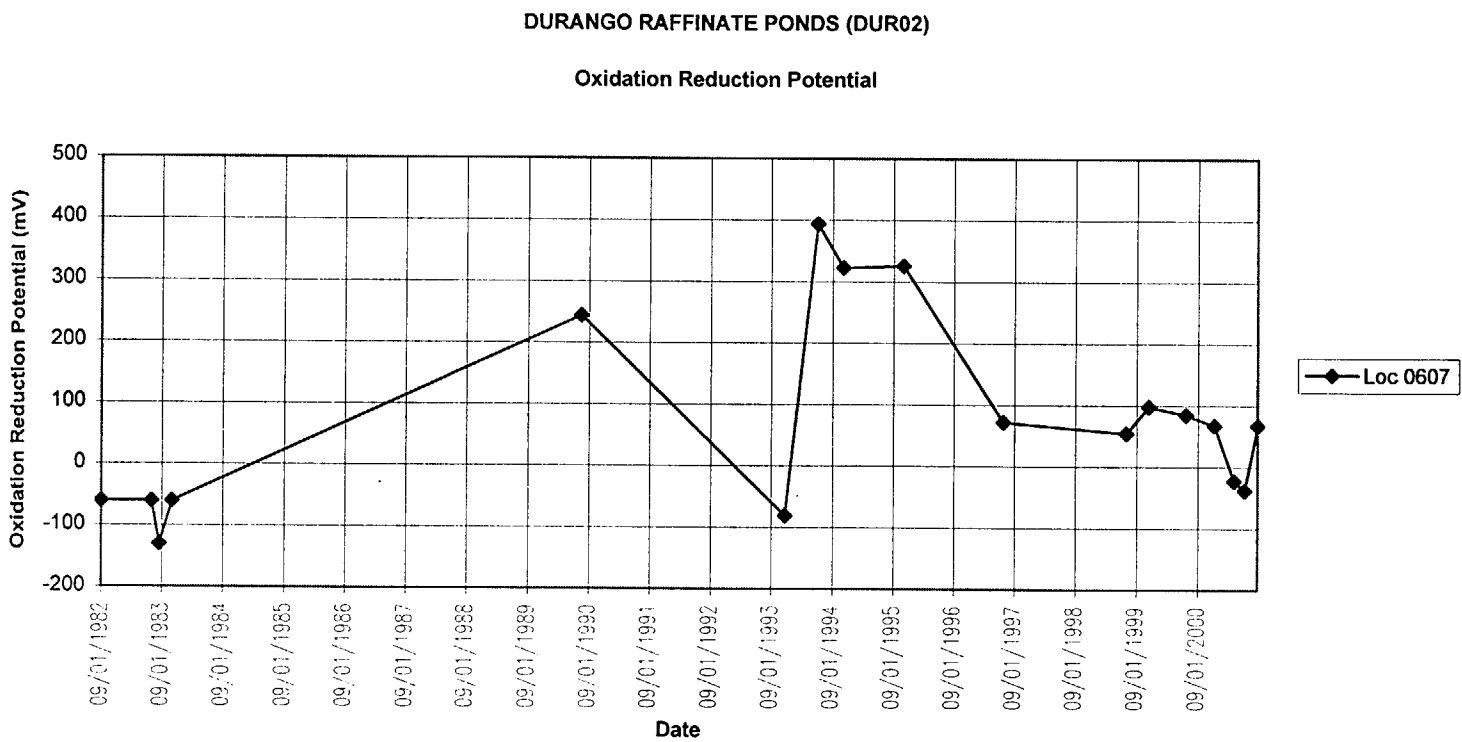


Figure 5-25. Oxidation Reduction Potential Measurements in Well 0607

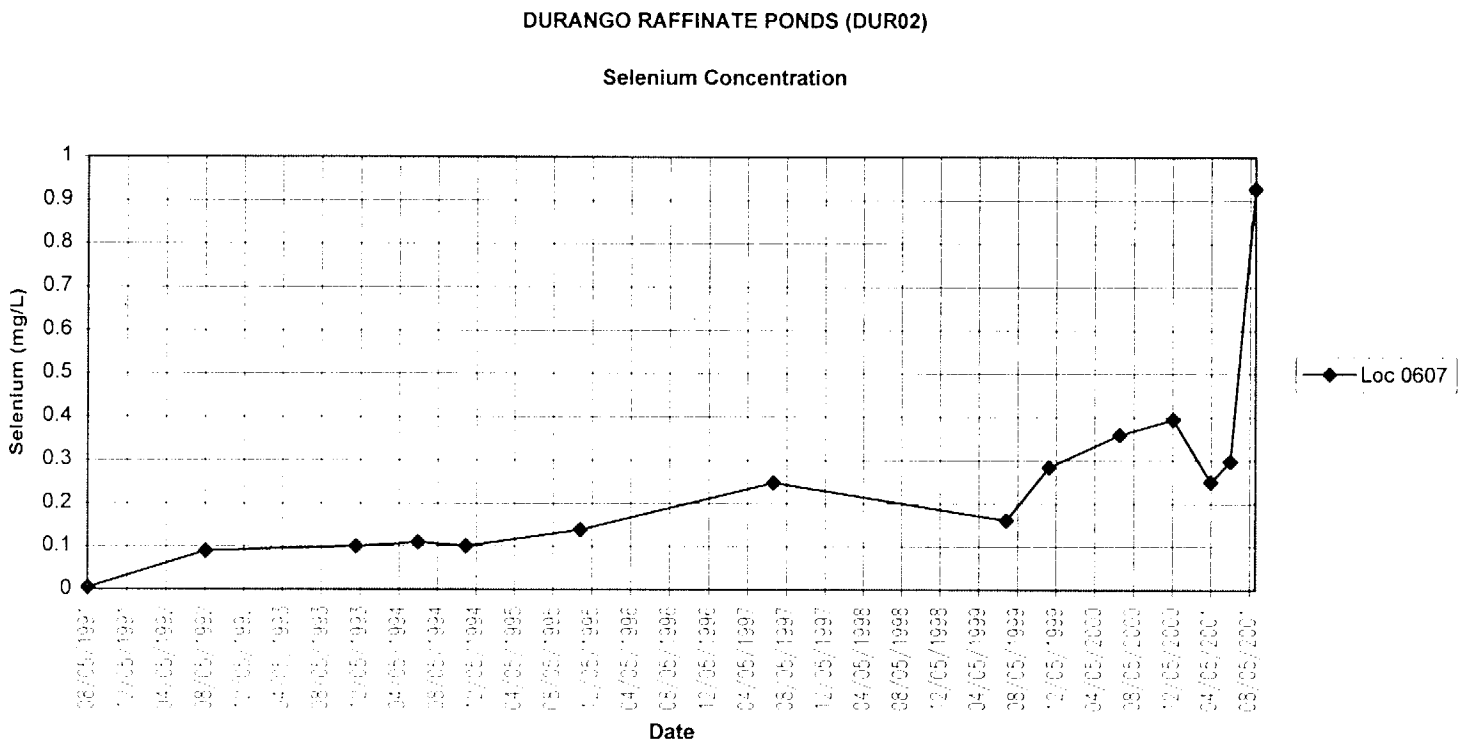


Figure 5-26. Time-Concentration Plot of Selenium in Well 0607

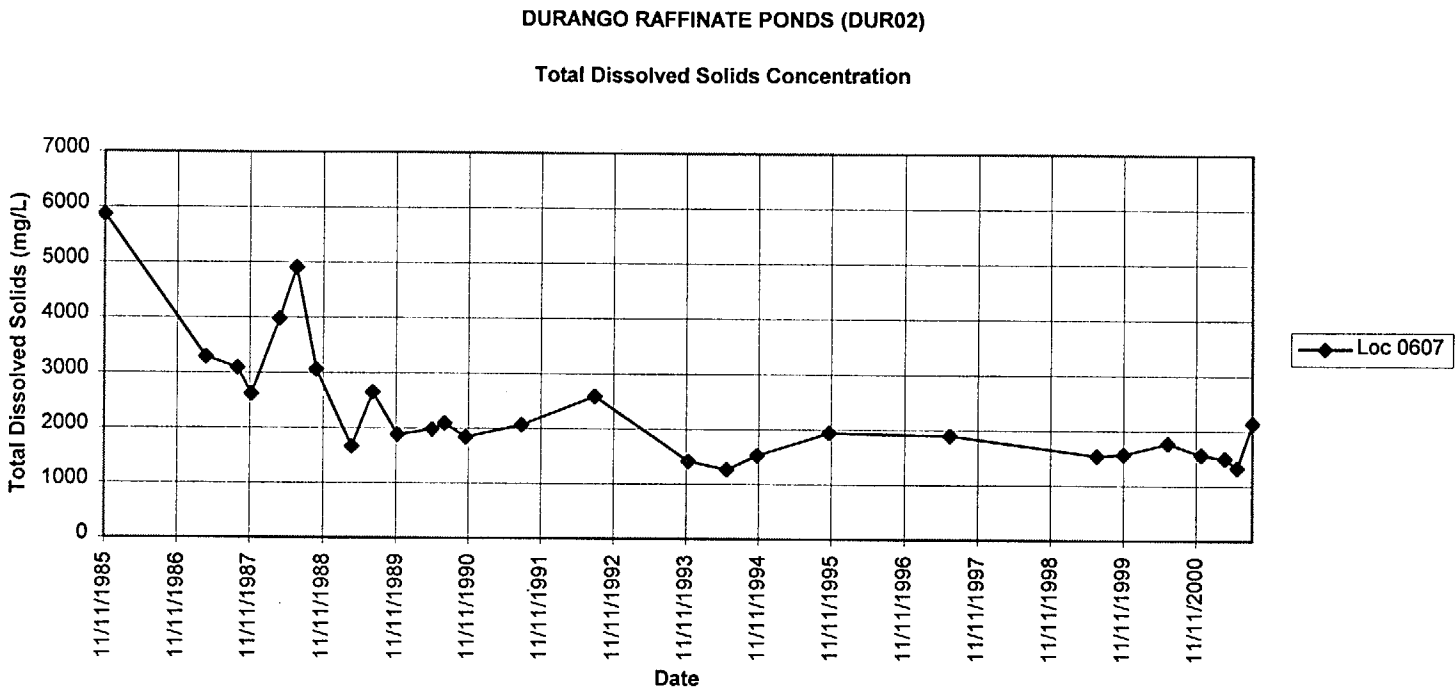


Figure 5-27. Time-Concentration Plot of TDS in Well 0607

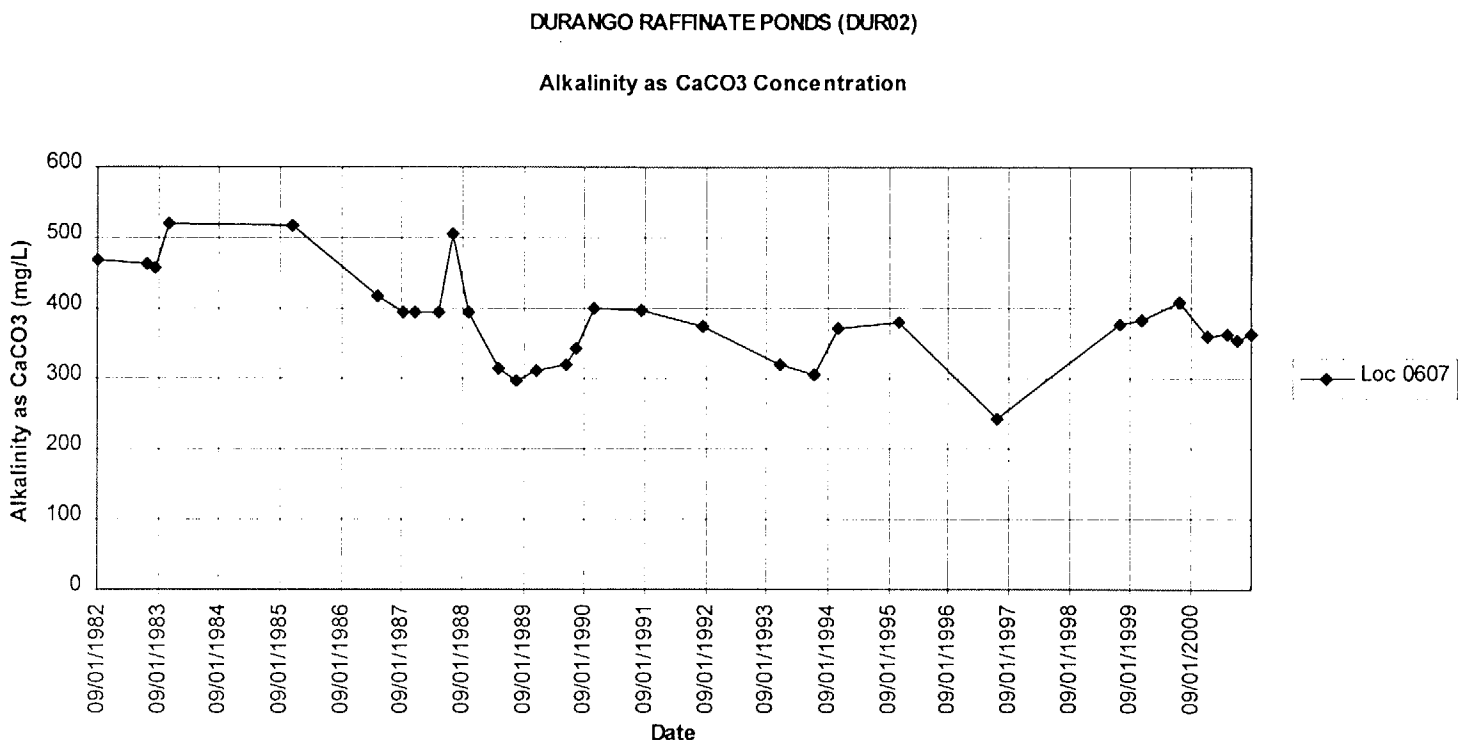


Figure 5-28. Time-Concentration Plot of Alkalinity as CaCO₃ in Well 0607

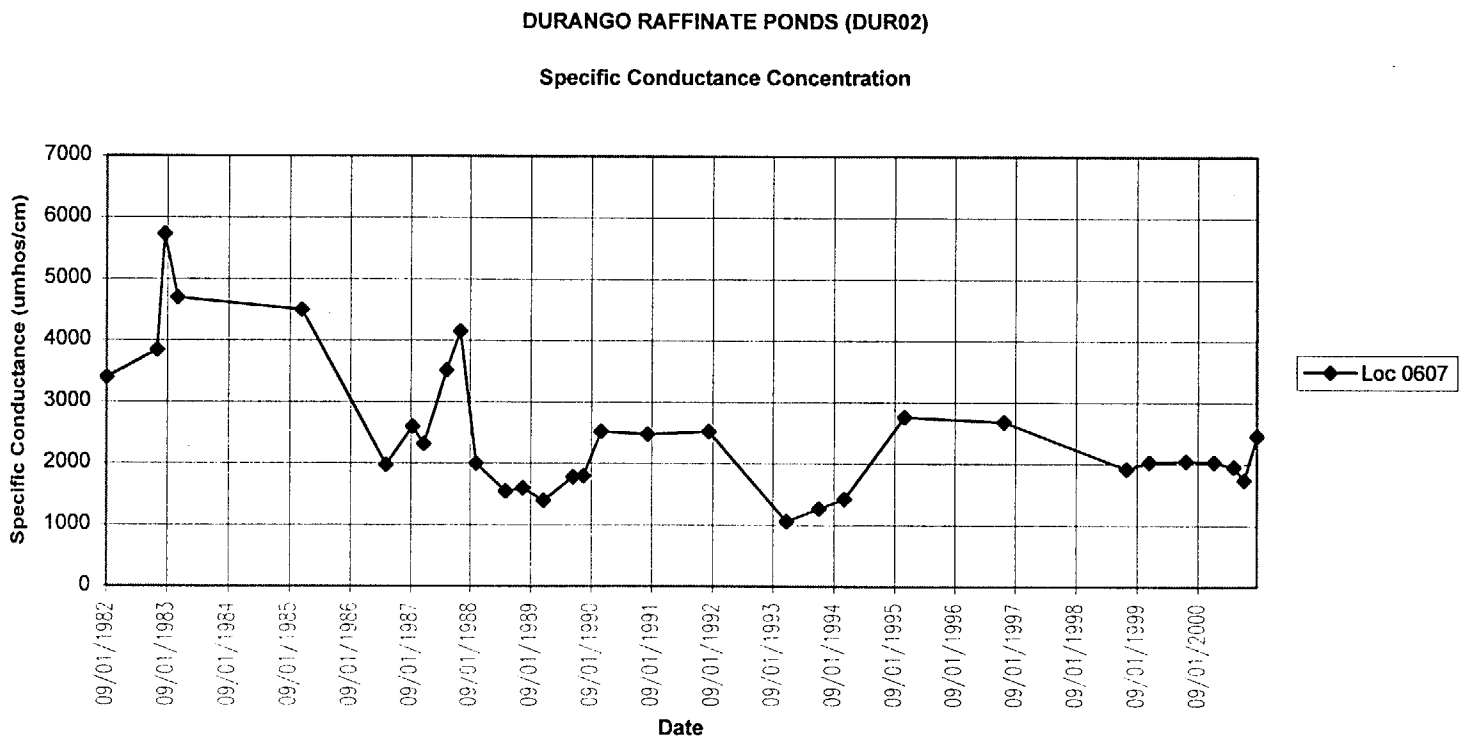


Figure 5-29. Specific Conductance in Well 0607

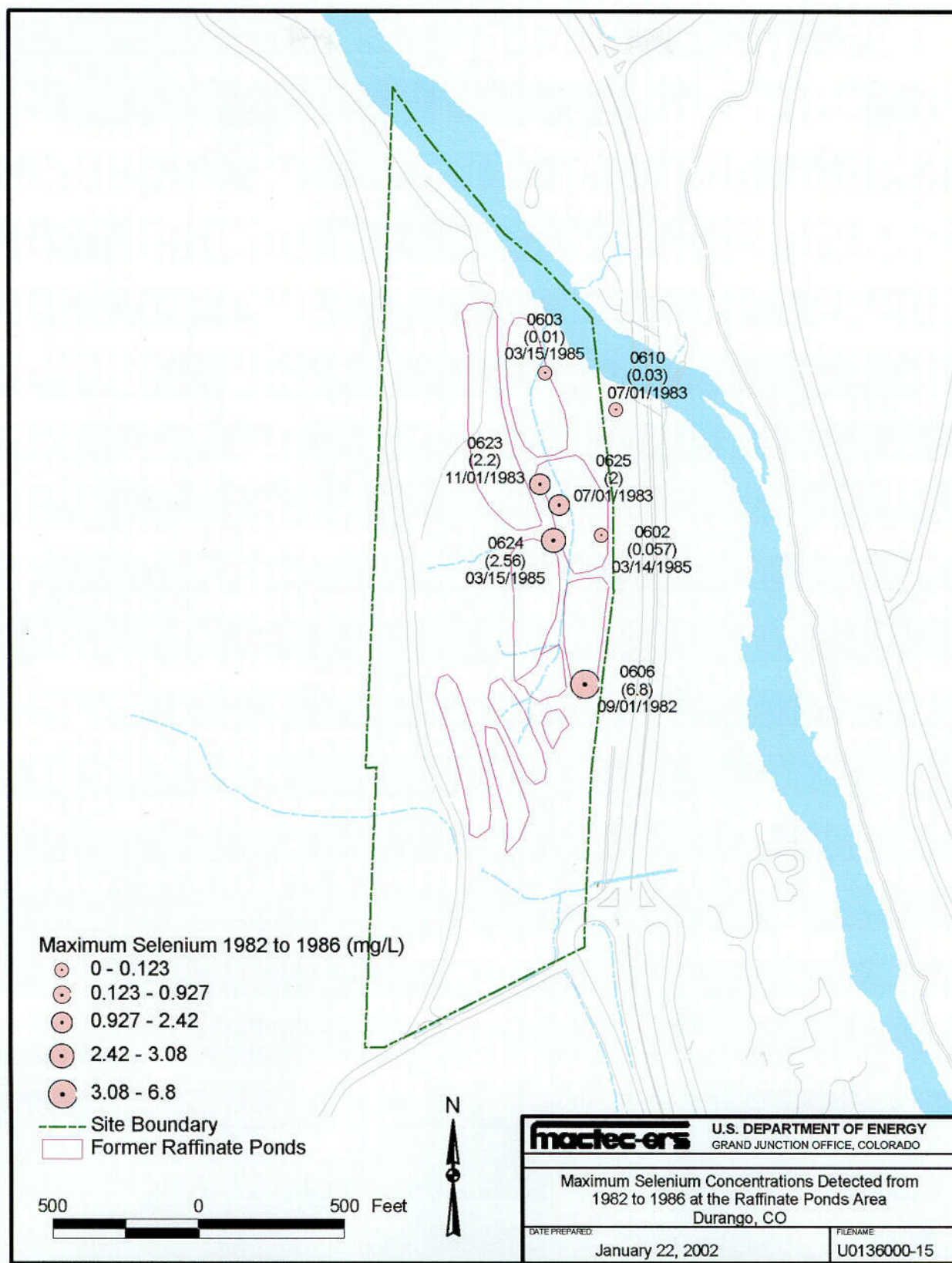


Figure 5-30. Maximum Selenium Concentrations Detected from 1982 to 1986 at the Raffinate Ponds Area

Selenium concentrations from historical alluvial wells are presented in Table 5–14. In alluvial well 0606, concentrations of selenium decreased from 1982 to 1985 (6.80 to 2.64 mg/L); uranium concentrations ranged from 76 to 1.10 mg/L, with one slightly higher occurrence of 2.0 mg/L. Concentrations of both constituents were above their respective MCLs. Well 0606 was identified as an alluvial well, but the well completion log shows it was screened in the upper shales of the Menefee Formation (Appendix A).

Alluvial well 0607 is not shown in Table 5–14 because all selenium and uranium values were below the detection limit during the 1982 to 1985 time period. This is the only historical well that still exists and is screened across gravels above the Menefee Formation and its contained coal and carbonaceous shales. This is the only present day occurrence of alluvial ground water at the raffinate ponds area.

In alluvial well 0623, concentrations of selenium increased from 0.929 to 2.20 mg/L; uranium concentrations remained relatively unchanged (between 0.50 and 0.80 mg/L). Concentrations of both constituents were above their respective MCLs. This well was screened in gravels directly above the upper shales of the Menefee Formation.

In alluvial well 0625, concentrations of selenium and uranium showed no specific trend; selenium results show one anomalously high value, and uranium results show one anomalously low value. Concentrations of both constituents were above their respective MCLs. This well was screened in gravels directly above the upper shales of the Menefee Formation.

If alluvial soils at the raffinate ponds area were a continuing source for selenium contamination in ground water prior to their removal, then selenium concentrations in alluvial wells would have been expected to remain at elevated concentrations as long as the source was present.

Selenium concentrations in bedrock wells from 1982 to 1985 are shown in Table 5–15. In bedrock well 0602, concentrations of selenium show no trend; some are below the detection limit and others above the MCL. Uranium levels trend upward during this period from 0.012 to 1.31 mg/L. This well was screened in two locations in the Menefee Formation; the upper screen was in sandstone and the lower screen was in coal.

Selenium concentrations in bedrock well 0603 show no trend; all concentrations are below the detection limit except for one value at the MCL. Uranium concentrations remained relatively unchanged (0.002 to 0.004 mg/L). A description of the lithology for this location is not available.

Table 5–16 shows selenium and uranium concentrations in wells completed in the Bodo Fault zone. In bedrock well 0610, only two values each were available for selenium and uranium.

In Bodo Fault well 0624, selenium values show no trend, although one value is significantly above the MCL at 2.56 mg/L. Uranium values show no real trend; concentrations range from 0.40 to 1.0 mg/L.

Data from wells that existed before surface remediation, monitor wells installed by the BOR, and the most recent monitor wells installed as part of this field investigation, indicate selenium concentrations across the site, historically and at present, are variable and in some cases increasing, and concentrations of other mill-related contaminants are decreasing. The variability (over short periods in some cases) suggests that levels of selenium are not a result of residual contamination but rather geochemical conditions. Under oxidizing conditions selenium exists

dominantly as selenate, and the selenite forms dominate under more reducing conditions. Under conditions at the raffinate ponds area, it is probable selenide in the coal or pyrites is oxidized (a rapidly occurring process) to selenite, which converts to hydrogen selenite because of the pH. Hydrogen selenite is then oxidized to selenate, which is a slow process (Korte 2000). Also, historical selenium concentrations above the MCL in wells that existed prior to surface remediation indicate that remediation activities did not contribute to increasing the selenium concentrations.

5.4.6 Selenium Summary

Several lines of evidence argue against the possibility that contamination associated with uranium-ore processing could be responsible for the recent increases and historical variability in selenium concentrations from certain wells. The most important is that selenium levels have increased without corresponding increases from the other site-related contaminants. Ground water investigations at numerous other UMTRA Project sites indicate selenium is not the dominant water-related contaminant from a uranium-ore processing operation. This experience is supported by examples shown by DeVoto (1978). When uranium ore is formed due to redox processes (the probable source for all the ore processed at Durango), selenium is the first oxyanion to precipitate when the dissolved constituents enter a reducing zone (DeVoto 1978). In the geochemical circumstances under review, uranium, arsenic, selenium, vanadium, and molybdenum are all oxyanions as dissolved species. Selenium levels can still be significantly elevated in the uranium ore, but typically molybdenum and vanadium will be present in higher concentrations. Thus, wherever selenium contamination related to uranium-ore processing is found, there are higher concentrations of other contaminants, particularly uranium and molybdenum. Vanadium and arsenic are also usually present in ground water contaminated by uranium processing. The fact that selenium is the sole element of this group to increase in concentration at the raffinate ponds area indicates the increase is not related to uranium-ore processing. Moreover, existing evidence demonstrates that selenium was not unusually abundant in the Durango processing operations, as shown by the following facts:

- Samples of raffinate from the original process water did not show selenium levels were elevated relative to other ore-related contaminants (Tsivoglou and others 1960).
- Present-day pore water associated with tailings from the site contained the oxyanion contaminants in the following proportions: uranium (2.6 mg/L), molybdenum (0.89 mg/L), selenium (0.17 mg/L), and arsenic (0.16 mg/L) (MSE 1999).

These data indicate selenium was not the dominant contaminant associated with either the raffinate or the tailings. This fact is further demonstrated by the zero-valent iron treatment cell used to remove contaminants in leachate from the tailings repository. A black-orange sludge formed on top of the iron on the inlet side of the tank. This sludge was 0.7 percent selenium, which was the highest of the oxyanions except for vanadium, showing that selenium was preferentially removed under somewhat less reducing conditions than other contaminants that precipitated to a greater degree farther inside the treatment cell. The mass balance for oxyanions removed from the treatment cell clearly demonstrated selenium was not the dominant oxyanion.

A similar situation was evident during surface and ground water remediation of the former uranium-ore processing mill in Monticello, Utah, under CERCLA. At Monticello, selenium levels began to increase dramatically in downgradient wells following remediation where

contaminated soil was removed above the Mancos Shale and Dakota Sandstone formations (DOE 2001c). Like the Point Lookout Sandstone and Menefee Formation, the Dakota Sandstone has an abundance of coal, carbonaceous shale, and pyrite.

5.5 Ground Water Flow and Transport Modeling

The BOR has developed a ground water flow model for the raffinate ponds area for purposes related to the proposed Animas-La Plata pumping plant. It would not be prudent for two federal agencies to expend effort in modeling the same site. Therefore, the DOE did not develop a ground water flow and transport model for the raffinate ponds area. Instead, the BOR model was reviewed and results were incorporated in the developing the hydrogeology portion of the conceptual site model (Section 5.2).

A ground water flow and transport model was developed for the mill tailings area to evaluate whether natural processes will reduce site-related contaminant concentrations below applicable standards within 100 years. The contaminants modeled were cadmium, manganese, molybdenum, selenium, sulfate, and uranium. Appendix G contains the details of this modeling.

The first step of the modeling process included development of a steady-state stochastic flow model, which was then used as the basis for a steady-state stochastic transport model. Both stochastic models are able to quantify uncertainty in both the flow and transport parameters. Contaminant transport was simulated for each of the six contaminants using the stochastic transport model.

Based on the modeling results, natural flushing appears to be an acceptable compliance strategy that allows natural processes to reduce ground water contaminant concentrations to levels below applicable UMTRA Project standards for molybdenum and uranium. Modeling results also indicate manganese and sulfate concentrations will be reduced below the risk-based and background concentrations, respectively. Because of the relatively high K_d values determined for selenium, modeled concentrations of this contaminant will not decrease below the UMTRA Project Standard of 0.01 mg/L. However, selenium will naturally flush below the value of 0.05 mg/L from the EPA's Safe Drinking Water Act (EPA 1996). The expected concentration after 100 years is 0.0246 mg/L. Cadmium concentrations will not drop below the UMTRA Project standard of 0.01 mg/L after 100 years because of the very high K_d value measured for this contaminant.

The existing ground water flow pattern at the mill tailings area was modeled using the MODFLOW software (McDonald and Harbaugh 1988), a finite-difference three-dimensional hydrologic flow model published by the USGS. Output from the flow model was used as input to MT3DMS (Zheng and Wang 1999), a version of a modular three-dimensional transport model that simulates advection, dispersion, and chemical reactions in the ground water system. 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. A summary of the modeling results is provided in the following section.

Steady State Stochastic Modeling Results

Input flow parameters with the most impact on results include horizontal hydraulic conductivity (for three different zones) and recharge; the most sensitive transport parameters include K_d and

longitudinal dispersivity. Table 5–17 presents the maximum average contaminant concentrations (the maximum concentration calculated for each realization, averaged over 100 realizations) for selected time intervals and the associated probability of exceeding the applicable standard for each contaminant.

Table 5–17. Predicted Maximum Average Contaminant Concentrations for Selected Time Intervals

	Contaminant											
	Cadmium		Manganese		Molybdenum		Selenium		Sulfate		Uranium	
Concentration Goal	0.01 mg/L		1.7 mg/L		0.1 mg/L		0.05 mg/L		1,276 mg/L		0.044 mg/L	
Source	MCL		Risk-based		MCL		EPA–SDWS ^c		Background		MCL	
Time (yrs)	Conc ^a (mg/L)	Prob ^b (%)	Conc ^a (mg/L)	Prob ^b (%)	Conc ^a (mg/L)	Prob ^b (%)	Conc ^a (mg/L)	Prob ^b (%)	Conc ^a (mg/L)	Prob ^b (%)	Conc ^a (mg/L)	Prob ^b (%)
5	0.0365	100	3.848	100	0.0812	0	0.0686	100	2,792	100	1.3650	100
10	0.0363	100	3.505	100	0.0652	0	0.0625	100	2,537	100	1.0820	100
15	0.0362	100	3.234	100	0.0519	0	0.0576	86	2,310	100	0.8628	100
25	0.0357	100	2.794	100	0.0318	0	0.0500	54	1,919	100	0.5311	100
50	0.0347	100	1.916	99	0.0094	0	0.0379	2	1,571	100	0.1301	100
60	0.0343	100	1.630	17	0.0061	0	0.0345	0	1,471	100	0.0726	100
70	0.0340	100	1.388	0	0.0038	0	0.0315	0	1,374	99	0.0442	51
80	0.0336	100	1.167	0	0.003	0	0.0289	0	1,280	54	0.0287	1
90	0.0333	100	0.973	0	0.003	0	0.0266	0	1,190	2	0.0185	0
100	0.033	100	0.815	0	0.003	0	0.0246	0	1,105	0	0.0118	0

^aValue represents the predicted maximum average contaminant concentration (mg/L).

^bValue represents the probability (%) that the applicable standard will be exceeded.

^cEPA Safe Drinking Water Standard.

As shown in Table 5–17, results of the steady state stochastic MT3DMS predictive simulations indicate:

- The maximum average cadmium concentrations only reduce slightly (0.033 mg/L) after 100 years of flushing. This very slight reduction in concentration is mainly a function of the high K_d (range of 17 to 418 mL/g, average of 60.4 mL/g) associated with this contaminant. The predicted maximum average concentration does not drop below the 0.01 mg/L UMTRA standard after 100 years.
- Manganese predicted maximum average concentrations drop below the 1.7 mg/L risk-based standard between 50 and 60 years. At 60 years there is a 17 percent probability that the concentration will exceed the standard, and at 70 years there is a 0 percent probability.
- The maximum average molybdenum concentration drops below the 0.1 mg/L MCL prior to 5 years, with a 0 percent probability of the standard being exceeded at 5 years. An initial concentration just above the standard in conjunction with a very low K_d results in rapid flushing of this contaminant below the standard.
- Predicted selenium concentrations drop below the 0.05 mg/L EPA Safe Drinking Water standard after 25 years, at which time there is a 54 percent probability of the standard being exceeded. At 50 years, there is only a 2 percent probability of exceeding 0.05 mg/L, and 0 percent probability at 60 years.

- Predicted sulfate maximum average concentrations drop below the 1,276 mg/L background concentration between 80 and 90 years. At 80 years there is a 54 percent probability that the background concentration will be exceeded, and by 90 years the probability drops to 2 percent. The probability drops to 0 percent at 100 years.
- Maximum average uranium concentrations reach the 0.044 mg/L standard at 70 years, with a 51 percent probability of exceeding the standard. At 80 years the maximum average concentration is predicted to be 0.0287 mg/L, with a 1 percent probability of exceeding the standard. The probability drops to 0 percent at 90 years.

End of current text

6.0 Summary of Human Health and Ecological Risk

6.1 Human Health Risk Assessment

A BLRA was previously prepared for the Durango site (DOE 1995a). Most of the methodology used in that risk assessment followed standard EPA risk assessment protocol (EPA 1989a), though the BLRA did not calculate potential risks for noncarcinogenic constituents. Instead, calculated exposure intakes were compared with a range of contaminant doses associated with various adverse effects. Risks for the former mill tailings and raffinate ponds areas were calculated separately. Data used in that report were collected primarily from 1990 to 1994, although ground water data for the site have been collected since 1982. Since the BLRA was developed, additional data have been collected to more completely characterize the site and to represent more recent site conditions. Updated and revised toxicological data are also available for some site-related constituents. These new data were used to reevaluate COPC identification and assessment of associated risks.

6.1.1 Summary of 1995 BLRA Methodology and Results

The 1995 BLRA identified 23 constituents at the mill tailings area present at levels statistically above background concentrations. This initial list was screened to first eliminate constituents with concentrations within nutritional ranges and then to eliminate contaminants of low toxicity and high dietary ranges. These two steps eliminated four and nine constituents, respectively, resulting in the following COPC list: antimony, cadmium, lead, manganese, molybdenum, selenium, sodium, sulfate, uranium, and vanadium. These contaminants were retained for further risk analysis.

The BLRA identified 28 constituents at the raffinate ponds area at levels statistically above background. After screening to eliminate constituents with low toxicity and high dietary ranges the following COPCs were identified: antimony, arsenic, cadmium, chloride, lead, manganese, molybdenum, selenium, sodium, sulfate, thallium, and uranium.

A number of potential routes of exposure were evaluated: ingestion of ground water as drinking water in a residential setting, dermal contact with ground water while bathing, ingestion of meat and milk from ground-water-fed livestock, ingestion of produce irrigated with contaminated ground water, and ingestion of fish from the Animas River. Results of the exposure assessment indicated intakes for all constituents were negligible from exposure routes other than ingestion of drinking water. Therefore, only exposure through ingestion of ground water as drinking water was retained for more detailed evaluation. Both children and adults were considered as likely receptors.

Calculated exposure intakes were presented along with contaminant intakes associated with a range of adverse health effects. Potential risks associated with exposure to noncarcinogenic constituents were discussed qualitatively or by comparing estimated daily intake values to the acceptable intake levels recommended; carcinogenic risks were quantified and compared to EPA's acceptable risk range of 1×10^{-4} to 1×10^{-6} .

For sulfate, the most sensitive receptor population is infants. Results of the BLRA showed that infants exposed to the levels of sulfate in ground water at the Durango site could experience significant adverse health effects due to diarrhea and dehydration. This risk was estimated to be

more at the raffinate ponds area where almost the entire exposure distribution for sulfate is within the range for severe diarrhea and resulting dehydration.

Exposure intakes for the other noncarcinogenic contaminants in ground water were calculated for the receptors with the highest intake to body weight ratio—children between the ages of 1 and 10. Manganese exposure from ground water consumption may result in the highest unacceptable noncarcinogenic risks. The entire distributions are above the threshold level of mild neurological symptoms and above the EPA acceptable intake levels (reference doses or RfDs) for both the mill tailings and raffinate ponds areas. The RfDs are generally established at levels below known toxicity values to account for uncertainty in toxicity studies and data.

In 1995 other noncarcinogenic contaminants that may result in unacceptable risk included molybdenum, cadmium, selenium, vanadium, and uranium. About 40 percent of the molybdenum intake distribution from contaminated ground water at the mill area was above the acceptable intake level; the estimated exposures at the raffinate ponds area were twice the oral RfD, if ground water were ingested for long periods of time. Cadmium levels at both the mill tailings and raffinate ponds areas might have resulted in mild kidney toxicity. For both areas of concern, selenium likely exceeded the oral RfD; the raffinate ponds area likely had the highest risks. Vanadium was mostly a concern for the mill tailings area; most of the exposure range exceeded the oral RfD. Uranium was of concern for both the mill tailings and raffinate ponds areas. Arsenic, uranium, and antimony concentrations exceeded EPA's acceptable intake levels (RfDs), but were below levels demonstrated to result in adverse health effects. Sodium and selenium concentrations were also typically below the dietary intake range. The original BLRA (DOE 1995a) provides detailed information on toxicity studies and effects.

Carcinogenic risks were calculated for adult exposure. Carcinogenic risks from exposure to uranium and its daughter products exceeded the upper bound of EPA's acceptable risk range of 1×10^{-4} by approximately 1 order of magnitude in the mill tailings area. Risks from uranium at the raffinate ponds area fell within EPA's acceptable range; however, risks from arsenic were greater than the upper bound of acceptable range (4×10^{-3}).

6.1.2 BLRA Update

The original BLRA considered several potential routes of exposure to contaminants and eliminated all but one, ingestion of ground water in a residential setting, as insignificant. Overall concentrations have declined for all COPCs since the BLRA was completed. Therefore, for this BLRA update, it is assumed that any pathway considered insignificant based on the original BLRA is still insignificant; risks will not be recalculated for those pathways. Though not considered a likely scenario, risks are recalculated assuming drinking water in a residential scenario using more recent monitoring data.

Risk calculations presented here follow EPA's *Risk Assessment Guidance for Superfund* (EPA 1989a), which involves determining a point estimate for excess cancer risk from current or potential carcinogenic exposures (risk is equal to lifetime intake times cancer slope factor) and a hazard quotient (HQ) for noncarcinogenic exposures (HQ is equal to exposure intake divided by reference dose). EPA's acceptable carcinogenic risk range is 1×10^{-6} to 1×10^{-4} , which is an excess cancer risk of 1 in 1,000,000 to 1 in 10,000 compared to the general population. Risks exceeding this range are potentially unacceptable. For noncarcinogenic exposures, an HQ exceeding 1 is potentially unacceptable. HQs from multiple contaminants and/or pathways are

often summed to estimate cumulative noncarcinogenic risks; these summed HQs are referred to as a hazard index (HI). An HI greater than 1 also represents potentially unacceptable exposures. Therefore, it is possible for a number of individual contaminants to each have “acceptable” HQs of less than 1, but, when summed, represent a potentially unacceptable cumulative risk. Figure 6–1 provides exposure intake equations and default assumptions used in intake calculations for this BLRA update.

Note that toxicological values used to estimate risks (reference doses and slope factors) are conservative values with uncertainty factors built in to be protective of sensitive populations.

Equations used in calculations

Chemicals: Ingestion from water: $\text{Intake (mg/kg-day)} = (\text{Cw} \times \text{IRw} \times \text{EF} \times \text{ED}) / (\text{BW} \times \text{AT})$

Radionuclides: Ingestion from water: $\text{Intake(lifetime in picocuries)} = \text{Cw} \times \text{IRw} \times \text{EF} \times \text{ED}$

Residential Exposure Scenario—Ground Water Ingestion

Where

Cw = contaminant concentration in water, mg/L

IRw = ingestion rate for water (2 liters per day default for adults; 1.5 liters per day children 6-12 years; 0.64 liter per day for infants)

EF = exposure frequency (350 days per year)

ED = exposure duration (30 years for adults, 7 years for children and 1 year for infants for noncarcinogens; 30 years for carcinogens)

BW = body weight (70 kilograms for adults; 38.3 kilograms for children; 4 kilograms for infants)

AT = averaging time (365 days x ED for noncarcinogens; 365 days x 70 years for carcinogens)

Figure 6–1. Exposure Intake and Risk Equations with Default Assumptions

Therefore, risks presented here are reasonable worst-case estimates and are quite likely much higher than those that actually exist.

In this update, which uses point-exposure doses, single values are used for each parameter required in the risk calculations. Calculations to determine contaminant intakes use standard exposure factors (EPA 1989b). The ground water data used to assess risks in this document are from the two rounds of sampling at the site, conducted in June and August 2001. These data were used to give an up-to-date look at the site. Risk calculations performed for ground water use the 95 percent upper confidence level (UCL₉₅) on the mean concentrations to provide reasonable worst-case risk estimates for probable future ground water uses.

The same methodology was used to calculate carcinogenic risks for this BLRA update as was used in the original BLRA (i.e., receptors are adults with exposure averaged over 70 years). For all risk calculations, benchmarks for acceptable contaminant intakes (e.g., reference doses and slope factors) are best available data from standard EPA sources (e.g., Integrated Risk Information System, Region III Risk-Based Concentration Table).

This BLRA update uses the COPC list from the original BLRA as a starting point to evaluate current data for ground water. The constituents listed in the original BLRA for the mill tailings and raffinate ponds areas are listed in Section 6.1.1.

Table 6–1 and Table 6–2 summarize background, current plume, and historical plume data for each COPC in the alluvial ground water associated with the mill tailings area and the raffinate ponds area, respectively. Also included for comparison are the applicable UMTRA ground water standards (if available) and risk-based concentrations (RBCs). The RBC for a given contaminant represents a concentration in drinking water that would be protective of human health provided that

- The residential exposure scenario is appropriate,
- Ingestion of contaminated drinking water is the only exposure pathway,
- The contaminant contributes nearly all the health risk, and
- EPA's risk level of 1×10^{-6} for carcinogens and an HQ of 1 for noncarcinogens is appropriate.

If any of these assumptions is *not* true, contaminant levels at or below RBCs cannot automatically be assumed to be protective. For example, if multiple contaminants are present in drinking water, a single contaminant may be below its RBC but still be a significant contributor to the total risk posed by drinking the water. However, if an RBC is exceeded, it is an indication further evaluation of the contaminant is warranted. RBCs are intended for use in screening-level evaluations.

No standards or benchmarks have been established for sodium based on human-health concerns. The secondary standard of 250 mg/L for sulfate is based on considerations of taste and odor and not on effects to human health. Because of the lack of toxicity data, potential risks from exposure to these two contaminants cannot be quantified. Exposure intakes are calculated for these constituents, but potential adverse effects are considered only qualitatively.

For the residential ground water pathway evaluated quantitatively in this BLRA update, both children and adults were evaluated as receptors. Children would be more sensitive receptors than adults due to higher intake to body weight ratios. Infants were also evaluated for exposure to sulfate in residential scenarios because they represent the most sensitive receptor population. Carcinogenic risks were calculated only for adults based on the much longer exposure duration and because risks are averaged over a lifetime.

Table 6-1. Durango Mill Tailings Area Alluvial Ground Water Data Summary

Contaminant	FOD ¹	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	UCL ₉₅ (mg/L)	UMTRA std (mg/L)	RBC (mg/L)
Antimony							0.015N
Background ²	2/8	< 0.0003	0.0008	< 0.00065			
Current plume ³	18/18	< 0.0002	0.0008	< 0.0005	0.000665		
Historic Plume ⁴	2/8	< 0.003	0.022	< 0.007			
Cadmium						0.01	
Background	2/8	< 0.0003	0.00071	< 0.00046			
Current plume	10/18	< 0.0004	0.037	< 0.0045	0.00863		
Historic Plume	7/14	< 0.001	0.070	< 0.032			
Lead						0.05	
Background	7/8	< 0.0001	0.00081	< 0.0006			
Current plume	13/18	< 0.0001	0.0023	< 0.0006	0.000879		
Historic Plume	1/14	< 0.003	< 0.01	< 0.02			
Manganese							1.7N ⁷
Background	8/8	0.126	1.05	0.654			
Current plume	18/18	0.0032	4.31	0.790	1.35		
Historic Plume	12/4	< 0.01	6.7	< 3.2			
Molybdenum						0.1	
Background	0/8	< 0.0003	< 0.0003	< 0.0003			
Current plume	14/18	< 0.003	0.116	0.0150	0.0304		
Historic Plume	9/14	< 0.01	0.21	< 0.10			
Selenium						0.01	0.05 ⁸
Background	4/8	< 0.0003	0.0148	< 0.057			
Current plume	10/18	< 0.0003	0.123	< 0.0189	0.0336		
Historic Plume	12/14	0.007	0.16	0.065			
Sodium							
Background	8/8	36.8	477	< 223			
Current plume	18/18	129	645	345	427		
Historic Plume	14/14	231	1,200	696			
Sulfate						250 ⁷	
Background	8/8	122	2,190	1,276			
Current plume	17/17	656	3,510	1,785	2,062		
Historic Plume	12/12	1,540	3,110	2,635			
Uranium						0.044	
Background	8/8	0.00057	0.0286	0.0079			
Current plume	18/18	0.00065	1.97	0.413	0.681		
Historic Plume	13/14	0.12	3.8	1.4			
Vanadium							0.33N
Background	1/8	< 0.0003	0.002	< 0.0005			
Current plume	10/18	< 0.0003	0.324	< 0.0401	0.0856		
Historic Plume	8/14	< 0.01	0.53	< 0.41			

Background wells: 0629, 0857, 0866

Current plume wells: 0612, 0617, 0630, 0631, 0633, 0634, 0635, 0859, and 0863.

¹Frequency of detection²Current background data collected 6/2001 and 8/2001.³Current plume data collected 6/2001 and 8/2001⁴Historical data collected 1989 through 1994; wells 0612 and 0617 (DOE 1995a)⁵N= noncarcinogenic risks⁶C= carcinogenic risks⁷Secondary drinking water standard⁸Safe Drinking Water Act Standard

Table 6–2. Durango Raffinate Ponds Area Alluvial Ground Water Data Summary

Contaminant	FOD ¹	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	UCL ₉₅ (mg/L)	UMTRA std (mg/L)	RBC (mg/L)
Antimony							0.015N
Background ²	4/13	< 0.0002	0.0008	< 0.000613			
Current plume ³	21/40	< 0.0002	0.002	< 0.000652	0.000756		
Historic Plume ⁴	1/4	< 0.003	0.166	< 0.025			
Arsenic						0.05	0.011N ⁵
Background	3/13	< 0.0005	0.0029	< 0.000585			0.000045C ⁶
Current plume	3/40	< 0.0005	0.00098	< 0.000531	0.000566		
Historic Plume	1/17	< 0.005	0.04	< 0.01			
Cadmium						0.01	
Background	5/13	< 0.0004	0.0011	< 0.000544			
Current plume	25/40	< 0.0004	0.0041	< 0.000873	0.00112		
Historic Plume	3/17	< 0.0001	0.0009	NA			
Chloride							
Background	13/13	22.2	82.8	52.4			
Current plume	40/40	41.2	1,240	486	561		
Historic Plume	15/15	1,100	2,400	2,000			
Lead						0.05	
Background	5/13	< 0.0001	0.0017	< 0.000288			
Current plume	14/40	< 0.0001	0.0075	< 0.000553	0.000965		
Historic Plume	2/17	< 0.002	0.070	< 0.021			
Manganese							1.7N
Background	13/13	0.00037	0.464	0.181			
Current plume	38/40	< 0.0001	6.94	1.04	1.62		
Historic Plume	4/4	4.7	7.3	6.6			
Molybdenum						0.1	
Background	2/13	< 0.003	0.0054	< 0.00327			
Current plume	1/40	< 0.003	0.0042	< 0.00303	0.00309		
Historic Plume	3/17	< 0.01	0.10	< 0.01			
Selenium						0.01	0.05 ⁸
Background	7/13	< 0.0003	0.087	< 0.0136			
Current plume	21/40	< 0.0003	19.4	< 1.10	2.17		
Historic Plume	4/17	< 0.005	0.08	< 0.05			
Sodium							
Background	13/13	214	722	342			
Current plume	40/40	135	3,140	1,520	1,750		
Historic Plume	4/4	3,500	4,600	4,200			
Sulfate						250 ⁷	
Background	13/13	1.92	1,660	760			
Current plume	40/40	580	8,240	3,740	4,320		
Historic Plume	9/9	7,310	10,000	8,600			
Thallium							
Background	5/13	< 0.0001	0.0002	< 0.00013			
Current plume	20/40	< 0.0001	0.00025	< 0.000142	0.000156		
Historic Plume	2/5	< 0.005	0.06	< 0.025			
Uranium						0.044	
Background	13/13	0.00014	0.0056	< 0.00211			
Current plume	37/40	0.0001	0.309	< 0.0488	0.0747		
Historic Plume	2/2	0.22	0.35	0.29			

Background wells: 0592, 0599, 0875, 0886, 0903.

Current plume wells: 0597, 0881, 0889, 0596, 0892, 0880, 0887, 0888, 0628, 0902, 0598, 0593, 0882, 0879, 0876, 0878, 0890, 0884, 0594, and 0607.

¹Frequency of detection.²Current background data collected 6/2001 and 8/2001.³Current plume data collected 6/2001 and 8/2001.⁴Historical data collected 1989 through 1994; wells 0593, 0602, or 0598 (DOE 1995a).⁵N= noncarcinogenic risks.⁶C= carcinogenic risks.⁷Secondary drinking water standard.⁸Safe Drinking Water Act

NA = not available