

UMTRA Ground Water Project

**Final Site Observational Work Plan for the
UMTRA Project Site at Grand Junction, Colorado**

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Acronyms and Abbreviations

ACL	alternate concentration limit
BAF	bioaccumulation factor
BLRA	baseline risk assessment
BOR	U.S. Bureau of Reclamation
CDPHE	Colorado Department of Public Health and Environment
cm	centimeter(s)
COPC	chemical of potential concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ft	foot (feet)
GJO	Grand Junction Office
gpm	gallons per minute
HI	hazard index
HQ	hazard quotient
in.	inch(es)
K _d	distribution coefficient
km	kilometer(s)
lb	pounds
m	meter(s)
µg/L	micrograms per liter
µm	micrometers
MCL	maximum concentration limit
mg/L	milligrams per liter
mi	mile
mL	milliliter
mL/g	milliliters per gram
NEPA	National Environmental Policy Act
ORNL	Oak Ridge National Laboratory
pCi/g	picocuries per gram
pCi/L	picocuries per liter
PEIS	Programmatic Environmental Impact Statement
PVC	polyvinyl chloride
RBC	risk-based concentration
RRM	residual radioactive materials
SEE	Site Environmental Evaluation
SI	saturation index
SOWP	Site Observational Work Plan
TAGR	Technical Approach to Groundwater Restoration
TDS	total dissolved solids
UMTRA	Uranium Mill Tailings Remedial Action (Project)
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey

Executive Summary

This document is the Site Observational Work Plan (SOWP) for the Grand Junction, Colorado, Uranium Mill Tailings Remedial Action (UMTRA) Project site. The purpose of this report is to provide a strategy for achieving compliance with requirements established in the Uranium Mill Tailings Radiation Control Act (42 *United States Code* 7901 *et seq.*) and the U.S. Environmental Protection Agency's (EPA's) "Health and Environmental Protection standards for Uranium and Thorium Mill Tailings" (Title 40, *Code of Federal Regulations*, Part 192).

The compliance strategy proposed for the Grand Junction, Colorado, site is no remediation and the application of supplemental standards based on the criterion of limited use ground water. Ground water in the alluvial aquifer is not a current or potential source of drinking water because the quality of the water is naturally poor. Average uranium and selenium concentrations in background ground water of the alluvial aquifer exceed UMTRA Project maximum concentration limits. Existing institutional controls imposed by the U.S. Department of Energy, the Colorado Department of Public Health and Environment, or the City of Grand Junction prevent use of the alluvial aquifer for drinking water on site and downgradient of the site. A feasibility study indicates that treatment of the ambient ground water for municipal use would be unreasonably expensive.

The Grand Junction millsite, also known as the Climax uranium mill, began as a sugar beet mill and was operated as a uranium/vanadium mill from 1950 to 1970. During that time the mill processed more than 2 million tons of ore, which produced about 12 million pounds of uranium oxide (U_3O_8) and 46 million pounds of vanadium oxide (V_2O_5). Ore was crushed, ground, salt roasted and water leached to remove vanadium; uranium was extracted with a sulfuric acid leach. The Climax Corporation demolished most of the mill buildings and seeded the tailings piles before leaving the site in 1976. From the late 1980s to 1994 the site was used as an interim repository for mill tailings removed from Grand Junction vicinity properties as part of the UMTRA Surface Project. By the end of 1994 all tailings and the remaining buildings, except the old sugar beet warehouse, had been demolished and hauled to the Grand Junction disposal site about 18 miles southeast of Grand Junction.

The original Site Observational Work Plan (DOE 1996d) indicated that applying the criterion of widespread ambient contamination of the alluvial aquifer might be justified on the basis of high concentrations of total dissolved solids and naturally high concentrations of molybdenum, selenium, and uranium in background alluvial ground water. The Baseline Risk Assessment (BLRA)(DOE 1995a) concluded that ground water quality in the alluvial aquifer in the area is naturally poor, the aquifer is not being used as a source of drinking water, and that institutional controls were in place to prevent its future use as a source of drinking water. A list of chemicals of potential concern (COPCs) was developed and consisted of arsenic, cadmium, cobalt, fluoride, iron, manganese, molybdenum, nickel, ^{226}Ra , sulfate, uranium, vanadium, and zinc. Risks to human health and the environment were considered minimal, but the BLRA recommended collection of additional information to further evaluate these risks and to further characterize the ground water.

For this 1999 Site Observational Work Plan, additional information was collected to evaluate the ground water and surface water quality and movement, determine any contribution of contamination from sediments, refine the hydrogeologic model, and provide updated information about risks to human health and the environment. Background ground water quality was

determined to be poor because average concentrations of uranium and selenium were above UMTRA Project maximum concentration limits, and average concentrations of chloride, iron, manganese, sulfate, and total dissolved solids were above secondary standards established in the Safe Drinking Water Act. Analytical results of samples of Colorado River water upgradient, at, and downgradient of the millsite indicated that ground water was not measurably contaminating the river.

Hydraulic conductivity in the alluvial aquifer was predicted in earlier studies to be about 70 feet per day. The latest study found more heterogeneity in flow rates beneath the site; estimated flow rates ranged from several feet per day to more than 200 feet per day. The alluvial aquifer consists of fill covering sandy to silty sediments and a lower cobbly zone that overlies bedrock of Dakota Sandstone shales. The description of the alluvial aquifer is similar to descriptions in previous studies, but the bedrock is redefined as dark gray shales of the Dakota Sandstone instead of dark shales of the Mancos Shale. This change in identification of bedrock formation does not change the description of the hydraulic properties of the material. Shales of both the Dakota Sandstone and the Mancos Shale are described as aquitards. Ground water in the underlying Dakota Sandstone shales does not have mill-related contaminants and was not considered susceptible to downward migration of contaminants.

The evaluations of human health and ecological risks were updated using data collected in 1998. For human health risk, only the potential drinking water ingestion pathway was evaluated, as the initial BLRA indicated that risks from all other pathways were negligible. Results from the BLRA update indicated that regular human consumption of plume and background ground water could produce adverse health effects, though risks associated with ingestion of plume ground water were considerably higher. Uranium was the largest risk component in plume ground water, followed by ammonia, arsenic, fluoride, iron, manganese, molybdenum, and vanadium. Greatest risk contributors to background ground water were manganese, selenium, fluoride, molybdenum, and uranium. The final COPC list for risks to human health consisted of ammonia, arsenic, iron, manganese, molybdenum, sulfate (because toxicity data are currently being evaluated by EPA), uranium, and vanadium. However, because alluvial ground water in the area of the Grand Junction site is not used for drinking, and because city zoning and development code prohibits its use as drinking water, this exposure pathway is incomplete. It was concluded that site water does not present a risk to human health in the present or the foreseeable future.

An ecological risk assessment compared surface water, sediment, and plant tissues from the millsite area with similar samples collected from a reference area about three miles upstream along the Colorado River. That evaluation did not find a statistically significant difference in contaminant concentrations in abiotic and biotic samples between the two areas, although slightly elevated concentrations of some contaminants (ammonia and some metals) were detected sporadically in samples from the millsite. Therefore, it is recommended that ammonia, uranium, vanadium, manganese, and molybdenum are retained as ecological COPCs for the Grand Junction site. The study found no unacceptable risks to the ecology.

1.0 Introduction

The U.S. Department of Energy (DOE) Grand Junction Office (GJO) in Grand Junction, Colorado, produced this Site Observational Work Plan (SOWP). Its purpose is to determine a site-specific approach to comply with the U.S. Environmental Protection Agency (EPA) ground water standards for the Grand Junction Uranium Mill Tailings Remedial Action (UMTRA) Project site (also called the Climax site). The Grand Junction SOWP presents a comprehensive summary of the site hydrogeologic data, delineates a conceptual model for the aquifer system, and discusses the origins of milling-related ground water contamination. It also defines the magnitude of ground water contamination, evaluates potential human health and ecological risks associated with ground water contamination, and proposes a compliance strategy.

Section 2.0 describes the requirements for meeting standards at UMTRA Project sites. Section 3.0 provides new information gathered in 1997 and 1998 about the site, Sections 4.0 and 5.0 provide site-specific data that support the proposed ground water compliance strategy, and Sections 6.0 and 7.0 present justification for the proposed compliance strategy.

1.1 Ground Water Compliance Strategy

The proposed ground water strategy for the Grand Junction site is no remediation and the application of supplemental standards based on the criterion of limited use ground water. Limited use ground water is ground water that is not a current or potential source of drinking water because of widespread ambient contamination that cannot be cleaned up with treatment methods reasonably employed by public water supply systems (Title 40, *Code of Federal Regulations* [CFR], Part 192.11). The shallow ground water in the alluvial aquifer is considered limited use ground water. However, EPA standards require DOE to consider the effect of milling contamination on current or future beneficial uses of the ground water. Because the quality of ground water in the site area is naturally poor, and because the City of Grand Junction prevents the use of ground water for domestic consumption, potential beneficial uses would be limited to watering livestock and plants.

1.2 UMTRA Project Programmatic Documents

Programmatic documents that guide the SOWP include the *UMTRA Ground Water Management Action Process* (DOE 1998), the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Groundwater Project* (PEIS) (DOE 1996c), and the *Technical Approach to Ground Water Restoration* (TAGR) (DOE 1993a). The Ground Water Management Action Process document states the mission needs and objectives for the UMTRA Ground Water Compliance Program and provides an overall technical and managerial approach for conducting the program. The PEIS provides an objective programmatic decision-making framework for conducting the UMTRA Ground Water Project, assesses the potential programmatic effects of conducting the project, provides a method for determining the site-specific ground water compliance strategies, and provides data and information that can be used to prepare site-specific National Environmental Policy Act (NEPA) documents (10 CFR 1021). The TAGR provides technical guidance for conducting the ground water program.

1.3 Relationship to Site-Specific Documents

The remedial action plan prepared for the cleanup of tailings, soils, and buildings provides site characterization information (DOE 1991). This information was updated in developing the SOWP to formulate the site conceptual model. If a ground water compliance strategy requiring remedial action was selected for this site, a ground water remedial action plan would be prepared; otherwise, a modification to the surface remedial action plan would suffice.

The *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site at Grand Junction, Colorado* (BLRA) (DOE 1995a) was prepared in 1995. Potential risks identified at the site are considered 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 Ground Water Compliance Action Plan, a site-specific NEPA document (e.g., an environmental assessment) will be prepared to evaluate the potential effects of implementing the proposed compliance strategy. DOE will implement the proposed compliance strategy after receiving concurrence from the U.S. Nuclear Regulatory Commission (NRC) and the Colorado Department of Public Health and Environment (CDPHE).

1.4 SOWP Revisions

This SOWP presents a summary of existing data, a conceptual model, and a recommended compliance strategy based on this conceptual model. Additional data were collected in 1997 and 1998. An additional 23 monitoring wells were drilled, and two rounds of ground water samples were collected and analyzed. An ecological reference area chosen to represent site conditions before milling operations began was studied and sampled; results were compared to analytical results of ecological samples collected at the Grand Junction site. This document presents the additional data, correlates the data to previous information, and updates the BLRA and the site conceptual model.

DOE will provide copies of the final SOWP (Revision 1) to the NRC, CDPHE, and to the public for comment. Public meetings were conducted during preparation of the PEIS for the Grand Junction site to ensure close coordination and consultation with potentially affected stakeholders.

1.5 Sources of Historical Data

An early engineering assessment of the site was conducted by Ford, Bacon, and Davis Utah Inc. in 1977 (Ford, Bacon, and Davis 1977). Surface remedial action data concerning the removal of tailings and final site conditions is in the *Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Site at Grand Junction, Colorado* (DOE 1991), and the *Grand Junction, Colorado, Process Site Draft Completion Report*, Volumes 1 and 2, January 1995 from MK Ferguson (no final report was produced). Information about the chemicals used during the mill operations and a description of the milling process were taken from *The Extractive Metallurgy of Uranium* (Merritt 1971).

Ground water information is presented in the TAGR (DOE 1993a); the *Site Observational Work Plan for the UMTRA Project Site at Grand Junction, Colorado* (DOE 1996d);

Potential Groundwater Contamination at Grand Junction UMTRAP Vicinity Properties (Cahn and others 1988); and 45 boxes of field notes, internal reports, and other information archived in the DOE–GJO vault. Information in these boxes was generated by various contractors performing assessment and construction work at the site.

Other publications dedicated to local ground water or associated studies include *Geology and Artesian Water Supply, Grand Junction Area, Colorado*, a U.S. Geological Survey Professional Paper by Lohman (1965); the *Cobble Aquifer Investigation*, U.S. Bureau of Reclamation (U.S. Bureau of Reclamation 1986); and U.S. Geological Survey Open-File Report 94-110 entitled *Physical, Chemical and Biological Data for Detailed Study of Irrigation Drainage in the Uncompahgre Project Area and in the Grand Valley, West-Central Colorado, 1991-92* (Butler and others 1994).

Human health and ecological risk information is described in the Environmental Impact Statement for the millsite (DOE 1986) and in the BLRA (DOE 1995a).

An important source of information and one used extensively for this report is the Site Environmental Evaluation (SEE) UMTRA database maintained at the DOE–GJO facility. The database produces reports, tables, and graphs of surface water, ground water, and sediment chemistry, monitoring well information, lithologic and well completion data, and map coordinate information. Data for Grand Junction start in the mid-1980s. All new data generated for this report reside in SEE UMTRA. Maps that display analytical data are generated using SEE UMTRA information merged with an ArcView GIS package.

End of current text

2.0 Regulatory Framework

A ground water compliance strategy is proposed for the Grand Junction 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 (40 CFR Part 192), 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 stabilize, dispose of, and control uranium mill tailings and other contaminated materials at 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, directs EPA to promulgate standards, mandates remedial action in accordance with standards prescribed by EPA, directs remedial action to be selected and performed with the concurrence of the NRC in consultation with states and Indian tribes, directs NRC to license the disposal sites for long-term care, and directs DOE to enter into cooperative agreements with the affected states and Indian tribes. Title II applies to active uranium mills, and Title III applies to certain uranium mills in New Mexico. The UMTRA Ground Water Project has responsibility for administering only Title I of UMTRCA.

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

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 with the resulting residual radioactive materials (RRM). On January 5, 1983, EPA published standards in 40 CFR 192 for the disposal and cleanup of RRM. The standards for ground water compliance were revised, and a final rule was published on January 11, 1995, and codified at 40 CFR 192.

The standards in 40 CFR 192.02 (c)(1) require that the Secretary of Energy determine which constituents listed in Appendix I of 40 CFR 192 are present in, or reasonably derived from, RRM. Those standards also require the Secretary to determine the areal extent of ground water contamination by listed constituent. Section 4.0 of this document, "Field Investigation Results," complies with these requirements and identifies the constituents of concern at the Grand Junction site.

The standards for cleanup address two ground water contamination scenarios in 40 CFR 192.02 (c)(2). The first scenario addresses ground water contaminated as a result of RRM associated with disposal cells. Future protection of ground water at the disposal sites is being addressed as part of the UMTRA Surface Project. The second scenario addresses ground

water contaminated as a result of RRM in the uppermost aquifer at the former processing site. 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 milling activities.
- Maximum concentration limit (MCL)—EPA's maximum concentration limits for certain hazardous constituents in ground water, as proposed for the UMTRA Project. The MCLs for inorganic constituents that apply to the UMTRA Project sites are given in Table 1 to Subpart A, 40 CFR 192.04.
- Alternate concentration limit (ACL)—An alternate concentration limit for a hazardous constituent that does not pose a substantial present or potential hazard 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.

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:

- Remedial action would pose a significant risk to workers or members of the public.
- Remedial action to meet the standards would directly produce harm to human health and the environment that is clearly excessive compared to the health and environmental benefits, now or in the future.
- The estimated cost of remedial action is unreasonably high relative to the long-term benefits, and the RRM does not pose a clear present or future hazard.
- There is no known remedial action.
- The remediation of ground water quality at any processing site is technically impracticable from an engineering standpoint.
- The ground water is considered limited use ground water if it 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 supply systems.
 - The quantity of water available for sustained continuous use 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)].

One of the four cleanup standards (i.e., clean up to background, MCLs, or ACLs, or apply 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, and no remediation. Section 5.0, "Site Conceptual Model," presents a summary of the geology, hydrology, geochemistry, and ecology of the site. That discussion provides the information relevant to selecting a ground water compliance strategy. Section 7.0, "Ground Water Compliance Strategy," presents a discussion of the proposed compliance strategy for the Grand Junction site and includes a justification for selection of the no-remediation compliance strategy.

The regulations in 40 CFR 192.22(c) also require DOE to inform landowners and occupants of the locations affected by hazardous constituents and to solicit their comments if supplemental standards are applied.

2.1.2 National Environmental Policy Act

DOE NEPA regulations are in 10 CFR part 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 the alternatives for conducting ground water compliance at the UMTRA Project processing sites.

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

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

2.1.3 Other Regulations

In addition to EPA ground water standards and requirements of NEPA, DOE must also 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 State and Tribal Regulations

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

2.3 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 protection of the public from radiation hazards. DOE guidance pertaining to NEPA 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).

2.4 Agreements

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

3.0 Site Conditions

3.1 Physical Setting and Climate

The Grand Junction site is at an elevation of approximately 4,600 feet (ft) (1,400 meters [m]) in the broad, arid Grand Valley and has historically been referred to as the Climax site. It is located in Mesa County, Colorado (Figure 3-1), along the southern side of Grand Junction in an industrial area (Plate 1). The site is bounded on the south by the west-flowing Colorado River, which joins the Gunnison River about 0.75 mile (1.2 kilometers [km]) to the west. The Grand Valley is bounded by the Book Cliffs to the northeast, about 9 miles (15 km) from the site; the Grand Mesa to the east, about 16 miles (26 km) from the site; and the Uncompahgre Plateau to the west, about 5 miles (8 km) from the site. The Grand Junction site encompasses approximately 114 acres (46 hectares) that underwent surface remedial action from 1989 to 1994.

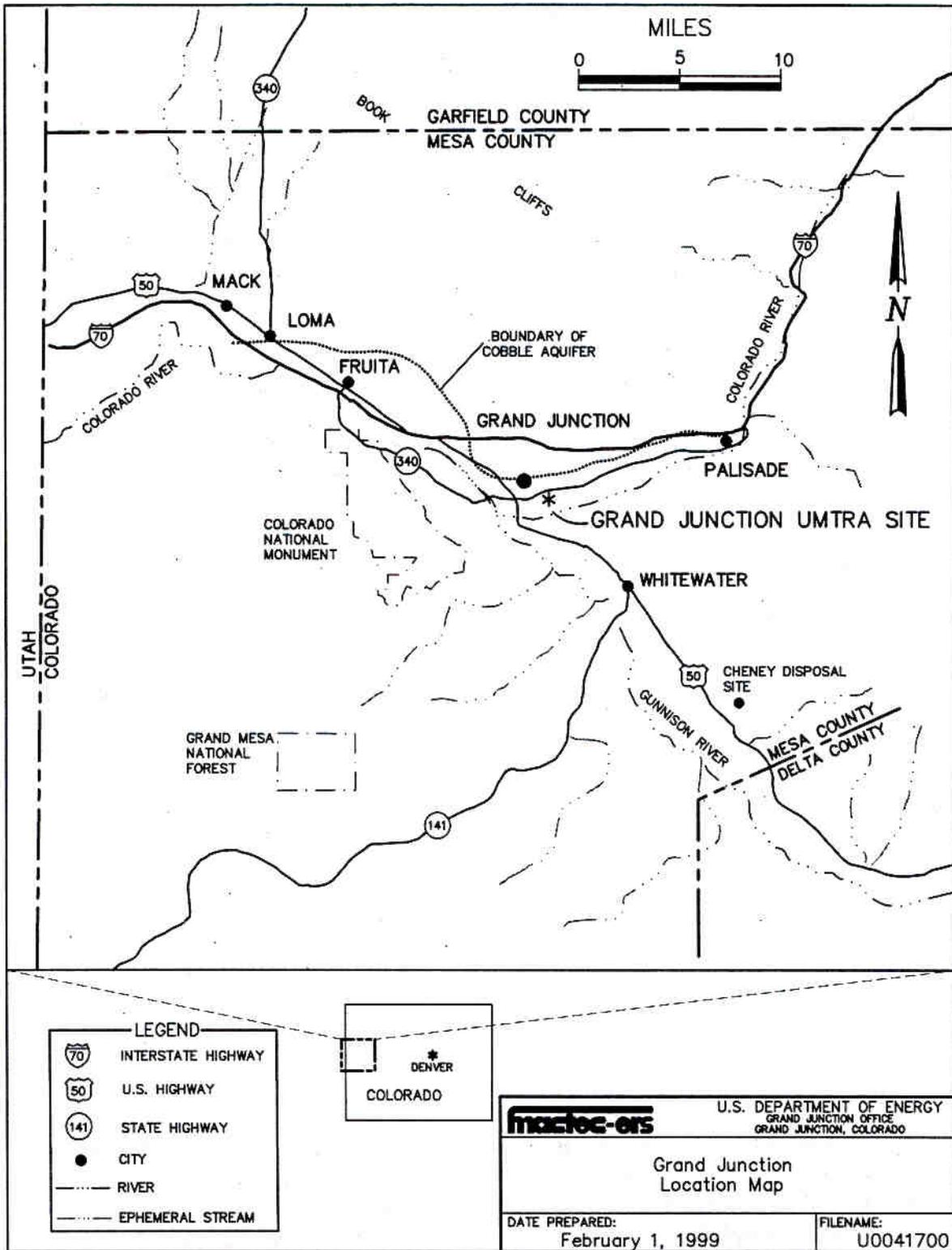
Annual precipitation in Grand Junction is approximately 9.1 inches (in.) (23 centimeters [cm]), and the mean annual temperature is 52.1°F (Lohman 1965). August and September are the wettest months; summer thunderstorms can produce more than an inch of rain. Potential evapotranspiration for the area is approximately 71 in. (180 cm) per year, making the potential evapotranspiration to precipitation ratio about 8:1.

3.2 Land and Ground Water Use

The original millsite was covered with 6 in. of clean soil and revegetated by 1994. Part of the original remedial action involved constructing wetlands, including eight ponds along the southern boundary of the property adjacent to the Colorado River (see Figure 3-10). River flooding in 1995 eroded the ponds and reconfigured the southern boundary of the site.

The area encompassing the former millsite is administered by the City of Grand Junction Parks and Recreation Department. In 1997 a pedestrian bridge was built across the Colorado River at the southeast corner of the site. In 1995 and 1996 the Army Corps of Engineers constructed a flood control levee through the southern part of the site. A concrete sidewalk built in 1997 on top of the levee is part of the city's riverfront trail corridor connecting the north side of the Colorado River to the south side at Orchard Mesa Middle School via the foot bridge. West of the site, the Western Colorado Botanical Society, in coordination with the city, constructed the Western Colorado Botanical Gardens, which contain a variety of indoor plants and butterflies and an outdoor reconstruction of the valley's geomorphology with associated flora. The gardens are located at the south end of 7th Street at the access to the Watson Island section of the Colorado River Trail.

No ground water is being used from the site. The deed transferring the site to the City of Grand Junction from the CDPHE specifies ground water use restrictions that are controlled by the state and DOE (see Section 7.2 for details). According to information from the State Engineer's Office, no wells are recorded for properties downgradient of the site. The Botanical Gardens uses a sump near the Colorado River to pump water into a lined pond for irrigating the gardens.



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Figure 3-1. Location of the Grand Junction Site

3.3 Site History

3.3.1 Milling History

The millsite and the remaining brick mill building were originally part of the Colorado Sugar Manufacturing Company; the building was constructed in 1899. Later it became the Holly Sugar Corporation and processed sugar from sugar beets; the plant closed before the pre-1947 photograph shown in [Figure 3-2](#). The site of four ponds used during the sugar processing era, located directly south of the mill, were used later for settling ponds during the uranium milling operation.

The site was reconfigured for uranium-ore processing and opened as the Climax mill in late 1950 (Mastrovich 1985). The mill was constructed and operated by the Climax Uranium Company, a subsidiary of Climax Molybdenum Corporation. The Climax mill had an initial production rate of 330 tons per day until 1955; modifications increased capacity to 500 tons per day, which was maintained until closure (Merritt 1971; Orr 1954). [Figure 3-3](#) is an oblique aerial photograph taken about 1956 looking northwest. The photograph shows the old sugar beet mill warehouse extending from the right side of the picture up to about the stack. Various other buildings, blending vats, labs, and ponds are also visible. Ore was brought by rail and truck and stored in the area shown in the upper left portion of the photograph. [Figure 3-4](#) is a 1954 aerial photograph that shows the size of the tailings area, the ore storage area, and the settling ponds. In 1960, Climax was incorporated into American Metals Climax, Inc., which operated the mill until closure in March 1970. [Figure 3-5](#) is an aerial photograph from 1961 showing the two solids disposal areas in the eastern and western sections of the property, where tailings in the form of sands and slimes were pumped (Merritt 1971). [Figure 3-6](#) from 1966 shows the three large evaporation ponds totaling 35 acres on the eastern part of the property, where effluent was pumped from the settling ponds just south of the mill.

This mill was the first in the United States that was designed for uranium production with vanadium as a byproduct. Ores were predominantly sandstones from the Morrison and Chinle Formations that contained primary uranium/vanadium oxide and silicate minerals, as well as oxidized ores containing predominantly carnotite (potassium uranium vanadate) and tyuyamunite (calcium uranium vanadate). Most of the mill feed came from about 20 company-owned mines in the Uravan Mineral Belt; the remainder came from independent producers (Merritt 1971).

The ore was crushed and ground; uranium was initially acid leached and neutralized before sands and slimes were separated. Sands were acid leached again. After separation, the slime fraction was salt roasted and water leached to remove vanadium, and finally acid leached again to remove uranium and water-insoluble vanadium. A solvent extraction process separated uranium from vanadium. The solvent extraction raffinate solution and other intermediate products were treated with acid again to remove additional uranium and vanadium (Merritt 1971). Tailings from the washing circuit and raffinate from the solvent extraction operation were sent to one or two small holding ponds near the mill, where fines settled out before the waters were sent to one of the three separate holding ponds where liquids were allowed to evaporate. The tailings piles were stabilized with vegetation during the years of operation, and erosion of tailings into the Colorado River was minimized. This complex milling process required a number of different chemicals. Inorganic chemicals included sulfuric acid, hydrochloric acid, sodium chlorate, ammonia, sodium chloride, sodium carbonate, hydrogen peroxide, and powdered iron metal; organic

chemicals included Number 2 fuel oil, di(2-ethylhexyl) phosphoric acid, tributyl phosphoric acid, and tertiary amines (DOE 1995a).

During 19 years of milling, 2,281,614 tons of ore were processed; the ore averaged 0.28 percent U_3O_8 and 1.41 percent V_2O_5 . A total of 11,698,736 pounds (lb) of U_3O_8 and 46,050,877 lb of V_2O_5 were produced. Uranium recovery averaged 93 percent and vanadium recovery averaged 72 percent over the history of the operation (Albrethson and McGinley 1982). An estimated 2.2 million dry tons of tailings in the form of fine sands and slimes were produced during the life of the mill. From 1950 to 1966, tailings were available to private citizens and contractors who used them for fill and other construction activities (e.g., concrete production). The Atomic Energy Commission denied having jurisdiction over the tailings because they contained less than 0.05 percent of the uranium source material, which was the criterion set forth in the *Code of Federal Regulations* (Mastrovich 1971). But in 1966 the tailings were sampled for radon, and preliminary results indicated elevated levels. Although that finding caused Climax to discontinue release of tailings from the site, an estimated 300,000 tons of sands containing uranium daughter products had been removed by that time (Mastrovich 1971).

3.3.2 Surface Remedial Action and Current Status

The mill was closed in March 1971. During 1970 and 1971 Climax demolished 8 of the 12 main mill buildings and sold slimes in the northernmost settling ponds to Union Carbide Corporation as ore. The bottoms of the large evaporation ponds were plowed and dikes surrounding them were leveled. Equipment that could be decontaminated was sold; other equipment that could not be decontaminated was buried in the tailings piles along with building rubble (Merritt 1971). Some building rubble was used as riprap along the river. [Figure 3-7](#) from 1977 shows the remaining mill buildings that Climax left and final reclamation efforts of the tailings piles. Climax personnel experimented with planting different types of grasses directly on the tailings. They found that crested wheat grass grew well if irrigated sufficiently (Merritt 1971). The circular patterns in this photograph ([Figure 3-7](#)) and, to a lesser extent, in the previous one ([Figure 3-6](#)), are irrigated areas of grasses. Climax deeded 40 acres, where the three evaporation ponds had been located, to the State of Colorado. This was the temporary or interim repository for vicinity property tailings during the next phase of remedial action. Climax sold its remaining property by 1976 (Mastrovich 1985).

After Climax left in 1976, the next and final phase of surface remedial action was the UMTRA effort that began in the mid-1980s. This cleanup was conducted in two phases. Phase I, completed in 1989, consisted of fencing, demolishing remaining buildings except the old sugar mill, constructing lined retention ponds, and preparing the wastewater treatment plant foundation at the old millsite. Phase II began in 1990 and included constructing and filling Grand Junction disposal site and assembling the wastewater treatment plant. [Figure 3-8](#), a May 1991 oblique aerial photograph looking west, shows the treatment plant, initial excavation and removal of contaminated materials, and the newly constructed rail car haul system. [Figure 3-9](#), a March 1993 oblique aerial photograph looking west, shows continued excavation of the mill tailings and interim storage of vicinity property materials on the site of the evaporation ponds. By the end of 1994 all contaminated materials from the old processing site and the vicinity property materials temporarily stored at the site had been transported to the Grand Junction disposal site. [Figure 3-10](#) is a May 1994 oblique aerial photograph looking west that shows the site fully excavated, backfilled, contoured, and seeded. The only building left is the original brick sugar mill warehouse that was cleaned, fitted with a new roof, and sold to the private sector in 1995. It

is now located outside of the fenced enclosure of the old Climax site (information from the completion report prepared by M. K. Ferguson, January 1995).

In 1994 eight ponds were constructed along the southern side of the site adjoining the Colorado River as part of a wetlands area. Floods in the spring and early summer of 1995 severely eroded some ponds and filled others with silt. The wetlands area was never reconstructed and today only indistinct traces of the eight ponds are visible. Sampling of the original ponds indicated that higher levels of contamination were present in the two westernmost ponds (DOE 1996d). However, the higher concentrations may have resulted from evaporation.

3.3.3 Sources of Ground Water Contamination

During the sugar beet milling period, excess vegetation and pulp from the sugar beets were used to feed livestock. The apparent remnants of these early stock yards can be seen in a pre-1947 photo (Figure 3–2) along the southeastern portion of the site. Later, an area along the west side of the site was used as corrals (see Plate 1). Both areas, but especially the area in the southeastern part of the site, may have contributed nitrogen to the ground water.

Ground water contamination at the site resulted from processing ore and from subsequent leaching of uranium mill tailings constituents by mill water, rain water, and ground water. During active milling, slimes and water from the operation were sent to four settling ponds located directly south of the mill (see Figure 3–3) and from there to three evaporation ponds located east and north of the mill (Figure 3–6 and Plate 1). The evaporation ponds apparently did not have enough surface area for complete evaporation of the water, and some liquids seeped into the underlying sediments. An estimated 50 million gallons (190,000 cubic meters) per year from 1951 to 1955, and 75 million gallons (285,000 cubic meters) per year from 1956 to 1970 were used to process ore. Based on this estimate, the total amount of process water that was available to seep into the sediments underlying the site over the history of milling operations was approximately 1,900 acre-feet, or 2.3 million cubic meters (DOE 1996d).

3.4 Future Uses of Land and Ground Water

DOE deeded the Climax site to CDPHE, who in turn deeded the site to the City of Grand Junction in April 1997. The deed specified that ground water from the site could not be used for any purpose without written approval of DOE and CDPHE. The City is developing a master plan for use of the land as an open park area. Possible uses include a city pedestrian park with trees, sidewalks, and grassy areas; a recreational area including ball fields; and an engineered area for holding ponds and wetlands that temporarily store excess storm flow before it is released to the river. The City has recently named the land occupied by the former millsite “Las Colonias Park,” from an earlier Latino community that existed in that part of town.

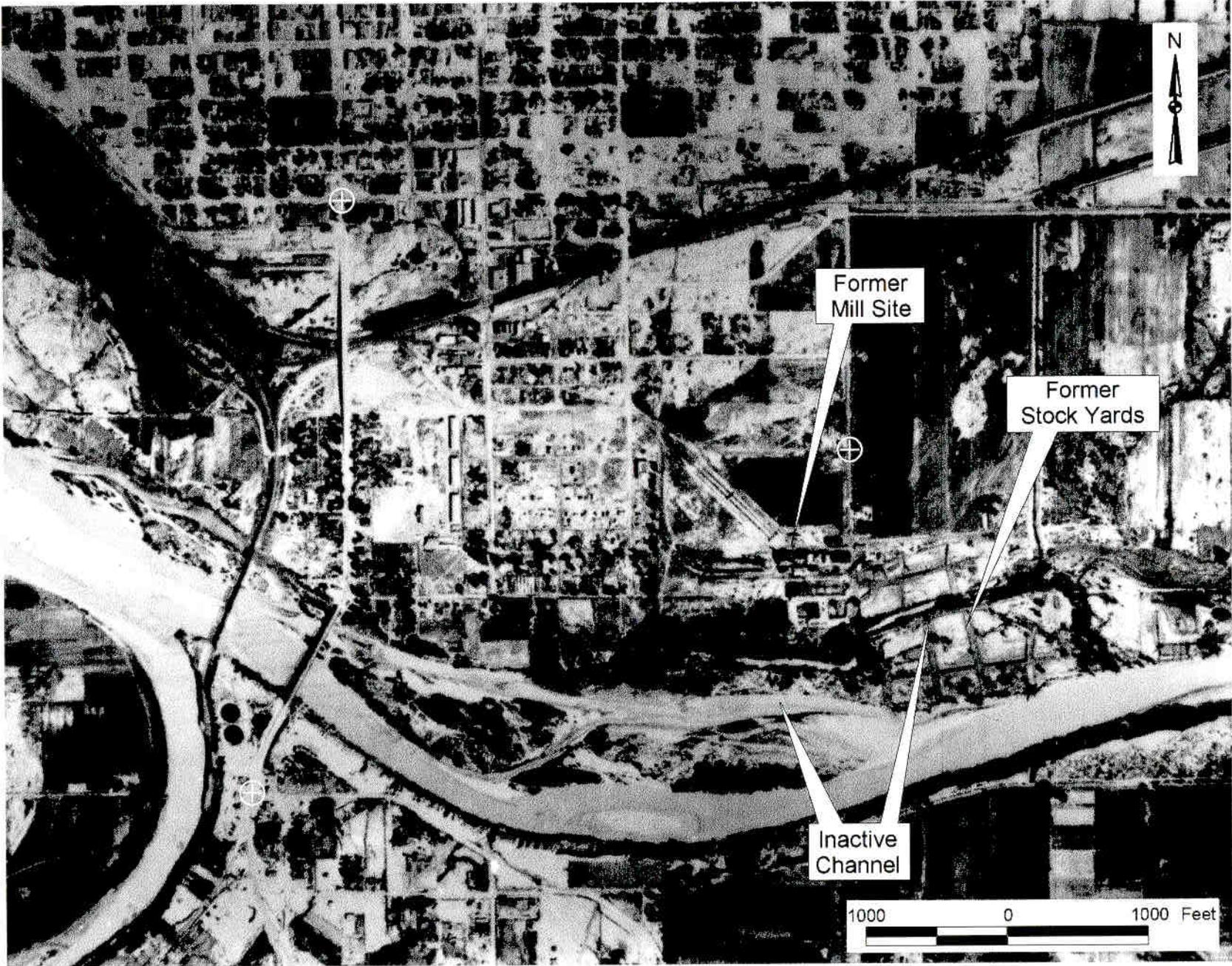
The City has also acquired some additional parcels of land downgradient (west) of the millsite. One narrow strip extends from the millsite to about 8th Street along the small northern channel of the Colorado River. Another parcel extends from 7th Street to 5th Street on the south side of Struthers Avenue. That parcel will have botanical gardens and a parking lot in the western section and already contains a building housing other botanical gardens and a butterfly house in the eastern part. Currently, the City does not plan to obtain other parcels of land in the region east of the millsite and south of Struthers Avenue extending west to 5th Street. Several commercial and private landowners have property in this corridor. On the west side of 5th Street,

the City now owns the old American Auto Salvage property and has constructed a dike along its southern perimeter that is connected to the dike farther north protecting the community surrounding Riverside Park. The area inside the old American Auto Salvage property north of the dike and south of Riverside Park Drive (or 4th Avenue) may be offered to light industry; the area south of the dike contains a large pond open to the Colorado/Gunnison River confluence that U.S. Fish and Wildlife hopes to use as a breeding area for fish during times of high water.

No future use of the ground water is planned or anticipated. The City requires persons or businesses inside the city limits to use municipal water hookups. No wells are registered with the State Engineer's Office in this area. The City pumps water from a sump near the Colorado River into a series of ponds along the west side of the botanical gardens property and plans to use this ponded water as irrigation for some of the gardens.

Explanation of aerial photographs (Figures 3-2 through 3-10)

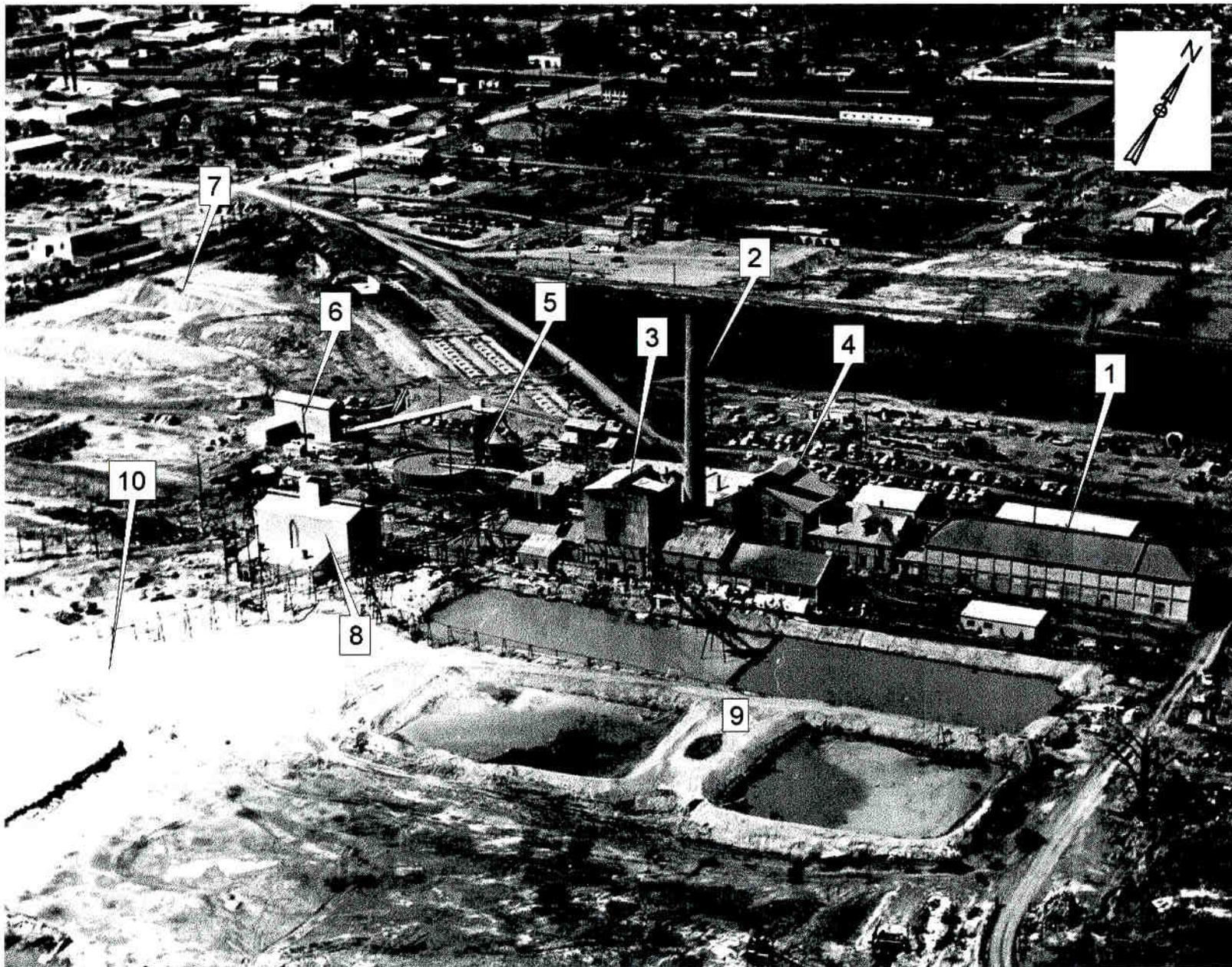
Figure 3-2: Pre-1947 Overhead Aerial Photograph. Sugar beet mill buildings and four ponds are visible. The semirectangular areas southeast of the mill near the Colorado River are interpreted to be remnants of stockyards. An old channel of the Colorado River crosses the southern part of the property.
Figure 3-3: 1956 Oblique Aerial Photograph of the Climax Mill—Looking Northwest. The large building on the right, which was the warehouse for the sugar beet mill (1), is being used in the uranium milling process. The dryer stack (2) is located between the roaster building (3) and the main mill buildings (4), and farther to the left are two thickener tanks (5). Left of the tanks is the ore crusher house (6) and ore piles (7)(mostly hauled in by rail). The tall, light-colored building in the left foreground is the vanadium plant (8). Four slimes ponds (9) are visible in the foreground and light-colored tailings (10) are visible in the left foreground.
Figure 3-4: 1954 Overhead Aerial Photograph. The mill has been in operation for about 4 years and the ponds south of the mill are being used for slimes ponds (sometimes called raffinate ponds). Tailings are being deposited southwest of the ponds.
Figure 3-5: 1961 Overhead Aerial Photograph. Considerably more tailings have been deposited since 1954 and are spread over most of the millsite area.
Figure 3-6: 1966 Overhead Aerial Photograph. Large evaporation ponds (ponds 1, 2, and 3 on Plate 1) are visible to the east of the mill. Circular areas are from American Metals Climax, Inc. irrigation and reseeding attempts on the tailings piles. Smoke can be seen emanating from the stack.
Figure 3-7: 1977 Overhead Aerial Photograph. The mill closed in 1971, and by 1977 American Metals Climax, Inc. had razed most of the buildings and attempted to vegetate the tailings piles.
Figure 3-8: October 1991 Oblique Aerial Photograph—Looking West (from DOE 1995b, Volume 1). This figure shows the removal of tailings and other materials. The wastewater retention basin is visible at the top of the photo and the rail out-load facility is shown on the right. Only the original sugar beet mill warehouse remains.
Figure 3-9: March 1993 Oblique Aerial Photograph—Looking West (from DOE 1995b, Volume 1). This figure depicts the continued removal of vicinity property tailings from the state's interim repository pile in the foreground. The rail out-load facility is seen on the right.
Figure 3-10: May 1994 Oblique Aerial Photograph—Looking West (from DOE 1995b, Volume 1). All facilities for remedial action are removed; the site is contoured, revegetated, and a series of 8 ponds are constructed along the Colorado River. In 1995, spring flood water from the Colorado River filled in or eroded the pond system, and little evidence of its existence is visible today.



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Figure 3-2. Pre-1947 Photograph



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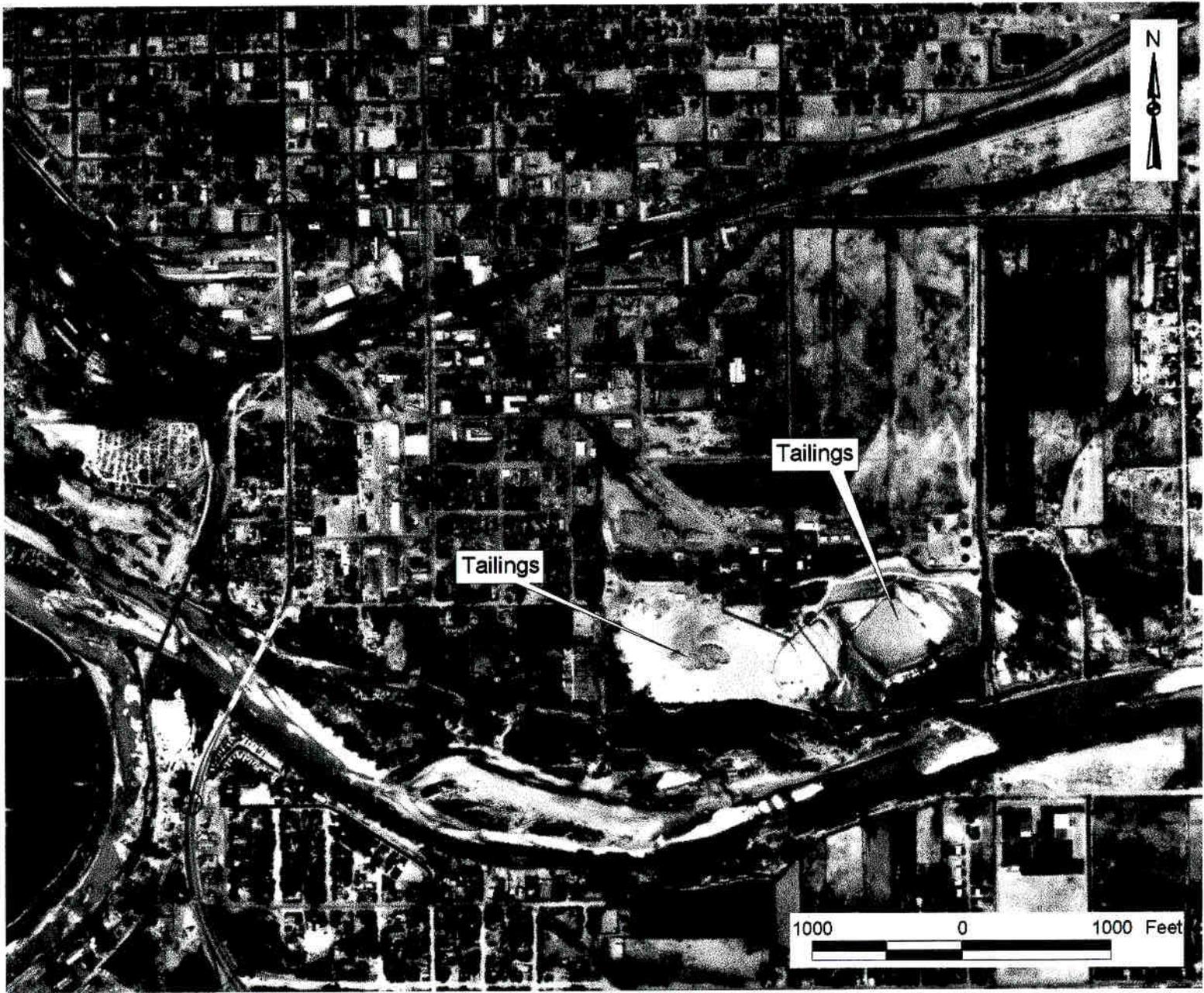
Figure 3-3. 1956 Photograph of the Mill—Looking Northwest



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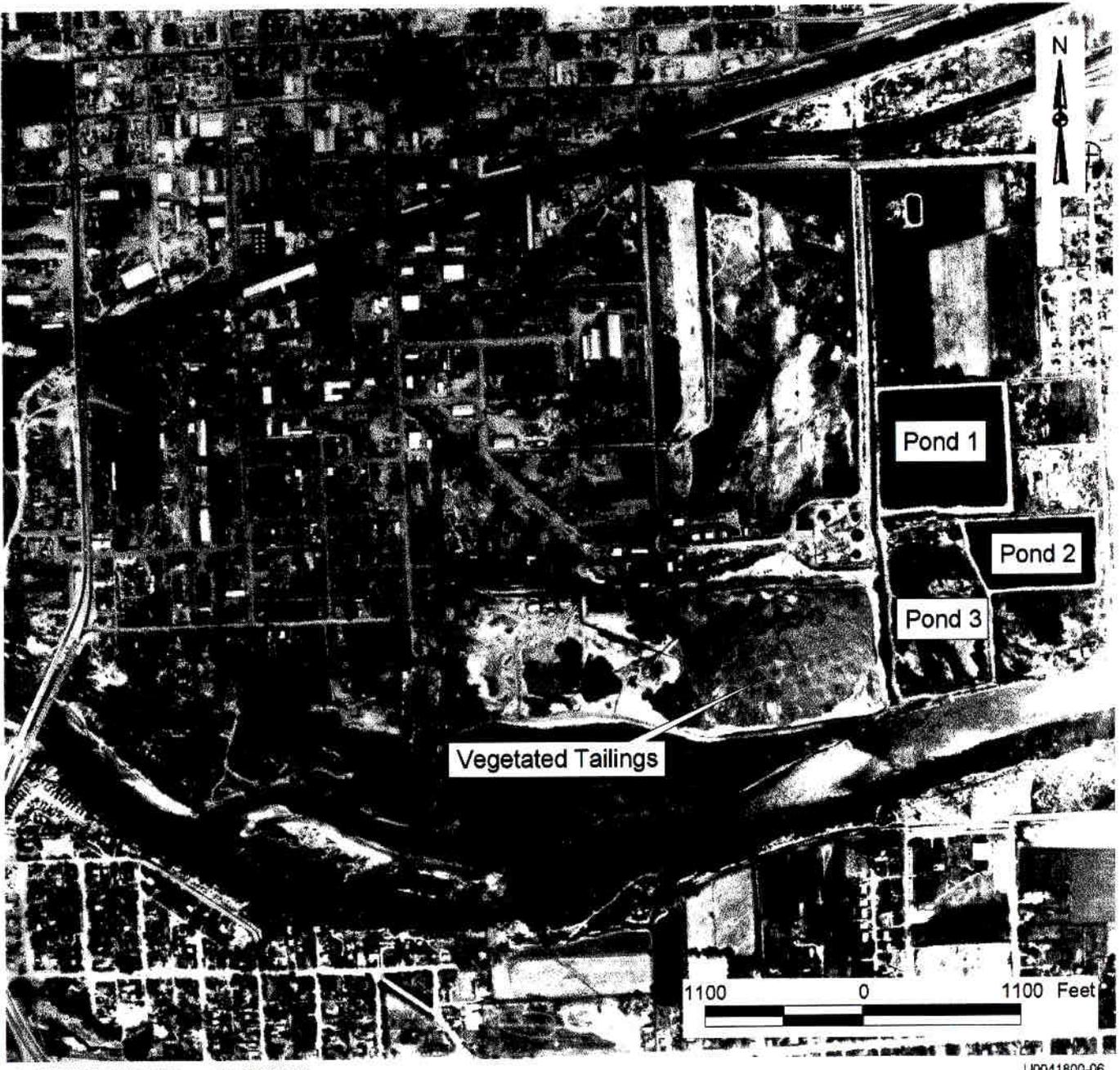
Figure 3-4. 1954 Aerial Photograph



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Figure 3-5. 1961 Aerial Photograph



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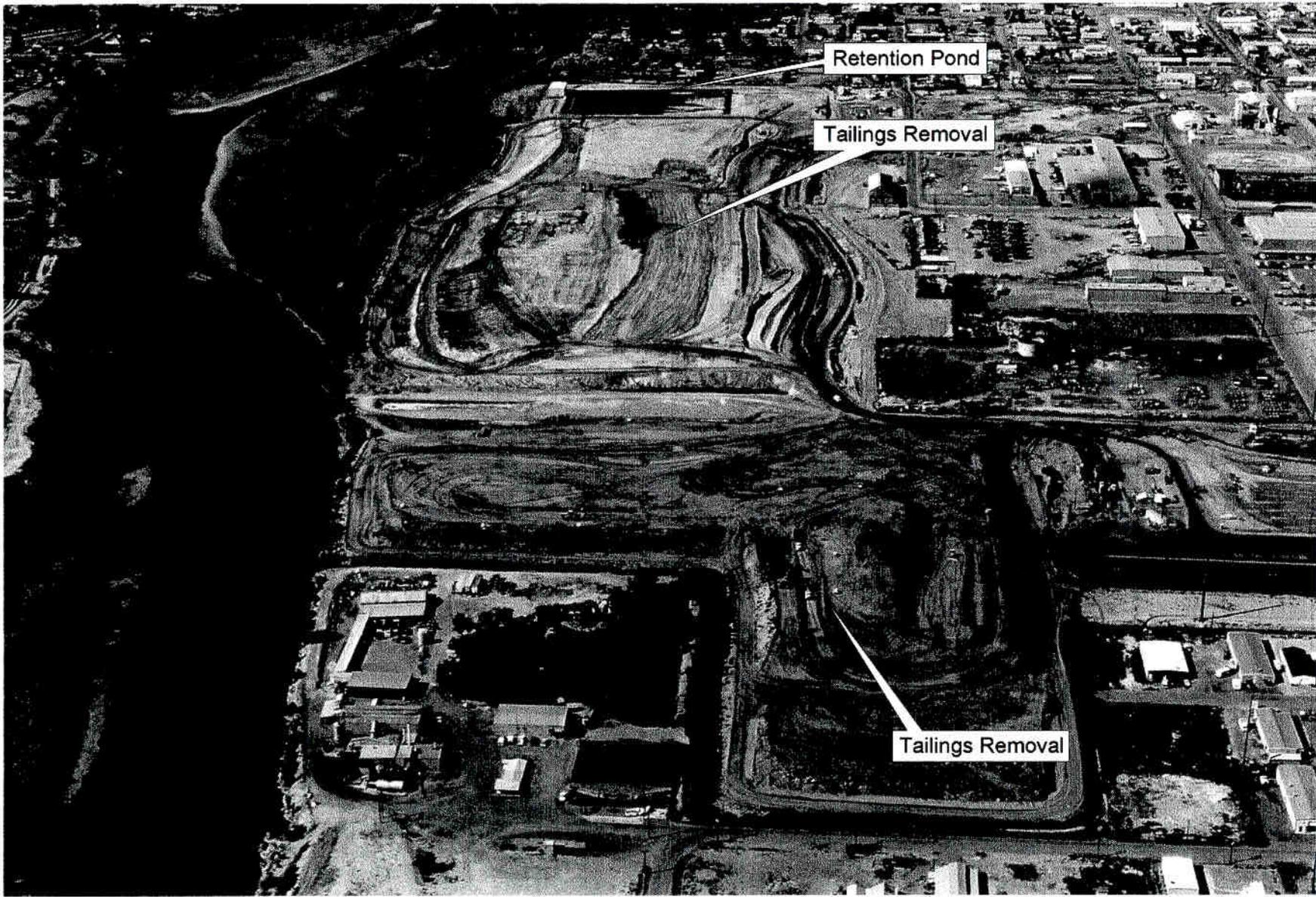
Figure 3-6. 1966 Aerial Photograph



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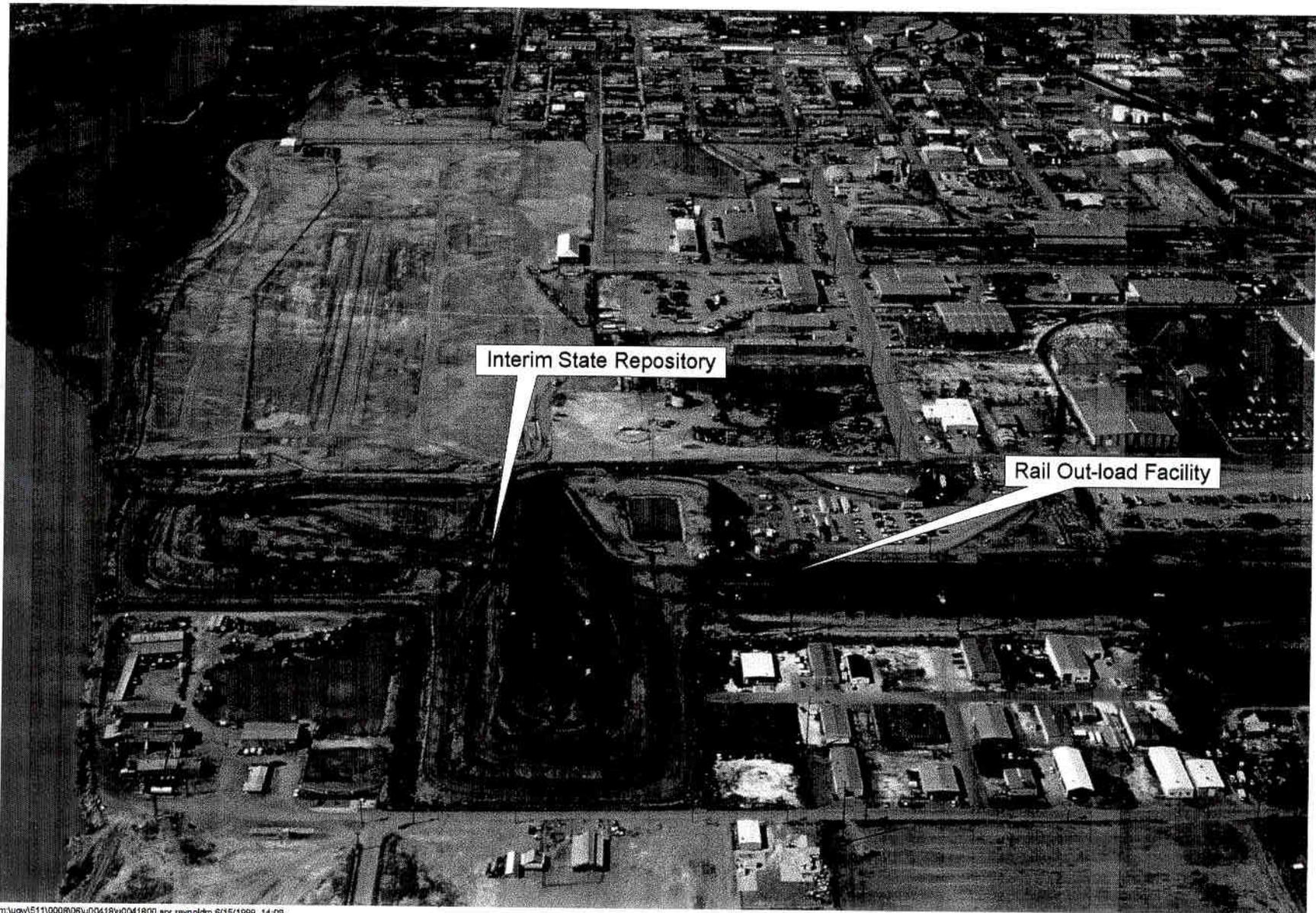
Figure 3-7. 1977 Photograph of the Climax Mill



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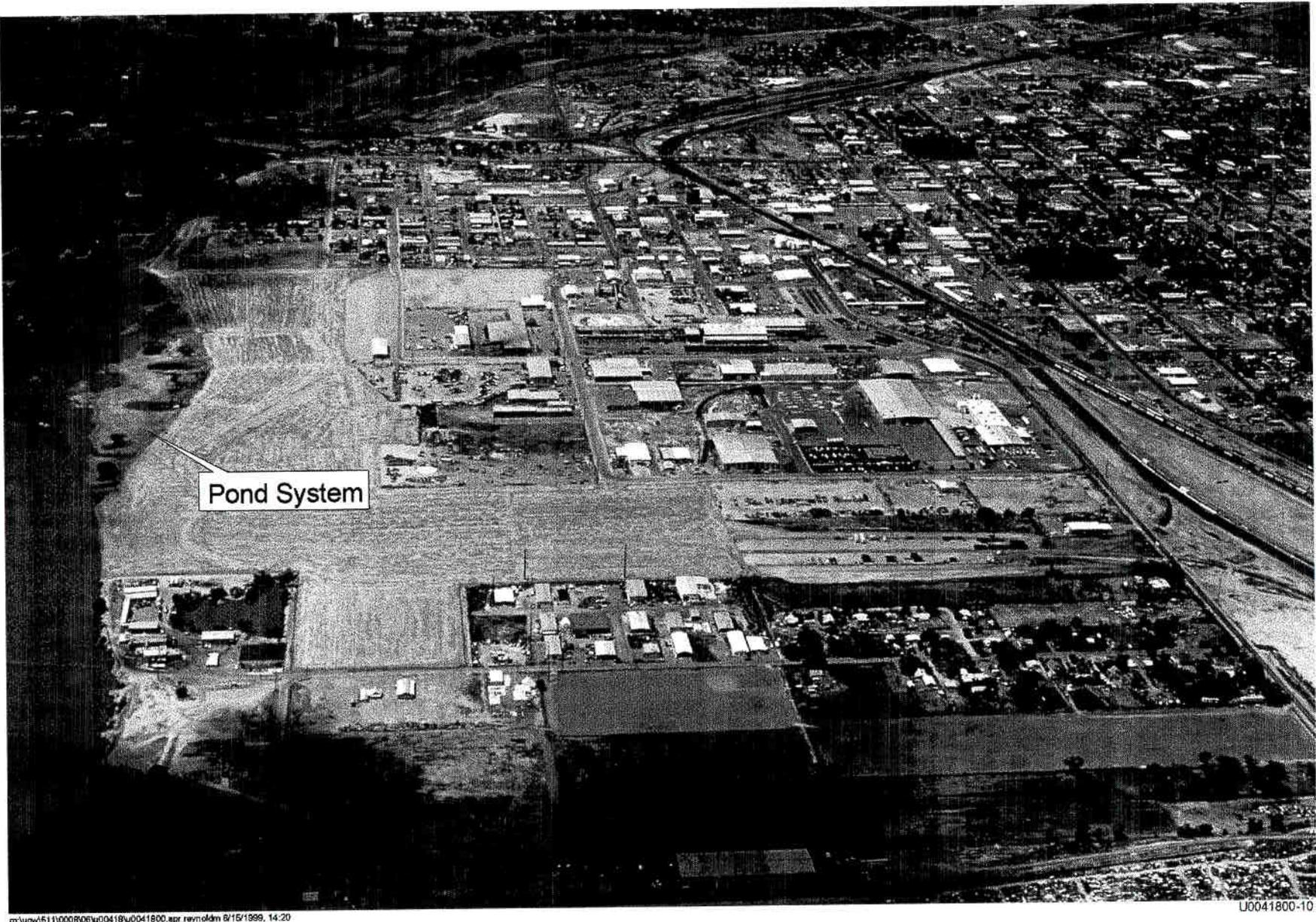
Figure 3-8. 1991 Photograph; Looking West at the Excavation of the Climax Tailings Piles



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Figure 3-9. 1993 Photograph; Looking West at the Excavation of the Tailings Piles



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Figure 3-10. 1994 Photograph; Looking West at the Completed Reclamation of the Millsite

4.0 Field Investigations Results

This section presents results of field studies performed to meet data needs. Application of the results is presented in Section 5, “Conceptual Site Model.”

4.1 Geology

The geology near the site is structurally and stratigraphically simple. The Cretaceous marine Mancos Shale and Cretaceous marginal marine Dakota Sandstone Formations dip gently to the northeast away from the Uncompahgre Plateau on the west. Unconsolidated alluvial sediments of Quaternary to Recent age overlie these rocks and form the alluvial aquifer, which contains contaminated ground water associated with the Grand Junction site.

The work plan for characterizing the Grand Junction site (DOE 1997) describes the geological data needs in Quaternary stratigraphy and bedrock identification. [Figure 4–1](#) is the A–A’ geologic cross section shown on Plates 1 and 2.

4.1.1 Alluvial Aquifer

The Colorado River has been prograding updip and southward across the Grand Valley, probably as a result of the eroding shales from the north clogging the river channel. Its current channels lie against the bluffs on the south side of the river. Thickness of the river alluvium, which forms the alluvial aquifer, ranges from 8 ft (2.4 m) to more than 78 ft (24 m) in the Grand Valley (U.S. Bureau of Reclamation 1986). The U.S. Bureau of Reclamation report describes the sediments near the site as Colorado River alluvium consisting of sandy to silty sediments underlain by the Cobble aquifer, which consists of unconsolidated sands, gravels, and cobbles.

Well logs developed during installation of 23 new monitoring wells are shown in Appendix B. Surface fill near the millsite is 9 to 10 ft (3 m) thick, so the upper sandy/silty zone in question was not identified with confidence as part of the alluvial aquifer. Cobbly sediments were below this zone, and depth to Dakota shale (i.e., bedrock) ranged from 13 ft (4 m) in well 1017 (nearest the river on the site) to 27 ft (8 m) in well 1019 (the northernmost well on the site). Well locations are shown in Plate 2.

An examination of background well lithologic logs indicated an organic-rich soil horizon developed in pastures and fields for the first 1 to 5 ft (0.3 to 1.5 m), with silty sands below this (wells 1024 and 1025). In most background wells and in wells in historically agricultural areas, silty sands extend from near surface to depths of 15 ft (4.6 m) or more (wells 1026 and 1028) and overlie the cobbly gravel zone. These cobbly gravels were drilled to a maximum depth of 32 ft (10 m) in well 1025. The work plan for these monitoring wells required installing 20 ft (6 m) of screened interval below the saturated zone or drilling to bedrock, whichever was less. Consequently, the alluvial aquifer was not fully penetrated in some background wells east of the site.

A pre-1947 aerial photograph of the millsite (Figure 3–2) shows a prominent channel crossing the site from east to west. Milling operations eliminated the trace of this old channel, as can be seen in subsequent photographs (Figures 3–4, 3–5, and 3–6), but its possible effect on hydrologic conditions is discussed in Section 5.1.3.

4.1.2 Bedrock Identification

Previous reports assign the shales underlying the site to the Mancos Shale (Ford, Bacon, and Davis 1977; DOE 1996c; DOE 1996d; and others). An effort was made to differentiate the gray shales of the Dakota Sandstone sequence from the gray shales of the Mancos Shale in the site area. To do this, contractor geologists requested assistance from Dr. Robert G. Young, a local consulting geologist, who had mapped these units for his dissertation. Dr. Young provided criteria for distinguishing the two formations and accompanied the contractor geologists into the field.

The criteria for distinguishing the formations are:

Dakota Sandstone	Mancos Shale
Carbonaceous (to lignitic), not calcareous	Calcareous (reacts to HCl), not carbonaceous
Silty to clayey	Clayey with few silty layers
Contains no marine fossils	Contains marine fossils
Some silty lenses in shales	Thin layer of white bentonite near the bottom of the unit
Some pyrite nodules or iron staining	No pyrite nodules, little or no iron staining

Rocks composing the bluffs on the south side of the Colorado River from the confluence of the Gunnison River about 2,000 ft (610 m) west of the site to approximately 2,000 ft (610 m) east of the site were field examined and evaluated using the criteria listed above. Dakota Sandstone shales crop out from a point about 100 yards (91 m) east of the 5th Street bridge eastward and dip beneath the site at about 1 to 2 degrees. The shales beneath the site area were described as Mancos Shale in earlier reports but actually belong to a middle shale unit of the Dakota Sandstone. The estimated trace of the Mancos subcrop is shown in Plate 1. It follows the estimated contact on the south side of the Colorado River (this section of the bank is overgrown with vegetation), crosses the river about 2,000 ft (610 m) upstream of the site at an elevation of about 4,570 ft (1,393 m) where a limy, resistant siltstone bed produces a small area of rapids, and continues to the northwest, where it comes within about 200 ft (61m) of the site boundary (Plate 1). Some intertonguing of these formations might be expected at this transitional contact between the marine Mancos Shale and the marginal marine Dakota Sandstone sequence. Ground water flowing from the north toward the south and southwest across the site would contain trace elements leached predominantly from the Mancos Shale as well as from the Dakota shales.

By use of these criteria, the total thickness of the Dakota Sandstone in the area of the site was determined to be about 200 ft (61 m). The same recognition criteria were applied to core from five previously drilled boreholes (724, 725, 735, 741, and 743) located near the site on the north side of the Colorado River. None of the core had these characteristics of Mancos Shale, indicating that the subcrop of Mancos is some distance north or east of the site. To further confirm this, the same criteria were used to evaluate cuttings from the bottom of wells. For all on-site wells, drilling continued through the alluvial aquifer into bedrock. Dakota shales were identified as bedrock in all wells drilled on site.

4.2 Hydrology

Hydrogeologic data needs for ground water and surface water were identified in Section 5.0 of the original SOWP (DOE 1996d) and Section 3.5 of the *Work Plan for Characterization Activities at the UMTRA Grand Junction Project Site* (DOE 1997b). Additional site

Figure 4–1. Geologic Cross Section A-A'

**FIGURE 4–1 will be provided upon request.
Click [Wendee Ryan](#) or [Michelle Smith](#) to request.**

characterization was performed to better define the water table surface, saturated thickness, lithology, and hydraulic parameters of the alluvial aquifer. New monitor wells were installed and developed, and water levels in selected monitor wells have been measured on a continuous basis using downhole dataloggers. Aquifer pumping tests were performed in a number of monitor wells to evaluate hydraulic conductivity beneath the site. Slug tests were also done in monitor wells to estimate hydraulic conductivity throughout the site. The recharge/discharge relationship between the Colorado River and the alluvial aquifer was evaluated by measuring water levels in the river and comparing these with ground water levels in adjacent monitor wells.

4.2.1 Alluvial Aquifer Analysis

Twenty-three new monitor wells (numbered between 1010 and 1035) were installed in the alluvium to provide additional information on lithology, saturated thickness, and hydraulic parameters (lithologic logs are in Appendix B, and well locations are shown on Plate 1).

Twenty-one wells were installed during September 1997 by using a hollow-stem auger. These consisted of eight on-site wells (1012–1019), five upgradient wells (1020, 1021, 1023, 1024, 1025), four downgradient wells (1010, 1011, 1022, and 1029), and four vicinity property wells (1026, 1027, 1028, and 1030). Boreholes 1031 and 1032 were used to obtain water level measurements. A CME-75 truck-mounted auger rig was used to drill 12¼-inch o.d. boreholes; the monitor wells installed were 4-inch schedule 40 PVC casing with 0.02-inch factory-slotted PVC screens and bottom caps. Soil samples were collected with a 2½-inch-diameter, 2-foot split barrel sampler using a 150-pound hydraulic drop hammer. A total of 99 split barrel samples were collected. Drilling protocol required that wells intercept bedrock or extend 20 ft into the saturated zone, whichever was less. All wells intercepted bedrock except wells 1025, 1026, 1027, and 1028 (1025 is an upgradient well, the other three are at the Regional Center). General information and surveyed locations are shown in Appendix A, and lithologic/well completion logs are in Appendix B.

All wells were developed by repeated surging and pumping. However, water production from most of the wells was still considered to be low for a typical fluvial sediment, so seven on-site wells were jetted to improve production and efficiency. Jetting consisted of using a five-horsepower pump to force a jet of potable water outward along the screened interval of the wells. Water was constricted from a 2-inch line to a 1-inch T-nozzle jetting tool. Approximately 425 gallons (1,610 liters) of water could be expelled into the well in five minutes. This process can remove smeared clays or other debris from the slotted screen. After this procedure, production was improved by 32 percent overall, but some wells were still only producing 2 to 3 gallons (7.6 to 11.4 liters) per minute. This prompted drilling two new wells (1034 and 1035) in September 1998 by a different method to improve well efficiency and to obtain more realistic hydraulic parameters of the aquifer. Monitor wells 1034 and 1035 were drilled using a casing-advance drilling method that resulted in less disturbance to the adjacent formation materials. A factory-slotted screen was installed in monitor well 1034, and a continuous-wrapped vee-wire screen was installed in monitor well 1035. Aquifer pumping tests in these two wells indicated significantly improved well efficiencies and higher hydraulic conductivity values for the alluvial aquifer than values obtained from the wells installed by the hollow-stem auger (see Appendix D).

Aquifer pumping and recovery tests were performed in selected monitor wells at the site to provide an estimate of the hydraulic conductivity in the alluvial aquifer. Single-well pumping

tests were run in monitor wells 1013, 1015, 1017, 1019, and 746 during January and February 1998. Additional single well pumping tests were conducted in wells 590, 1001, and 1018 during August 1998. Multiple-well pumping tests were run in monitor wells 1034 and 1035 during September 1998; drawdown response and recovery of water levels were measured in three adjacent observation wells (1002, 1013, and 1034/1035). The calculation of hydraulic parameters (see Appendix D) focused on the multiple-well pumping tests in wells 1034 and 1035 because the most reliable data are obtained from drawdown and recovery in observation wells. Recovery data collected from the single-well tests in wells 590 and 1018 appeared reasonable, so results of those tests are also included.

Results of selected aquifer pumping test calculations (estimations) of hydraulic parameters are summarized in [Table 4-1](#). Data collected from aquifer pumping tests in alluvial aquifer wells in the west (0590), central (1034/1035), and east (1018) portions of the site indicate that transmissivity ranges from 161 to 2,434 ft²/day (15 to 226 m²/day). Hydraulic conductivity ranges from 18 to 304 ft/day (5.5 to 93 m/day) based on saturated thickness in the alluvial aquifer ranging from 6 to 9 ft (1.8 to 2.7 m) in the wells. As expected, the values of hydraulic conductivity are variable across the site, even in the relative proximity of wells 1034 and 1035. Variation in these values is a result of several factors: (1) lateral and vertical lithologic changes typical of alluvial deposits, including the possible effects of old channels in the alluvium, (2) the Colorado River as a boundary condition, especially near well 0590 (about 60 ft [18 m] from the river), and (3) well construction and screen type that may cause variable well efficiency and response to pumping stress (e.g., screen type in well 1035 has greater area of exposure to the aquifer than in well 1034). The average linear ground water velocity beneath the millsite is about 2.0 ft/day (0.6 m/day) based on an average estimated hydraulic conductivity of 100 ft/day (30 m/day), a hydraulic gradient of 0.004, and an effective porosity of 20 percent. Many variables affect hydraulic parameter values in an aquifer system, so the results are an approximation that provides a general idea of the characteristics of the alluvial aquifer.

Slug tests were performed in 13 monitor wells, and hydraulic conductivity was estimated where possible (water levels in some wells recovered too rapidly for meaningful estimation). Slug tests provide only a rough approximation of hydraulic conductivity, and the values should be considered as order-of magnitude estimates. Also, the area of influence of a slug test extends only a short distance from the borehole, and results should not be inferred to be valid at any distance from the area of influence. Consequently, slug test estimates are not used in the evaluation because of their limited extent and also because of the more reliable estimates from the aquifer pumping test analyses. Hydraulic conductivity values from slug tests are summarized in [Table 4-1](#), and calculations are on file in the Grand Junction Office.

Water levels in nine monitor wells (0590, 0743, 0744, 0746, 1001, 1002, 1013, 1017, and 1022) were measured continuously during 1998 using downhole dataloggers (locations are shown in [Plate 1](#)). Results were used to determine variations in ground water levels through time and to correlate these with fluctuations in the level of surface water in the Colorado River (see [Section 4.2.3](#)).

4.2.2 Dakota Sandstone and Mancos Shale Analysis

Since ground water in these underlying units has not been affected by site-related activities, the bedrock units have not been extensively investigated. The alluvium directly overlies both

formations, depending on the relation to the subcrop. Figure 4-2 is a contour map of the top of the Dakota Sandstone. The previous interpretation of these underlying units has been modified with additional characterization, and the consensus is that the alluvium beneath the main portion of the processing site directly overlies shaly units of the Dakota Sandstone. Both the Dakota Sandstone and the Mancos Shale form an effective aquitard beneath the alluvial aquifer.

Table 4-1. Summary of Hydraulic Parameters in the Alluvial Aquifer at the Grand Junction Site

Well	P/O/S	D/R	Q gpm	t min	T ft ² /day	K ft/day	Notes
1034	P	R	4	717	1613	202	Factory slotted screen
1002	O	D			556	93	
1002	O	R			408	68	
1013	O	D			450	56	
1013	O	R			340	43	
1035	O	D			N/R	N/R	Response <1 ft
1035	P	R	8 to 6	707	2261	282	Continuous-wrapped V-wire screen
1002	O	D			942	157	
1002	O	R			969	161	
1013	O	D			1987	249	
1013	O	R			2434	304	
1034	O	D			1120	140	
1034	O	R			2290	287	
590	P	R	30	840	408	68	
1018	P	R	1	820	161	18	
1012	S					11	On Site
1013	S					2	On Site
1014	S					2	On Site
1015	S					4	On Site
1016	S					2	On Site
1018	S					5	On Site
1019	S					1	On Site
1021	S					1	Background
1023	S					12	Background
1025	S					4	Background
1026	S					4	Resource Center
1027	S					3	Resource Center
1028	S					5	Resource Center

Notes:

- D = discharge
- K = hydraulic conductivity
- N/R = Not reliable
- O = observation well
- P = pumping well
- Q = discharge rate
- R = recovery
- S = slug test
- t = duration of test
- T = transmissivity

4.2.3 Surface Water Analysis

Surface water levels in the Colorado River have been continuously measured since February 1998 with a datalogger in a stilling well (SW-1033 on [Figure 4-3](#)) at the western end of the site. Manual measurements of the Colorado River were taken every 2 weeks from the footbridge at the eastern end of the site ([Figure 4-3](#)).

The stilling well was installed along the southwestern side of Watson Island in late January 1998. A transducer was placed inside a capped and perforated PVC pipe that was anchored into the river bed, with the transducer cable (also enclosed in a PVC pipe) running up the bank to an elevation considered protected from spring flooding. A steel upright pipe was cemented in and a locked cover installed to protect the transducer recorder.

Comparison of water levels with mean stream flow (in cubic feet per second) measured at the USGS gauging station at Palisade (about 15 miles [24 km] east of the millsite) shows good correlation (RVR-FLW on [Figure 4-4](#)). A comparison of water elevations in the river with fluctuations in water levels in several monitor wells near the river (wells 0744 and 1001) also shows some correlation, indicating some connection between shallow ground water and the water in the Colorado River ([Figure 4-3](#)).

4.3 Geochemistry

Surface water, ground water, soil, sediments, and alluvial aquifer materials were sampled and analyzed. Sample locations, collection methods, analytical methods, tests performed, and analytical results are presented in this section.

4.3.1 Water and Sediment Chemistry Sampling and Sample Analysis

Ground water monitoring wells were sampled in January and July 1998 to characterize the current contaminant levels. The results of sampling and analysis are presented in this section. All results reported here are for filtered samples.

Contaminants that enter the surface environment through natural discharge of ground water to the surface should be detectable by analysis of surface water and sediments. The results can be used to estimate the risk of exposure to the accessible environment. Surface water and surface sediments were sampled in October and November 1997 to supplement previous samplings. The alluvial aquifer discharges to the Colorado River. Water and sediments were sampled from the river to determine if the river's water quality is affected by millsite contaminants. Ponds are present on the Colorado River floodplain; some are seasonal and are present only after flooding, and some may be fed by ground water. Water and sediments were collected from the ponds and analyzed for chemicals of potential concern (COPCs). Because the valley alluvium is affected by irrigation, water was also sampled from several irrigation ditches.

4.3.1.1 Ground Water

Two rounds of ground water sampling were conducted in 1998—one in January and one in July. A total of 33 alluvial and 5 bedrock wells were sampled during each round. A summary of the sampling results is presented in Appendix E. As expected, the alluvial wells located on site have the highest concentrations of contaminants associated with site processes (e.g., uranium,

Figure 4–2. Contour Map of the Bedrock Surface Beneath and Near the Grand Junction Site

FIGURE 4–2 will be provided upon request.
Click [Wendee Ryan](#) or [Michelle Smith](#) to request.

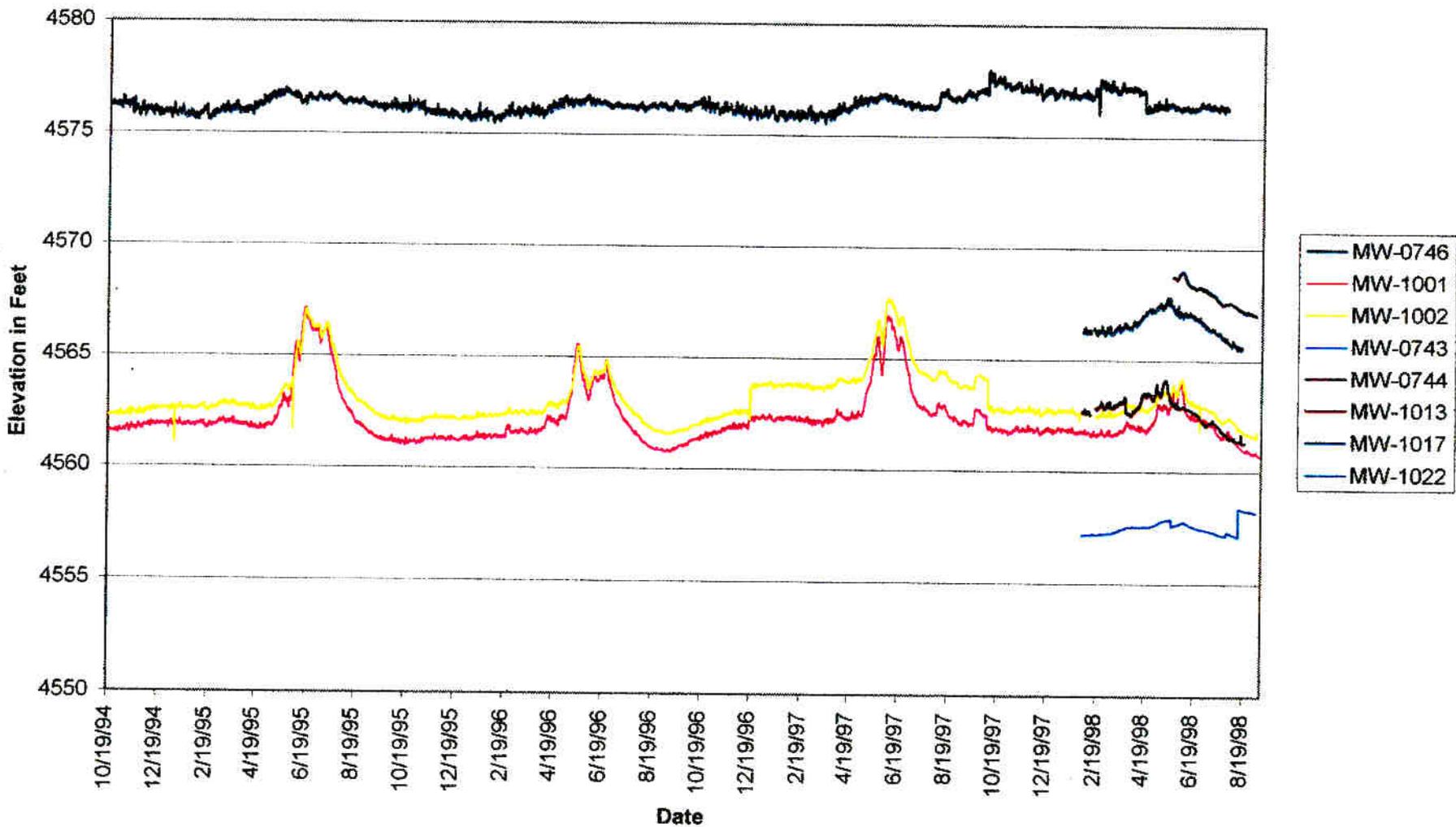


Figure 4-3. Datalogger Ground Water Elevations in the Alluvial Aquifer

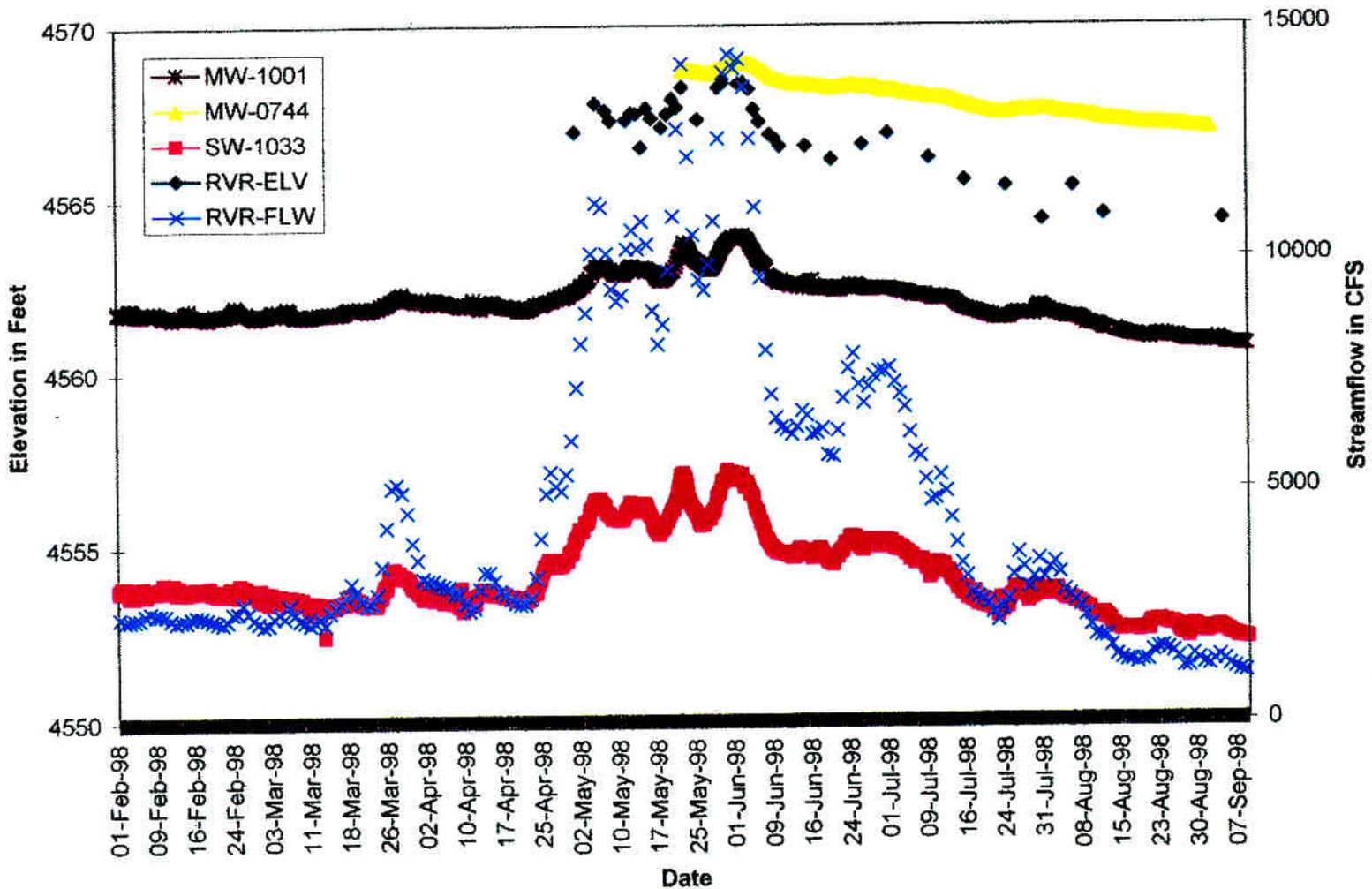


Figure 4-4. Ground Water and Colorado River Elevations

vanadium, arsenic) compared to upgradient and downgradient locations (see Section 5.3.1 for further discussion of background water quality; see Section 5.3.3 for a discussion of the extent of contamination).

Chemistry of the ground water from bedrock wells is distinctly different from that of alluvial ground water. Bedrock wells are generally lower in gross alpha and gross beta radiation as well as in concentrations of uranium, calcium, manganese, magnesium, and potassium. Bedrock ground water is generally higher than alluvial ground water in concentrations of chloride and sodium and is slightly more basic in pH.

Ground Water Major-Ion Chemistry

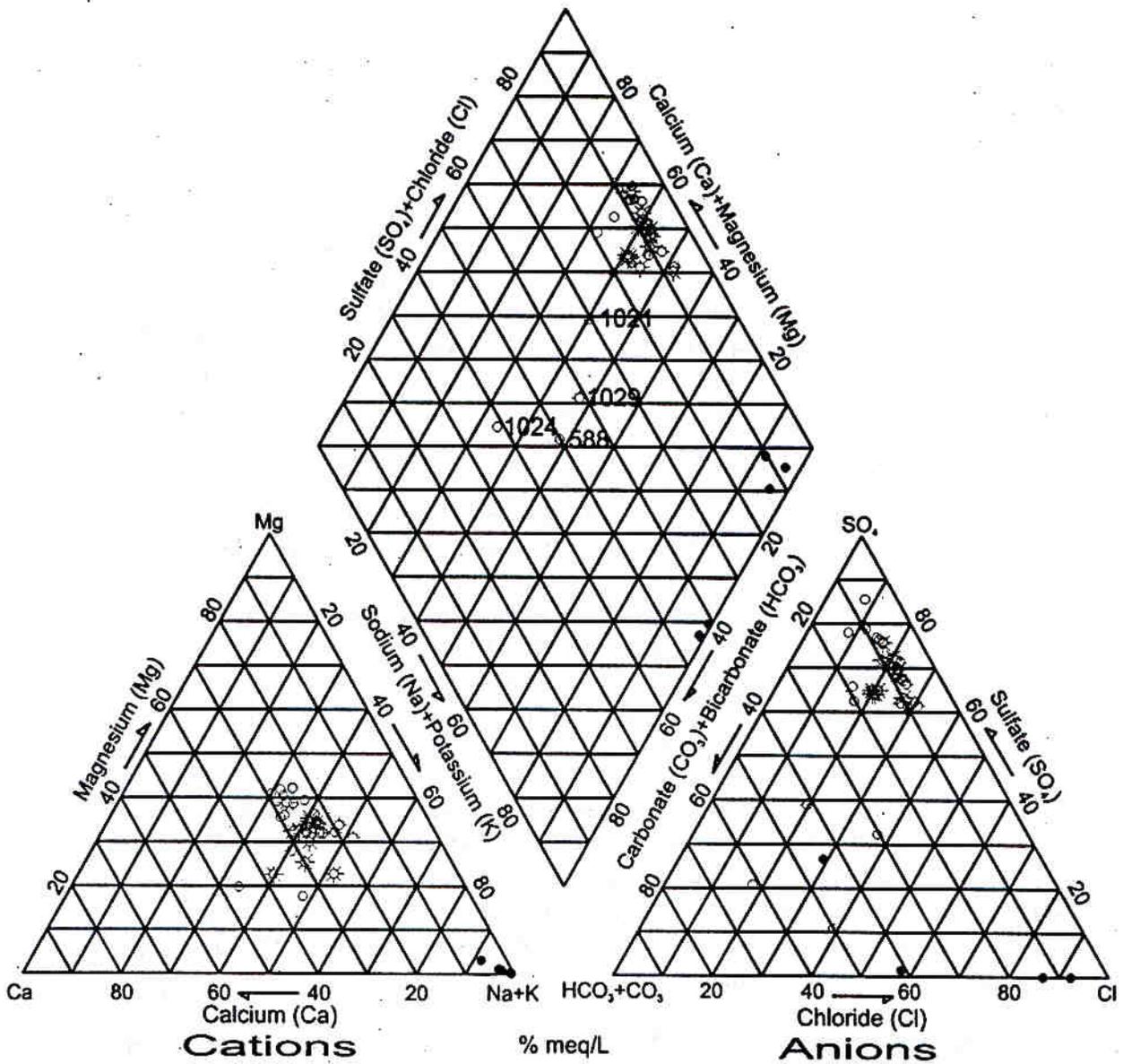
Piper diagrams are commonly used to help classify water types by composition and to differentiate between water types. Major-ion chemistry data from the June 1998 sampling round were plotted on a Piper diagram (Figure 4-5). Anions in the alluvial ground water are dominated by sulfate, and cations are nearly equally distributed among calcium, magnesium, and sodium. The major-ion chemistry in the alluvium at the millsite and downgradient is similar to upgradient. Total dissolved solids concentrations are also similar among on-site, downgradient, and upgradient alluvial ground water samples (Figure 4-6).

Four locations (588, 1021, 1024, and 1029) sampled for alluvial ground water have major-ion compositions distinctly different from the norm (Figure 4-5). Location 588 is downgradient from a large pond at the Grand Valley Rendering Plant; location 1021 is west (possibly downgradient) of several large recreation ponds; location 1024 is downgradient of the Clifton Water Works, where water is being discharged into the alluvial aquifer; and location 1029 is downgradient from a large pond at the American Auto Salvage yard. Thus, ground water at all four anomalous locations is likely to have been affected by water locally recharging the aquifer and is not representative of “typical” alluvial ground water.

The major-ion composition of Dakota Sandstone ground water is highly variable. The variability is likely due to the variable depths from which the ground water samples were collected. Some wells were sampled from the gray shales that lie at shallow depths, and others were sampled from deeper sandstones. In all cases, however, the Dakota wells are readily distinguished from alluvial wells on a Piper diagram (Figures 4-5 and 4-6). Anions in the Dakota Sandstone ground water are dominated by chloride, and cations are dominated by sodium.

Mineral precipitation and dissolution causes chemical changes in the ground water system. The chemical speciation program PHREEQC (Parkhurst 1995) was used to calculate the concentrations of aqueous species and mineral saturation indices (SIs) for the January 1998 sampling of the ground water. A mineral SI provides a measure of whether a ground water has a tendency to precipitate or dissolve a mineral. A positive SI indicates oversaturation and the tendency to precipitate the mineral, whereas a negative SI indicates undersaturation and the tendency to dissolve the mineral.

Average mineral SIs for calcite and gypsum, two commonly occurring minerals in the alluvial aquifer, are presented in Table 4-2. The alluvial aquifer ground water is nearly saturated with calcite (CaCO_3) upgradient and downgradient of the millsite and slightly oversaturated at the millsite. The differences between the on-site and upgradient averages are probably due to localized influences on sample locations. In the upgradient area, some sample locations



- Background alluvium
- ✱ On-site alluvium
- ◇ Downgradient alluvium
- Dakota Sandstone Formation

Figure 4-5. Piper Diagram of Major-Ion Chemistry in Alluvial Ground Water

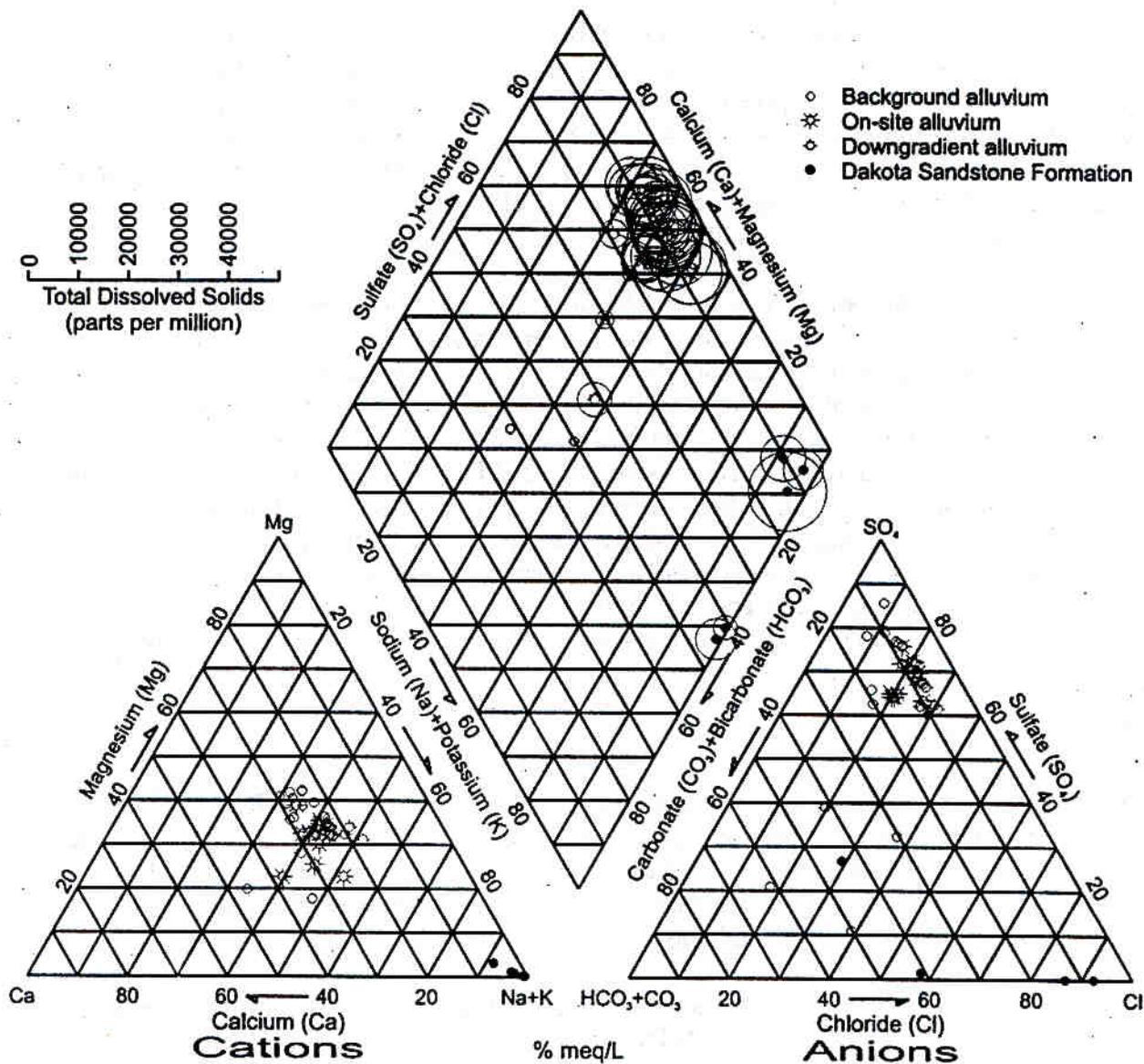


Figure 4-6. Piper Diagram Showing Total Dissolved Solids

Table 4–2. Average Mineral Saturation Indices for Calcite and Gypsum

Location	Number Of Samples	Calcite SI	Gypsum SI
Upgradient Alluvium	16	–0.04	–0.40
On-Site Alluvium	12	0.32	–0.06
Downgradient Alluvium	8	0.06	–0.14

are downgradient from standing water that probably diluted the samples. The SIs for calcite presented in Table 4–2, therefore, are all considered close to saturation and indicate that the entire aquifer (except where diluted by local recharge) is at equilibrium with calcite. Gypsum is also close to saturation except where the aquifer may be influenced by recharge. These calculated SI values are consistent with the observation that calcite and gypsum are common in the alluvial aquifer and surrounding rocks. The calculations suggest that the alluvial ground water at the millsite has reached equilibrium with the aquifer solids.

The PHREEQC program was also used to determine the speciation of one trace component present in elevated concentrations in site ground water. Analytical results for ammonia report total ammonia as NH_4 (ammonium). However, to evaluate risks associated with the use of ground water, it is important to know how much of the total ammonia is actually present in the NH_3 form. NH_3 is highly volatile and is much more toxic when inhaled as a gas than is NH_4 when ingested in solution as a constituent of water. The PHREEQC program was run using the most recent chemical analysis from the on-site well with the highest total ammonia concentration (well 1017). That well, which had a total NH_4 concentration of 233 mg/L, had an actual NH_3 concentration of 1.1 mg/L. The mean total NH_4 concentration for the plume wells of 71.4 mg/L corresponds to an actual NH_3 concentration of 0.337 mg/L. These values for NH_3 were used in the updated human health risk calculations presented in Section 6.1. See Appendix I for raw data and more detail on the PHREEQC modeling results.

4.3.1.2 Surface Water

A variety of surface water locations (ponds, irrigation ditches, and Colorado River) were sampled in the Grand Junction area to characterize both background surface water quality and potential effects of site contamination on surface water at and downgradient of the millsite. Surface water sample locations are shown on Figure 4–7. Uranium was selected as a key indicator contaminant to identify the likely extent of site-related contamination.

A subset of the field screening locations was subsequently sampled for laboratory analysis of a larger number of analytes; Table 4–3 lists locations for which laboratory data were obtained and indicates the dates of sample collection. These locations were chosen as representative of upgradient, on-site, and downgradient water quality based on field screening results and results of historical sampling. Analytical results for river and pond samples are discussed separately in the following sections. All results are for filtered water samples.

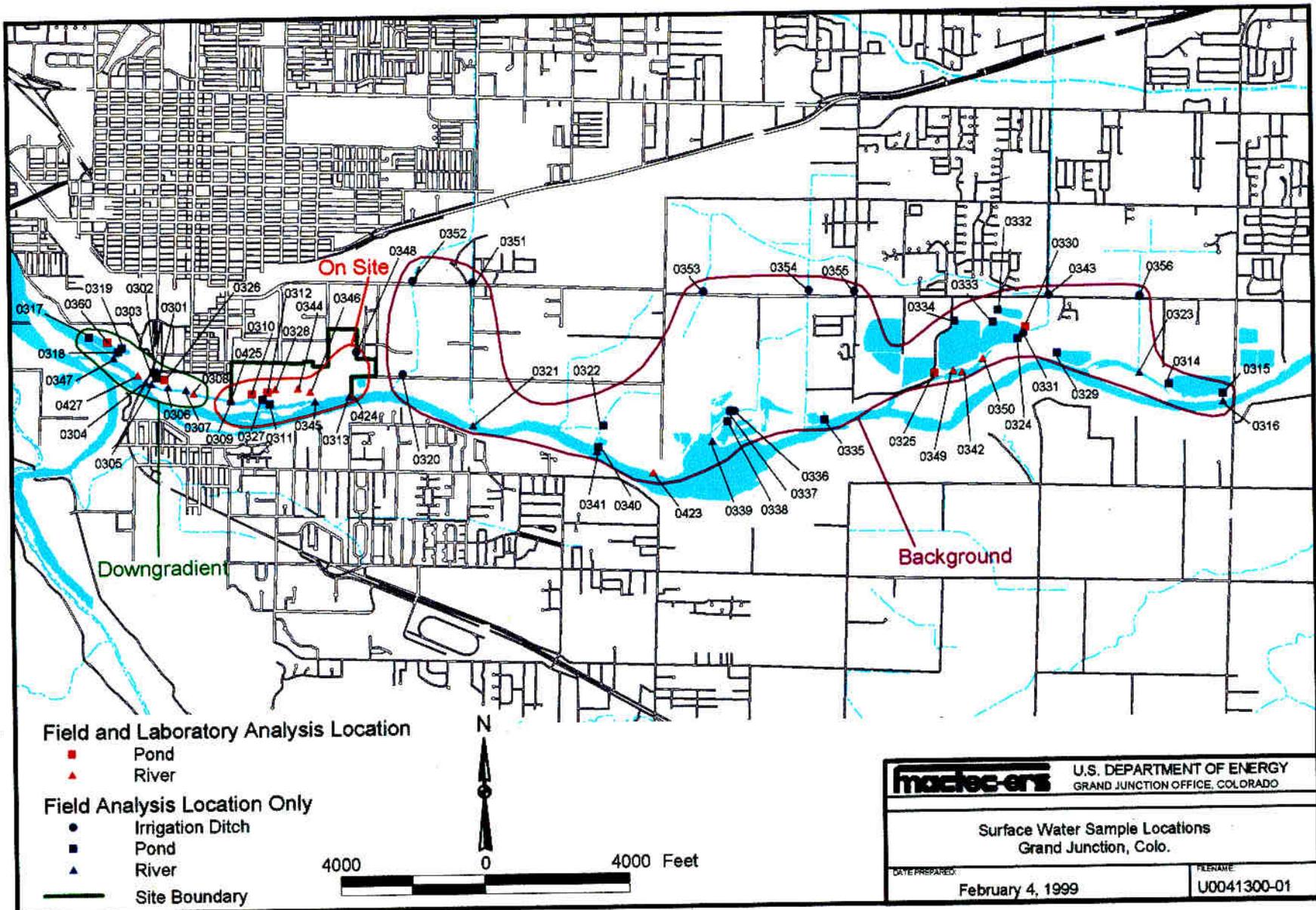


Figure 4-7. Surface Water Sample Locations

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Table 4–3. Surface Water Samples Collected for Laboratory Analysis

Type of Surface Water Sample	Location No.	Location	Date Sampled	Analytes
Pond	325, 330	Upgradient	Nov 1997, Jan and June 1998	As, Cd, Co, F, Fe, Mn, Mo, Ni, NO ₃ , Se, SO ₄ , U, V
	310, 312, 328	On site	Nov 1997, Jan and June 1998	
	326, 360	Downgradient	Nov 1997, Jan and July 1998 (326), July 1998 (360)	
Colorado River	342, 349, 350, 423	Upgradient	Nov 1997 (342, 349, 350) Jan 1998, June 1998 (all)	
	312, 344, 346, 424, 425	On site	Nov 1997 (312, 344, 346) Jan 1998, June 1998 (all)	
	308, 427	Downgradient	Nov 1997 (308) Jan 1998, June 1998 (all)	

Colorado River Water Quality

Historically, samples of Colorado River water have been collected from locations 423, 424, 425, and 427. Between 1991 and 1993, seven rounds of water samples were collected; an additional sampling event was conducted in December 1996. Some samples were collected at low flows to maximize the possibility of detecting contaminants. The results of these analyses indicate that site contamination has not adversely affected the water quality of the Colorado River (DOE 1996d).

On October 22, 1997, Colorado River water was sampled at eight upgradient locations (316, 321, 323, 339, 341, 342, 349, and 350), five on-site locations (309, 312, 344, 345, and 346), and six downgradient locations (304, 305, 306, 307, 308, and 347) (Figure 4–8). These samples were collected for field screening to evaluate the effect, if any, that site-related contaminants might have on Colorado River water quality. The samples were analyzed in the field for uranium, which was selected as an indicator of contamination because it has high concentrations in the alluvial ground water at the millsite and is relatively mobile. The distribution of uranium concentrations in the Colorado River is shown in Figure 4–8. Mean concentrations at the upgradient, on-site, and downgradient locations are 0.0068, 0.0063, and 0.0055 mg/L, respectively. These results support the conclusion that the Colorado River is not affected by millsite contamination.

Additional sampling was conducted in November 1997, January 1998, and June 1998 as indicated in Table 4–3. All samples were collected for laboratory analysis of the analytes listed in Table 4–3. For all samples at all locations, concentrations of arsenic, cadmium, cobalt, iron, nickel, selenium, vanadium, and zinc were at or below method detection limits. A summary of results for the remaining analytes is presented in Table 4–4 for the three sampling events.

Analytical results of samples of river water collected over a 7-year period show that concentrations of COPCs in the Colorado River at the millsite have consistently been similar to those upgradient of the millsite. The results do not necessarily indicate that no contamination is entering the river. A small flux of contaminated ground water to the Colorado River would not be detected because dilution by the river is substantial.

Table 4–4. Concentrations of Selected Constituents in Samples of Colorado River Water Collected for Laboratory Analysis

Sampling Location		Analyte Concentration, mg/L					
		F	Mn	Mo	NO ₃	SO ₄	U
River Upgradient (432, 349, 350, 423)	Max	0.375	0.907	0.014	6.30	1810	0.025
	Min	0.155	0.017	0.002	0.036	56	0.001
	Mean	0.223	0.472	0.0093	3.00	905	0.012
River On Site (312, 344, 346, 424, 425)	Max	1.26	3.03	0.088	26.4	2990	0.073
	Min	0.158	0.005	0.002	0.011	62.3	0.001
	Mean	0.286	0.273	0.118	2.68	365	0.008
River Downgradient (308, 427)	Max	0.241	0.029	0.008	0.664	156	0.003
	Min	0.159	0.005	0.002	0.011	63.7	0.001
	Mean	0.191	0.014	0.005	0.308	107	0.002

Pond Water Quality

Shallow ground water in the alluvial aquifer could discharge to surface water in ponds and create an exposure pathway for humans and the environment. To investigate the extent of surface exposure, water was sampled from ponds at the millsite, and the results were compared to those from upgradient and downgradient samples.

Eight ponds were constructed on the floodplain of the Colorado River at the millsite in 1994. These ponds were fed by ground water from the millsite. The ponds were sampled in January 1995 and were subsequently destroyed by flooding later that year. Uranium concentrations up to 0.473 mg/L were measured in the 1995 samples. Much of the contamination in these ponds was attributed to evaporation (DOE 1996d).

On October 22, 1997, pond water was sampled at 12 upgradient locations (314, 315, 322, 325, 329, 330, 332, 333, 334, 335, 337, and 340), four on-site locations (310, 311, 327, and 328), and seven downgradient locations (301, 302, 303, 317, 318, 319, and 326) (Figure 4–9). These samples were analyzed in the field for uranium, which was selected as an indicator of contamination because it has high concentrations in the alluvial ground water at the millsite and is relatively mobile.

The distribution of uranium concentrations in the ponds is shown in Figure 4–9. Only two values exceeded the UMTRA uranium standard (assuming isotopic equilibrium) of 0.044 mg/L. Both samples (317 and 318) were collected from the same pond at the American Auto Salvage vicinity property. Recent soil remediation at American Auto Salvage has likely influenced the uranium concentrations in this pond. Another sample (319) collected from a nearby pond also had a relatively high uranium concentration (0.025 mg/L), which was also probably related to the remediation at American Auto Salvage.

Mean concentrations of uranium in the upgradient, on-site, and downgradient field screening samples of pond water are 0.010, 0.009, and 0.027 mg/L, respectively. If the three samples from the American Auto Salvage ponds (317, 318, and 319) are omitted, the mean downgradient uranium concentration is reduced to 0.015 mg/L.

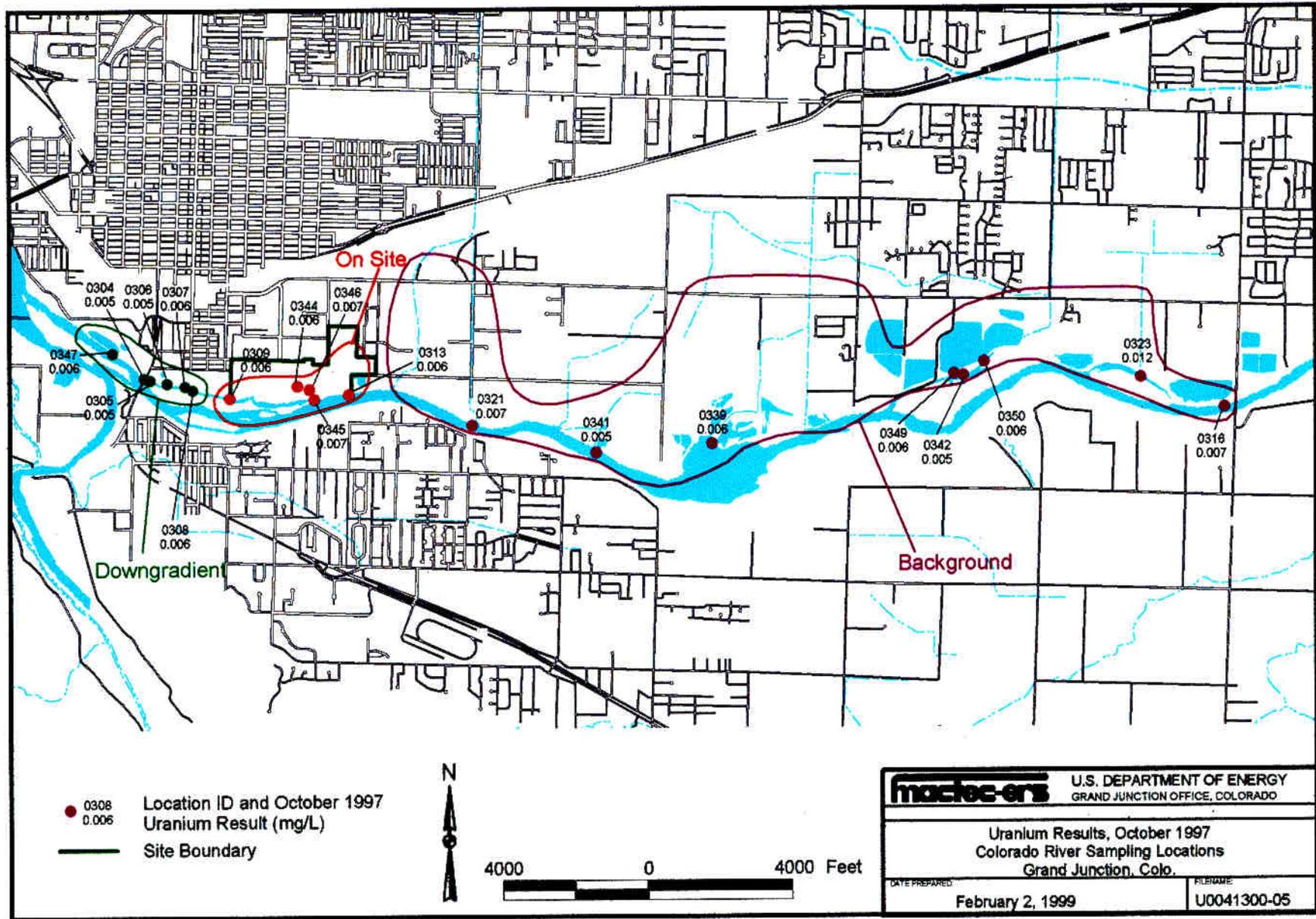


Figure 4-8. Distribution of Uranium Concentrations in the Colorado River, October 22, 1997

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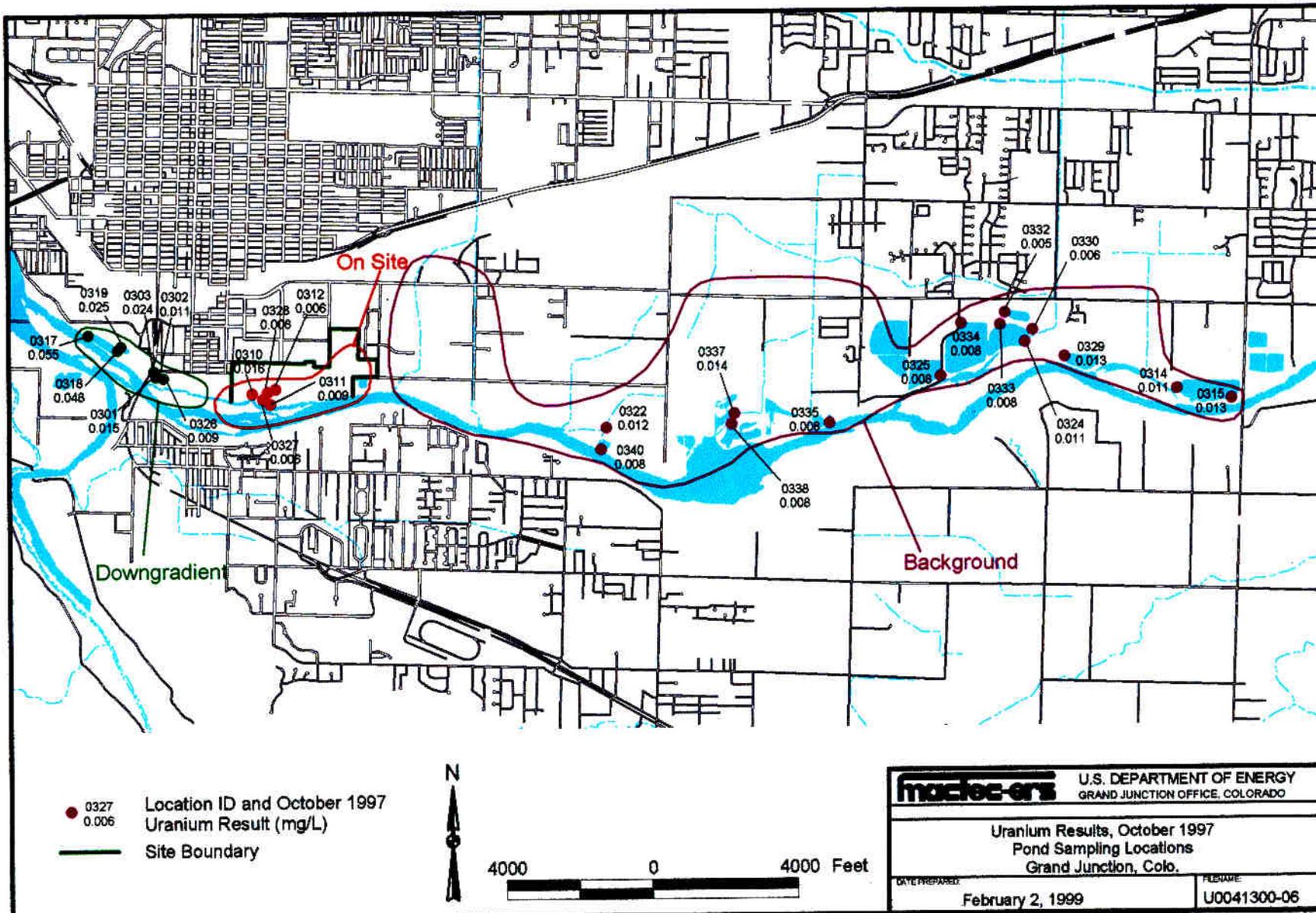


Figure 4-9. Pond Water Sample Results

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Pond water analyses are more difficult to interpret than ground water analyses because of the effect of evaporation and ground water–surface water interaction. However, these results suggest that pond water near the millsite is not significantly contaminated from uranium.

Pond water sampling for laboratory analysis was conducted in November 1997, January 1998, and June 1998 as indicated in Table 4–3. All samples were analyzed for the constituents shown in the table. For all samples at all locations, concentrations of arsenic, cadmium, cobalt, iron, nickel, selenium, vanadium, and zinc were at or below method detection limits. A summary of results for the remaining analytes is presented in Table 4–5 for the three sampling events.

Mean concentrations of fluoride and molybdenum in on-site and downgradient pond samples are elevated but not significantly above concentrations in the upgradient samples. Manganese, nitrate, sulfate, and uranium concentrations are higher in the on-site ponds than in upgradient ponds. These, however, are mainly the result of sampling location 310. This location may be contaminated from ground water, or the elevated concentrations may be the result of evaporation.

Table 4–5. Concentrations of Selected Constituents in Samples of Pond Water Collected for Laboratory Analysis

Sampling Locations		Analyte concentration, mg/L					
		F	Mn	Mo	No ₃	SO ₄	U
Ponds, Upgradient (325, 330)	Max	0.324	0.006	0.014	0.070	237	0.005
	Min	0.097	0.001	0.002	0.021	55.9	0.001
	Mean	0.210	0.002	0.008	0.047	161	0.004
Ponds, On Site (310, 312, 328)	Max	1.21	0.928	0.026	7.07	2820	0.094
	Min	0.119	0.006	0.002	0.011	67	0.001
	Mean	0.372	0.200	0.009	1.20	702	0.022
Ponds, Downgradient (360, 326)	Max	0.794	0.104	0.056	0.113	5550	0.066
	Min	0.132	0.001	0.008	0.011	466	0.004
	Mean	0.438	0.032	0.031	0.040	2160	0.028

The results show that concentrations of COPCs in most of the ponds near the millsite are typically similar to those in upgradient locations. At one sampling location at the millsite (1228 on Figure 4–15), concentrations of several COPCs are elevated, suggesting that contaminated ground water may be feeding that area. However, the contribution from contaminated ground water cannot be separated from the possible influence of evaporation. (See further discussion in Section 5.3.2.)

One sample of a white efflorescence was collected from the north (south facing) bank of a pond at sample point 1228, and a second sample was collected about 20 feet (6 m) north of the first sample from the south-facing bank of the next uphill scarp. The ground is saturated nearly to the surface in this area, and these crystalline salts probably represent desiccation of ground water by capillary action. The samples were ground to a powder and analyzed by x-ray diffraction using a Rigaku Miniflex instrument. Samples were run at diffraction angles from 3 to 60 degrees using CuK-alpha radiation and a nickel filter. A peaks search-and-match routine was used to identify the mineral phases. Results indicated that the sodium sulfate species, bl`dite (Na₂Mg(SO₄)₂ · 4H₂O), thenardite (Na₂SO₄), and watevillite (Na₂Ca(SO₄)₂ · 4H₂O) as well as halite (NaCl) were

precipitating on the ground surface in these areas. These minerals are all soluble and are easily dissolved during periods of rainfall or high river waters and reprecipitated during drier periods.

4.3.1.3 Surface Sediments

A total of 30 sediment samples were collected in October 1997 from ponds, streams, and the Colorado River at a subset of field screening locations that were also sampled for water (Section 4.3.1.2). The samples were collected from beneath or close to standing water and were used to determine if mill-related contaminants were in the benthic zone. Sample locations are shown on [Figure 4–10](#). A description of the sampling sites is included in Appendix E.

Uranium was selected as a key indicator contaminant. Samples were air dried and sieved to less than 2 mm. A 2.5-g sample was leached with 50 mL of 5 percent nitric acid by end-over-end agitation for 4 hours. The effluent was filtered through a 0.45 µm filter and analyzed for uranium by laser-induced fluorescence. Leachate and sample volumes were used to convert leachate analyses (in milligrams per liter) to sediment concentration (in milligrams per kilogram). See discussion in Section 4.3.3.2 for sample calculation. Samples were analyzed within a few days of collection.

Samples were collected upgradient, downgradient, and at the millsite ([Figure 4–10](#)). Minimum, maximum, and mean concentrations of uranium for each group are listed in [Table 4–6](#). The downgradient samples had a higher mean uranium concentration than on-site or upgradient samples. The downgradient sample mean is skewed because of sample 317 at American Auto Salvage, which had a concentration of 4.36 mg/kg. A sample of surface water at this location also had an elevated concentration of uranium. The contamination in this newly formed pond is probably associated with the recent remediation at this vicinity property (Section 4.3.1.2). Without sample 317, the downgradient mean is 1.47 mg/kg. Thus, except for the vicinity property pond, there is no significant difference in uranium concentrations at upgradient, on-site, and downgradient sample locations.

Table 4–6. Uranium Concentrations in Nitric-Acid-Leached Sediments Collected October 22, 1997

Group	Number ^a	Minimum	Maximum	Mean
Upgradient	12/12	1.00	2.60	1.41
On Site	11/11	1.04	2.20	1.53
Downgradient	7/7	1.24	4.36	1.88

^anumber of detections/number of samples analyzed

A subset of 12 of the 30 sampling locations was selected for laboratory analysis of uranium and additional analytes. These 12 locations are the same locations used for surface water sampling in November 1997. The sediment samples were collected on October 22. Samples were leached with a 5 percent nitric acid solution; the leachate was analyzed in the Analytical Chemistry Laboratory for As, Cd, Co, F, Fe, Mn, Mo, Ni, NO₃, Se, SO₄, U, V, and Zn. Except for fluoride and selenium, COPCs had higher concentrations in either on-site or downgradient samples than in upgradient samples ([Table 4–7](#)). For some COPCs the differences in the means between on-site and upgradient locations are small. The results suggest that there is still some influence of the millsite in the sediments. The sediments probably contain small amounts of residual tailings that were not removed during remediation.

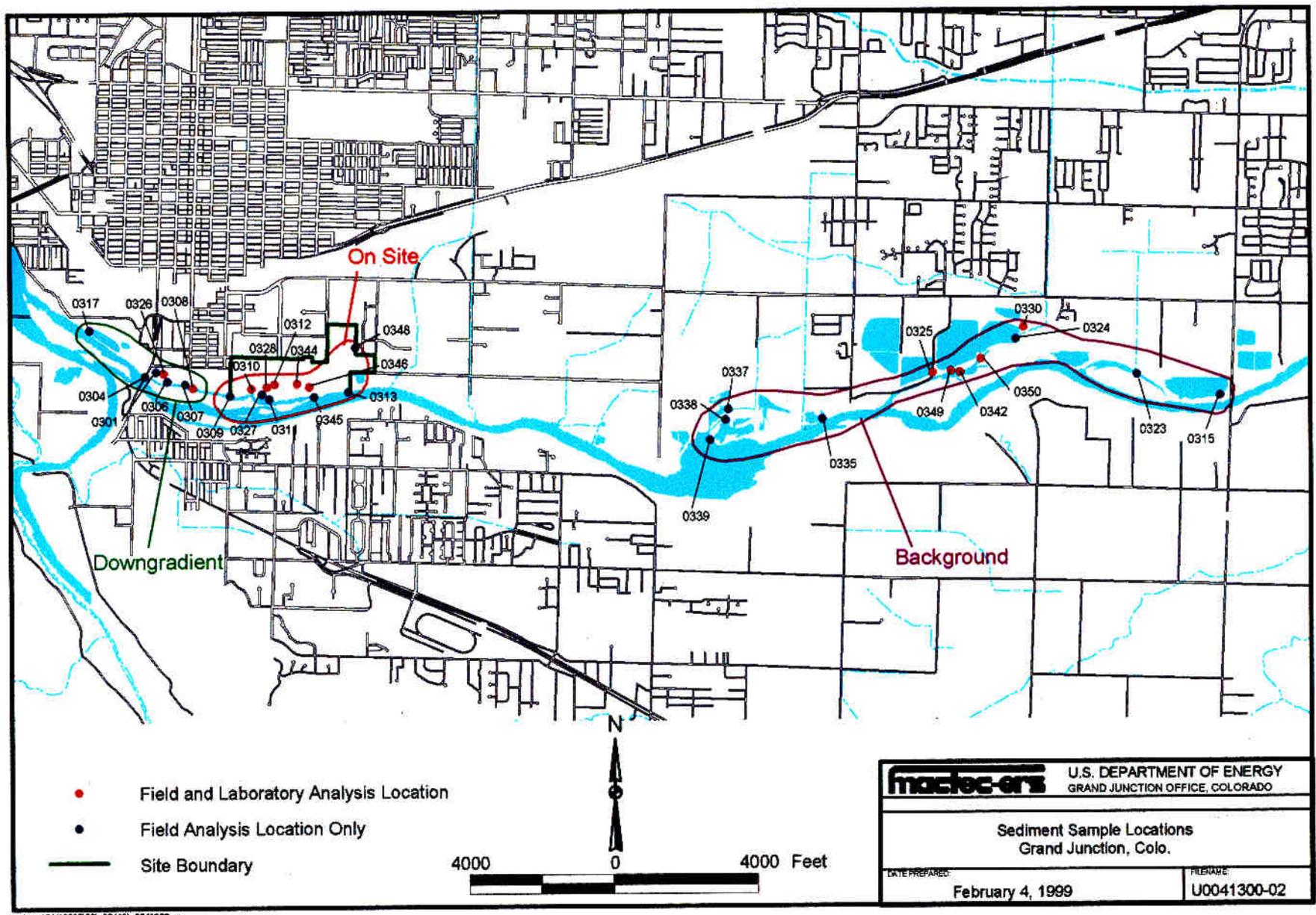


Figure 4-10. Sediment Sample Locations

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Table 4-7. Analyte Concentrations in 5 Percent Acid Leachate From Sediment Samples Collected October 22, 1997

Analyte	Group	Number ^a	Minimum	Maximum	Mean
As	Downgradient	2/2	1.1	1.8	1.45
	On Site	5/5	1.5	3.4	2.2
	Upgradient	5/5	0.48	1.5	1.15
Cd	Downgradient	2/2	0.37	0.59	0.48
	On Site	5/5	0.5	1.1	0.65
	Upgradient	5/5	0.38	0.77	0.5
Co	Downgradient	2/2	1.4	2.0	1.7
	On Site	5/5	1.8	2.6	2.24
	Upgradient	5/5	1.0	2.2	1.66
F	Downgradient	2/2	43.6	69	56.3
	On Site	5/5	34.7	77.5	52.6
	Upgradient	5/5	38.7	83.0	63.0
Fe	Downgradient	2/2	1720	1890	1805
	On Site	5/5	2360	4170	3028
	Upgradient	5/5	1780	3240	2378
Mn	Downgradient	2/2	300	302	301
	On Site	5/5	170	342	297
	Upgradient	5/5	117	278	210
Mo	Downgradient	2/2	0.07	0.36	0.215
	On Site	5/5	0.09	0.49	0.19
	Upgradient	5/5	0.05	0.12	0.09
Ni	Downgradient	2/2	1.8	2.6	2.2
	On Site	5/5	2.7	5.2	3.7
	Upgradient	5/5	1.4	5.3	3.22
NO ₃	Downgradient	2/2	8.6	11.7	10.2
	On Site	5/5	6.3	15.8	12.3
	Upgradient	5/5	5.9	10.2	7.32
Se	Downgradient	0/2	<0.04	<0.04	<0.04
	On Site	0/5	<0.04	<0.04	<0.04
	Upgradient	1/5	<0.04	0.11	0.054
SO ₄	Downgradient	2/2	387	2,140	1,264
	On Site	5/5	515	4,100	1,265
	Upgradient	5/5	226	701	485
U	Downgradient	2/2	0.58	1.6	1.09
	On Site	5/5	0.65	1.5	1.02
	Upgradient	5/5	0.42	2.5	1.01
V	Downgradient	2/2	4.0	4.4	4.2
	On Site	5/5	7.4	34.8	15.6
	Upgradient	5/5	3.1	6.7	5.12
Zn	Downgradient	2/2	16.1	43.5	29.8
	On Site	5/5	17.5	50.9	32.0
	Upgradient	5/5	15.8	51.2	31.0

^anumber of detections/number of samples analyzed

4.3.2 Distribution Coefficients

Distribution coefficient (K_d) is a measure of the degree of interaction between a dissolved contaminant and the aquifer minerals. Distribution coefficients were measured during this investigation to aid in predicting contaminant transport. Details of the experimental methods and calculations are shown in Appendix F, calculation U0032900, a summary of which is presented below. Laboratory data were collected using ASTM procedure D4646-87, "Standard Test Method for 24-h Batch-Type Measurement of Contaminant Sorption by Soils and Sediments." A representative portion of a core sample was air dried at room temperature. All samples were collected in upgradient areas to avoid the complication of having contamination present in the solid before the analysis. The samples were sieved to less than 10 mesh (2 mm). A synthetic solution was prepared that simulates ground water at the Grand Junction site. The pH was adjusted to about 7.0, and the measured alkalinity was about 260 mg/L as CaCO_3 . Five grams of each core sample was placed in a 125-mL Nalge bottle with 100 mL of the synthetic ground water. Samples were agitated for 24 hours, centrifuged, and filtered through a 0.45 μm filter. They were then preserved with 1 percent nitric acid and submitted to the Analytical Chemistry Laboratory for analysis of arsenic, cadmium, molybdenum, and uranium. These contaminants were selected because previous sampling indicated that they were present in concentrations that exceed background and because they are the regulated COPCs. For additional detail on calculations and data used, see Appendix F.

The results of single-point K_d measurements are presented in Table 4–8. K_d values for arsenic range from 75 to 8,241 milliliters per gram (mL/g) and have a mean of 1,149 mL/g. The sample with the K_d value of 8,241 mL/g was collected in soil immediately above the alluvial aquifer. K_d values for the alluvial aquifer (omitting the soil sample) range from 75 to 1,168 mL/g and have a mean of 361 mL/g. The two alluvial aquifer samples with the highest K_d values (1,168 and 635 mL/g) had plant roots in them; some of the arsenic present may be a result of root uptake. Even without the root-bearing samples, however, K_d values are relatively high, ranging from 75 to 358 mL/g with a mean of 207 mL/g. The high K_d values indicate that arsenic migration will be retarded as ground water migrates through the alluvial aquifer.

Table 4–8. Calculated K_d Values (mL/g)

Well Number	Description ^a	Depth (Ft)	Arsenic	Cadmium	Molybdenum	Uranium
1020	Sandy gravel	10–12	84	182	0.10	2.41
1021	Silty sand, dark brown	5–7	358	356	0.72	3.64
1023	Soil, clayey silt	5–7	8,241	248	1.27	1.79
1023	Silty sand, dark brown	10–12	75	49	0.10	0.97
1023	Sandy gravel	15–15.4	137	64	0.51	1.08
1024	Silty sand, dark brown	5–7	356	134	0.72	3.35
1025	Clayey silt, dark brown, roots	5–7	635	280	1.27	2.29
1025	Clayey silt, dark brown, roots	10–12	1,168	279	1.50	2.67
1025	Silty sand, dark brown	15–17	228	64	0.30	1.43
1028	Clayey silty gravel, dark brown	5–7	209	181	0.41	1.91
Mean			1,149	184	0.69	2.15

^aAll samples are alluvial aquifer except 1023, 5–7ft, which is soil.

K_d values for cadmium range from 49 to 356 mL/g and have a mean of 184 mL/g. K_d values for the alluvial aquifer (omitting the sample collected from the soil above the alluvial aquifer) have a mean of 177 mL/g. This mean is nearly the same as that of arsenic and indicates that cadmium migration also will be retarded as ground water migrates through the alluvial aquifer. As with arsenic, K_d values for the root-bearing sediments are well above the mean, suggesting that some cadmium may have been sorbed by the roots.

K_d values for molybdenum range from 0.1 to 1.50 mL/g and have a mean of 0.69 mL/g. All the final concentrations are within 10 percent of the initial concentration and within the analytical uncertainty; some of the K_d values could be close to 0 mL/g. One of the three highest K_d values is from the soil just above the alluvial aquifer. When this value is omitted, the mean of the alluvial aquifer K_d values is 0.6 mL/g. The other two highest values are from the root-bearing samples. Without the three highest values, the mean is 0.4 mL/g. The results indicate that molybdenum is relatively mobile in the alluvial aquifer.

Single-point K_d values for uranium range from 1.08 to 3.64 mL/g and have a mean of 2.15 mL/g (Table 4–8). The values show little correlation to sample type (such as root-bearing samples). These results indicate that uranium migration is slightly retarded in the alluvial aquifer but much less so than migration of arsenic or cadmium.

K_d values sometimes vary with the concentration of contaminant. Therefore, multiple K_d determinations for uranium were made on two samples collected from well 1023. In Figure 4–11, the final concentration of dissolved uranium is plotted against the mass of sediment used for one of the samples (depth 10 to 12 feet). Data are plotted with 10 percent error bars (a reasonable value for analytical uncertainty) and are compared to calculated curves for various K_d values. Within the 10 percent uncertainty, all but one data point are consistent with a K_d value of 1 mL/g. Data from the other sample are plotted on Figure 4–12. Within the 10 percent error bars, these data are also consistent with a K_d value of 1 mL/g. The results indicate that, at least for uranium, transport models do not need to be corrected for variable uranium concentrations.

The K_d results indicate that migration of arsenic and cadmium is much more retarded in the alluvial aquifer sediments than the migration of molybdenum or uranium. This finding is consistent with observations at other uranium mill tailings sites, where typically the mill-related uranium and molybdenum have migrated farther from the processing sites than have the mill-related arsenic or cadmium. Recommended K_d values for the alluvial aquifer are provided in Table 4–9. Values for arsenic, cadmium, and molybdenum are the means of the alluvial aquifer samples excluding the soil sample collected above the alluvial aquifer. The value for uranium is the best fit to the plots of the multiple-point determinations.

Table 4–9. Recommended K_d Values for the Grand Junction Alluvial Aquifer

COPC	K_d (mL/g)
As	361
Cd	177
Mo	0.6
U	1.0

Well 1023 10-12 ft
10 % Error Bars

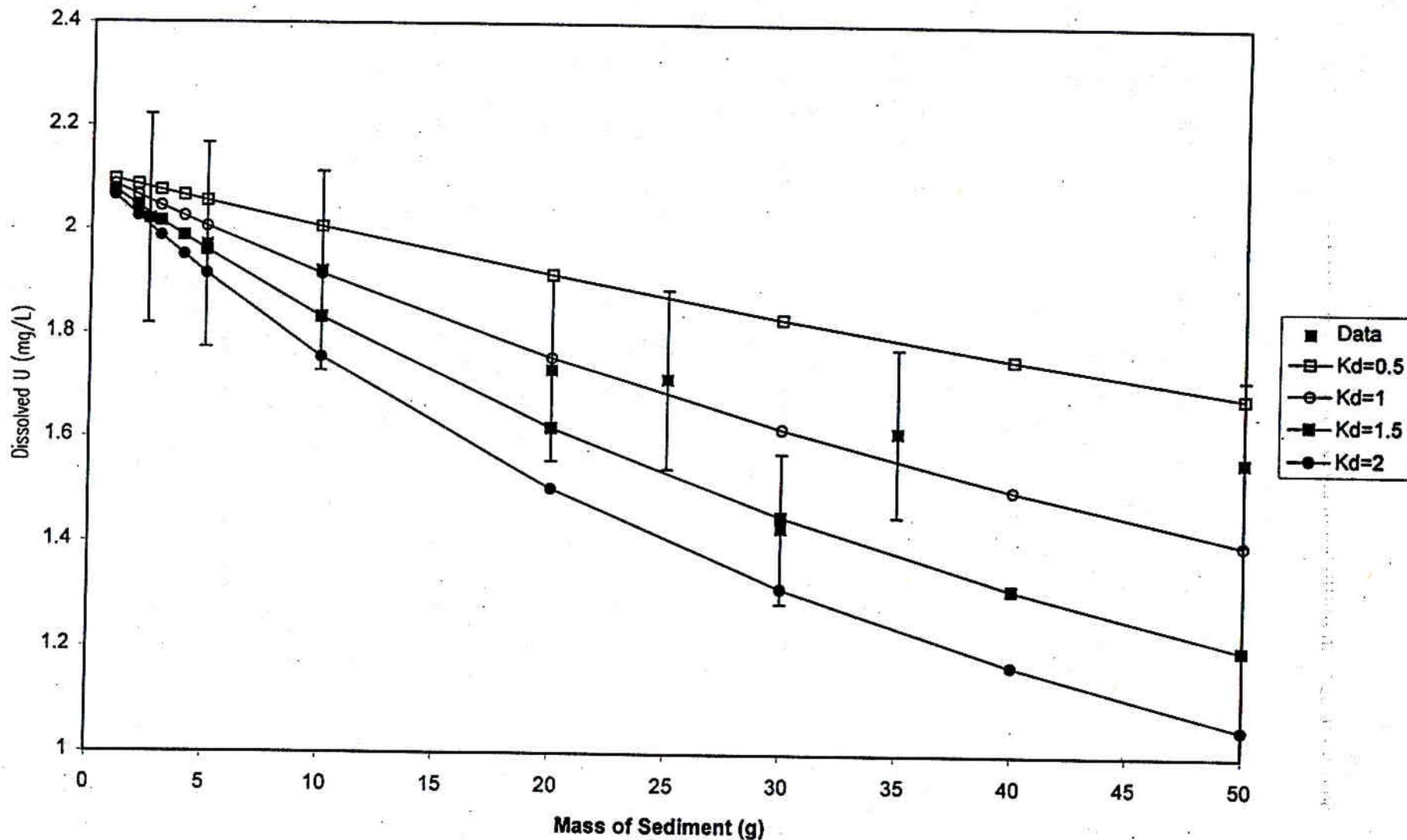


Figure 4-11. Dissolved Uranium Concentration Compared to Mass of Sediment, Well 1023, 10-12 ft

Well 1023 15-15.4 ft
10 % Error Bars

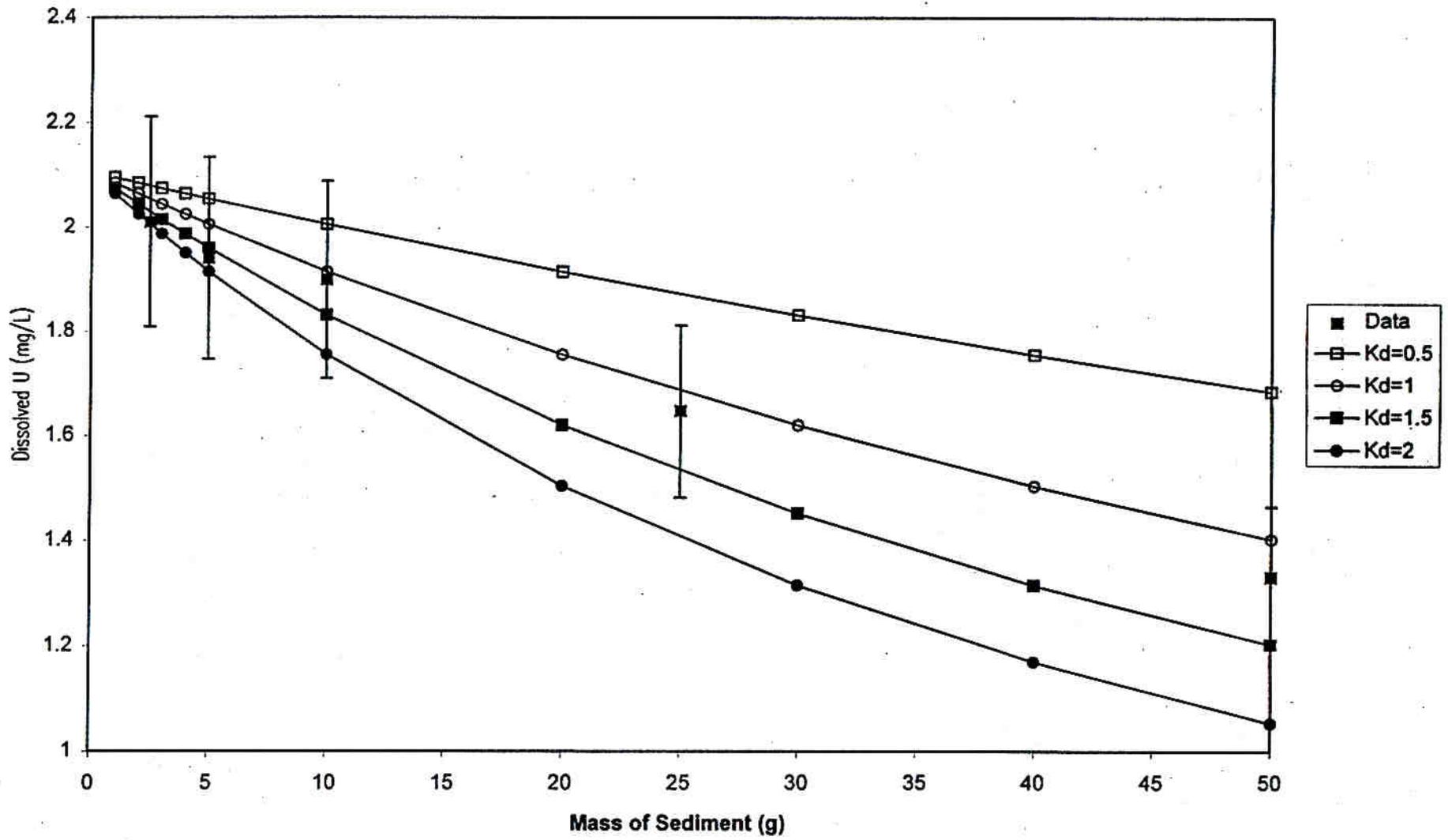


Figure 4-12. Dissolved Uranium Concentration Compared to Mass of Sediment, Well 1023, 15-15.4 ft

4.3.3 Subpile Soil Analysis

4.3.3.1 Background

During the uranium milling and processing operations at the Grand Junction site, several ponds were used for disposal and evaporation of process-related fluids. Mill tailings from operations at the site and from remediation of Grand Junction vicinity properties were temporarily stored in and around the evaporation ponds. Surface cleanup of the Grand Junction site took place in the early 1990s, and material contaminated with radionuclides was removed and disposed of in the Grand Junction disposal site southeast of Grand Junction. Disturbed areas of the Grand Junction site were covered with at least 6 inches of clean soil and sown with vegetation.

Remediation of the Grand Junction site was based on standards in 40 CFR Part 192, Subpart B, that apply to the cleanup of residual radioactive material from land and buildings. The standards call for remediation until the concentration of ^{226}Ra in land averaged over any area of 100 square meters does not exceed the background level by more than 5 picocuries per gram (pCi/g) in the first 15 cm of soil below the surface and 15 pCi/g in 15-cm-thick layers of soil more than 15 cm below the surface. The purpose of these standards for land cleanup is to limit the risk from inhalation of radon decay products in houses built on land contaminated with tailings and to limit gamma radiation exposure to people using contaminated land. However, milling-related radionuclides and nonradionuclides remaining in place after remediation to surface cleanup standards may still pose a potentially unacceptable source of ground water contamination. Leachate from the former evaporation ponds and tailings piles may have migrated downward and contaminated the underlying soils. Therefore, these “subpile soils” have the greatest potential for acting as a continuing source of ground water contamination.

To evaluate the possibility that subpile soils are a continuing contaminant source, leaching studies were conducted on soils collected from locations representing former on-site evaporation ponds and tailings piles (see Plate 1) to estimate the amount of remaining contamination; samples were also collected from three background locations for comparison. The subpile soil testing procedure is summarized below. For additional detail, see Appendix G.

4.3.3.2 Subpile Soil Test Procedure Summary

Samples were collected from eight on-site and three background locations (Figure 4–13). Samples were collected from two depths at five of the on-site and one of the background locations. The objective of the study was to sample soil horizons below the former tailings piles and evaporation ponds and determine the amount of residual contamination. Soils, as opposed to sediments or rocks, are more likely to serve as a continuing contaminant source through adsorption and retention of contaminants, largely due to their fine-grained nature and high organic content. However, an examination of the well logs for Grand Junction sample locations indicates that most, if not all, samples collected were actually of alluvial material. Any true soils that once existed on site were probably removed and replaced by fill during remediation. Because the Grand Junction climate is arid, and because the borehole sample locations are near the Colorado River and other surface drainage features, no well-developed soil horizons were observed during drilling at the subpile sample locations.

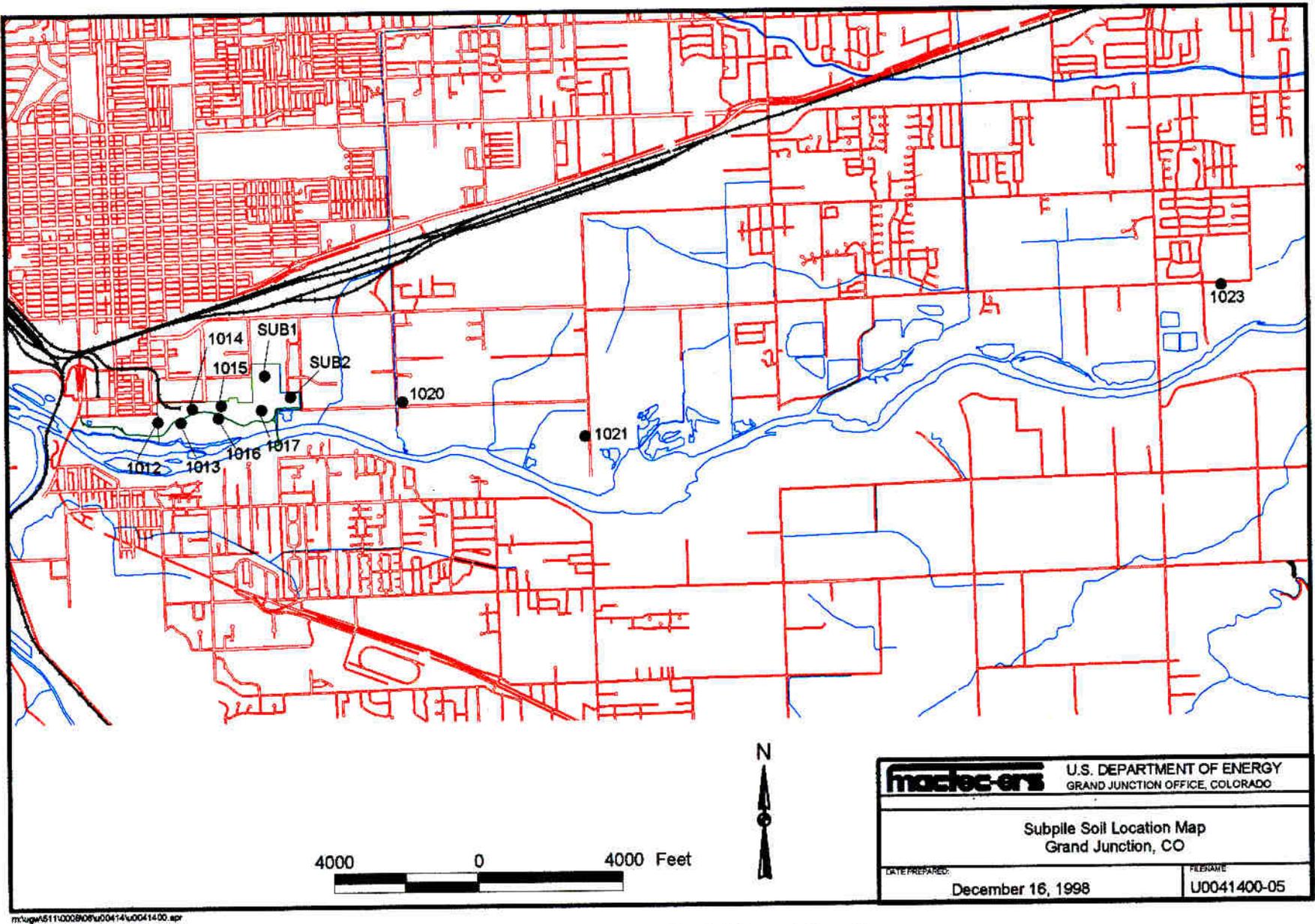


Figure 4-13. Subpile Soil Sample Locations

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Samples were sieved to separate the <2 mm size fraction for further testing. This fraction was leached in a 5 percent nitric acid solution. The nitric acid solution is assumed to extract all leachable contaminants but not the contaminants locked in recalcitrant minerals such as apatites or other heavy mineral grains. The extractants from the leaching tests were analyzed for several COPCs regulated under UMTRA—arsenic, cadmium, molybdenum, ²²⁶Ra, and uranium. Results of the leachate analyses were used along with volume of material extracted to estimate the amount of extractable contaminant per volume of soil (i.e., an estimated soil concentration that represents a continuing source term; see Table 4–10). For example, for the arsenic analysis for sample SUB1, 2 g of sample were extracted with 200 mL of 5 percent nitric acid. The concentration of arsenic in milligrams per kilogram (mg/kg) of soil is calculated as follows:

Volume of nitric acid solution = 200 mL

Volume of soil sample used = 2 g

Concentration of arsenic in leachate = 9.8 micrograms per liter (µg/L)

$$\frac{200 \text{ mL}}{2 \text{ g}} \times \frac{9.8 \text{ } \mu\text{g}}{\text{L}} \times \frac{1 \text{ L}}{1,000 \text{ mL}} \times \frac{1 \text{ mg}}{1,000 \text{ } \mu\text{g}} \times \frac{1,000 \text{ g}}{\text{kg}} = 0.98 \text{ mg/kg (concentration of arsenic in soil)}$$

A statistical analysis comparing concentrations of contaminants in on-site subpile soil samples to background soil samples indicates that on-site sample concentrations are not significantly elevated over background concentrations in cadmium and ²²⁶Ra at the 95 percent confidence level. On-site samples do contain elevated concentrations of arsenic, molybdenum, and uranium.

Distribution coefficients calculated for site samples (as described in Section 4.3.2) were used in conjunction with subpile soil analyses to give a rough estimate of the importance of subpile soils as a continuing contaminant source (Table 4–10). Calculations were performed to determine the concentration of contaminants in water that would be in equilibrium with the calculated soil concentrations.

For example, for the concentration of arsenic in sample SUB1 as calculated above, and the recommended K_d for arsenic of 361 L/kg, the equilibrium water concentration for arsenic is determined by:

$$\begin{aligned} C_{\text{water, As}} \text{ mg/L} &= C_{\text{soil mg/kg}} \div K_d \text{ L/kg} \\ &= 0.98 \text{ mg/kg} \div 361 \text{ L/kg} \\ &= 0.00271 \text{ mg/L} \end{aligned}$$

Results indicate that concentrations of arsenic and cadmium in subpile soils are so low that partitioning to ground water is expected to be insignificant. However, uranium and molybdenum concentrations are high enough in subpile soils and their K_d values are low enough that significant amounts of these contaminants (exceeding UMTRA standards) could partition to the ground water. Water concentrations calculated for some of the uranium and molybdenum samples are probably unrealistic based on known solubility data; however, results can be used qualitatively to assess the potential of these contaminants to act as a continuing source of ground water contamination.

Table 4-10. Results of Subpile Soil Testing

5 percent Nitric Acid Extraction											
Calculated Soil Concentrations							Equilibrium Water Concentrations				
Sample	Area	Depth (ft)	As (mg/kg)	Cd (mg/kg)	Mo (mg/kg)	Ra-226 (pCi/g)	U (mg/kg)	Cw - As (mg/L)	Cw - Cd (mg/L)	Cw - Mo (mg/L)	Cw - U (mg/L)
								Kd=361	Kd=177	Kd=0.6	Kd=1.0
SUB 1	pile/pond	.5'+	0.98	0.4	0.33	0.602	1.2	0.00271	0.0023	0.55	1.20
SUB 2	pile/pond	1'+	1.8	0.22	0.5	0.614	1.4	0.00499	0.0012	0.83	1.40
1012-1	pile	12-13.25'	0.74	0.4	1.4	0.473	1.5	0.00205	0.0023	2.33	1.50
1013-1	pile	9-11'	3.3	0.28	7.5	0.423	23.9	0.00914	0.0016	12.5	23.90
1013-2	pile	11-13'	3.7	0.23	3.5	0.289	10.4	0.01025	0.0013	5.833	10.40
1014-1	pile	13-14.25'	3.2	0.97	1.3	0.492	45.2	0.00886	0.0055	2.167	45.20
1014-2	pile	17-19'	1.4	0.73	0.8	0.309	7.7	0.00388	0.0041	1.333	7.70
1015-1	pile	10-12'	1.1	0.36	0.79	0.443	0.95	0.00305	0.0020	1.317	0.95
1015-2	pile	14-15.4'	0.82	0.37	1	0.249	0.56	0.00227	0.0021	1.667	0.56
1016-1	pile	9-11'	1.5	0.18	0.77	0.229	1.7	0.00416	0.0010	1.283	1.70
1016-2	pile	13-14.3'	1.2	0.23	0.34	0.319	0.6	0.00332	0.0013	0.567	0.60
1017-1	pond	9-11'	1	0.29	0.68	0.472	0.99	0.00277	0.0016	1.133	0.99
1017-2	pond	11-13'	1.6	0.18	0.53	0.38	0.59	0.00443	0.0010	0.883	0.59
1020-1	bkgd	5-7'	1.2	0.4	0.3	0.646	0.78	0.00332	0.0023	0.5	0.78
1021-1	bkgd	5-7'	0.9	0.32	0.33	0.472	1.1	0.00249	0.0018	0.55	1.10
1023-1	bkgd	5-7'	1	0.42	0.14	0.611	0.74	0.00277	0.0024	0.233	0.74
1023-2	bkgd	10-12'	0.92	0.25	0.21	0.24	0.44	0.00255	0.0014	0.35	0.44
UMTRA STANDARDS (mg/L)			0.05	0.01	0.1	5.0	0.044				

However, because of the high mobility of these contaminants, they would be expected to flush from the aquifer in a relatively short period of time (see further discussion in Section 5.3).

4.4 Ecological Field Investigations

Ecological investigations at the former millsite and surrounding areas were conducted to satisfy data needs to update the baseline risk assessment (BLRA; DOE 1995a). Section 5.2 of the *Work Plan for Characterization Activities at the UMTRA Grand Junction Project Site* (DOE 1997b) identified the following ecological data needs:

- Characterization of current plant communities overlying contaminated ground water and projections of the future plant ecology of the area given land-use scenarios.
- Selection and characterization of the plant ecology of a reference (background) area.
- Comparison of ecological COPCs in vegetation, sediment, and surface water, on site and in the reference areas, with ecotoxicity benchmarks.
- Screening assessment of ecological risks associated with irrigation ponds constructed at the botanical gardens since publication of the BLRA.

4.4.1 Plant Ecology Investigation

Vegetation at the former millsite and at the reference area was characterized using a semiquantitative relevé technique (Bonham 1989). The species composition and relative abundance of plant communities were evaluated by subjectively selecting representative stands of each vegetation type, walking through the stands, and compiling a list of all species observed. Each species was then assigned one of six cover classes. Cover was not measured precisely. The millsite and reference area were traversed on May 12, 1998.

4.4.1.1 Millsite Ecology

The millsite was seeded with a mixture of grasses, forbs, and shrubs after the removal of tailings in 1994. Since then, two types of upland vegetation and two types of riparian vegetation have developed on the site (See [Figure 4–14](#)). In one small area the seeding of crested wheatgrass (*Agropyron cristatum*) was successful. No other seeded grasses, forbs, or shrubs were found. The rest of the upland area is dominated by the invasive weed kochia (*Kochia scoparia*). A few young greasewood (*Sarcobatus vermiculatus*) shrubs are also present in this area. Overall, the millsite revegetation was unsuccessful.

Two riparian vegetation types along the Colorado River were identified on the basis of the relative abundance of tamarisk and cottonwood. The tamarisk type is dominated by tamarisk (*Tamarix ramosissima*) with some reed canarygrass (*Phalaris arundinaceae*), willows (*Salix exigua*), and cottonwood seedlings (*Populus fremontii*). Downgradient from the plume and mainly on Watson Island is the cottonwood type, which is dominated in the canopy by cottonwoods and has a weedy subcanopy of tamarisk, Russian olive (*Eleagnus angustifolia*), and Chinese elm (*Ulmus pumila*). The understory consists of a variety of grasses; the most prevalent are slender wheatgrass (*Elymus trachycaulus* spp. *trachycaulus*), inland saltgrass (*Distichlis*

spicata), blue wildrye (*Elymus glauca*), and reed canarygrass. There are also forbs in the understory, both native plants and invasive weeds such as Russian knapweed (*Centaurea repens*). Table 4–11 details the cover class of each species in the different vegetation types.

Table 4–11. Relevé Data Showing Species Cover of Plant Types at the Grand Junction Site

Latin Name	Common Name	Kochia Type	Wheat Grass Type	Tamarisk Type	Cotton-Wood Type
<i>Agropyron cristatum</i>	Crested wheatgrass	1	3		1
<i>Aster sp.</i>	Aster				1
<i>Atriplex canescens</i>	Fourwing saltbush				+
<i>Bromus inermis</i>	Smooth brome	2			
<i>Bromus tectorum</i>	Cheatgrass				1
<i>Centaurea repens</i>	Russian knapweed				1
<i>Chenopodium simplex</i>	Goosefoot				1
<i>Conyza canadensis</i>	Horseweed				+
<i>Descurania pinnata</i>	Tansy mustard		1		+
<i>Distichlis spicata</i>	Inland saltgrass				2
<i>Eleagnus angustifolia</i>	Russian olive			1	2
<i>Elymus elymoides</i>	Bottlebrush squirreltail				1
<i>Elymus sp.</i>	Wildrye				2
<i>Elymus trachycaulis</i>	Slender wheatgrass				2
<i>Kochia scoparia</i>	Kochia	4	2	3	2
<i>Phalaris arundinaceae</i>	Reed canary grass			2	2
<i>Phragmites communis</i>	Common reed				1
<i>Polygonum sp.</i>	Knotweed			+	
<i>Populus fremontii</i>	Cottonwood			2	3
<i>Salix exigua</i>	Sandbar willow			2	1
<i>Sarcobatus vermiculatus</i>	Greasewood	+			
<i>Scirpus acutus</i>	Bulrush			1	
<i>Sporobolus airoides</i>	Alkali sacaton				1
<i>Typha latifolia</i>	Cattail			1	
<i>Tamarix ramosissima</i>	Tamarisk			4	3
<i>Ulmus pumila</i>	Chinese elm				2
<i>Xanthium strumarium</i>	Cocklebur			1	

COVER CLASSES: +: <1 percent, 1: 1-5 percent, 2: 5-25 percent, 3: 25-50 percent, 4: 50-75 percent, 5: 75-100 percent

4.4.1.2 Reference Area Ecology

The reference area is upgradient of the millsite at the Wildlife Area section of Colorado River State Park. It consists of wildlife habitat areas and a series of ponds created from reclaimed gravel pits. The ponds are lined with cattails, common reed, and sandbar willow and provide habitat for geese, ducks, herons, and other waterfowl. The upland area is on a bench between the ponds and a small channel of the Colorado River. Characteristic upland vegetation continues east of the ponds. A pedestrian trail traverses these upland areas. The upland vegetation on this site is a good example of the potential vegetation of the millsite. It captures the range of conditions that demonstrate possible pathways of succession at the millsite, depending on future land-use scenarios.

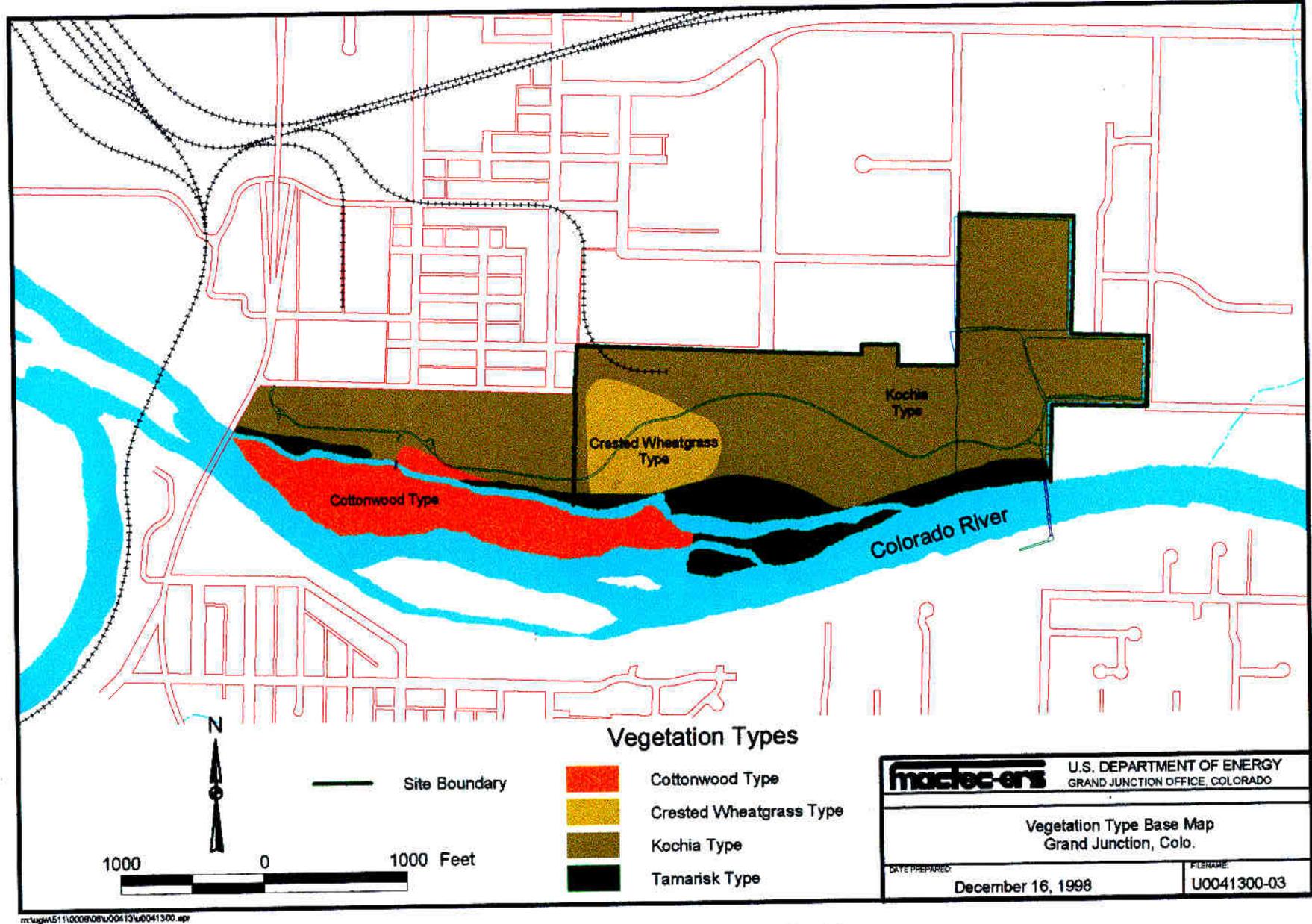


Figure 4-14. Base Map of Vegetation Types

Three vegetation types were delineated in the reference area. An upland vegetation type is dominated by either greasewood or rabbitbrush (*Chrysothamnus nauseosus*) in a mosaic pattern reflecting complex soil, geologic, and hydrologic interaction. A riparian vegetation type is found on the south side of the site along a backwater channel of the Colorado River. It is dominated by tamarisk, sandbar willow, and reed canarygrass. A wetland vegetation type is located on the pond margins and in other low-lying areas on the site. The dominant wetland plant species are cattails and sandbar willow. Table 4–12 shows the cover class of each species found in the three vegetation types in the reference area.

Table 4–12. Relevé Data Showing Species Cover of Vegetation Types at the Reference Area

Latin Name	Common Name	Upland Type	Riparian Type	Wetland Type
<i>Bromus tectorum</i>	cheatgrass	3	2	
<i>Centaurea repens</i>	Russian knapweed		1	
<i>Chrysothamnus nauseosus</i>	rubber rabbitbrush	4	1	
<i>Distichlis spicata</i>	inland saltgrass	2		
<i>Eleagnus angustifolia</i>	Russian olive		1	
<i>Elymus glauca</i>	blue wildrye	3		
<i>Kochia scoparia</i>	kochia	1		
<i>Phalaris arundinacea</i>	reed canarygrass		3	
<i>Phragmites communis</i>	common reed			2
<i>Polypogon monspeliensis</i>	rabbitsfoot grass		1	
<i>Populus fremontii</i>	Fremont cottonwood		2	1
<i>Rhus trilobata</i>	skunkbush sumac		1	
<i>Salix exigua</i>	sandbar willow		3	3
<i>Sarcobatus vermiculatus</i>	greasewood	3		
<i>Scirpus acutus</i>	hard stem bulrush		1	2
<i>Tamarix ramosissima</i>	tamarisk		3	
<i>Typha latifolia</i>	cattails		+	3
<i>Ulmus pumila</i>	Chinese elm		1	

COVER CLASSES: +: <1 percent, 1: 1–5 percent, 2: 5–25 percent, 3: 25–50 percent, 4: 50–75 percent, 5: 75–100 percent

4.4.1.3 Future Millsite Ecology

In the absence of disturbance, the upland plant community at the millsite will trend toward shrubland dominated by either greasewood or rabbitbrush. The riparian plant communities are being dominated by invasive weeds such as tamarisk, Russian olive, and reed canarygrass. Over time these plants may completely dominate, inhibiting reproduction of cottonwood, willow, and other more desirable plant species. Currently, greasewood, cottonwood, and tamarisk inhabit the site. These plants are all phreatophytes (plants that root in ground water), creating the potential for exposure pathways on the site.

4.4.2 Sampling for Chemical Analysis

Field sampling to support the BLRA update was conducted from June 22 through July 1, 1998. Surface water, sediment, and vegetation samples were collected along the Colorado River adjacent to and downstream of the Grand Junction site, at the botanical gardens irrigation pond located downstream from the Grand Junction site, and at the upstream reference area east of the site. This sampling was completed in addition to sediment and surface water sampling described in Sections 4.3.1.2 and 4.3.1.3. Results of the sampling and analyses are discussed in Section 5.4 and reported in Appendix I.

The selection of a reference area with the desired phreatophytic vegetation was limited to two areas upgradient of the Grand Junction site: the Colorado River Wildlife Area and Corn Lake farther east. Both areas were considered representative of background conditions and had been previously sampled for surface water. The Colorado River Wildlife area was chosen since it was closer to and ecologically similar to the Grand Junction site.

4.4.3 Abiotic Sampling

Surface water and sediment samples were collected at the Grand Junction site and the upgradient reference area (Figures 4-15 and 4-16). Co-located samples of sediment and surface water were collected at each of ten locations at each site. Five of the sampling locations at both the site and the reference area had been sampled previously. These existing 300-series sampling locations were surveyed and identified with tags attached to metal t-posts. Only four of the surveyed 300-series locations could be re-located by the field team. As a result, six locations were chosen using stratified random sampling. Five 300-series and five random locations were also selected at the reference area; only areas (strata) having appropriate plant species were selected.

The number of samples (10 each) was chosen to satisfy a coefficient of variation of 20, a minimum detectable relative percent difference of 20, a confidence of 95 (Type I error, false positive), and a power of 90 (Type II error, false negative) based on a 1-sided, single sample distribution. This is consistent with EPA guidance (EPA 1989a). Other factors that were considered in the selection of sample size were the small areal extent of the affected sites, the amount of historical data available, and generally low contaminant concentrations. The surface water samples were collected as grab samples, and the sediment samples consisted of materials collected from a nominal depth of 0–6 in. (0–15 cm) below the sediment surface. Surface water sample collection preceded sediment and vegetation sample collection. All surface water and sediment sampling containers were obtained pre-cleaned from an industrial supplier and accompanied by a cleanliness certificate.

Sample locations were identified as follows:

Locations 1216–1225: Reference area

Locations 1226–1235: Grand Junction site and downstream (west) of the site

Random sample locations not associated with 300-series location codes were originally established using a Garmin GPS (global positioning system) III unit; these locations were subsequently verified using a Trimble mapping-grade GPS unit. Location coordinates were collected using the WGS 84 datum, converted into state plane coordinates, and entered into the SEE UMTRA database.

4.4.3.1 Surface Water

Both filtered and unfiltered surface water samples were collected at the same locations as the sediment samples. The filtered sample represents the soluble component for aquatic receptors, whereas terrestrial receptors ingest unfiltered surface water. The analyte list for filtered surface water samples collected at locations 310, 312, 325, 326, 328, 330, 342, 349, and 350 differed only slightly from the analyte list for the remaining field locations.

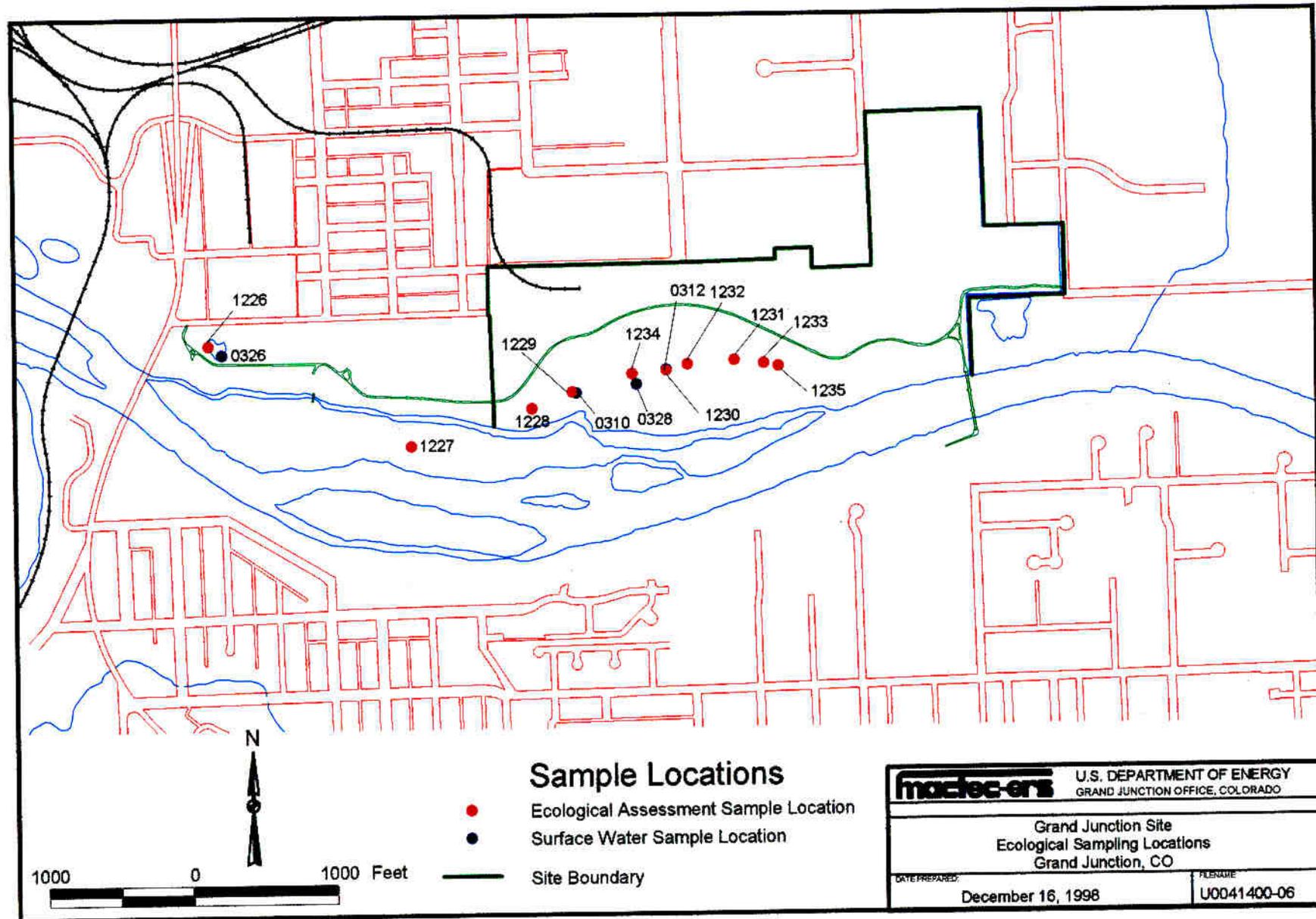


Figure 4-15. Grand Junction Site Ecological Sampling Locations

m:\ugw\611\000\00hu\0414\0041400.apr

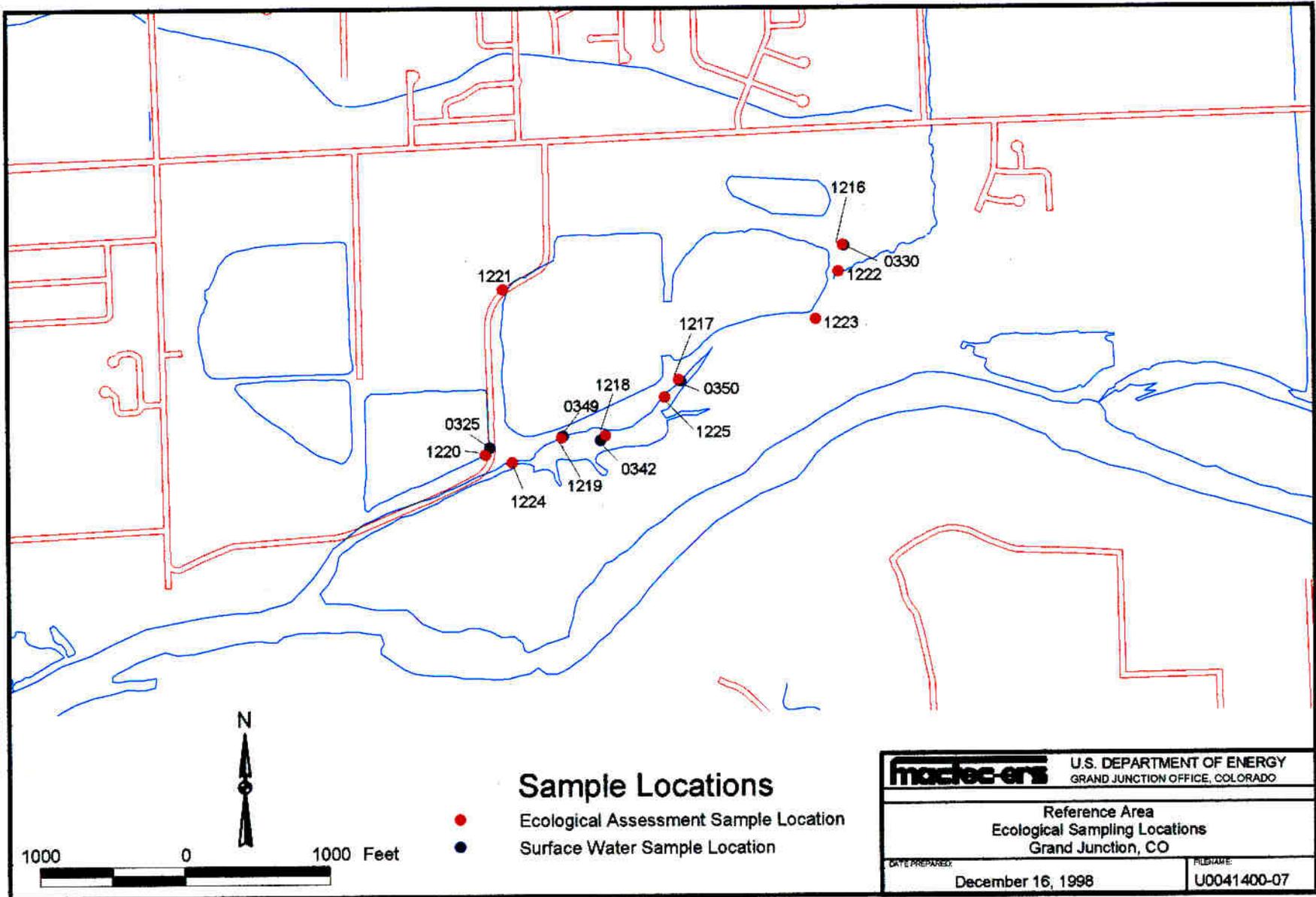


Figure 4-16. Reference Area Ecological Sampling Locations

Filtered surface water samples were identified with an 'F' suffix to the sample identification number, and unfiltered samples received a 'U' suffix. Each sample bottle was first rinsed with the surface water before sample collection. The sample was collected by immersing the bottle just below the water surface and filling to just below the lid. Samples were then filtered through a 0.45 µm filter and acidified accordingly. Table 4-13 provides a summary of analytes, preservatives, containers, and other information pertaining to surface water sample collection.

Table 4-13. Surface Water Sample Collection, Preservation, and Analysis

Analyte	Preservative	Container	Holding Time	Method
Arsenic	HNO ₃ to pH<2; cool 4 °C	500 mL amber HDPE	6 months	ICPAES
Cadmium				ICPMS
Cobalt				ICPAES
Copper				ICPAES
Iron				ICPAES
Manganese				ICPAES
Molybdenum				ICPMS
Nickel				ICPAES
Selenium				ICPAES
Strontium				ICPAES
Uranium				ICPMS
Vanadium				ICPAES
Zinc				ICPAES
²²⁶ Ra				HNO ₃ to pH <2; 4 °C
²²⁸ Ra	LSS			
Ammonia as NH ₄	H ₂ SO ₄ to pH <2; 4 °C	125 mL HDPE	28 days	SPEC
Fluoride	cool 4 °C	125 mL HDPE	28 days	IC
Sulfate				IC

Note:

HDPE = high density polyethylene
H₂SO₄ = sulfuric acid
HNO₃ = nitric acid
mL = milliliter
C = centigrade or Celsius
ICPMS = Inductively-coupled plasma mass spectrometry
ICPAES = Inductively-coupled plasma atomic emission spectroscopy
IC = Ion chromatography
LSS = Liquid scintillation spectrometry
SPEC = Spectroscopy

Sample labels showing the date, time, location, laboratory bar code, sampler, analyses requested, preservatives, and comments were applied to each container and secured with clear plastic tape. All sample containers were placed in coolers containing ice until transported to the Analytical Chemistry Laboratory. A chain of custody form was completed for all samples and a custody seal was placed over each cooler. All samples were maintained under strict chain of custody.

Because of a laboratory omission, data for ammonia as ammonium (NH₄), sulfate, and fluoride were not obtained on the unfiltered portions for locations 1222, 1223, 1224, and 1225. Nitrate was not detected in filtered surface water for locations 1226, 1229, 1230, and 1234 but was detected in the reference area. Because nitrate is present in the surface water at other locations, the nitrate results for the on-site locations are not considered reliable. Nitrate was not analyzed in unfiltered surface water since it was not identified as an ecological COPC in the work plan (DOE 1997b).

4.4.3.2 Sediment

Each sediment sample represented a composite of typically three or four locations where vegetation was present. The collection area was typically a circle of radius less than 5 ft. Excess organic matter and larger rocks and pebbles were removed from the sample before compositing. The contents of one stainless steel auger (i.e., one subsample) was collected at each composite location and placed in a large stainless steel mixing pan. All subsamples were mixed thoroughly with a stainless steel spoon, and about 4 ounces (114 g) of material were removed for metals analysis. An additional subsample was placed in a 125-mL HDPE bottle for analysis of ammonia and another for fluoride and sulfate analysis. Table 4–14 provides a summary of information pertaining to sediment sample collection and analysis.

Table 4–14. Sediment Sample Collection, Preservation, and Analysis

Analyte	Preservative	Container	Holding Time	Method ^a
Arsenic	cool 4 EC	4 oz. amber glass	6 months	ICPAES
Cadmium				ICPMS
Cobalt				ICPAES
Copper				ICPAES
Iron				ICPAES
Manganese				ICPAES
Molybdenum				ICPMS
Nickel				ICPAES
Selenium				ICPAES
Strontium				ICPAES
Uranium				ICPMS
Vanadium				ICPAES
Zinc				ICPAES
²²⁶ Ra				cool 4 EC
²²⁸ Ra	LSS			
Ammonia as NH ₄	cool 4 EC	125 mL HDPE	28 days	SPEC
Fluoride	cool 4 EC	125 mL HDPE	28 days	IC
Sulfate				IC

^aICPMS = Inductively-coupled plasma mass spectrometry
 ICPAES = Inductively-coupled plasma atomic emission spectroscopy
 IC = Ion chromatography
 LSS = Liquid scintillation spectrometry
 SPEC = Spectroscopy

Sample labels were applied to each container and secured with clear plastic tape. All sample containers were placed in coolers containing ice until transport to the Analytical Chemistry Laboratory. A chain of custody form was completed for all samples and a custody seal was placed over each cooler. All samples were maintained under strict chain of custody. The analytical method for the sediment samples specified above included a complete acid digestion rather than an acid leach as in previous sediment sample analyses discussed in Section 4.3.1.3. Therefore, analytical results for these sets of samples are not directly comparable.

4.4.3.3 Quality Assurance Samples

One unfiltered field blank and one equipment rinsate were collected at the reference area. The field blank was prepared by pouring distilled, deionized water directly into the appropriate sample bottle and preserving as necessary. The equipment rinsate consisted of pouring distilled, deionized water over the cleaned sampling equipment (auger, sampling pan, shears, and spoons)

and collecting the rinsate in the appropriate sample containers and preserving and cooling as necessary.

Field duplicate surface water and sediment samples were collected at reference location 1221 and at Grand Junction site location 1229. Field duplicates were identified with a D suffix to the sample identification number.

4.4.4 Biotic Sampling

4.4.4.1 Field Sampling Methods

Vegetation samples consisting of cattails (*Typha* sp.), reed canarygrass (*Phalaris arundinaceae*) and sandbar willow (*Salix exigua*) were collected at the reference and Grand Junction site locations. A single bulrush (*Scirpus* sp.) sample was collected at the reference area; the quantity of bulrush available at the millsite was insufficient for a sample. Because the reference area sample could not be compared to an on-site sample, results of the bulrush analysis were not used for the ecological risk assessment. The biota samples were co-located with the surface water and sediment samples. Samples were collected by using a stainless-steel shovel to dig up an entire plant or cluster of plants. Sediment was rinsed off the plants, and the roots and stems were separated with pruning shears having stainless steel and polyethylene cutting edges. The roots and stems were rinsed thoroughly with surface water, followed by tap and distilled deionized water rinses until rinsates contained no visible soil or sand particles. All plant materials received a final distilled, deionized water rinse before bagging. Stems and roots were composited separately from three or four samples, depending on the size of the original plant or plant cluster. Stems and roots were double-bagged in clean plastic zipper-type storage bags. Sample labels were applied to each outer bag and secured with clear plastic tape. All samples were kept in coolers containing ice for transporting to the Analytical Chemistry Laboratory. A chain of custody form was completed for all samples and a custody seal was placed over each cooler. All samples were maintained under strict chain of custody.

Samples that could not be processed directly at the laboratory by freeze-drying were placed in refrigerators at 4 EC. [Table 4–15](#) provides a summary of information pertaining to biota tissue collection and analysis.

Sample locations were identified as follows:

Locations 1216–1225: Reference Area

Locations 1226–1235: Grand Junction site and downstream (west) of the site

Vegetation samples were identified by adding an *R* (root) or *S* (stem) suffix to each sample identification number. All sample bags for each field location containing the same laboratory identification number were processed as one sample (i.e., all roots for the same sample identification and field location number were processed as one sample). The same procedure applied to the stem material for each field sampling location. All analyses are based on total sample digestion.

Due to the scarcity of desirable vegetation species along the Colorado River adjacent to the Grand Junction site, the same numbers and types of species could not be collected at both the site and reference areas. [Table 4–16](#) summarizes the species collected at each location.

Table 4–15. Biota Sample Collection, Preservation, and Analysis

Analyte	Matrix	Preservative	Container	Holding Time	Method ^a
Arsenic	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Cadmium	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPMS
Cobalt	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Copper	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Iron	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Manganese	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Molybdenum	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPMS
Nickel	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Selenium	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Strontium	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Uranium	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPMS
Vanadium	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
Zinc	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	ICPAES
²²⁶ Ra	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	LSS
²²⁸ Ra	cattail, reed canarygrass, willow	Cool 4 EC	double 1-gal plastic zipper bags	6 months	LSS

^aICPMS = Inductively-coupled plasma mass spectrometry

ICPAES = Inductively-coupled plasma atomic emission spectroscopy

LSS = Liquid scintillation spectrometry

Table 4–16. Summary of Vegetation Collected by Location

Location Code	300-Series Code	Location	Vegetation (includes both roots and stems)
1216	330	Reference	Cattail, bulrush
1217	342	Reference	Reed canarygrass
1218	350	Reference	Willow
1219	349	Reference	Willow
1220	325	Reference	Reed canarygrass
1221	None	Reference	Cattail
1222	None	Reference	Cattail
1223	None	Reference	Reed canarygrass
1224	None	Reference	Willow
1225	None	Reference	Cattail
1226	326	On Site	Cattail
1227	None	On Site	Reed canarygrass
1228	None	On Site	Reed canarygrass
1229	310	On Site	Willow
1230	312	On Site	Reed canarygrass
1231	None	On Site	Cattail
1232	None	On Site	Willow
1233	None	On Site	Reed canarygrass
1234	328	On Site	Reed canarygrass
1235	None	On Site	Cattail

4.4.4.2 Quality Assurance Samples

A field duplicate cattail sample was collected at reference location 1222, and a field duplicate reed canarygrass sample was collected at on-site location 1228. These field duplicates do not correspond to the surface water and sediment duplicate samples because of the variable availability of vegetation at the locations. Field duplicates were identified with a ?D? suffix added to the sample identification number. Equipment rinsates and field blanks applied to the biota collection as well.

4.5 Land Surveys

A new survey was performed on all currently sampled and new monitoring wells, the stilling well, surface sampling locations, and various other locations including the new dike/sidewalk, footbridge and a brass cap on the footbridge, the north side of the Colorado River, and ponds in the Western Colorado Botanical Gardens area. This information was entered into the SEE UMTRA database and used for generating maps, tables, and references for this SOWP. XY coordinates used the NAD 83 format, and elevations were tied to the North American Vertical Datum of 1929. All lithologic and well completion logs in Appendix B use this information.

4.6 Vicinity Property Study

DOE, in conjunction with CDPHE, recently completed removal of uranium mill tailings, which had been used as fill and for other construction purposes, from over 4,000 private and commercial properties in the Grand Junction area. Most of the tailings were removed from these properties, known as vicinity properties, but some tailings were left in place through the application of supplemental standards or area averaging. DOE and CDPHE were concerned that mill tailings left in place at vicinity properties could leach contaminants into ground water at

these sites. To address this concern, one large complex commercial property, the Regional Center and one collection of residential properties, West Main Street, were studied. Large volumes of tailings had been removed from the Regional Center property, and substantial volumes of tailings were left in place at both properties through the application of supplemental standards or area averaging. These properties were considered to represent worst case scenarios for potential ground water contamination. A separate report entitled *Ground Water Study at Two UMTRA Project Vicinity Properties in Grand Junction, Colorado* (DOE 1999) addressing the vicinity property study is being prepared concurrently with this final Grand Junction SOWP.

5.0 Conceptual Site Model

5.1 Geology

5.1.1 Regional Structure and Setting

The Grand Junction site is in the Grand Valley on the eastern edge of the Colorado Plateau, a large region encompassing parts of Colorado, Utah, New Mexico, and Arizona that began to be uplifted during the Laramide orogeny; the uplifting intensified about 10 million years ago in response to the North American plate overriding the East Pacific plate (Kluth and Coney 1981). The Uncompahgre Plateau, which is the eastern part of the Colorado Plateau and west and southwest of the Grand Junction site, is a recurring structural high that formed part of the Ancestral Rocky Mountains during late Paleozoic time. During the Late Cretaceous into Tertiary time, the Uncompahgre Uplift tilted Mesozoic and early Tertiary rocks from Grand Junction to Montrose, Colorado, away from the plateau toward the northeast and east (Lohman 1965). Bedrock in the subsurface of the site dips gently northeast at 1 to 3 degrees. Bedrock strike is parallel to the axis of the Uncompahgre Uplift to the southwest, and the dip is away from the uplift toward the Piceance Basin to the northeast.

In the Grand Valley, unconsolidated Quaternary deposits consisting of sand, silt, gravel, and cobbles laid down by the Colorado River cover sedimentary bedrock formations of Late Cretaceous age. In places, the Quaternary material is covered by soil or fill material that was hauled in to replace contaminated soil that was excavated during surface remediation. Bedrock exposures closest to the site are to the south in the escarpment about 75 ft (23 m) high along the south side of the Colorado River. Approximately 15 ft (4.6 m) of Quaternary sand, silt, gravel, and cobbles overlies the bedrock and forms the top of the escarpment. This alluvial terrace material was deposited by the ancestral Colorado River, and the surface formed on the terrace is known as Orchard Mesa.

5.1.2 Stratigraphy

Bedrock underlying the site and exposed along cliffs south of the Colorado River directly south of the site consists of shales of the Late Cretaceous Dakota Sandstone. Mancos Shale, also of Late Cretaceous age, overlies the Dakota Sandstone and is exposed in an outcrop east of the site along the south side of the Colorado River and is present in the subcrop within 200 to 300 ft (61 to 91 m) east of the site. These formations and the overlying Quaternary material are shown in Figure 4? 1, a southwest-to-northeast cross section A–A'. Below the Dakota Sandstone is the Early Cretaceous Burro Canyon Formation that does not crop out in the site area. Characteristics of the unconsolidated Quaternary material and fill, Mancos Shale, and Dakota Sandstone are described below.

5.1.2.1 Quaternary Sediments and Fill

Unconsolidated alluvial material and fill underlie portions of the site north of the Colorado River and range in thickness from 4 ft (1.3 m) to about 25 ft (7.6 m). The thickness generally increases northward from the river and reaches its greatest thickness locally in an east-trending area about 2 mi (3.2 km) north of the site around North Avenue (U.S. Bureau of Reclamation 1986). About 3 mi (5 km) east of the site, the alluvial material is thicker, as determined from borehole data. The thickest alluvium found in these boreholes was 78 ft (24 m) in borehole 717 about 2 mi

(3.2 km) north of the river (U.S. Bureau of Reclamation 1986). Quaternary material south of the site and south of the Colorado River caps the escarpment as a layer about 15 ft (5 m) thick and is a terrace deposit composed of cobbles and gravel with a sand and silt matrix.

Quaternary material north of the river can generally be divided into two types of deposits: bedload cobbles and gravel of the alluvial aquifer, and overlying floodplain deposits of sand, silt, and clay. The “cobble aquifer” was first recognized by Schneider (1975), who proposed that the Colorado River was formerly about 3 mi (5 km) north of its present channel, and the cobble aquifer was deposited as bedload during lateral migration of the river to its present position. As part of the Colorado River Basin salinity control project in the late 1970s and 1980s, the U.S. Bureau of Reclamation investigated the cobble aquifer and identified a boundary (U.S. Bureau of Reclamation 1986). The cobble aquifer is as much as 40 ft (12 m) thick in the Clifton area and is from 5 to 15 ft (1.5 to 5 m) thick in the millsite area. Material composing the cobble aquifer and lowest part of the alluvial aquifer in the site area includes silty gravel and silty gravel with sand.

Fine-grained floodplain deposits generally from 5 to 10 ft (1.5 to 3 m) thick composed of sandy clay, clayey sand, sandy silt, and silty sand overlie the cobble aquifer in the site area. Cahn and others (1988) noted that in places the base of the floodplain deposits consisted of clay in discontinuous lenses. Where continuous, this clay could confine the underlying cobble aquifer. This clay was not found in the site area.

5.1.2.2 Mancos Shale

Approximately 4,000 ft (1,200 m) of Mancos Shale deposited in the interior epicontinental seaway are present in the Grand Valley in the Grand Junction area. Only the lowermost part of the Mancos Shale, the nonresistant Tununk Member (about 200 ft [62 m] thick), is present less than 1 mile north of the site area. The lower part of the Tununk Member consists of calcareous, medium- to dark-gray shale and silty shale that weathers to yellowish brown or olive gray. The lower 20 ft (6 m) contains a zone of abundant oysters (*Pycnodonte newberryi*) (Willis 1994). Bentonite beds up to a few inches thick that have altered to montmorillonite (swelling) clay are common in the lowermost shales.

An in-place exposure of lowermost Mancos Shale was found in only one area along the escarpment south of the site area. This exposure (Plate 1) is just east of the slide area in the upper part of the escarpment slope immediately below the Quaternary terrace material. Here erosional “pillars” of olive-gray, calcareous, gypsiferous shale and silty shale are present starting about 25 ft (8 m) above the level of the Colorado River and extending up about 20 ft (6 m) to the contact of the Quaternary terrace material. Just south of the pedestrian bridge on the south bank, a thin, calcareous, fine-grained sandstone bed may also mark the lowermost Mancos.

An outcrop of Mancos Shale along the south bank of the Colorado River just northwest of the lower Mancos “pillars” was reported in the 1996 SOWP (DOE 1996d). This outcrop of dark-gray shale contained some *Pycnodonte newberryi*, a bentonite bed several inches thick, and was calcareous, placing it in the lowermost part of the Mancos. However, outcrops of carbonaceous, noncalcareous siltstone along the river just to the west and the presence of slump blocks in the slide area just to the south indicate that this Mancos outcrop is probably part of the slide area and not in place.

Organic-rich dark marine shales are known to carry anomalously high concentrations of a number of cations including uranium. Levinson (1980) described black marine shales that had

uranium concentrations ranging from 3 to 1250 mg/kg, and a specific example, the marine Chattanooga Shale of Tennessee, has large areas that average 57 mg/kg uranium (Mickle and Mathews 1978). Butler and others (1994) analyzed six samples of Mancos Shale from the Grand Valley in which uranium concentrations ranged from 3.7 to 11.2 mg/kg and averaged 6.2 mg/kg. The crustal abundance of uranium averages 1.8 mg/kg (Mason and Moore 1982), and the average concentration in all shales is 4 mg/kg (Levinson 1980). Ground water passing through the Mancos Shale and over the interface between saturated Mancos Shale and the alluvial aquifer could leach uranium from this formation.

Selenium is known to be concentrated especially in Cretaceous marine shales found in many western states (Larkin and Byers 1941). The U.S. Geological Survey has been studying selenium origins and contamination because high selenium concentrations are present in the Imperial Valley of California and other locations downstream in the Colorado River drainage. High selenium values are not indigenous to those locations, and the problem is thought to result from upstream irrigation. Selenium leached from soil by irrigation water is eventually carried into the Colorado River. Therefore, the Colorado River is receiving selenium from various lithologies in its drainage system. The Grand Valley has been classified by the U.S. Geological Survey as having irrigation-induced selenium contamination because 25 percent of the surface water samples contain levels of selenium equal to or greater than 0.005 mg/L (USGS 1997). This situation is caused by high evaporation rates and high concentrations of naturally occurring selenium in the Mancos Shale.

5.1.2.3 Dakota Sandstone

Lohman (1965) and Young (1959) determined that the Dakota Sandstone was about 150 ft (46 m) thick in the Grand Junction area. However, field investigations suggest that it may be up to 200 ft thick in the immediate area of the site. In the project area, the Dakota consists of approximately one-third sandstone and two-thirds shale and siltstone. Unconformably underlying the Dakota are fluvial-lacustrine sandstones and siltstones of the Burro Canyon Formation of Early Cretaceous age. The Dakota, which represents the last terrestrial deposition before transgression of the Mancos sea, in this area has been subdivided into three informal members on the basis of lithology (Young 1959; Willis 1994). The lower member is resistant and consists mainly of crossbedded sandstone and conglomeratic sandstone. The middle member is nonresistant and consists of interbedded carbonaceous shale and sandstone, mudstone, impure coal, and bentonitic clay. The upper member is resistant and consists of fine-grained sandstone.

The lower sandstone member is exposed in the escarpment on the south side of the Colorado River west of the site and is present in the subsurface west of the site. Several sandstone beds, each several feet thick, crop out as ledges at the south end of the railroad bridge that crosses the Colorado River. The south bridge abutment rests on one of these sandstone layers. These sandstone beds occur along the south bank of the Colorado River eastward for about 500 ft (150 m) east of the U.S. Highway 50 bridge. The middle shale member is present in the escarpment along the south side of the Colorado River directly south of the site and was described in cores and cuttings from boreholes and augured boreholes on the site as well as north and east of the site. The upper sandstone member was not observed in the area of the site.

The middle shaley member of the Dakota is exposed above the lower member sandstones in many places along the escarpment from the railroad bridge eastward to the new pedestrian bridge and farther east. Carbonaceous shale and thin, carbonaceous, fine-grained sandstone along with

mudstone are the most common rock types exposed along the escarpment. Thin (less than 2 ft [0.6 m] thick) beds of impure coal (with a lignitic appearance) occur in this member. Remains of old underground coal workings are present just west of the south end of the U.S. Highway 50 bridge (Lohman 1965).

The middle Dakota was deposited in paludal or deltaic marginal marine environments and appears similar to Mancos Shale when viewed in isolated outcrops. Characteristics of the Dakota that distinguish it from the Mancos are discussed in Section 4.1 and include carbonaceous material and impure coal, common sandy/silty grain size, noncalcareous matrix, presence of pyrite, bioturbated bedding, and bentonitic clay in which the volcanic ash has altered to kaolinite (nonswelling clay).

Sandstone of the upper member is rarely exposed along the escarpment; this member may be only a few feet thick or absent in places. Several sandstone slabs less than 1 ft (0.3 m) thick, possibly representing an offshore beach environment, occur in the upper part of the slide area (Plate 1). Also, a thin, calcareous, fine-grained sandstone bed occurs near the top of the escarpment just south of the pedestrian bridge, possibly marking the top of the Dakota or base of the Mancos.

Exposed members of the Dakota along the escarpment south of the Colorado River and their projected dip at 2 to 3 degrees northeastward beneath the site indicate that Dakota Sandstone, rather than Mancos Shale as stated in the original SOWP (DOE 1996d), is the first bedrock formation present beneath the site area. The estimated trace of the subcrop is shown in Plate 1. The cross section in Figure 4?1 shows the geologic relationships in boreholes in the area just west of the site. Recognition criteria for Dakota Sandstone (described in Section 4.1.2) were applied to core from five boreholes near the site on the north side of the Colorado River. All the core had characteristics of Dakota Sandstone; the deepest parts of holes 724 and 725 may have penetrated a coarser upper part of the underlying Burro Canyon Formation.

5.1.3 Bedrock Topography and Geomorphology

Figure 4–2 shows the top of the Dakota, the bedrock that underlies the entire site, based on old and new monitoring well data. Under the site, the top of the Dakota is higher in the east and drops off 6 feet to the south and to the west. West of the site the Dakota drops off more steeply to the south along the edge of the Colorado River channel and toward the confluence of the Gunnison and Colorado Rivers. The pre-1947 aerial photograph (Figure 3–1) shows an obvious channel crossing the site from the east, dog-legging to the south, and extending to the west. This photograph was enlarged and superimposed on Figure 4–2 to test for any correlation. None was found and it is assumed that channels were not cut deeply enough or extensively enough into the Dakota to be manifested in the well log information.

5.2 Hydrology

The three main hydrogeologic units beneath the Grand Junction site include the unconfined alluvial aquifer, the underlying aquitard composed primarily of shale units in the Cretaceous Dakota Sandstone, and the confined aquifer in sandstones of the Dakota Sandstone. Geologic descriptions of these units are provided in Section 5.1.2. The alluvial aquifer is considered the uppermost aquifer at the Grand Junction the site. Surface components of the hydrologic system in the area of the site include the Colorado River and irrigation canals and ditches north of the site.

5.2.1 Alluvial Aquifer

The alluvial aquifer is the uppermost hydrogeologic unit beneath the Grand Junction site and is composed of unconsolidated clays, silts, sands, gravels, and cobbles. The informal name “cobble aquifer” is commonly used in Grand Valley hydrologic literature (U.S. Bureau of Reclamation 1986). The cobble aquifer underlies most of Grand Junction and covers the Dakota Sandstone and Mancos Shale in a 1.5- to 3-mile-wide (0.9- 1.8-km) strip between Loma and Palisade (Figure 3–1 and Plate 2). Most of the cobble aquifer extends north of the Colorado River, although some parts occur to the south. The name “cobble aquifer” may be misleading, because the composition can range from 90 percent gravel, 9 percent sand, and 1 percent fines, to 1 percent gravel, 90 percent sand, and 9 percent fines (U.S. Bureau of Reclamation 1986). In many places in the valley, the cobble aquifer is overlain by a silty-clay unit. The base of this unit consists of discontinuous lenses of clay. Where intact, the clay layer confines the cobble aquifer. Together, the cobble aquifer and overlying silty clay lenses are called the alluvial aquifer. The alluvial sediments above the clay are variable and range from sand to silt or clay. Typically, the uppermost layers have low hydraulic conductivity.

Ground water is present under unconfined conditions in the alluvial aquifer beneath the Grand Junction site. Depth to ground water ranges from zero near the river to approximately 20 ft (6 m) at the northern end of the site. The saturated thickness of the aquifer ranges from 10 to 20 ft (3 to 6 m). Ground water generally flows to the southwest toward the Colorado River at a hydraulic gradient of approximately 0.004 (Figure 5–1).

The alluvial aquifer is recharged by infiltration of precipitation directly on the site, leakage from upgradient irrigation canals and ditches in the area (passing through Mancos Shale), and infiltration of river water during spring runoff in the Colorado River. During periods of high water in the Colorado River, recharge enters the alluvial aquifer from the river along its southern boundary, flattening hydraulic gradients and creating a more westerly ground water flow orientation. Seasonal fluctuations in water levels beneath the site range from 2 to 5 ft (0.6 to 1.5 m) in response to changes in river stage. Limited amounts of recharge also occur as upward leakage of ground water from the underlying Dakota Sandstone aquifer. Ground water discharge is primarily limited to drainage into the river during low stage. Some discharge also occurs as evapotranspiration from vegetation growing in areas of shallow ground water depth near the Colorado River.

Ground water levels were measured with dataloggers in several monitor wells, including wells 0743, 0744, 0746, 1001, 1002, 1013, 1017, and 1022 (Figure 4–3). Results were used to observe variations in ground water levels through time and to correlate these with water level fluctuations in the Colorado River. During the period of observation, ground water levels fluctuated several feet in response to infiltration of precipitation and interaction with surface water.

Data collected from aquifer pumping tests in alluvial aquifer wells in the west (0590), central (1034/1035), and east (1018) portions of the site indicate that transmissivity ranges from 161 to 2,434 ft²/day (15 to 226 m²/day). Hydraulic conductivity ranges from 18 to 304 ft/day (5.5 to 93 m/day) based on saturated thickness in the alluvial aquifer ranging from 6 to 9 ft (1.8 to 2.7 m) in the wells. The estimated hydraulic conductivity near monitor well 0590 is 70 ft/day. This well is near the river and is likely in hydraulic connection. A discharge rate of 30 gallons per minute (gpm) was maintained for a 12-hour period. Recovery was relatively slow, indicating

lower hydraulic conductivity in the vicinity of the well, but the high sustained rate of discharge indicates connection to the river, which was the principle source of water pumped during the test. The estimated hydraulic conductivity near monitor well 1018 is 20 ft/day. A sustained rate of discharge of only 1 gpm was attainable during the 12-hour test. In the middle of the site, multi-well aquifer pumping tests were performed in monitor wells 1034 and 1035 (with drawdown response measured in three adjacent observation wells). Pumping rates of 4 gpm in well 1034 and 6 gpm in well 1035 were sustained during these tests. The average linear ground water velocity beneath the processing site is about 2.0 ft/day (0.6 m/day) based on an average estimated hydraulic conductivity of 100 ft/day (30 m/day), a hydraulic gradient of 0.004, and an effective porosity of 20 percent.

As expected, the values of hydraulic conductivity are variable across the site, even in the relative proximity of wells 1034 and 1035. Variation in these values is a result of several factors: (1) lateral and vertical lithologic changes typical of alluvial depositions, including the possible effects of old channels in the alluvium; (2) Colorado River as a boundary condition, particularly in the vicinity of well 0590 (about 60 ft [18 m] from the river); and (3) well construction and screen type that may cause variable well efficiency and response to pumping stress (e.g., screen type in 1035 has greater area of exposure to the aquifer than in 1034). Because variables affect hydraulic parameter values in an aquifer system, the results are an approximation that provides a general idea of the characteristics of the alluvial aquifer.

5.2.2 Dakota Sandstone Aquitard

Underlying the alluvial aquifer is an aquitard composed of low-permeability shale units in the Dakota Sandstone. It was verified during site characterization that bedrock beneath the alluvium at the site generally consists of shales and siltstones of the Dakota Sandstone. The Mancos Shale was previously thought to underlie the alluvium at the site, but it appears to pinch out in the subcrop just east of the site (Plate 1). Lithologic data indicate that the contact between the alluvium and the shale dips westward at approximately 10 to 20 ft/mi (1.9 to 3.8 m/km). A subtle bedrock high has tentatively been mapped near the eastern boundary of the site, and this local feature may contribute to the apparent increased westerly hydraulic gradient in the cobble aquifer in this area. The uppermost portions of the shale aquitard were logged during previous investigations as “highly weathered” and may behave as part of the cobble aquifer. Thickness of the shale aquitard in the Dakota may be as much as 50 ft; depths to the top of the aquitard range from less than 10 ft to more than 75 ft below the ground surface.

Although the shale unit is regarded as an aquitard, wells completed within the unit indicate that it is saturated with ground water. Horizontal hydraulic conductivity for the aquitard varies depending on the degree of weathering of the unit, but the lower end of the range for unweathered material may be as low as 0.02 ft/day. Vertical hydraulic conductivities are probably one to several orders of magnitude less than the horizontal values. Several wells were installed in the shale aquitard to form paired installations with wells in the cobble aquifer. Although these wells have since been decommissioned, previously collected data indicate that vertical hydraulic gradients are generally upward, with a few exceptions noted during high water levels in the cobble aquifer associated with high river stages (DOE 1996d).

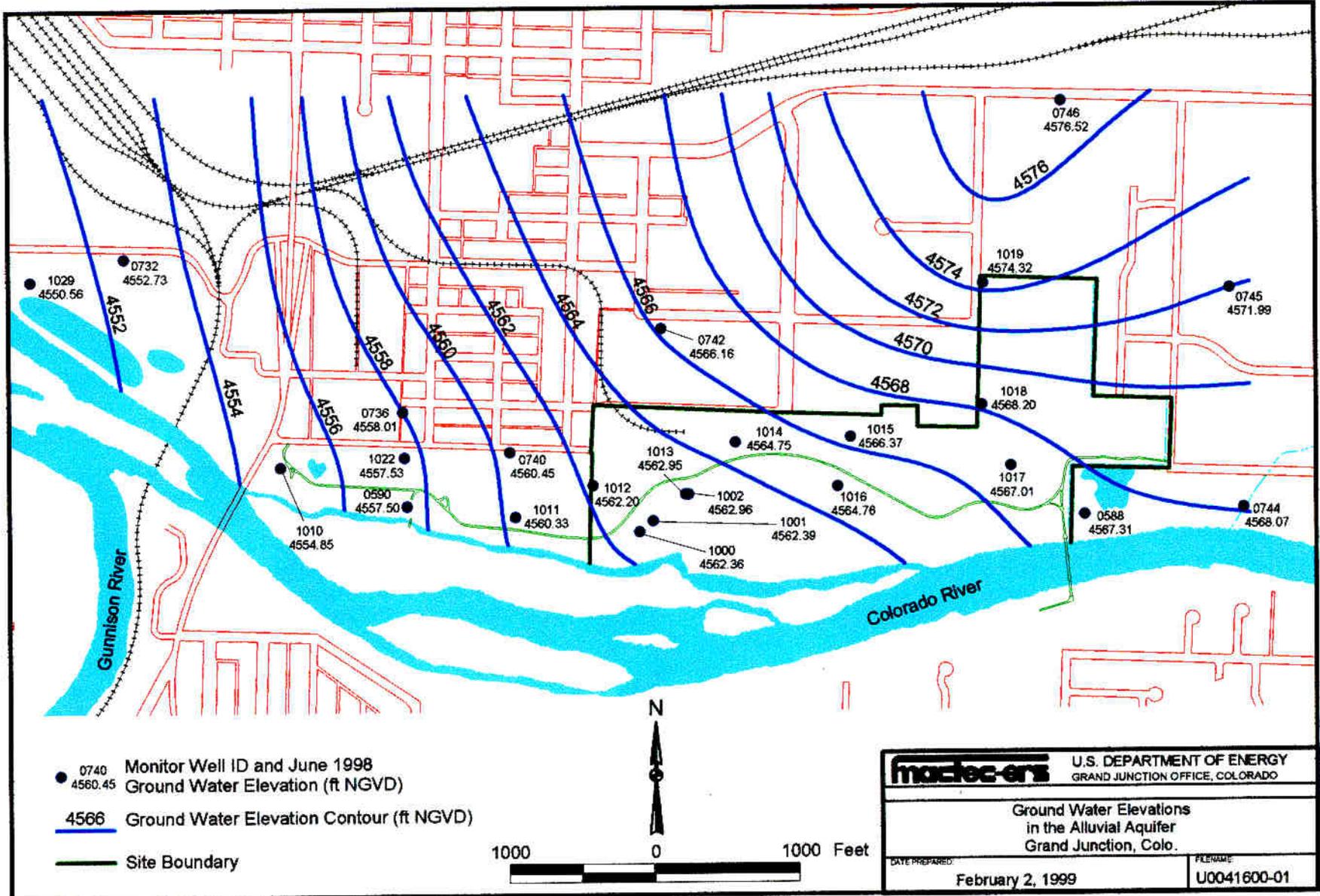


Figure 5-1. Ground Water Elevation in the Alluvial Aquifer

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5.2.3 Dakota Sandstone Aquifer

The confined aquifer in sandstones of the Dakota Sandstone underlies the shale aquitard (Lohman 1965). This aquifer was not extensively characterized during site investigations because the presence of the overlying aquitard and vertical upward hydraulic gradients minimize the potential for infiltration of contamination from the alluvial aquifer. This is confirmed by the lack of site-related COPCs detected in ground water in the Dakota aquifer. Recharge to the Dakota Sandstone occurs as infiltration of precipitation on outcrops to the south and west. Although not sufficiently mapped by on-site monitor wells, ground water flow direction in the Dakota beneath the site likely follows regional gradients, which vary between a northwest and a northeast orientation.

5.2.4 Surface Water Hydrology

The Colorado River is the dominant surface water feature in the vicinity of the Grand Junction site. The river forms the southern boundary of the site and flows from east to west. River stage fluctuates in response to snowmelt runoff, which typically occurs between April and July. Data collected during 1998 showed a 5-ft difference between high and low water levels during the period of measurement (Figure 4-4). These fluctuations cause the river to behave as the main point of ground water discharge from the alluvial aquifer during periods of low water and a source of recharge to the alluvial aquifer during periods of high water. During the high river stage, large portions of the site along the southern boundary are commonly flooded when the river crests its bank. Precipitation falling on the site drains to the south directly into the river and east into a surface drainage ditch that borders the eastern edge of the site (Plate 1).

In addition to the Colorado River, irrigation canals and ditches also influence ground water in the vicinity of the Grand Junction site. These unlined canals and ditches, which are used to irrigate (from April through November) and drain land in the site vicinity, have a seasonal influence on ground water levels and act as a local source of recharge to the alluvial aquifer.

5.2.5 Site Water Balance

The development of a site water balance is important to support numerical modeling at a site. Since this activity is not anticipated as part of the Grand Junction site characterization, the site water balance has not been evaluated in detail. The site water balance describes the various steady-state flow components that dictate the ground water flow in the vicinity of the site. Inflows to the system in the vicinity of the Grand Junction site include (1) ground water inflow from the east and north, (2) recharge from precipitation over the entire site, (3) recharge from the Colorado River during high-water stages, (4) recharge from irrigation canals and ditches during the period of operation, and (5) vertical ground water flow from the underlying Dakota Sandstone aquifer. Discharge from the flow system occurs as (1) evapotranspiration in vegetated areas of the site, (2) ground water discharge to the Colorado River, and (3) downgradient ground water discharge.

5.3 Geochemistry

5.3.1 Background Water Quality of the Alluvial Aquifer

Data from monitoring wells upgradient of the former millsite were evaluated to determine which wells were representative of background conditions. Statistical analyses were performed on 1998 analytical results of samples from the selected background wells to determine if the background population contained constituent concentrations that could be characterized as widespread ambient contamination. UMTRA ground water standards (40 CFR 192) and primary and secondary drinking water standards (40 CFR 141 and 143) were used as benchmarks for this determination.

Wells representative of background were selected for analysis. Locations were selected that were upgradient of the Grand Junction site and outside the potential influence of UMTRA vicinity properties. Initial candidates for background wells were wells 588, 713, 715, 744, 745, 746, 1020, 1021, 1023, 1024, 1025, and CW21 (see locations on Plate 2). Well 1024 was subsequently eliminated because of its location immediately downgradient from discharge ponds at the Clifton Water Treatment Plant. Discharge from the ponds could dilute natural constituent concentrations and the water would therefore not be representative of the alluvial aquifer. Well 746 was eliminated at the request of CDPHE because of its location in an area near a vicinity property.

Wells 588 and 744 were examined to determine if water quality in those wells was affected by recharge from the Colorado River and other surface water features near those locations. Well 588 is located directly downgradient of a pond containing a significant quantity of surface water. Well 744 is located next to a surface drainage that is expected to provide ground water recharge.

Major-ion chemistry for wells 588 and 744 was compared with data from two wells farther upgradient and away from the river—wells 745 and 746—along with surface water samples from location 424, collected from the river near well 588. Although constituent concentrations in well 746 may not be indicative of background water quality, major-ion chemistry should still be reflective of background ground water in the site vicinity. Processing at the site may have altered major-ion chemistry of on-site or downgradient ground water but not water upgradient of the site. Major-ion chemistry for wells 745 and 746 was distinct from that of the river water sample; water from wells 588 and 744 showed a composition between that of wells 745 and 746 and the river water sample but closer to the composition of the river water sample. This suggests a mixing relationship between ground and surface water, with surface water being dominant. If mixing occurs, these wells do not truly produce samples of the alluvial aquifer. Therefore, wells 588 and 744 were eliminated from the background data set as unrepresentative of the alluvial aquifer (for additional information see Appendix H).

The remainder of the background wells were retained (713, 715, 745, 1020, 1021, 1023, 1025, and CW21) and descriptive statistics were performed on the data for selected constituents. Results for uranium expressed as total uranium in milligrams per liter and as $^{234}\text{U} + ^{238}\text{U}$ in picocuries per liter (pCi/L) are presented in [Tables 5-1](#) and [5-2](#), respectively. Results for selenium are presented in [Table 5-3](#). The analysis in [Tables 5-1](#) and [5-2](#) indicates that data for uranium fit both a normal and a lognormal distribution. The description of selenium data is not normal, but is bimodal.

Background wells were also examined to determine concentrations of chloride, iron, manganese, and sulfate. Although no UMTRA ground water standards exist for these contaminants, secondary drinking water standards have been developed for them largely based on considerations of taste or odor. Data for all these contaminants are included in [Table 5-4](#).

On the average, background concentrations of uranium and selenium in alluvial ground water in the Grand Valley exceed UMTRA ground water protection standards. The mean for uranium exceeds the standard established based on combined activities of ^{234}U and ^{238}U of 30 pCi/L as well as the standard based on mass of 0.044 mg/L total uranium (assuming secular equilibrium). Secondary drinking water standards are exceeded for chloride, iron, manganese, and sulfate. Non-site-related "contamination" is widespread across the area. These data support the conclusion that the background alluvial water can be considered limited use ground water as defined by the UMTRA regulations. Although some background samples had constituent concentrations below standards, particularly for selenium, the average (mean) concentrations probably more realistically approximate the concentrations that would be obtained over time from a well installed for domestic purposes into the alluvial aquifer.

As discussed in Section 4.3.3.1, major-ion composition in alluvial ground water is distinctly different from that of the Dakota Formation; this difference supports the conclusion that the two waters are not intermixing. Also, major-ion chemistry of contaminated on-site alluvial ground water is similar to that of the upgradient area, which suggests that past activities at the millsite have not significantly altered the major-ion composition of the aquifer.

5.3.2 Surface Water and Sediment Chemistry

The Climax uranium mill was located next to the Colorado River. The river received contaminated fluids and sediments from the millsite while the mill was operating from 1951 through 1970. The flux of contaminants to the surface environment decreased when the tailings piles were stabilized in 1971. Since the completion of the tailings removal in 1994, the flux of contaminants to the surface environment has nearly ceased. After 1994, only two pathways remained to contaminate the surface environment: (1) surface expression of contaminated ground water, and (2) continued erosion of residual contaminated soils. The UMTRA Surface Project used a radiometric standard based on activity of ^{226}Ra to guide the tailings removal. Although this was a reasonably effective practice, uranium and other contaminants that had separated from the ^{226}Ra by migrating into the subsurface could have been left in place. The results of subpile sampling (Section 4.3) indicate that a small amount of contamination remained after remediation.

The contaminated alluvial ground water system at the millsite discharges into the Colorado River. Sampling of the Colorado River (described in Section 4.3.3) indicated that the flux of contaminants is low enough, relative to the flux of river water, that it does not produce a detectable chemical signature in the river.

Table 5-1. Statistical Description of Background Uranium Concentrations in the Alluvial Aquifer (mg/L)

DATA EVALUATION STATISTICS

Data Description

Grand Junction Background Alluvial Ground Water

Uranium:

Action Level 0.044

Sample Data

UNITS - mg/L
0.0652
0.0662
0.0602
0.0535
0.0381
0.038
0.0566
0.0573
0.0305
0.0228
0.0468
0.0452
0.0435
0.0437
0.036

Descriptive Statistics

Number of Samples	15.000
Mean	0.0469
Median	0.0452
Standard Deviation	0.0128
CV	0.2721
Range	0.0434
Minimum	0.0228
Maximum	0.0662
GM	0.0451
GSD	1.3459
Mean of LN(Data)	-3.0981
SD of LN(Data)	0.2970
Percent > Limit	53.3333

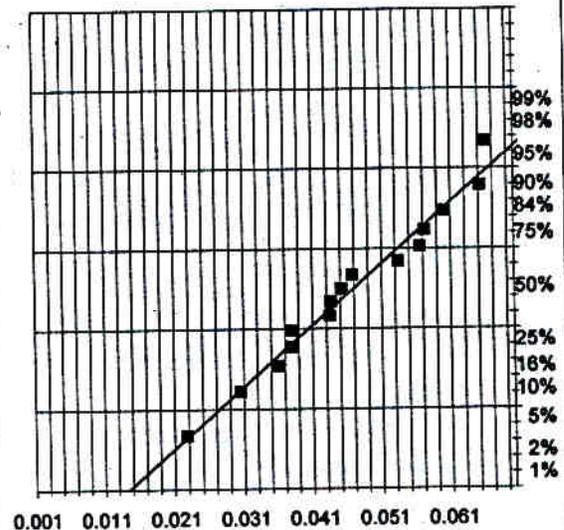
Normal Statistics

n>30 Upper (95% CI mean) - Z	0.0534
n>30 Lower (95% CI mean) - Z	0.0404
Upper (95% 1-tail CL mean) - Z	0.0523
Upper (95%ile data) - Z	0.0679
n<30 Upper (95% CI mean) - Norm t	0.0540
n<30 Lower (95% CI mean) - Norm t	0.0398
Upper (95% 1-tail CL mean) - Normal	0.0527
UTL (min 95%, 95%) - K	0.0797
UTL (avg 95%, 95%) - K	0.0701
Percent > Limit	59.0086
W Test (Data)	0.9690
Normal (a=0.05)?	Yes

Lognormal Statistics

n>30 Upper (95% CI mean) - Z	0.0548
n>30 Lower (95% CI mean) - Z	0.0406
Upper (95% 1-tail CL mean) - Z	0.0535
Upper (95%ile data) - Z	0.0736
n<30 Upper (95% CI mean) - LogNorm t	0.0556
n<30 Lower (95% CI mean) - LogNorm t	0.0400
Upper (95% 1-tail CL mean) - LogNorm	0.0540
UTL (min 95%, 95%) - K	0.0967
UTL (avg 95%, 95%) - K	0.0775
Percent > Limit	53.4150
W Test (Data)	0.9448
Normal (a=0.05)?	Yes

Probability Plot and Least Squares Best Fit Line



Log-Probability Plot and Least Squares Best Fit Line

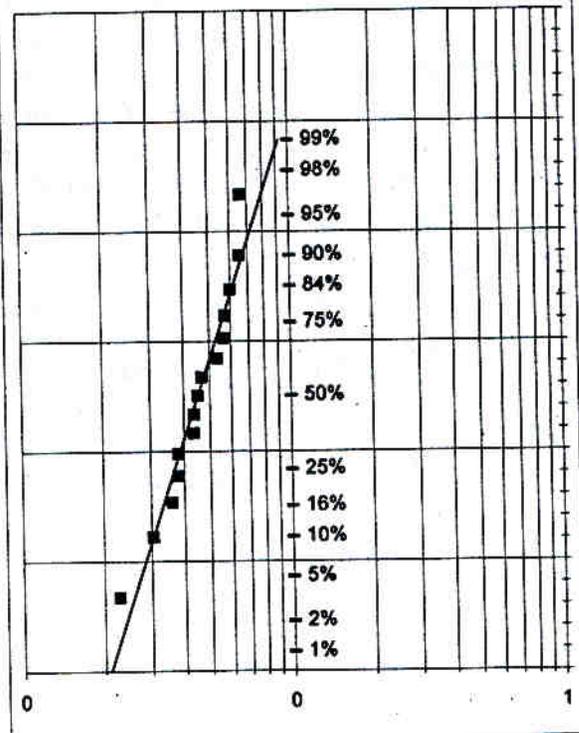


Table 5-2. Statistical Description of Background Uranium Concentrations in the Alluvial Aquifer (pCi/L)

DATA EVALUATION STATISTICS

Grand Junction Background Alluvial Ground Water

Data Description

Action Level 30

Sample Data
UNITS - pCi/L

57
55
31.5
48.1
25.1
39.4
35

Descriptive Statistics

Number of Samples	7.000
Mean	41.5857
Median	39.4000
Standard Deviation	12.1218
CV	0.2915
Range	31.9000
Minimum	25.1000
Maximum	57.0000
GM	40.0199
GSD	1.3548
Mean of LN(Data)	3.6894
SD of LN(Data)	0.3036
Percent > Limit	85.7143

Normal Statistics

n>30	Upper (95% CI mean) - Z	50.5657
n>30	Lower (95% CI mean) - Z	32.6058
	Upper (95% 1-tail CL mean) - Z	49.1225
	Upper (95%ile data) - Z	61.5261
n<30	Upper (95% CI mean) - Norm t	52.7965
n<30	Lower (95% CI mean) - Norm t	30.3749
	Upper (95% 1-tail CL mean) - Normal	50.4886
	UTL (min 95%, 95%) - K	82.7877
	UTL (avg 95%, 95%) - K	66.7689
	Percent > Limit	83.0407
	W Test (Data)	0.9435
	Normal (a=0.05)?	Yes

Lognormal Statistics

n>30	Upper (95% CI mean) - Z	52.4786
n>30	Lower (95% CI mean) - Z	33.4683
	Upper (95% 1-tail CL mean) - Z	50.6153
	Upper (95%ile data) - Z	65.9468
n<30	Upper (95% CI mean) - LogNorm t	55.4945
n<30	Lower (95% CI mean) - LogNorm t	31.6476
	Upper (95% 1-tail CL mean) - LogNorm	52.3774
	UTL (min 95%, 95%) - K	112.3272
	UTL (avg 95%, 95%) - K	75.1978
	Percent > Limit	82.8718
	W Test (Data)	0.9494
	Normal (a=0.05)?	Yes

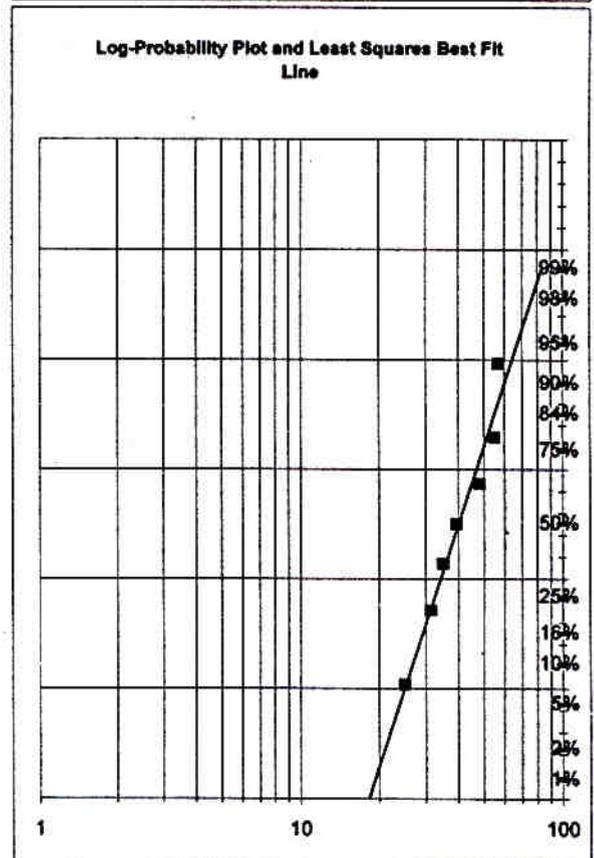
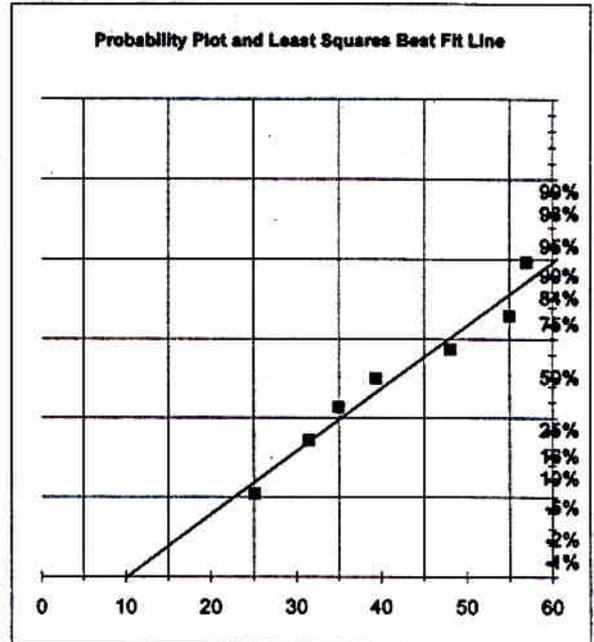


Table 5-3. Statistical Description of Background Selenium Concentrations in the Alluvial Aquifer

DATA EVALUATION STATISTICS

Grand Junction Background Alluvial Ground Water

Data Description

Selenium

Action Level 0.010

Sample Data
UNITS - mg/L

0.048
0.049
0.0318
0.0404
0.001
0.001
0.001
0.001
0.001
0.001
0.001
0.001
0.137
0.116
0.0518
0.001
0.058

Descriptive Statistics

Number of Samples	15.000
Mean	0.0359
Median	0.0318
Standard Deviation	0.0433
CV	1.2053
Range	0.1360
Minimum	0.0010
Maximum	0.1370
GM	0.0088
GSD	8.4536
Mean of LN(Data)	-4.7342
SD of LN(Data)	2.1346
Percent > Limit	53.3333

Normal Statistics

n>30 Upper (95% CI mean) - Z	0.0579
n>30 Lower (95% CI mean) - Z	0.0140
Upper (95% 1-tail CL mean) - Z	0.0543
Upper (95%ile data) - Z	0.1072
n<30 Upper (95% CI mean) - Norm t	0.0599
n<30 Lower (95% CI mean) - Norm t	0.0119
Upper (95% 1-tail CL mean) - Normal	0.0556
UTL (min 95%, 95%) - K	0.1471
UTL (avg 95%, 95%) - K	0.1147
Percent > Limit	72.5345
W Test (Data)	0.7914
Normal (a=0.05)?	No

Lognormal Statistics

n>30 Upper (95% CI mean) - Z	0.2527
n>30 Lower (95% CI mean) - Z	0.0291
Upper (95% 1-tail CL mean) - Z	0.2124
Upper (95%ile data) - Z	0.2944
n<30 Upper (95% CI mean) - LogNorm t	0.2797
n<30 Lower (95% CI mean) - LogNorm t	0.0263
Upper (95% 1-tail CL mean) - LogNorm	0.2264
UTL (min 95%, 95%) - K	2.1025
UTL (avg 95%, 95%) - K	0.4269
Percent > Limit	47.5892
W Test (Data)	0.7436
Normal (a=0.05)?	No

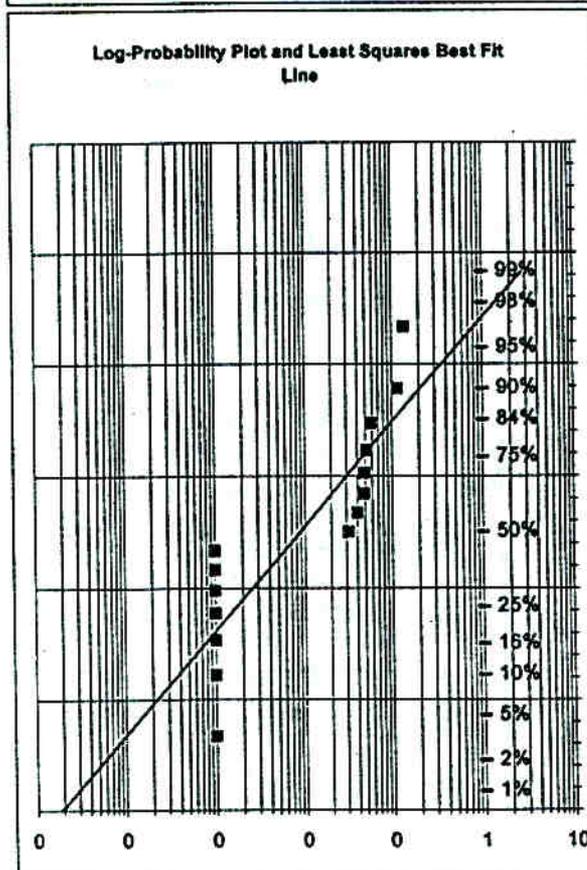
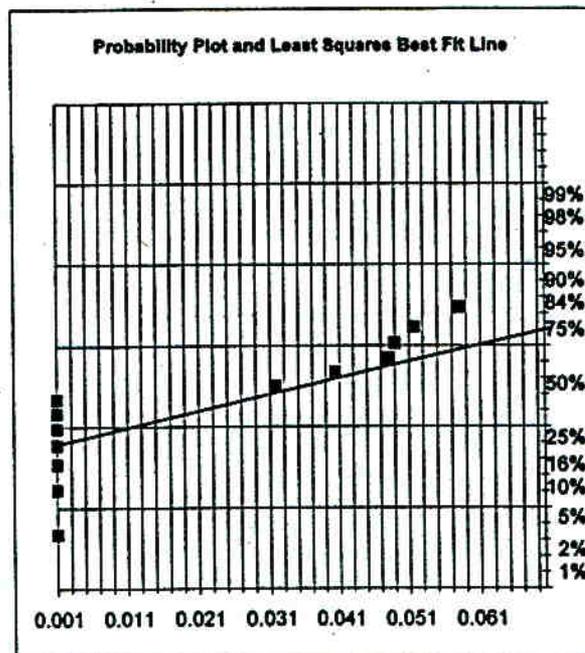


Table 5-4. Mean Background Ground Water Concentrations of Selected Constituents

Contaminant	Mean (background)	SMCL
Chloride	437	250
Iron	0.552	0.3
Manganese	1.4	0.05
Sulfate	2,566	250
TDS	5,238	500

SMCL = Secondary Maximum Contaminant Level

Water enters the ponds as surface runoff, ground water, or irrigation water. If the pond has continuous flow, the water maintains a composition similar to the inflow composition. If the pond is closed, the concentration of all dissolved constituents will increase as water evaporates. As dissolved constituents increase in concentration, minerals may precipitate. Calcite and gypsum are close to saturation concentrations in the ground water and will precipitate relatively early as the water evaporates. Some contaminants preferentially partition to these phases. If the ponds subsequently become diluted, these phases will redissolve, and any coprecipitated contaminants will be released back to the water. Dilution will only occur during storm events or during high river levels. Dissolved iron is also likely to precipitate as ferric oxyhydroxides due to the oxidizing environment in some of the ponds. Ferric oxyhydroxides are strong scavengers of uranium and metals.

Contaminated alluvial ground water may discharge into surface ponds before entering the river. A low scarp has begun to form on the south side of the millsite where it intersects the Colorado River channel. The scarp appears approximately where Watson Island begins on the east and extends westward nearly to the end of the millsite. In places this scarp is 2 to 4 feet high. The same floodwaters that formed the scarp left narrow linear depressions that support a few small ponds on the south side of this scarp. Some of these ponds are ephemeral, but some maintain surface water year round. During the ecological sampling, which occurred during low water, sample 1228 was collected from the largest of these linear ponds. The pond is about 50 ft (15 m) long, 3 to 9 ft (1 to 3 m) wide, and is probably fed by ground water that surfaces along the scarp forming its northern side. This pond may be the last remnant of the westernmost of the original 8 ponds developed as a wetlands area during final surface remedial action construction. These ponds were essentially removed during spring flooding in 1995 (see Section 3.3.2). Analysis of this pond water sample showed that concentrations of fluoride, manganese, iron, molybdenum, ammonia, sulfate, strontium, uranium, and vanadium were unusually high in this pond compared to other surface samples in the study (Appendix I). These elevated concentrations may be attributed to evaporation because water from a nearby monitoring well (well 1000 is about 200 ft [61 m] northeast) has lower concentrations of fluoride, molybdenum, ammonia, sulfate, uranium, and vanadium. These small ponds will continue to migrate or change locations as spring floodwaters infill and scour this scarp area along the southern millsite boundary. Several ponds were recently constructed downgradient of the millsite to irrigate the botanical gardens. These ponds are lined, which prevents hydraulic communication with the alluvial aquifer. However, unlined ponds could be constructed in the future.

The flux of contamination to the ponds should be higher at present than in the future because the tailings have been removed. Thus, the average concentration of contaminants in the ponds should currently be at a maximum.

Subaqueous sediment may contain contamination from three sources: (1) uptake from contaminated water in contact with it, (2) residual contamination (e.g., tailings) that was incorporated during milling, and (3) recently deposited contaminated sediments eroded from the millsite. Periodic flushing of the ephemeral ponds and the Colorado River will remove any contaminants present in the sediments. Because the tailings have been removed, the surface environments are becoming cleaner over time; thus, the ephemeral ponds should be getting cleaner as well. There are currently no significant persistent (unlined) ponds on site or downgradient of the millsite except for the small linear ponds and the pond at American Auto Salvage. These sediments will become less contaminated as surface runoff water desorbs contaminants by percolating through and entering the river and as clean sediments enter the pond and dilute the contaminant concentrations.

5.3.3 Extent of Ground Water Contamination

5.3.3.1 Contaminant Sources

All major sources of contamination have been removed from the site to meet UMTRA surface cleanup standards; only subpile soils may present a continuing source of ground water contamination. Alluvial ground water from the site flows in a southwesterly to westerly direction (Figure 5-1). Therefore any contaminant plumes in the alluvial ground water should extend from the site in that direction.

5.3.3.2 Current/Temporal Distribution of Contaminants in Ground Water

Current Conditions

Figures 5-2 through 5-9 are “spot plots” of on-site and downgradient alluvial well locations, showing concentrations of selected contaminants historically associated with the site. The data are averages of the two 1998 sampling rounds. In most instances, contaminant concentrations detected in a given well did not vary significantly between the two sampling events. For contaminants with an MCL, the MCL value is used as a cutoff point between two concentration ranges. For contaminants that do not have an MCL, a risk-based concentration was used as a cutoff point (see Section 6.1 for further discussion of risk-based concentrations).

Most of the contaminant plots indicate that the maximum contaminant concentrations are in on-site wells. This generality holds true for molybdenum, manganese, uranium, arsenic, and vanadium, though background wells for some of these contaminants (e.g., uranium and molybdenum) have concentrations that are nearly as high as those in on-site wells. Plots for iron and sulfate are less definitive and no clear concentration trends are apparent. Each of these figures is discussed individually below.

Ammonia. The highest concentrations of ammonium were from on-site wells and were detected in two locations. Ammonium concentration was 83 mg/L in well 1017 in the eastern section and 189 mg/L in well 1018. These wells are in the area of former uranium mill evaporation ponds and also in the area of the former stockyards that were in use when the sugar beet mill was in operation. The other area with higher concentrations of ammonium is in the southwestern part of the site; a sample from well 1001 contained 182 mg/L. This well is probably downgradient from

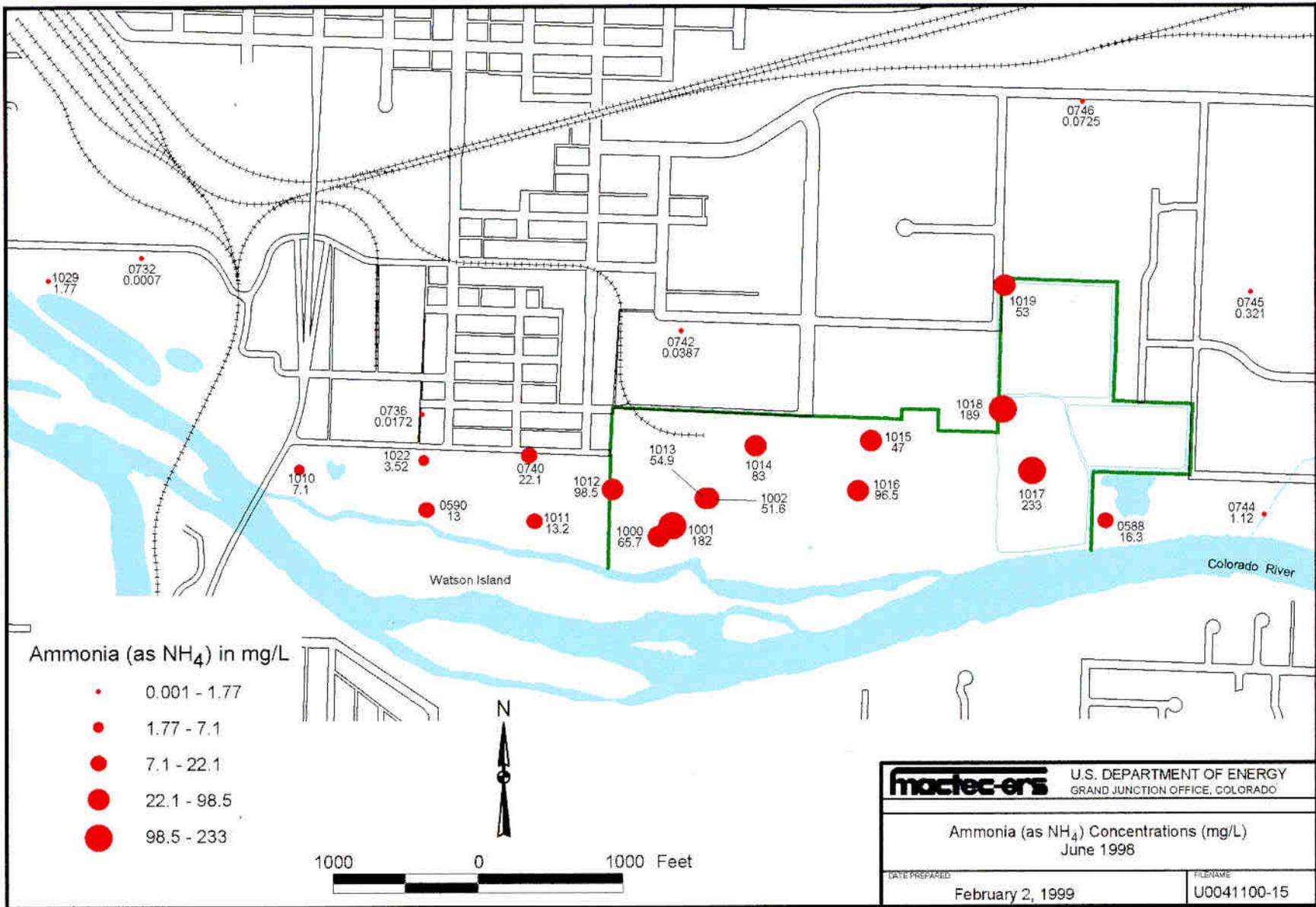


Figure 5-2. Ammonia Concentrations in the Alluvial Aquifer

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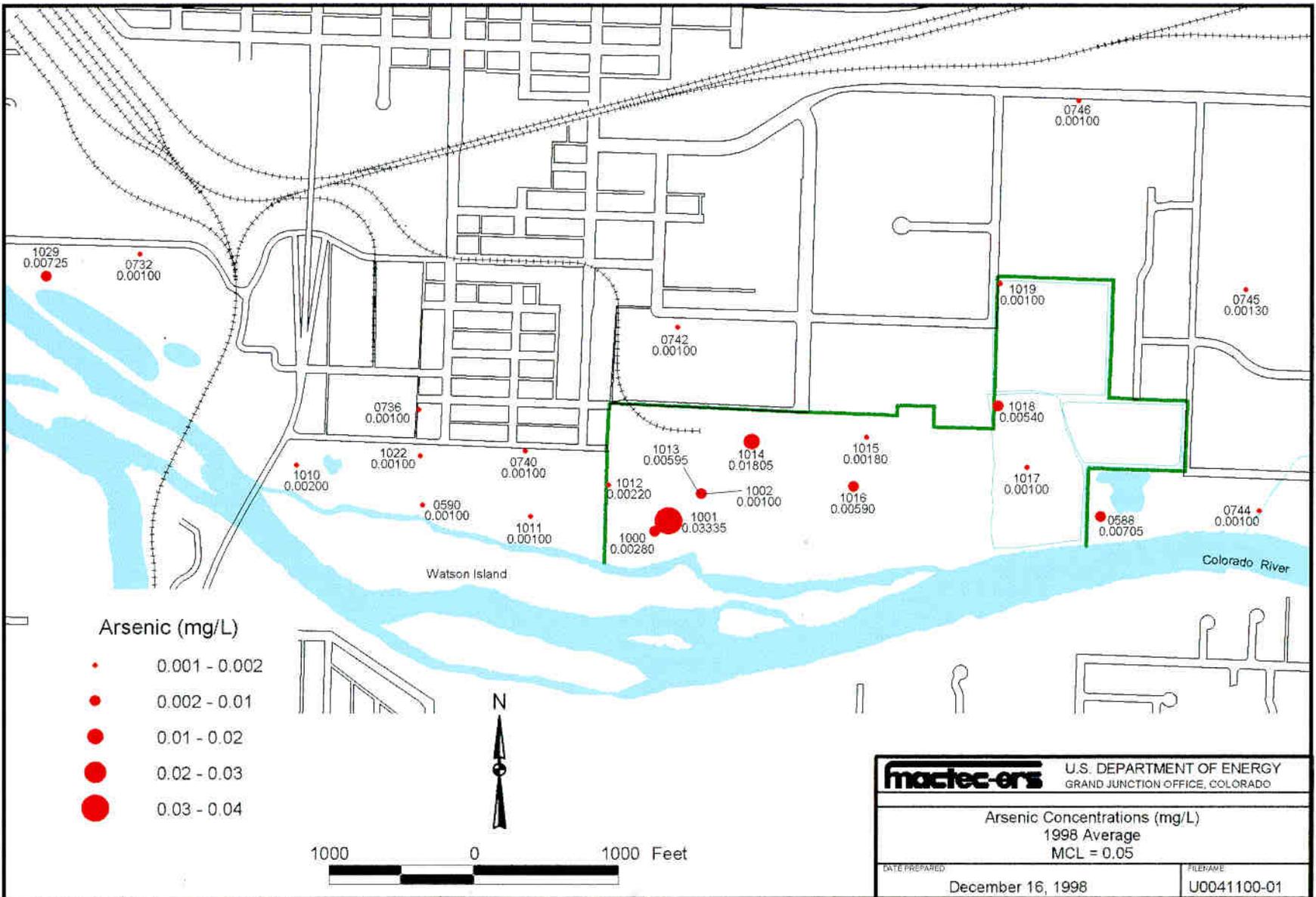
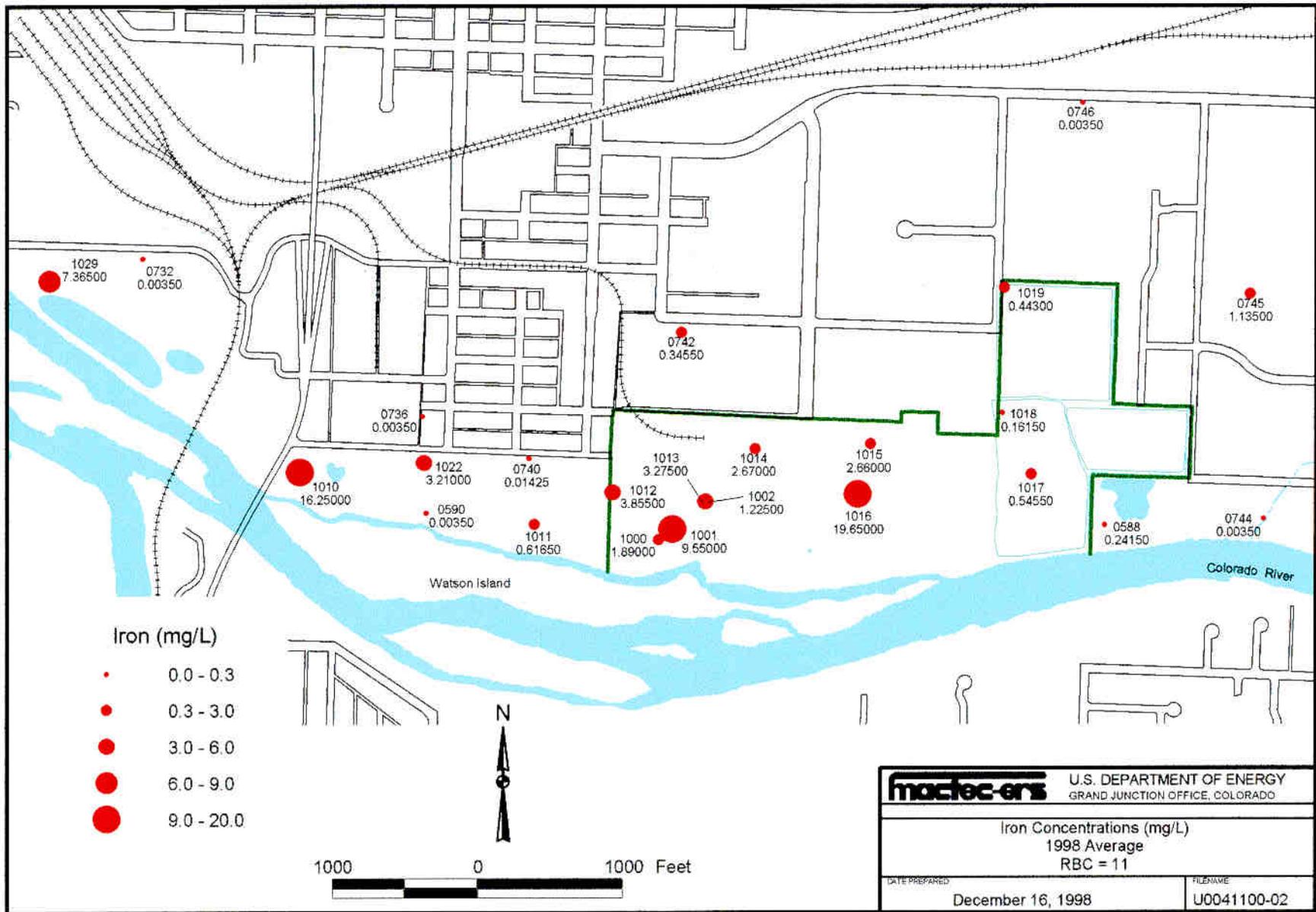


Figure 5-3. Arsenic Concentrations in the Alluvial Aquifer

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macroc-ers		U.S. DEPARTMENT OF ENERGY GRAND JUNCTION OFFICE, COLORADO	
Iron Concentrations (mg/L) 1998 Average RBC = 11			
DATE PREPARED	December 16, 1998		FILENAME
			U0041100-02

Figure 5-4. Iron Concentrations in the Alluvial Aquifer

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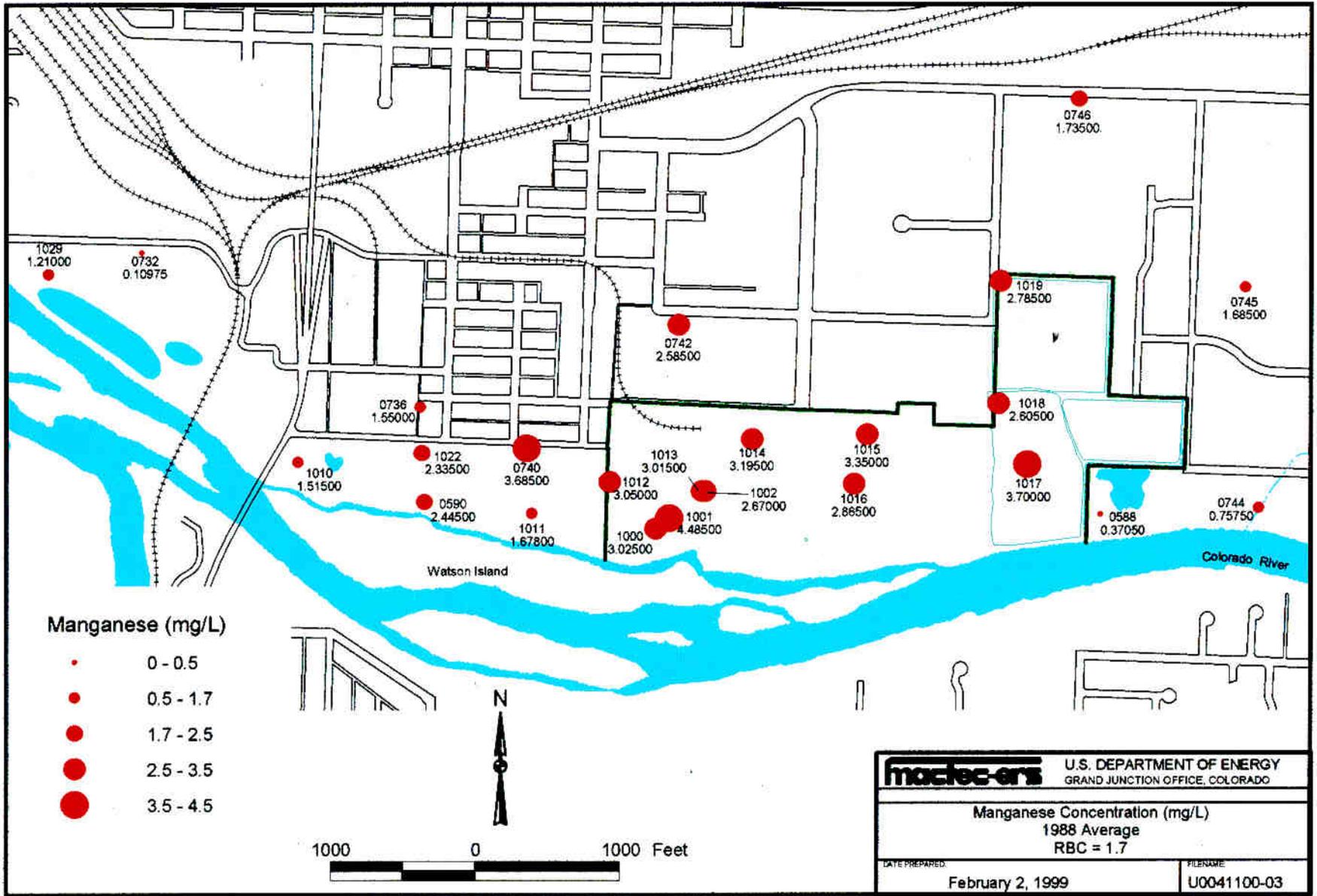


Figure 5-5. Manganese Concentrations in the Alluvial Aquifer

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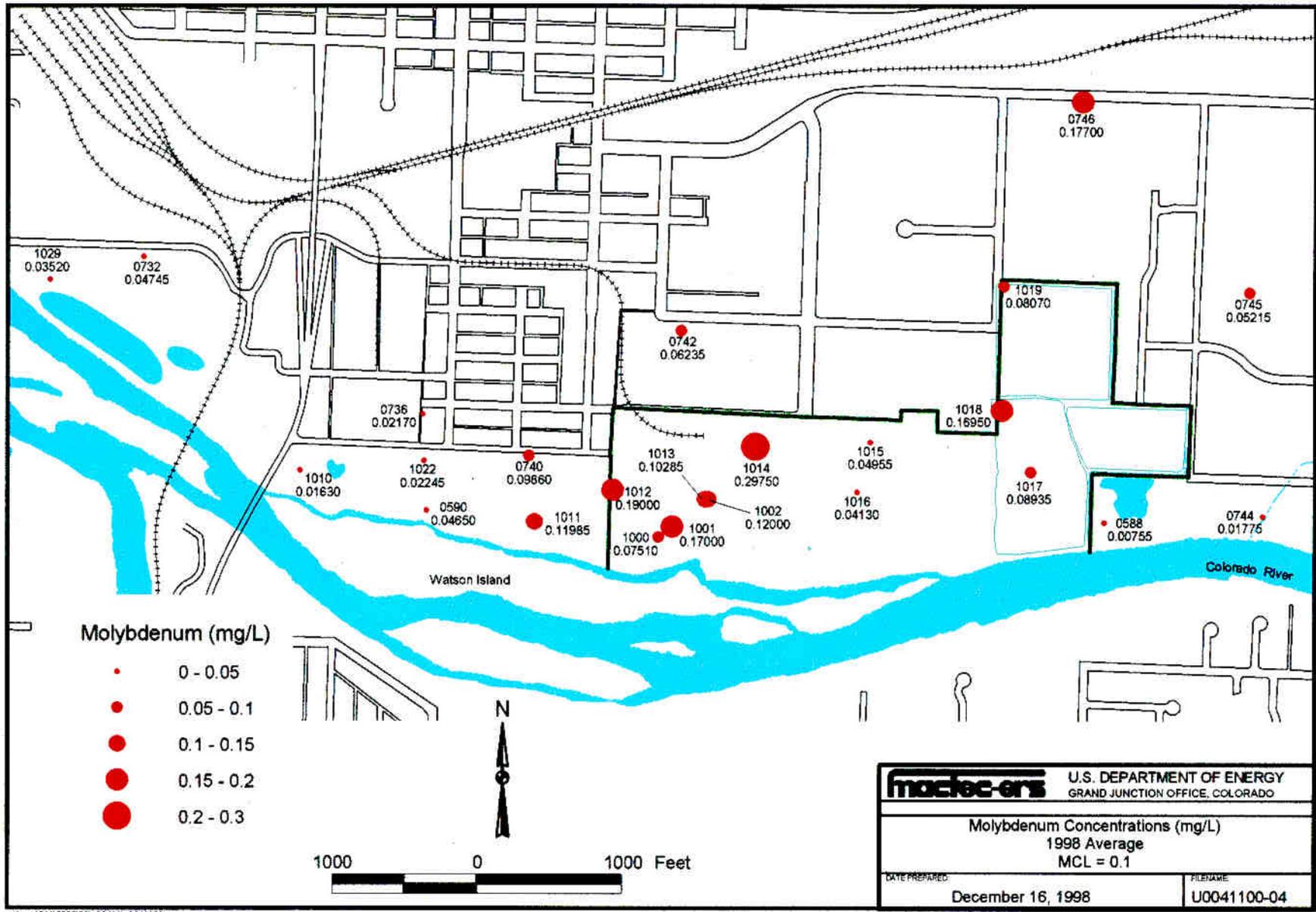


Figure 5-6. Molybdenum Concentrations in the Alluvial Aquifer

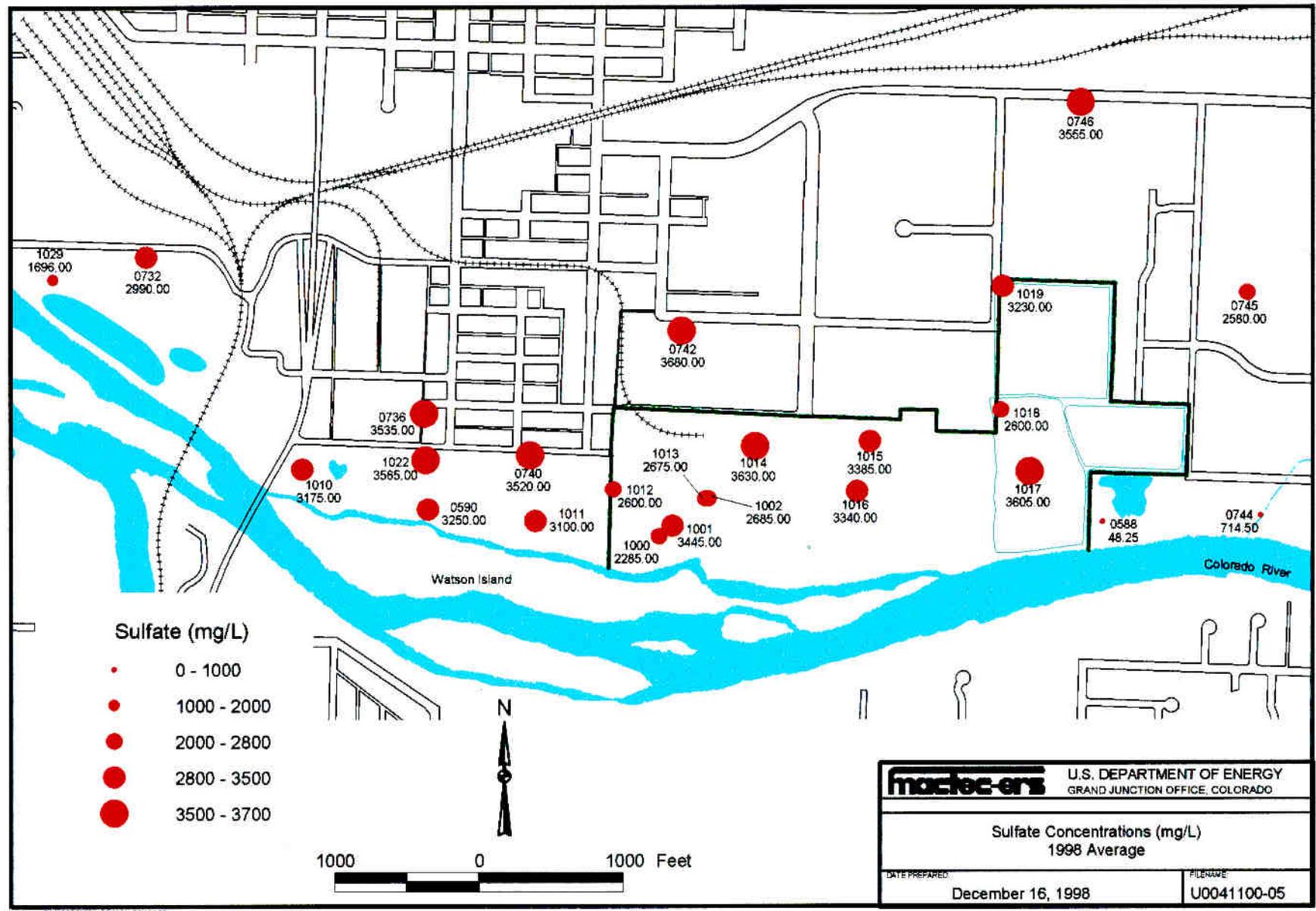


Figure 5-7. Sulfate Concentrations in the Alluvial Aquifer

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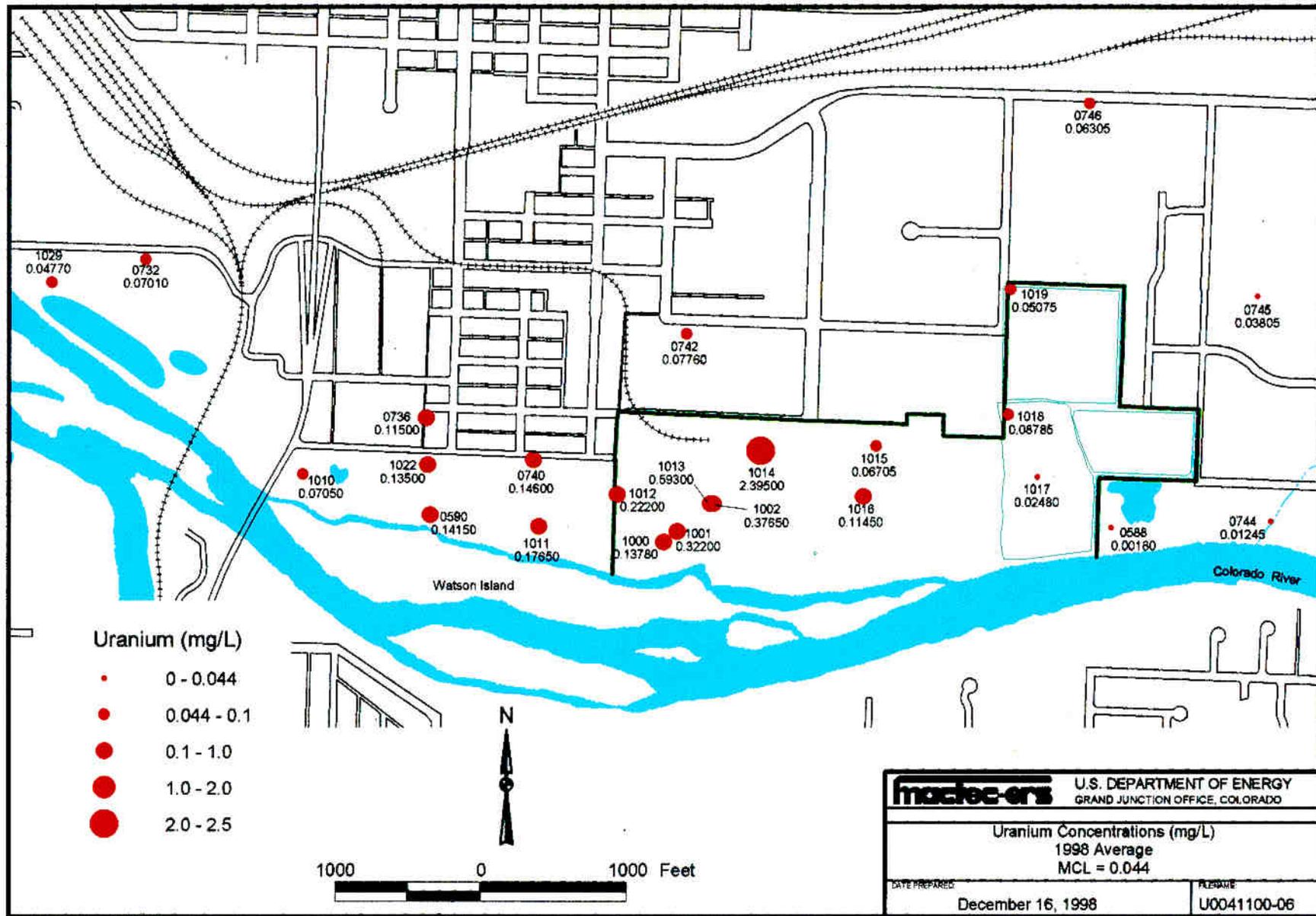
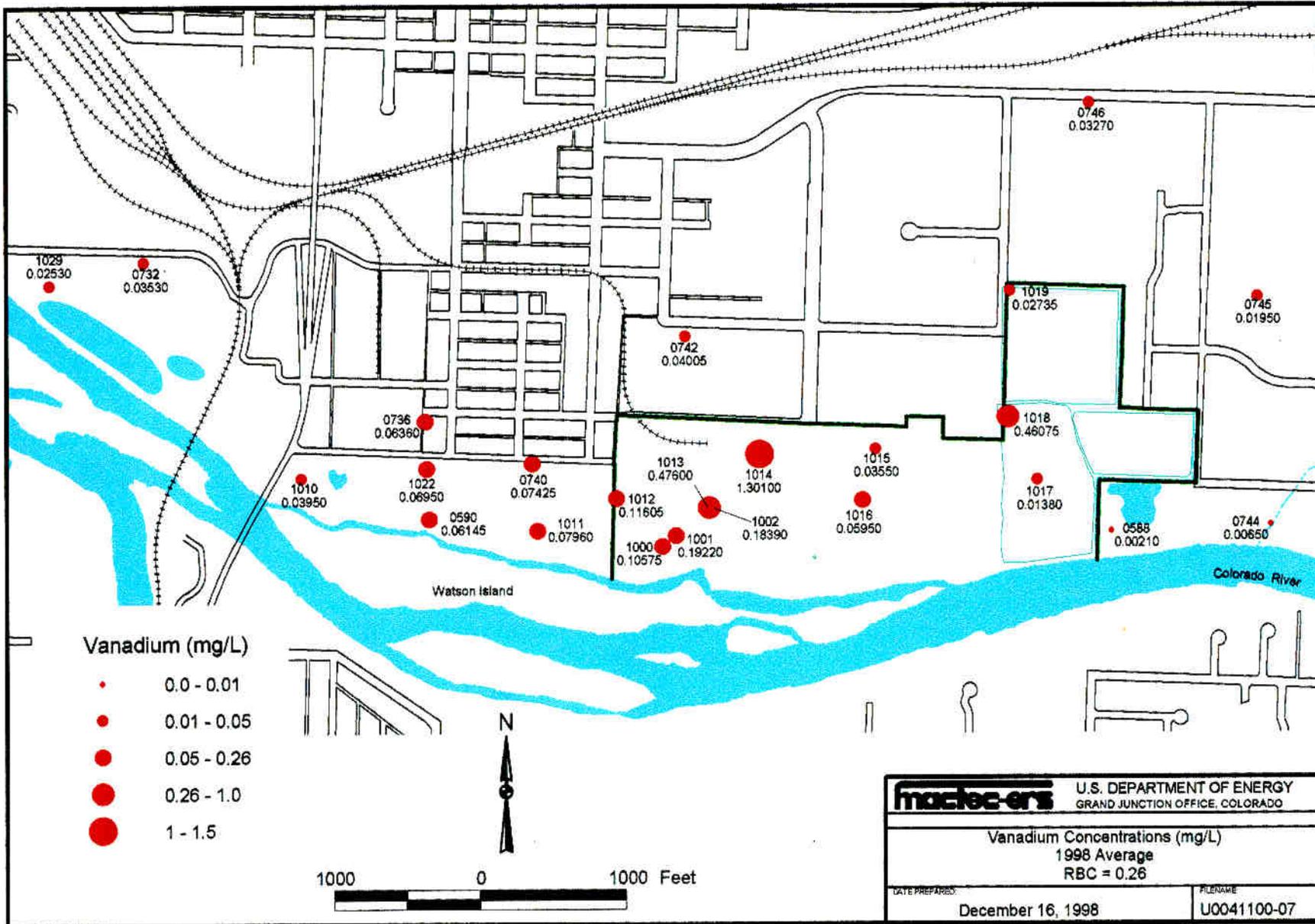


Figure 5-8. Uranium Concentrations in the Alluvial Aquifer

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Figure 5-9. Vanadium Concentrations in the Alluvial Aquifer

the millsite. Ammonium was used in the uranium milling process to neutralize acids used to leach ores in the early processing stage (Merritt 1971). Ammonium concentrations are elevated in downgradient wells to about 5th Street, then decrease to background (0.093 mg/L) beyond this point.

Arsenic. The highest concentrations of arsenic are in on-site wells, though all concentrations are below the MCL of 0.05 mg/L. Concentrations in nearly all the off-site wells, both upgradient and downgradient, are at or near the detection limit of 0.001 mg/L. The lack of significant off-site migration of the arsenic “plume” is consistent with the K_d calculated for arsenic (see Section 4.3.1), which indicated that arsenic should be relatively immobile.

Iron. In general, the most consistently high concentrations of iron are in on-site wells, and the spatial distribution of concentrations displays no well-defined pattern or trend. Downgradient well 1010 has one of the highest concentrations (16.2 mg/L) but is separated from the site by downgradient wells with very low iron concentrations.

Manganese. The most consistently high concentrations of manganese are in on-site wells and in wells directly downgradient of the site. Manganese concentrations generally decrease with distance from the site. However, it is difficult to actually define a “plume” that is attributable to site activities because of the relatively high concentrations of manganese in background wells (the average background concentration is 1.44 mg/L).

Molybdenum. The highest concentrations of molybdenum are from samples collected from on-site wells. A number of wells have concentrations exceeding the MCL of 0.1 mg/L. Off-site, molybdenum concentrations generally decrease, though two background wells have concentrations that exceed the MCL.

Sulfate. Sulfate concentrations show no well-defined pattern. Concentrations in on-site and off-site wells are generally high and exceed the secondary drinking water standard of 250 mg/L at all locations except in well 588.

Uranium. The highest concentrations of uranium are in on-site and downgradient wells. Concentrations in most of these wells exceed the MCL of 0.044 mg/L. Because of the high mobility of uranium predicted by measured K_{ds} (see Section 4.3.1), it is reasonable to infer that wells immediately downgradient of the site are affected by site contamination. However, because of the high background concentrations of uranium (mean of 0.047 mg/L), it is difficult to accurately define the boundary of site-related contamination.

Vanadium. Highest vanadium concentrations are in the on-site wells, although these concentrations vary considerably. Vanadium concentrations generally decrease with distance downgradient. Significant differences in concentration (almost two orders of magnitude) exist between the most contaminated on-site wells and wells located off-site. Based on the high K_{ds} calculated for vanadium, the relative immobility of vanadium is to be expected. Only on-site wells exceed risk-based concentrations for vanadium.

Historical Changes in Ground Water Chemistry

Figures 5–2 through 5–9 are updated plots of figures prepared for the characterization work plan for the site (DOE 1997b), which were based on data collected from sampling events that took

place from 1985 to 1996. Many of the higher contaminant concentrations, particularly for metals, were in some of the earliest samples collected and tended to be from one location (well 584). The 1998 sampling data indicates that many of these contaminant concentrations have decreased to levels below detection or are indistinguishable from background.

A comparison of average values and ranges of COPCs identified in the original SOWP (DOE 1996d) with averages and ranges of the same constituents detected in the 1998 sampling indicates that, qualitatively, nearly all COPCs have decreased in concentration. Only results for uranium and nitrate appear to be inconclusive. However, historical and 1998 data come from different wells, and historical data were collected over a number of years. Therefore, only a qualitative comparison of these data sets is made here.

Time-concentration plots for selected wells and contaminants are shown in Figures 5–10 through 5–17. Data from three sets of wells were examined in an attempt to discern any trends in concentration through time. Wells 590, 736, and 740 are generally downgradient of the site, and 742 is in a former ore-storage area; all have data going back to the early 1980s. These wells were selected to identify changes in the plume through time. Wells 745 and 746 have historically been regarded as upgradient wells and also have data collected as far back as the early 1980s. Wells 1000, 1001, and 1002 are on-site wells; these were installed following surface remediation and have data extending back to early 1995.

The older plume wells (Figures 5–10, 5–12, 5–13, 5–14, 5–15, and 5–16) do not show any clearly consistent upward or downward concentration trends through time. Concentrations show considerable fluctuation from 1990 through 1993, though inflection points for many wells appear to be coincident (though not consistently increasing or decreasing even for the same contaminant). These large fluctuations may be related to changing conditions associated with millsite surface remediation. Excavation of tailings piles and ponds, particularly in areas where the water table is shallow, would be expected to affect ground water chemistry.

A prominent inflection point in the 1992 time frame is present even for background wells. This suggests that changes in concentrations were related to an event more far-reaching than remediation activities.

Post-remediation on-site wells (Figures 5–11 and 5–17) indicate a generally decreasing trend for uranium and molybdenum (two contaminants that can be attributed to site activities). However, the limited range in concentration and the small number of data points available make this conclusion tentative.

Isotopic concentrations of ^{234}U and ^{238}U were measured for one round of samples from background and plume locations. Tables 5–5 and 5–6 show the results of background and plume analyses. Isotopic concentrations of combined ^{234}U and ^{238}U were converted to total uranium in milligrams per liter to compare with the 0.044 mg/L standard (which assumes secular equilibrium between the two isotopes). Ratios of ^{234}U : ^{238}U indicate that the two isotopes are not in equilibrium and that ^{234}U is the dominant radionuclide. No significant difference exists between the mean concentrations in plume and background wells, though the isotopic ratios for plume samples span a wider range. These data also indicate that a lower total elemental uranium standard would be applicable for the Grand Junction site than the 0.044 mg/L to adjust for disequilibrium conditions. An adjusted standard of approximately 0.037 or 0.038 mg/L would be

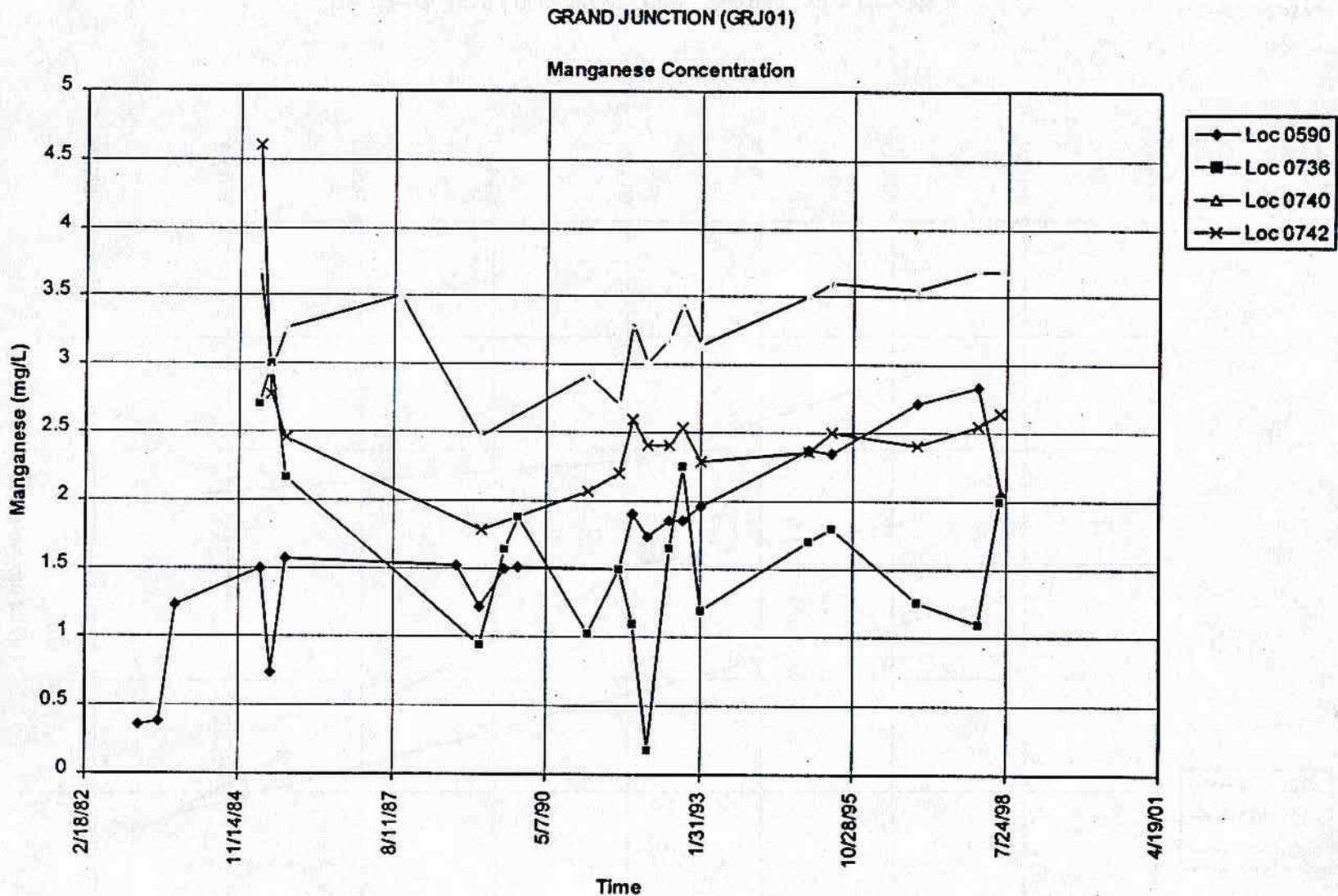


Figure 5-10. Time Concentration Plot—Manganese in Old Wells

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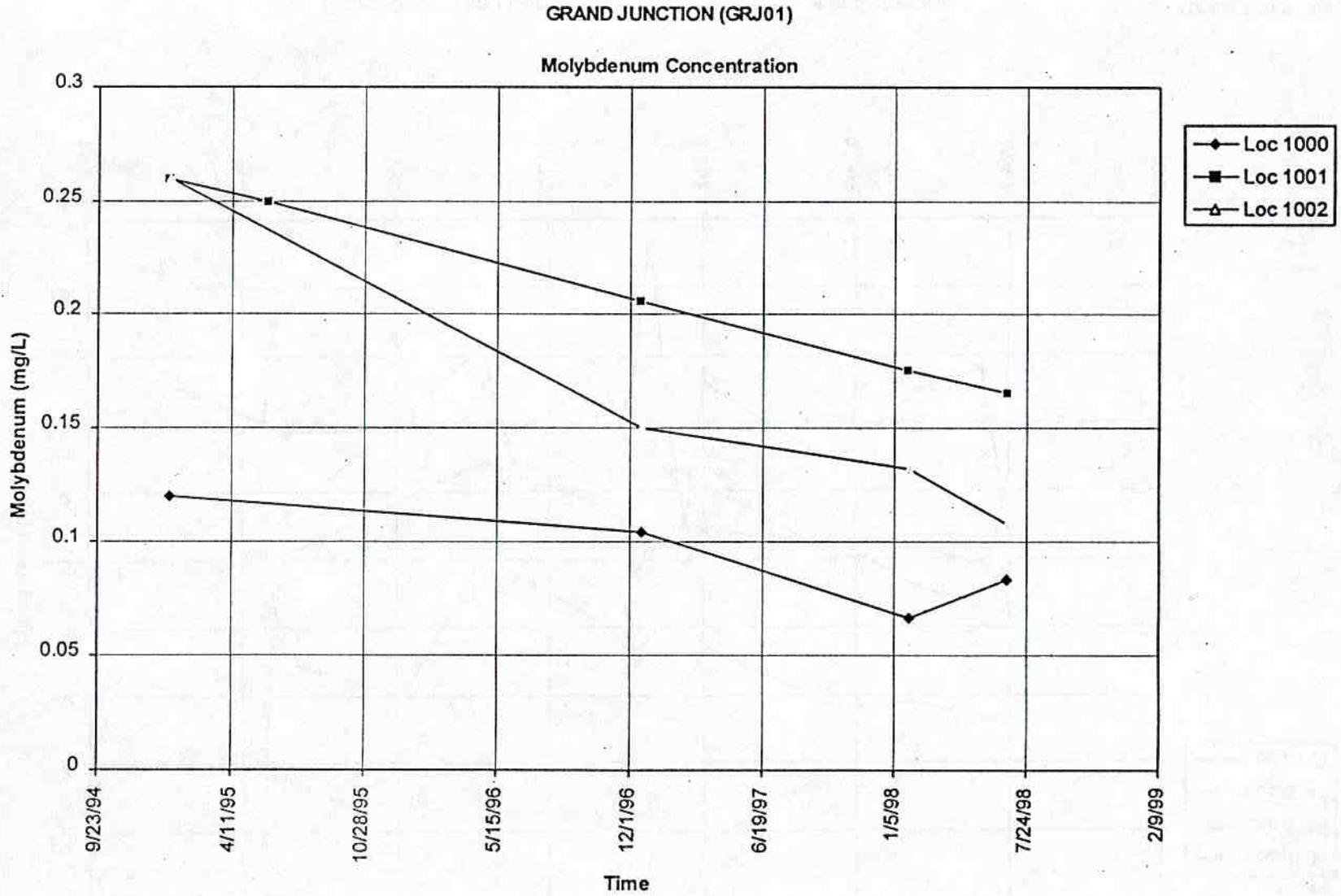


Figure 5-11. Time Concentration Plot—Molybdenum in New Wells

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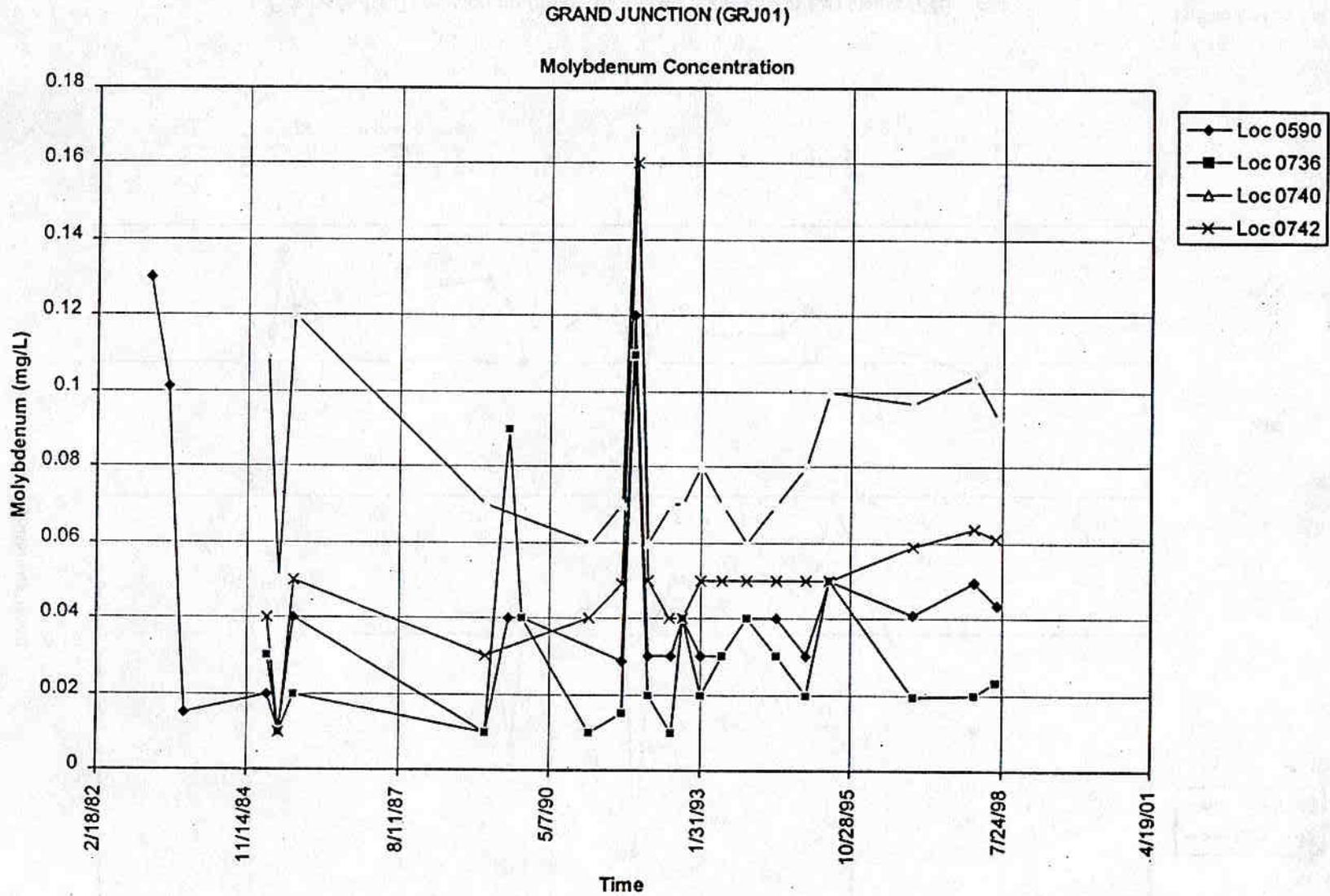


Figure 5-12. Time Concentration Plot—Molybdenum in Old Wells (590, 736, 740, 742)

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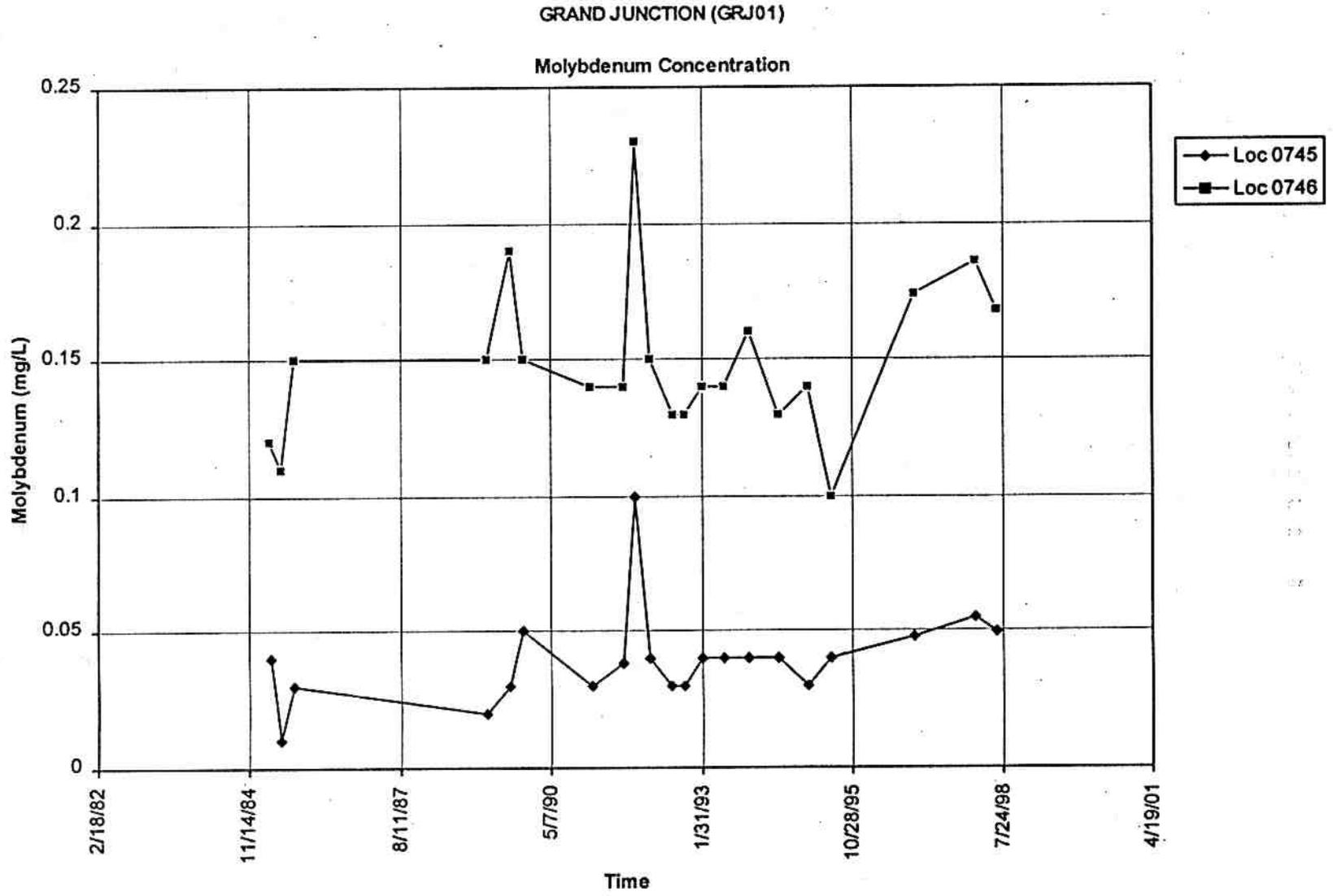
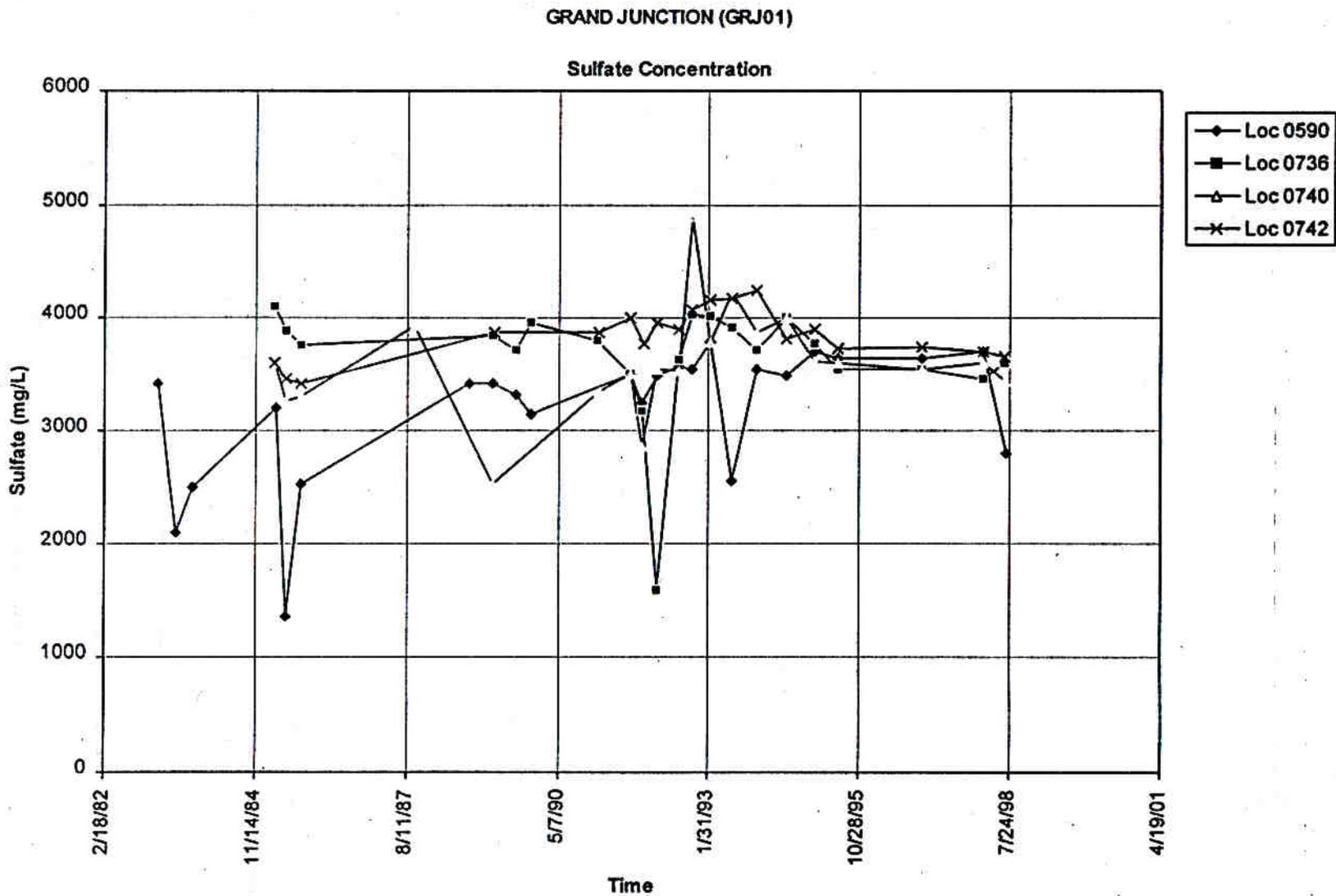


Figure 5-13. Time Concentration Plot—Molybdenum in Old Wells (745, 746)

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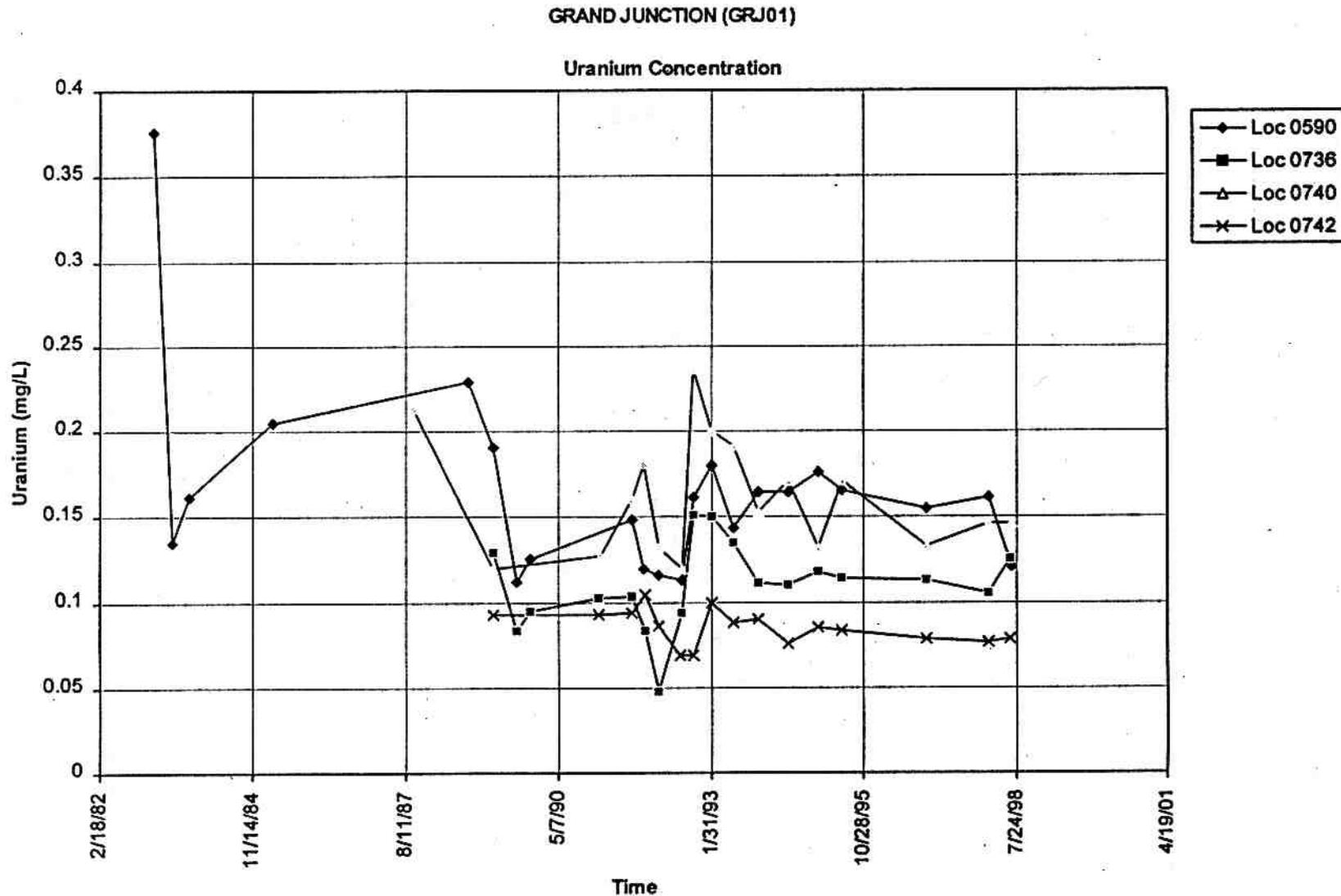


Figure 5-15. Time Concentration Plot—Uranium in Old Wells (590, 736, 740, 742)

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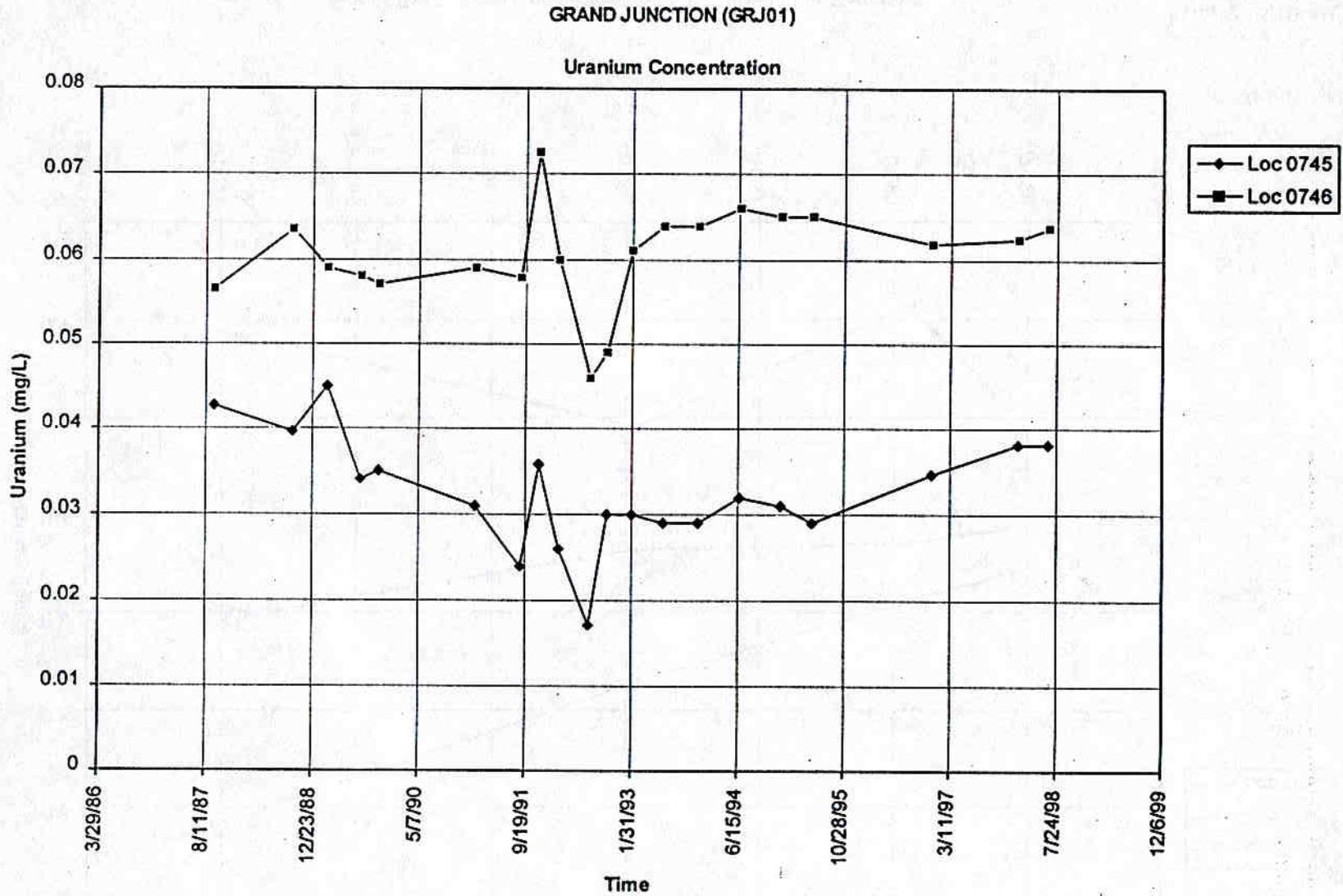


Figure 5-16. Time Concentration Plot—Uranium in Old Wells (745, 746)

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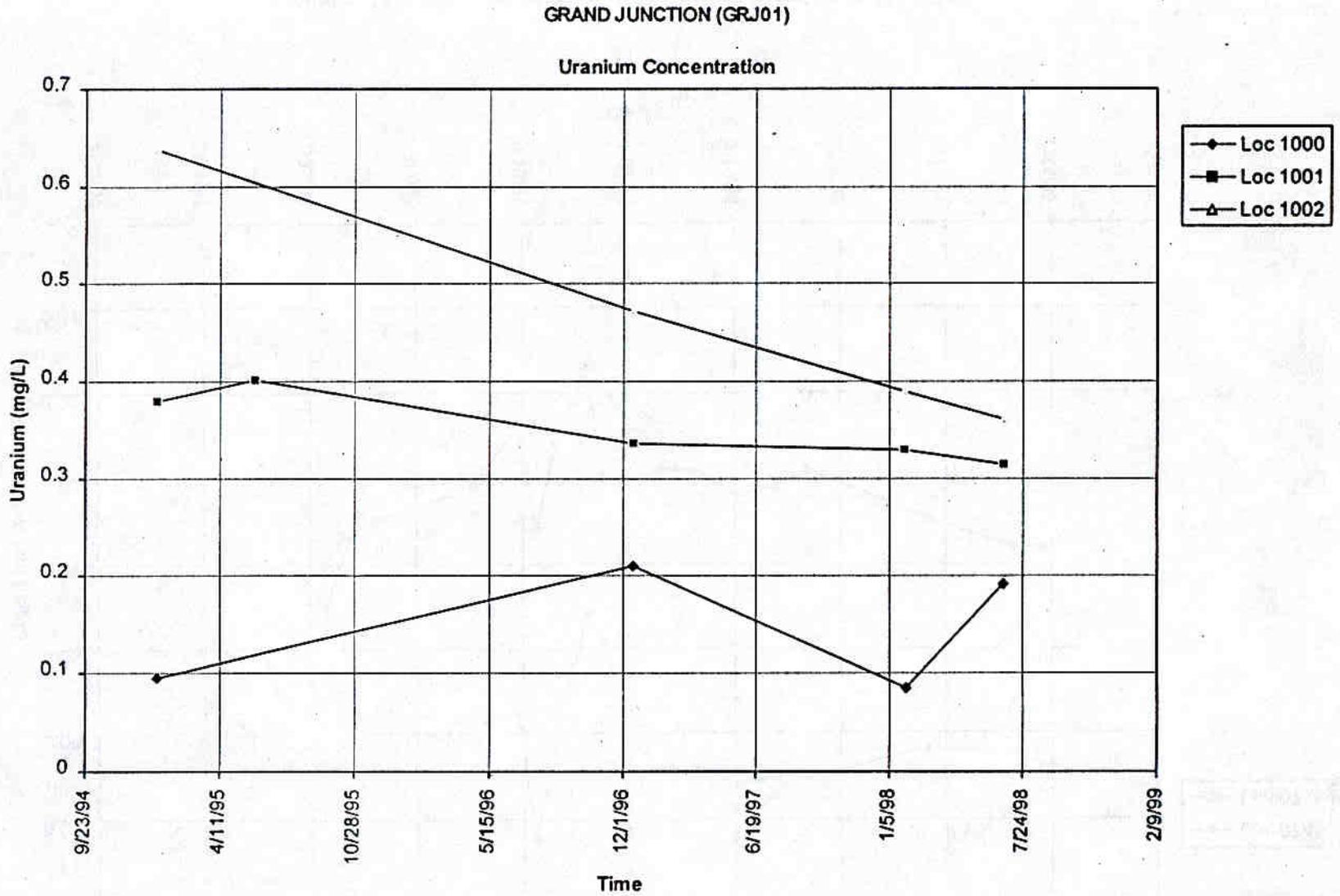


Figure 5-17. Time Concentration Plot—Uranium in New Wells

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more appropriate to account for site-specific uranium concentrations and the higher proportion of ^{234}U .

5.3.4 COPC Fate and Transport

This section presents discussion of the evolution of the contaminated ground water system. Understanding the chemistry of the ground water will aid in making quantitative predictions or assessing general trends to be expected of the migration of the contaminant plume and the fate of contaminated sediments. Geochemical considerations that influence transport modeling and a general discussion of the fate of individual COPCs are also presented. The geochemical considerations presented below, together with knowledge of the milling history and the ground water flow characteristics, indicate that the average contaminant concentrations in the alluvial aquifer, surface water, and surface sediments should decrease over time. However, some areas may show interim increases as constituents migrate before eventual decreases occur.

5.3.4.1 Evolution of Ground Water Geochemistry After Uranium Milling

Because of its importance to regulatory compliance, this discussion focuses on uranium.

The milling process at the Grand Junction site used acids to extract uranium from the ores. The acids produced low pH and oxidizing conditions. Under these conditions, uranium forms a uranyl cation (UO_2^{2+}) that favors uranium partitioning to the aqueous phase. Probably much of this acidic solution was neutralized before it was released from the mill. However, when the mill was operating, remnant uranyl-bearing, acidic solution entered the ground water from tailings pond seepage. The water table would have been mounded at the site due to the elevated flux of water recharging from the ponds. The mounding would have caused the contamination to spread rapidly. Due to the high rate of ground water flow and the chemical conditions that favored partitioning to the aqueous phase, it is likely that much of the plume migration occurred during and shortly after the milling.

As the acidic solutions passed through the alluvial aquifer they interacted with aquifer minerals. Dissolution of carbonate minerals caused addition of carbonate to the aqueous phase and a rise in pH due to consumption of H^+ . Mixing with carbonate-bearing ground water also caused the pH to increase. Reactions with silicate minerals such as feldspars and clays also caused neutralization of the acidic solutions but at a slower rate than reaction with carbonate minerals. The rates of neutralization were probably high for the milling fluids that had pH values less than 2 but decreased as pH increased. It is likely that pH values increased significantly before the milling fluids migrated more than a few hundred feet from the mill ponds. No pH value less than 6.43 is currently measured in the ground water, and the pH values are similar on site, upgradient, and downgradient.

Uranium chemistry evolved as contaminated, low-pH fluids entered the ground water and became neutralized. Dissolved carbonate has a strong tendency to form aqueous complexes with uranium. The dominance of the uranyl ion in the milling solutions was replaced by uranyl dicarbonate ions [$\text{UO}_2(\text{CO}_3)_2^{2-}$]. Uranyl dicarbonate currently dominates the dissolved uranium distribution in the alluvial ground water both at the site and in the upgradient area. As indicated by the low distribution coefficients (about 1 mL/g), uranium is still relatively mobile in the ground water. Without carbonate complexing, the mobility would be much lower.

Table 5-5. Isotopic Uranium Concentrations—Background Locations

Uranium Disequilibrium at Grand Junction - Background Locations										
Easting	Northing	Location	Total U (mg/L) Lab	U-234 (pCi/L) Lab	U-234 (mg/L) Calculated	U-238 (pCi/L) Lab	U-238 (mg/L) Calculated	U-234 & 238 (pCi/L) Lab	U-234 & 238 (mg/L) Calculated	Ratio pCi/L 234/238
		715	0.0602	34.9	0.00000560	20.1	0.060	55	0.060	1.74
		713	0.0652	35.2	0.00000565	21.8	0.065	57	0.065	1.61
		1020	0.0566	29.2	0.00000469	18.9	0.056	48.1	0.056	1.54
		1023	0.0468	23.8	0.00000382	15.6	0.047	39.4	0.047	1.53
		1025	0.0436	21.5	0.00000345	14.5	0.043	36	0.043	1.48
		745	0.0381	18.8	0.00000302	12.7	0.038	31.5	0.038	1.48
		1021	0.0305	14.9	0.00000239	10.2	0.030	25.1	0.030	1.46
									average	1.55
		Disequilibrium factor	Ratio pCi/L (234/238)	U-234 MCL (pCi/L)	U-234 MCL (mg/L)	U-238 MCL (pCi/L)	U-238 MCL (mg/L)	U-234 & 238 (pCi/L)	U-234 & 238 (mg/L)	
example; assumes equilibrium at std			1.0	15.0	0.00000241	15.0	0.045	30	0.045	
actual average			1.55	18.2	0.00000293	11.8	0.035	30	0.035	

Table 5-6. Isotopic Uranium Concentrations—Plume Locations

Uranium Disequilibrium at Grand Junction - Plume Locations

Easting	Northing	Location	Total U (mg/L) Lab	U-234 (pCi/L) Lab	U-234 (mg/L) Calculated	U-238 (pCi/L) Lab	U-238 (mg/L) Calculated	U-234 & 238 (pCi/L) Lab	U-234 & 238 (mg/L) Calculated	Ratio pCi/L 234/238
		1015	0.0641	37.8	0.00000607	21.4	0.064	59.2	0.064	1.77
		1017	0.0241	13.2	0.00000212	8.1	0.024	21.3	0.024	1.63
		1019	0.0486	25.7	0.00000412	16.2	0.048	41.9	0.048	1.59
		736	0.105	49	0.00000786	35.2	0.105	84.2	0.105	1.39
		1018	0.0862	39.1	0.00000627	28.8	0.086	67.9	0.086	1.36
		1010	0.0637	25.4	0.00000408	21.3	0.064	46.7	0.064	1.19
		1022	0.132	52.5	0.00000843	44.2	0.132	96.7	0.132	1.19
		740	0.146	57.3	0.00000920	48.7	0.146	106	0.146	1.18
		590	0.162	62.6	0.00001005	54.1	0.162	116.7	0.162	1.16
		1012	0.22	84.7	0.00001359	73.5	0.220	158.2	0.220	1.15
		1016	0.113	42.2	0.00000677	37.6	0.112	79.8	0.112	1.12
		1011	0.199	73.5	0.00001180	66.5	0.199	140	0.199	1.11
		1013	0.604	220	0.00003531	202	0.604	422	0.604	1.09
		1000	0.0816	30.6	0.00000491	28.2	0.084	58.8	0.084	1.09
		1001	0.33	115	0.00001845	110	0.329	225	0.329	1.05
		1002	0.391	136	0.00002183	131	0.392	267	0.392	1.04
		1014	2.5	833	0.00013368	835	2.496	1668	2.496	1.00
								average		1.24
		Disequilibrium factor	Ratio pCi/L (234/238)	U-234 MCL (pCi/L)	U-234 MCL (mg/L)	U-238 MCL (pCi/L)	U-238 MCL (mg/L)	U-234 & 238 (pCi/L)	U-234 & 238 (mg/L)	
		example; assumes equilibrium at std	1.0	15.0	0.00000241	15.0	0.045	30	0.045	
		actual average	1.24	16.6	0.00000267	13.4	0.040	30	0.040	

After the mill closed, the infiltration of contaminated processing fluids ceased, which significantly reduced the amount of contaminants entering the ground water. At that time the only contribution to ground water contamination was percolation of water through the tailings. The percolating water was a combination of atmospheric precipitation and water applied to irrigate vegetation used to stabilize the tailings. During this period, some of the tailings pores probably still contained residual low-pH fluids. As water percolated through the tailings, these contaminated low-pH fluids were gradually swept into the ground water. After removal of the tailings, the flux of contamination to ground water was essentially eliminated. As indicated by the soil-leaching tests, however, there is still some leachable uranium in the subpile soils. The contribution of contaminants from these soils is much less than from the former tailings. Residual uranium is also present in the aquifer solids and is gradually being leached out as cleaner water passes through.

The major-ion chemistry of the alluvial ground water at the millsite is similar to that of the upgradient area, as indicated by their similar locations on a Piper diagram (Figures 4–5 and 4–6). The chemical composition of the alluvial aquifer system at the millsite is apparently dominated by the same factors (e.g., interaction with the aquifer solids, irrigation practices, recharge and evaporation rates) that control its composition in the upgradient area. The entire alluvial aquifer is nearly at equilibrium with calcite and gypsum, indicating that these minerals are partially controlling the major-ion composition.

5.3.4.2 Fate and Transport of Individual COPCs

As contaminated ground water migrates through soils and rocks, some of the contaminants transfer between the solid and liquid phases. This phenomenon causes the contaminants to travel at a slower rate than the average ground water velocity. The chemical processes that cause this retardation include adsorption, absorption, precipitation, diffusion into immobile porosity, transfer to vapor phases, and accumulation in plants. Although it is generally not possible to differentiate among these processes, for many aquifer systems a bulk parameter (the distribution coefficient, or K_d) has been used with some success to describe the retardation of contaminant migration. Most numerical ground water models use the K_d concept to simulate contaminant transport. Thus, a laboratory study was conducted during this investigation to determine K_d values applicable to the alluvial aquifer.

Distribution coefficients (K_{ds}) were determined for the regulated COPCs (As, Cd, Mo, and U). The K_d value is a measure of the degree of chemical interaction between the dissolved component and the aquifer solids. High values of K_d indicate more partitioning to the solid phases. K_d values give no direct indication of the chemical mechanisms responsible for the partitioning.

To use K_d values for ground water transport modeling, the following assumptions must be made: (1) the 24-hour shake time is sufficient to bring the system to chemical equilibrium, (2) the modeled system is always in chemical equilibrium, (3) an adequate portrayal of the areal and vertical distributions of K_d values is manifested in the model domain, (4) K_d values do not vary within the range of major-ion chemistry or pH values present (or expected) in the ground water, (5) processes such as mineral precipitation or preferential extraction by plant roots do not occur, and (6) K_d values do not vary with contaminant concentrations present in the ground water.

Some studies have shown that K_d values decrease as the concentration of adsorbate increases (assumption 6). At low concentrations this effect is usually minimal; that is, for low contaminant concentrations the adsorption isotherm is usually linear. If high concentrations are present a nonlinear isotherm such as the Freundlich isotherm is required for more accurate simulations. Although the effect of nonlinearity of the isotherm is likely to exert only a small effect on plume migration compared to other factors (such as aquifer heterogeneity, dispersion, ground water flow velocities, or retardation by mechanisms other than adsorption), an isotherm for uranium was measured. Within experimental uncertainties the isotherm is linear, supporting the use of a K_d for transport modeling. Because other COPCs are present at lower concentrations than uranium, it is reasonable to use a K_d approach as a first approximation to simulate plume migration.

Mineral precipitation can occur if concentrations of the dissolved components increase to saturation. If COPCs transfer to or from the solid phases by precipitation/dissolution, the K_d modeling approach is unlikely to produce a realistic simulation of plume migration. Therefore, it is useful to examine conditions that may cause mineral precipitation. It was determined that calcite and gypsum are nearly at equilibrium with the aquifer. These minerals in part control the concentrations of Ca, HCO_3^- , and SO_4^{2-} , and the pH in the aquifer. Some of the COPCs, including uranium, will partition somewhat into calcite.

Although it is likely that sorption is the predominant retardation mechanism for the COPCs, other mechanisms may control migration under specific circumstances. All the COPCs except fluoride are sensitive to oxidation-reduction changes. A general discussion of retardation mechanisms that may exert control on the specific COPCs (As, Cd, Co, F, Fe, Mn, Mo, Ni, NO_3 , Se, SO_4 , U, V, and Zn) follows.

Arsenic. Arsenic occurs in ground water predominantly in two oxidation states: arsenite (As^{3+}) and arsenate (As^{5+}). The monovalent species H_2AsO_4^- predominates between about pH 3 and 7, and the divalent species HAsO_4^{2-} dominates at higher pH. Some metal arsenates have low solubilities, which may control arsenic concentrations in ground water. In particular, arsenic is able to coprecipitate with ferric iron. At low oxidation states, arsenic can precipitate as native arsenic metal.

Adsorption to alluvial aquifer mineral grains, which are mostly quartz, feldspar, and clay, is expected to be relatively minor unless the grains have oxide or oxyhydroxide coatings. Arsenic, however, is known to adsorb to ferric oxyhydroxides in relatively high concentrations (Dzombak and Morel 1990). Arsenic adsorption would increase in those portions of the aquifer that have higher concentrations of iron and manganese oxides.

Cadmium. Cadmium is present in ground water as the uncomplexed cation Cd^{2+} or complexed with an anion (e.g., CdSO_4^0). Cadmium readily substitutes for Ca in carbonate minerals. Coprecipitation with calcite ($[\text{Ca}, \text{Cd}]\text{CO}_3$) is the most likely mechanism for removal of Cd from the alluvial ground water. Since the aquifer is saturated with calcite, this mechanism is likely to keep Cd concentrations low. Cadmium can precipitate as Greenockite (CdS) under sulfate-reducing conditions. Cadmium will also effectively adsorb to ferric oxyhydroxides.

Cobalt. Cobalt occurs in the 2+ and 3+ oxidation states in aqueous solution and readily coprecipitates with ferric iron and manganese oxyhydroxides. This coprecipitation is most likely

the limiting mechanism for Co transport in the alluvial aquifer. Under sulfate-reducing conditions, Co can form CoS. Cobalt will also adsorb to ferric oxyhydroxides.

Fluoride. Fluoride exists mainly as the uncomplexed F^- in ground water. It is likely that the F^- concentrations in the alluvial aquifer are too low to form minerals; however, with high concentrations of Ca^{2+} , fluoride can form the mineral fluorite (CaF_2). Although some ion exchange may occur with the clay minerals in the aquifer, most of the fluoride probably remains in solution as a conserved species.

Iron. Iron occurs in two oxidation states in ground water: ferrous (Fe^{2+}) and ferric (Fe^{3+}). At the pH values in the alluvial aquifer, transport occurs as ferrous iron, which will complex with aqueous anions such as chloride (e.g., $FeCl_2^0$). Ferric iron forms insoluble oxyhydroxide precipitates. Thus, oxidizing conditions in the aquifer tend to immobilize iron. Ferric oxyhydroxides are believed to migrate in aquifers in colloidal suspension; however, there is limited evidence that this is a dominant transport mechanism. Reducing conditions in the aquifer will mobilize iron through dissolution of the oxyhydroxide phases. Ferric oxyhydroxides are capable of adsorbing many of the COPCs; thus, the iron cycle is likely to be important in understanding the migration behavior of many of these contaminants. Under sulfate-reducing conditions, iron can form insoluble sulfide minerals such as FeS and FeS_2 .

Manganese. Manganese occurs in the 2+ and 4+ oxidation states in the alluvial aquifer. In the dissolved state it is present mainly as the Mn^{2+} ion. Its redox chemistry is similar to that of iron in that oxidation will promote the precipitation of hydroxide or oxide minerals. Manganese will substitute readily for Ca in calcite. Because the alluvial aquifer is saturated with calcite, this mechanism could be important at the Grand Junction site. Like iron, manganese minerals are effective scavengers of many COPCs.

Molybdenum. Molybdenum occurs naturally in the 4+ and a 6+ oxidation states, but the 6+ state is most likely present in the Grand Junction ground water because of the high oxidation potential. Dissolved molybdenum species are dominated by the molybdate anion (MoO_4^{2-}) in the pH range of interest. At low pH, $HMoO_4^-$ or $H_2MoO_4^0$ may become important. High concentrations of sodium and calcium can form sodium and calcium molybdate complexes (e.g., $NaMoO_4^-$ and $Ca MoO_4^0$).

Because of the low concentrations in ground water at the site, no molybdenum minerals are expected to form unless reducing conditions are present in the aquifer. At low redox states, Mo can precipitate as ferrous molybdate ($FeMoO_4$) or under sulfate-reducing conditions as molybdenite (MoS_2). Adsorption to alluvial aquifer mineral grains, which are mostly quartz, feldspar, and clay, is expected to be relatively minor unless the grains have oxide or oxyhydroxide coatings. Molybdenum, is known to adsorb to ferric oxyhydroxides in relatively high concentrations (Morrison and Spangler 1993). Molybdenum adsorption would increase in those portions of the aquifer that have higher concentrations of iron and manganese oxides.

Nickel. Nickel is present in ground water mainly as the uncomplexed Ni^{2+} species. Nickel can coprecipitate with calcite and form sulfide minerals under sulfate-reducing conditions. Nickel can also adsorb to ferric oxyhydroxides.

Nitrate. Nitrate (NO_3^-) does not complex significantly with other ions under ground water conditions. It is transported without significant interaction with the rock matrix. If appropriate nitrate-reducing microbiota and nutrients are present, nitrate can undergo reduction to nitrogen

gas (N_2). Significant denitrification is not expected to occur without a suitable organic nutritional source such as acetate. Therefore, nitrate probably transports nearly conservatively through the aquifer. Concentrations decrease by mixing with other ground water and by dispersion. If the aquifer is within about 50 feet of the ground surface, plants will remove nitrate from the ground water.

Selenium. Aqueous selenium occurs predominately as selenate (SeO_4^{2-}) or selenite (SeO_3^{2-}); selenate is probably favored under the oxidized conditions of the alluvial aquifer. Concentrations of selenium are not high enough to precipitate selenium minerals. Selenium can substitute for sulfur in sulfur-bearing minerals and can precipitate as ferroselite ($FeSe_2$) or coprecipitate with pyrite (FeS_2) under reducing conditions. Plants, such as the genus *Astragalus*, common to the Grand Junction area, can preferentially utilize Se if the ground water is shallow.

Selenium is not likely to adsorb appreciably to the mineral grains. Both selenite and selenate, however, will adsorb to ferric oxyhydroxides (Dzombak and Morel 1990). Selenate adsorption requires low pH and is not likely to be significant in the alluvial aquifer. Thus, selenium is likely to remain in solution with concentration gradients developed mainly by advection and dispersion.

Sulfate. In alluvial ground water, dissolved sulfur occurs mainly as the unassociated sulfate ion (SO_4^{2-}). The only mechanism likely to partition significant amounts of sulfate into the solid phase is the precipitation of gypsum. The amount that precipitates is likely to be relatively minor compared to the high concentrations of sulfate in solution. Therefore, most of the concentration gradient is produced by mixing with other ground water and dispersion. Under reducing conditions brought about by microbial stimulation, sulfate can form sulfide minerals.

Uranium. Most naturally occurring uranium is either in the uranyl (6+) or uranous (4+) oxidation state. The uranyl form is predominant in oxidized ground water. The uranyl ion forms strong aqueous complexes with carbonate, and uranyl dicarbonate [$UO_2(CO_3)_2^{2-}$] is the dominant aqueous uranium species at the Grand Junction site.

Uranyl concentrations in the alluvial aquifer are too low to form uranium minerals. Uranous minerals would precipitate if the aquifer were to become reduced. Adsorption of uranyl to mineral grains in the alluvial aquifer is likely to be insignificant. However, uranyl is known to adsorb to ferric oxyhydroxide in relatively high concentrations (Morrison et al. 1995). It is likely that adsorption to ferric or manganese minerals is the principal mode that retards uranium migration at the site.

Vanadium. Vanadium exists in the 3+ and 5+ oxidation states in aquifers. Dissolved vanadium exists mainly as vanadate (VO_4^{3-}) oxyanions such as $H_2VO_4^-$. Vanadate can combine with cations to form minerals such as $Ca_3(VO_4)_2$. Under reducing conditions it forms insoluble minerals such as paramontroseite (V_2O_4). Vanadate adsorbs effectively on ferric oxyhydroxides. Vanadium can combine with uranium to form low-solubility uranyl vanadates such as carnotite [$K_2(UO_2)_2(VO_4)_2$].

Zinc. Zinc is present in ground water as Zn^{2+} and readily complexes with many anions such as chloride. Zinc substitutes for Ca^{2+} in calcite, which is a likely retardation mechanism in the alluvial aquifer. Under sulfate-reducing conditions, zinc forms sphalerite (ZnS). Zinc also effectively adsorbs on ferric oxyhydroxides.

5.4 Ecological Risk Assessment Model

The purpose of the ecological risk assessment (ERA) is to identify and characterize adverse effects, if any, on the ecosystem at the Grand Junction site. For ecological risks to occur at the Grand Junction site, pathways must exist for exposure of biological receptors to biotic and abiotic media contaminated by ground water. The Grand Junction ERA is based on EPA guidance provided in *Guidelines for Ecological Risk Assessment* (EPA 1998b) and *Framework for Ecological Risk Assessment* (EPA 1992). A screening-level assessment of ecological risks at the site, the BLRA (DOE 1995a), evaluated COPCs, potential pathways, receptors, and adverse effects. This section presents a conceptual ecological risk model. Section 6.2 is an update of the BLRA based on this conceptual model and the results of the 1998 field investigations (Section 4.4). The risk assessment methodology and calculations are presented in Appendix I.

Conceptual models for ecological risk assessments are developed from information about stressors, potential exposure, and predicted effects on an ecological entity (the assessment endpoint). Conceptual models consist of two principal components (EPA 1998b):

- A set of risk hypotheses that describe predicted relationships among stressor, exposure, and assessment endpoint response, along with the rationale for their selection.
- A diagram that illustrates the relationships presented in the risk hypotheses.

5.4.1 Risk Hypothesis

Milling operations at the Grand Junction site have resulted in low levels of ground water contamination. Hydrogeologic information regarding plume migration suggests that contamination might be present in the Colorado River adjacent to and downgradient of the Grand Junction site. This could result in contaminant exposure directly or indirectly to wildlife and plant receptors that use or inhabit the site. [Figure 5–18](#) illustrates current and potential exposure pathways based on all the available data.

An exposure pathway is the mechanism by which a contaminant in an environmental medium (i.e., the source) contacts an ecological receptor. A complete exposure pathway includes

- Contaminant source
- Release mechanism that allows contaminants to become mobile or accessible
- Transport mechanism that moves contaminants away from the release
- Ecological receptor
- Route of exposure (e.g., dermal or direct contact, inhalation, or ingestion).

Ecological receptors that could potentially be exposed to COPCs were identified in the BLRA (DOE 1995a) and included mammalian and avian species. A food web for the Grand Junction site ([Figure 5–19](#)) illustrates the significant dietary interactions between the terrestrial and aquatic receptors.

- The food web also depicts the major trophic-level interactions and describes nutrient flow and transfer of matter and energy through these levels. It was developed from the species lists and consideration of the exposure pathways. The food web diagram was used to portray potential

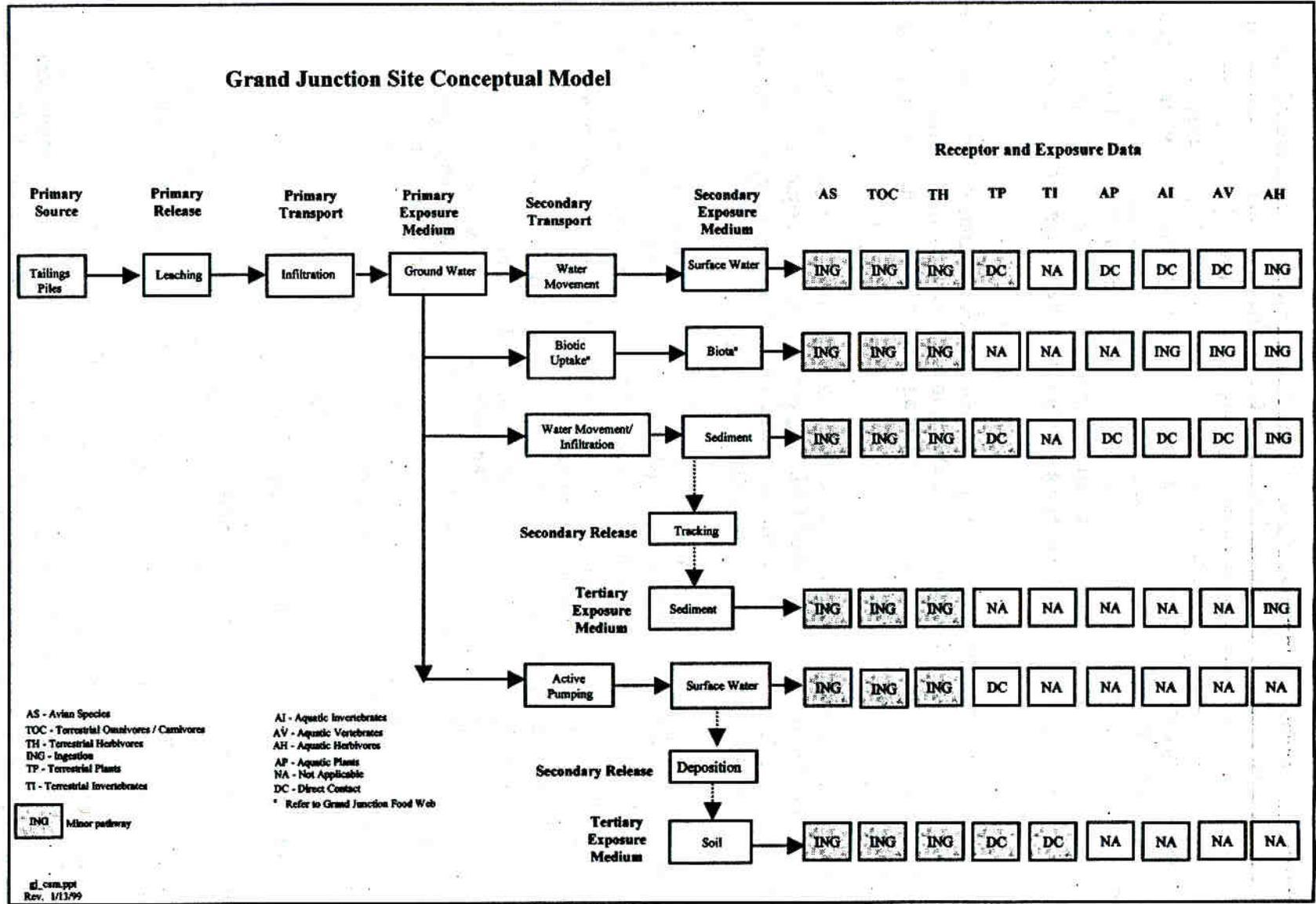


Figure 5-18. Grand Junction Site Conceptual Model

habitat at the site is a storm-water discharge canal on the western property boundary. Consequently, surface water ingestion was not evaluated for the terrestrial habitat.

The riparian and aquatic habitats associated with the Colorado River at the Grand Junction site represent the areas of significant potential exposure. Contaminated ground water associated with the former milling operations discharges into the Colorado River where COPCs may be deposited in sediment or may be present in the surface water as well as downstream of the site.

Phreatophytes rooted in sediment may uptake contaminants through their root systems. Such species include sandbar willow (*Salix exigua*), cattail (*Typha sp.*), cottonwood (*Populus fremontii*), common reed (*Phragmites communis*), bulrushes, tamarisk (*Tamarix ramosissima*), and reed canarygrass (*Phalaris arundinaceae*). As mentioned in the characterization work plan (DOE 1997b), elevated concentrations of some constituents were present in the wetlands mitigation ponds.

Although the prominent boundaries of these ponds no longer exist, remnants of these ponds may still contain some elevated concentrations of COPCs. In addition, the sediments may act as sinks for COPCs in ground water discharging into the area and thus represent potential sources of contamination.

Terrestrial receptors such as foxes, coyotes, skunks, raccoons, deer, and rodents are likely to use the riparian corridor for food items and as a drinking water source. Consequently, they are also exposed to potentially contaminated sediments. These terrestrial receptors typically do not spend most of their time in the riparian or aquatic areas.

Aquatic receptors living in the riparian and aquatic habitats adjacent to and downstream from the millsite have the potential to ingest contaminated sediment, surface water, and vegetation. These species have the potential for the greatest exposures. Larger herbivores prefer to browse on leafy material; smaller mammals and birds seek plant seeds and roots. Field observations in the reference area found evidence of wildlife browsing on cattails. Beaver (an herbivore) and muskrat (an omnivore that feeds chiefly on aquatic plants) forage on the types of vegetation found along the river banks. Higher trophic receptors such as coyotes, eagles, and hawks may in turn feed on small mammals or birds that have ingested contaminated food items. Aquatic avian species such as the great blue heron, ducks, geese, and killdeer frequent the Colorado River and represent ecological receptors with significant exposure potential. Aquatic invertebrates, amphibians, reptiles, and fish are also in direct contact with potentially contaminated sediment, surface water, and aquatic vegetation. These receptors can also serve as prey for eagles, herons, and other wildlife.

5.4.2 Future Hypothetical Exposure Scenario

Because no significant habitat changes from the present scenario are expected, the future exposure scenario includes all of the current exposure scenarios associated with the riparian and aquatic habitats on the Colorado River. Localized flooding will likely continue to erode the vestiges of the wetlands mitigation ponds and reshape the river banks.

Without institutional controls, ground water could possibly be pumped and used for irrigation and livestock watering or other industrial uses. This would create a source for ground water and surface water ingestion, direct contact with terrestrial vegetation, and deposition of ground water and surface water on the soil. The soil would then represent an additional source medium for

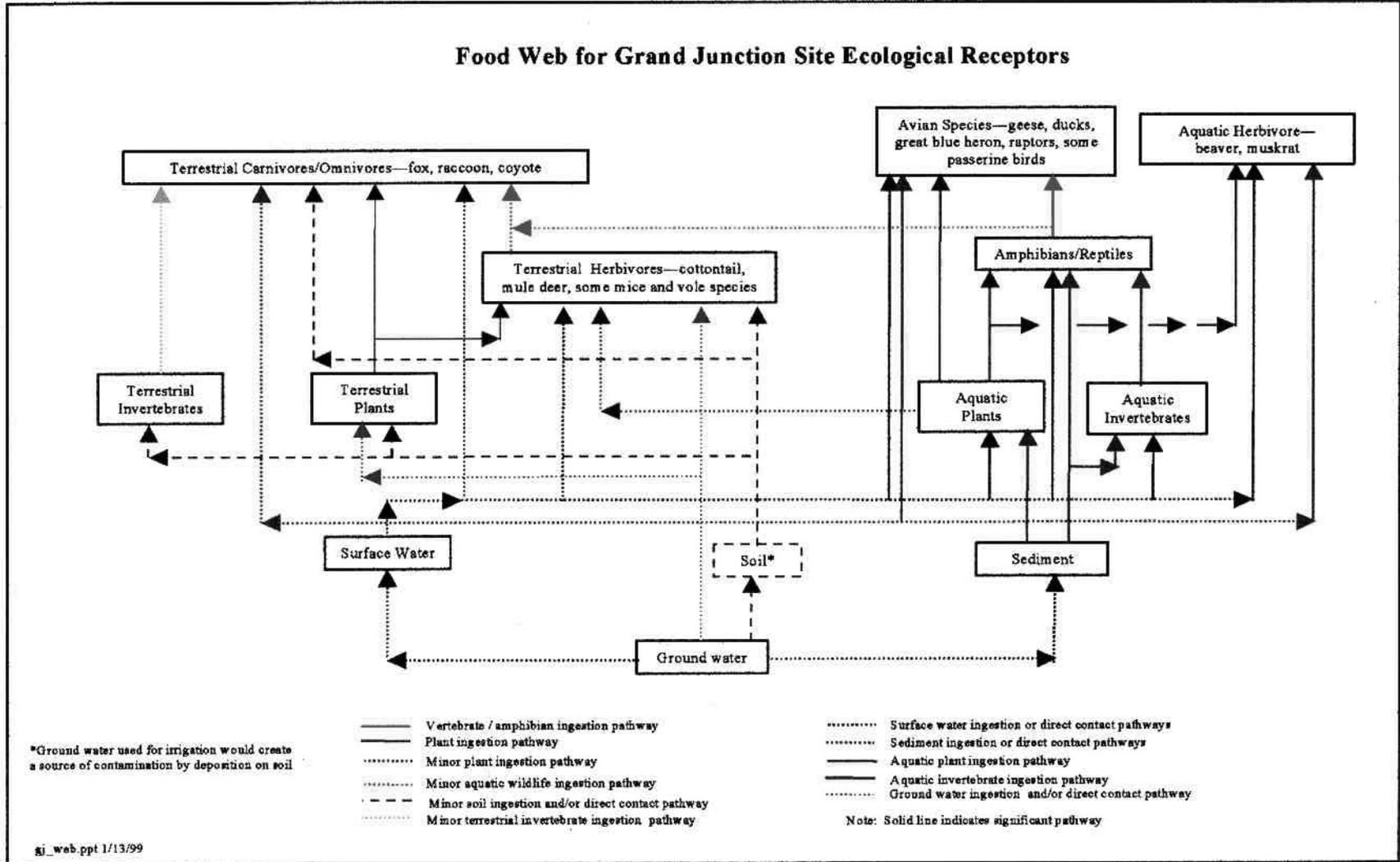


Figure 5-19. Grand Junction Site Food Web

ingestion and direct contact. At present, both of these secondary exposure routes are considered incomplete since ground water is not currently used for these purposes, nor is ground water likely to be pumped in the future. Large-scale irrigation with ground water is not considered a likely future pathway because surface water is the main source of irrigation water in the Grand Junction area. As long as there is the possibility of pumping ground water for agricultural purposes, it is assumed that the potential exists for these two hypothetical exposure pathways.

The land use plans for the Grand Junction site have not been made final. One possible use is the construction of a recreation area, which would likely include the planting of various tree species. Since the potential exists for phreatophytes (e.g., cottonwood, willow, and greasewood) to inhabit the terrestrial portion of the site, contaminants in ground water could be taken up by those plants through extensive root systems. Contaminants could possibly bioaccumulate in various plant parts and exert a range of influences, depending on the specific COPC. Plant uptake rates and toxicities vary greatly among species and are affected by factors such as soil characteristics (e.g., pH, redox potential, organic matter), plant sensitivity, input-output balance, and cumulative effects. Foraging wildlife could be indirectly exposed to contaminants in ground water by ingesting plants that have bioaccumulated certain contaminants.

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6.0 Summary of Human Health and Ecological Risk

6.1 Human Health Risk Assessment

A baseline risk assessment was previously prepared for the Grand Junction site (DOE 1995a) according to methods provided in the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project* (DOE 1996c). Much of the data used in that risk analysis was collected before completion of surface remediation (data for characterizing the contaminant plume were collected from 1983 to 1989). As described in Section 5.3.3, additional wells were installed during the 1990s and more recent samples were collected. Many contaminants have shown significant changes, mainly decreases, in concentration since completion of the original BLRA. This necessitates a reevaluation of COPC identification and assessment of associated risks. The intent of this BLRA update is to use those earlier results and conclusions as a starting point from which to evaluate the more recent data.

6.1.1 Summary of 1995 Risk Assessment Methodology and Results

The 1995 BLRA identified 19 contaminants associated with the Grand Junction site as being at levels statistically above background concentrations for the area. This initial list of contaminants was screened first to eliminate contaminants in concentrations within nutritional ranges and then to eliminate contaminants of low toxicity and high dietary ranges. These two steps eliminated three contaminants each, resulting in the following COPC list: arsenic, cadmium, cobalt, fluoride, iron, manganese, molybdenum, nickel, ^{226}Ra , sulfate, uranium, vanadium, and zinc. These contaminants were retained for further risk analysis.

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 garden produce irrigated with ground water, ingestion of milk/livestock watered with ground water, ingestion of fish from the Colorado River, and recreational exposure to Colorado River water. Results indicated that adverse toxic responses from exposure to contaminants from routes other than drinking water would not be expected. Therefore, it was determined that ingesting ground water as drinking water would be the primary contributor to total exposure. Consequently, the use of ground water as drinking water in a residential setting was evaluated probabilistically. For additional information on other potential exposure routes and for the probabilistic methodology, see the BLRA (DOE 1995a).

Results of the BLRA showed that the most severe noncarcinogenic health effects could occur from the water's sulfate and manganese content and to a lesser extent from fluoride, vanadium, cadmium, iron, arsenic, molybdenum, zinc, and nickel. Refer to the BLRA for specific toxicological effects (DOE 1995a). The estimated risk levels for maximum detected concentrations of the carcinogens arsenic, $^{234+238}\text{U}$, and ^{226}Ra each exceeded the highest EPA-recommended excess lifetime cancer risk of 1×10^{-4} .

Potential public health effects from using background water as drinking water were also assessed in the BLRA by calculating point-exposure doses and comparing the exposure doses to toxic effect levels observed for the COPCs. Background exposure doses were calculated for all plume-related COPCs. Maximum concentrations of the constituents in the upgradient and regional background wells were used in these calculations. Selenium was also evaluated because it is detected in high concentrations in regional ground water (as discussed in Section 5.3.1). The

potential receptors assessed were infants, children, and adults. The exposure dose calculations followed UMTRA Ground Water Project methodology (DOE 1996c).

The results of the assessment indicated that, if the regional alluvial ground water were ingested as drinking water, sulfate, selenium, manganese, sodium, chloride, and fluoride have the potential to cause adverse health effects. The individual excess lifetime cancer risk calculated for the upgradient background ground water shows that the cancer risk for arsenic (8×10^{-4}) exceeds the upper end EPA-recommended risk level of 1×10^{-4} . The point-exposure dose evaluation and comparison to standards of upgradient and regional background water substantiates the conclusion that the background water quality in the Grand Junction area is poor. That is, drinking the background alluvial ground water could cause adverse health effects. In addition, the water is unpalatable because of high levels of sulfate, TDS, manganese, iron, fluoride, and chloride.

6.1.2 BLRA Update

6.1.2.1 COPC List Update

This BLRA update uses the COPC list from the original BLRA as a starting point to evaluate current data. Table 6–1 lists the COPCs identified in the 1995 BLRA along with a summary of historical plume data (from the 1996 SOWP and BLRA) and current (1998) plume and background data. In addition to the 13 COPCs from the original BLRA, nitrate also is included at the request of CDPHE; ammonia is included because it is present in significantly elevated concentrations at the site and was an important constituent in the ecological risk evaluation. MCLs and risk-based concentrations (RBCs) are also included for comparison of data to benchmarks (EPA 1998a). Background locations were determined as described in Section 5.3.1 of this document. Plume data include on-site wells and wells immediately downgradient of the site that can reasonably be assumed to be influenced by site activities. Table 6–1 lists wells included in both plume and background groupings for 1998 data.

The risk-based concentration presented in Table 6–1 for a given contaminant represents a concentration in drinking water that would be protective of human health provided that

- A residential exposure scenario is appropriate.
- Ingestion of contaminated drinking water is the only exposure pathway. [Note: Does not apply to ammonia. See discussion in Section 6.1.2.2.]
- The contaminant contributes nearly all of the health risk.
- EPA's risk level of 1×10^{-6} for carcinogens and a hazard index 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 that further evaluation of the contaminant is warranted. RBCs are intended to be used in screening-level evaluations.

Table 6–1. Grand Junction Site Data Summary

Contaminant	No.	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	MCL (mg/L)	RBC ^a (mg/L)	% exceeding benchmark ^b
Ammonia (as NH ₄)						0.2N (as NH ₃)	
Background	8/8	0.014	0.321	0.093		43 (as NH ₄) ^d	0
Current Plume	17/17	0.017	233	71.4			65
Historical Plume ^c	N/A	N/A	N/A	N/A			
Arsenic					0.05	0.011N	
Background	3/15	0.001	0.0014	N/A		0.000045C	0
Current Plume	18/34	0.001	0.0349	0.005			0
Historical Plume		0.007	0.18	0.007			
Cadmium					0.01		
Background	0/15	0.001	0.001	N/A			0
Current Plume	2/34	0.001	0.0013	N/A			0
Historical Plume		0.073	0.42	1.2			
Cobalt						2.2N	
Background	0/15	0.006	0.008	N/A			0
Current Plume	6/34	0.006	0.0162	N/A			0
Historical Plume		0.05	0.66	0.14			
Fluoride					4	2.2N	
Background	15/15	0.453	1.62	0.895			0
Current Plume	34/34	0.335	7.57	1.93			9/24
Historical Plume		4.3	4.8	4.6			
Iron						11N	
Background	10/15	0.003	3.13	0.552			0.00
Current Plume	29/34	0.003	21.2	3.88			12
Historical Plume		1.3	16	11			
Manganese						1.7N	
Background	15/15	0.233	2.22	1.4			53
Current Plume	34/34	0.436	4.54	2.82			97
Historical Plume		1.8	10	4.1			
^{234 + 238} U (pCi/L)					30 pCi/L		
Background	7/7	25.1	57	42			86
Current Plume	17/17	21.3	1668	215.3			94
Historical Plume							
Molybdenum					0.1	0.18	
Background	15/15	0.0158	0.124	0.0587			13
Current Plume	34/34	0.0147	0.299	0.101			38
Historical Plume		0.13	0.53	0.28			
Nickel						0.73	
Background	10/15	0.0074	0.0281	0.015			0
Current Plume	28/34	0.01	0.111	0.035			0
Historical Plume		0.28	0.38	0.32			
Nitrate					44		
Background	15/15	0.0579	71.4	21.85			20
Current Plume	31/34	0.011	65	5.43			3
Historical Plume		<.01	50				
²²⁶ Ra (pCi/L)					5 pCi/L		
Background	7/15	0.04	0.34	N/A			0
Current Plume	17/34	0.04	0.62	0.167			0
Historical Plume		0	29	2.1			

Table 6-1 (continued). Grand Junction Site Data Summary

Contaminant	No.	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	MCL (mg/L)	RBC ^a (mg/L)	% exceeding benchmark ^b
Sulfate					N/A	N/A	
Background	15/15	416	3720	2566			
Current Plume	34/34	1650	3700	3154			
Historical Plume		3100	4900	3945			
Uranium					0.044		
Background	15/15	0.0228	0.0662	0.0469			53
Current Plume	34/34	0.0241	2.5	0.304			94
Historical Plume		0.29	0.45	0.3			
Vanadium						0.26N	
Background	10/15	0.001	0.0049	0.0019			0
Current Plume	16/34	0.001	0.832	0.0857			18
Historical Plume		5.2	14	7.1			
Zinc						11N	
Background	1/17	0.004	0.0051	N/A			0
Current Plume	19/34	0.004	0.352	0.0349			0
Historical Plume		2.6	6.7	4.5			
Background Wells: 713, 715, 745, 1020, 1021, 1023, 1025, CW21							
Plume Wells: 590, 736, 740, 1000-1002, 1010-1019, 1022							

MCL=maximum concentration limit

RBC = risk based concentration

^a N—noncarcinogenic risk, C—carcinogenic risk^b Benchmark = MCL if available; risk-based concentration (RBC) used if no MCL.^c Historical data were collected 1983 to 1989.^d Site-specific value determined through geochemical modeling; inhalation pathway.

For contaminants with MCLs, it is interesting to compare these with calculated RBCs. For example, the MCL for arsenic is 0.05 mg/L; the RBCs are 0.001 and 0.000045 mg/L for noncarcinogenic and carcinogenic effects, respectively. Thus the MCL was set at a level higher than that believed to result in some adverse health effect. On the other hand, the MCL for molybdenum is 0.1 mg/L and the RBC is 0.18 mg/L. Therefore, the MCL is more protective than the RBC. There are a variety of contaminant-specific reasons for differences between MCLs and RBCs; however, for purposes of risk management and decision making, it is necessary to have some appreciation of what these benchmarks mean.

A comparison of historical and current plume data indicates that concentrations of many constituents have decreased. This is true for all COPCs except uranium and nitrate, though maximum plume concentrations for iron and fluoride are higher compared to historical data. A comparison of current background and plume data indicates that plume concentrations for nitrate and ²²⁶Ra + ²²⁸Ra (which is mostly ²²⁶Ra) are within the range obtained for background. Mean plume concentrations of nitrate are far below the average background mean; plume and background mean concentrations for ²²⁶Ra + ²²⁸Ra are essentially the same. Therefore, on the basis of a comparison to background, it is possible to eliminate nitrate and ²²⁶Ra + ²²⁸Ra from further consideration as COPCs.

The presence of fluoride in elevated levels associated with the site is problematic. Although fluoride is a process-related contaminant at other uranium milling sites, research of milling operations at the Grand Junction site gave no indication that fluoride was used in any form. However, the maximum and mean concentrations of fluoride in plume-related wells are four-times and two-times that of background, respectively. Although process knowledge would seem

reason to eliminate fluoride as a site-related contaminant, it is retained for further analysis pending some explanation for its elevated concentrations in alluvial ground water at the site.

Sulfate is present in alluvial ground water throughout the Grand Valley in relatively high concentrations, though concentrations are higher, on average, in association with the Grand Junction site. Sulfuric acid was used in processing operations at the site, and some of the ores processed were known to contain sulfide minerals. Therefore, sulfate is a site-related contaminant. However, the highest background concentration of sulfate exceeds any values detected in plume-related wells. Also, sulfate in ground water near the site shows no distribution, such as decreasing concentrations with distance from the site, as would be expected for a plume that is clearly associated with site practices. In terms of risk to human health, there is still no consensus regarding what levels of sulfate intake are detrimental. A secondary drinking water standard of 250 mg/L has been established on the basis of aesthetic concerns, though significantly higher concentrations are believed to produce no ill effects in humans. Because of the lack of an established risk-based benchmark for sulfate, it is not carried through the risk calculations presented in this section. However, because of the elevated levels that are present in plume-related ground water, it is retained as a COPC.

Through a qualitative evaluation, all the other COPCs are deemed to be present in concentrations sufficiently elevated above background to be retained for further consideration in the update of risk calculations.

6.1.2.2 Risk Assessment Methodology

As mentioned previously, 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. Therefore, the ground water ingestion pathway is the only route of exposure considered in this BLRA update (with the exception of ammonia as discussed below). Note that all risks discussed in this document are hypothetical with respect to human health. Based on current ground water use, no risks are present because no exposure pathways are complete. Thus, this assessment concerns only potential risks that could exist in the future if land and water usage changes.

Risk calculations presented here follow EPA's *Risk Assessment Guidance for Superfund Methodology* (EPA 1989a), which involves determining a point estimate for excess cancer risk from current or potential carcinogenic exposures and a hazard quotient (HQ; ratio of exposure intake to an acceptable intake) for noncarcinogenic exposures. It is assumed that the receptors for ground water are residents who use alluvial ground water as their primary source of drinking water. This is an unlikely scenario because of current land use in the vicinity of the site and because of the institutional controls in place (see Section 7.2) but is consistent with the scenario evaluated in the original BLRA. However, for the purpose of making risk management decisions, results of these risk calculations are based on very conservative assumptions.

The original BLRA calculated noncarcinogenic risks using a probabilistic approach. Essentially, this means that instead of using a single value for each parameter required in the risk calculations (e.g., ground water concentration, body weight, frequency of exposure), a range of values with a given probability distribution was used. By performing numerous iterations of the standard risk calculations, with a value selected at random from each parameter distribution, a range of

exposures and associated risks results. The original BLRA reported results for the most sensitive receptor population modeled—children.

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 for the adult population (EPA 1989b). Ground water concentrations used to calculate risks associated with ingestion of plume-related ground water are the maximum concentrations detected during the 1998 sampling events, most of which were from on-site wells. Although use of adult exposure data is probably less conservative than use of the exposure data for children, use of maximum ground water concentrations and point-exposure dose calculations is probably more conservative; the net effect is to produce comparably conservative results. For the purpose of making risk management decisions, results of both methodologies are usable and both have advantages and limitations.

Risks associated with ammonia were generally calculated as described above for other noncarcinogens with one important exception. For all contaminants except ammonia, risks were determined for ingestion of contaminated ground water (i.e., an oral exposure route) in a residential setting. The major risk from ammonia is not through oral ingestion in ground water, but rather from inhalation of gaseous ammonia through volatilization in ground water. Risks were calculated using default inhalation exposure parameters for a residential setting (EPA 1991). The volatilization factor for ammonia and the fraction of ammonia actually present as the dissolved gas, NH_3 , were determined through site-specific geochemical modeling with the PHREEQC modeling code (see Section 4.3.3.1 and Appendix I for more details).

Risks associated with ammonia for a residential setting require that exposure occur within a closed structure (i.e., a residence) in which volatilized ammonia is trapped through its use for all other purposes (drinking, bathing, laundry, etc.). For exposure scenarios where a closed structure is absent (e.g., irrigation and agricultural), volatilized ammonia would quickly dissipate to the atmosphere and risks would be negligible (at least at the concentrations present in ground water at the Grand Junction site). Therefore, exposure to ammonia is only evaluated here for a residential setting.

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, slope factors) are best available data from standard EPA sources (e.g., Integrated Risk Information System, Region III Risk-Based Concentration Table).

6.1.2.3 Results

Results of the risk calculations are included in Tables 6-2 and 6-3. Table 6-2 shows risk calculations for maximum and mean plume concentrations for both noncarcinogenic and carcinogenic contaminants. Values for ammonia represent concentrations present as NH_3 as determined through geochemical modeling. Table 6-3 shows the same calculations for maximum background concentrations. The tables also show the percentage that each noncarcinogenic contaminant contributes to the total hazard index (HI) (or overall risk).

Table 6–2. Risk Calculations for 1998 Maximum and Mean Plume Concentrations

Non Carcinogens—Ground Water Ingestion Only (Adults)

Contaminant	CW-MAX	HQ-MAX	%Risk	CW-MEAN	HQ-MEAN	%Risk
	mg/L			mg/L		
Arsenic	0.0349	3.187	8.13	0.005	0.4566	6.42
Cadmium	0.0013	0.071	0.18	0.001	0.0548	0.77
Cobalt	0.0162	0.007	0.02	0.007	0.0032	0.04
Fluoride	7.57	3.457	8.81	1.93	0.8813	12.39
Iron	21.2	1.936	4.94	3.88	0.3543	4.98
Manganese	4.54	2.646	6.75	2.82	1.6438	23.12
Molybdenum	0.299	1.638	4.18	0.101	0.5534	7.78
Nickel	0.111	0.152	0.39	0.035	0.0479	0.67
Uranium	2.5	22.831	58.22	0.304	2.7763	39.05
Vanadium	0.832	3.256	8.30	0.0857	0.3354	4.72
Zinc	0.352	0.032	0.08	0.0349	0.0032	0.04
	HI=	39.215		HI=	7.1103	

Non carcinogens—Inhalation through water use in residential setting*

Ammonia	0.655	4.706	100	0.201	1.444	100
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*IR = 15 m³/day of air default; concentration in air = water concentration x site-specific volatilization factor x conversion factor
 For Grand Junction, volatilization factor =0.000595; conversion factor is 1,000L/m³
 Maximum NH₃ in Grand Junction ground water is 1.1 mg/L, mean is 0.337 mg/L

Contaminant		CW	Risk
Arsenic	max	0.0349	6.15E-04
	mean	0.005	8.81E-05
U234+238	max	1668	1.86E-03
	2nd	422	4.71E-04
	mean	2.15E+02	2.41E-04

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Table 6–3. Risk Calculations for 1998 Maximum Background Concentrations

Non Carcinogens—Background Ground Water Ingestion Only (Adults)

Contaminant	CW	HQ	%Risk
	mg/L		
Arsenic	0.0014	0.128	2.82
Selenium	0.137	0.751	16.53
Fluoride	1.62	0.740	16.29
Iron	3.13	0.286	6.30
Manganese	2.22	1.294	28.50
Molybdenum	0.124	0.679	14.96
Nickel	0.0281	0.038	0.85
Uranium	0.0662	0.605	13.32
Vanadium	0.0049	0.019	0.42
Zinc	0.0051	0.000	0.01
	HI=	4.540	

Carcinogens—Ground Water Ingestion Only (Adults)

Contaminant	CW	Risk
Arsenic	mg/L	0.0014
U234+238	pCi/L	57

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The following major observations are based on these results:

- Risks associated with maximum concentrations of contaminants in plume ground water greatly exceed the acceptable HI of 1 for noncarcinogens. Risks calculated using mean contaminant concentrations are significantly lower, though still unacceptable.
- Uranium is the main risk contributor to noncarcinogenic risks posed by plume ground water (58 percent contribution to the HI using maximum concentrations).
- All carcinogenic risks calculated for $^{234}\text{U} + ^{238}\text{U}$ associated with plume ground water exceed the upper end of EPA's acceptable risk range (1×10^{-4} to 1×10^{-6}). Carcinogenic risks calculated for background ground water are within EPA's risk range.
- Noncarcinogenic risks posed by background ground water (calculated using maximum detected contaminant concentration) exceed the acceptable HI of 1.

It was noted previously that several metals identified as COPCs in the original BLRA have decreased significantly in concentration since that time, though they still were somewhat above background. These metals include cadmium, cobalt, nickel, and zinc. The relative contribution of these contaminants to overall noncarcinogenic risk indicates that they are insignificant, both individually and collectively. These four metals make up less than 1 percent of the total risk considering maximum plume concentrations and less than 2 percent for mean concentrations. Therefore, these contaminants can be eliminated from further consideration as final COPCs for the site.

As mentioned above, the major risk contributor for ground water ingestion is uranium. Other significant risk contributors (4 percent or greater) are the same for maximum and average calculations, though relative contributions vary. Those other contaminants are arsenic, fluoride, iron, manganese, molybdenum, and vanadium. Risks associated with inhalation of ammonia exceed acceptable levels. In terms of carcinogenic risk, maximum plume concentrations of arsenic exceed EPA's acceptable risk range, though the mean risk values lie within this range. All levels of $^{234}\text{U} + ^{238}\text{U}$, from mean to maximum, exceed EPA's acceptable risk range.

Several of the contaminants included as significant risk contributors do not exceed their individual RBCs. However, they cannot be eliminated from further consideration because, in terms of collective risk posed by ground water, they are important. Likewise, although arsenic does not exceed its MCL, from a risk perspective it is still a significant contributor to site risks.

The greatest contributors to background risks through ground water ingestion are manganese, selenium, fluoride, and molybdenum; uranium is of lesser importance. However, those contaminants collectively responsible for the majority of background and plume risks are the same, with two exceptions. Vanadium makes up a significant amount of risk for plume ground water but is unimportant in terms of background. Selenium, which is essentially nondetectable in plume wells, is a significant contributor to background risk. Other than these two constituents, the majority of risk in both instances is made up of arsenic, fluoride, iron, manganese, molybdenum, and uranium. (Risks were not determined for inhalation of ammonia because of insignificant concentrations of actual NH_3 .)

To summarize, ingestion of either site-related or background ground water as the sole source of drinking water would result in unacceptable human health risks. Site-related ground water may pose both carcinogenic and noncarcinogenic risks, both of which are primarily attributed to uranium (in isotopic and chemical forms). The other significant contributors to risk are ammonia (through inhalation), arsenic, fluoride, and vanadium, and to a lesser extent iron, manganese, and molybdenum. Background water quality is a threat to human health from a noncarcinogenic standpoint; carcinogenic risks are within the EPA acceptable range. Noncarcinogenic risks for background ground water are primarily due to manganese, molybdenum, selenium, and fluoride, and to a lesser extent iron and arsenic. A summary of the updated evaluation of COPCs is presented in [Table 7-2](#).

Although risks posed by sulfate were not assessed due to lack of acceptable toxicity data, sulfate concentrations are high in both plume and background ground water. Sulfate should be considered a potential threat to human health for plume and background ground water pending additional guidance on assessing sulfate-related risks.

All risk estimates are based on the assumption that contaminated ground water will be used as the primary source of drinking water in a residential setting. This is a worst case assumption because of the poor water quality of the alluvial aquifer and the availability of a municipal water supply. No human health risks are currently posed by contaminated ground water, nor are any expected, as water is not currently or likely to be used for residential purposes. As long as ground water use is prohibited for this use, no exposure pathway is complete and no risks exist.

6.2 Ecological Risk Assessment

The BLRA prepared for the Grand Junction site (DOE 1995a) included a screening-level assessment of ecological risks. The BLRA identified ecological COPCs and potential exposure pathways, receptors, and adverse effects. During the 1998 investigation (Section 4.4) additional field data were collected to evaluate risks associated with the exposure pathways. Results were used to update the BLRA. The approach used for the BLRA update was based on guidance in *Guidelines for Ecological Risk Assessment* (EPA 1998b) and *Framework for Ecological Risk Assessment* (EPA 1992).

This section summarizes the 1995 BLRA and the results of the 1999 BLRA update. Appendix I contains the complete BLRA update.

6.2.1 Summary of 1995 Risk Assessment

The 1995 BLRA (DOE 1995a) evaluated potential exposure of terrestrial and aquatic organisms to contaminated ground water and to surface water or sediment contaminated by ground water. Known concentrations of ecological COPCs in ground water, surface water, and sediment were compared to toxicity standards and guidelines for various ecological receptors.

6.2.1.1 Potential Receptors

The 1995 BLRA identified ecological receptors that could be exposed to site-related contaminants. The information was derived from qualitative surveys and observations made before tailings were removed and, therefore, is not necessarily indicative of current conditions or future land use.

Before tailings were removed, the ecology of the site consisted of an interspersed of riparian and aquatic habitats. Riparian vegetation dominated by salt cedar thickets covered several small islands and shorelines formed by Colorado River side channels and backwaters. Cottonwood, Russian olive, and willow, which broke up the salt cedar thickets in some places, were less abundant. The understory vegetation consisted of several dense, open stands of reed canary grass, spotted knapweed, and giant reed with rushes, sedges, spikerushes, bullrush, and arrowhead common along the shores of side channels and in small wetlands on the islands. Yellow warbler, mourning dove, song sparrow, and black-billed magpie were observed in the salt cedar and willow stands. Mallard and great blue heron were common on the water or on the shore. Evidence of beaver, muskrat, raccoon, and skunk was also common, as was evidence of bull frog and leopard frog. Bald eagles, the only endangered terrestrial species potentially exposed to site contaminants, are known to winter in the area.

The following aquatic organisms were observed in the vicinity of surface water sampling locations in the Colorado River: mayfly nymphs, damselfly nymphs, dragonfly nymphs, water striders, backswimmers, and Cyprinidae minnows. Game fish known to inhabit the area include green sunfish, bluegill, largemouth bass, black crappie, black bullhead, and channel catfish. Bluehead sucker, flannelmouth sucker, common carp, roundtail chub, red shiner, sand shiner, and fathead minnow also inhabit the area. Threatened or endangered fish potentially exposed to site contaminants include the humpback chub, bonytail chub, Colorado squawfish, and razorback sucker.

After the removal of tailings in 1994, the site was seeded with a mixture of grasses, forbs, and shrubs, and eight ponds were constructed along the southern boundary of the site between the flood control levee and the Colorado River. The ponds were constructed as part of a U.S. Army Corps of Engineers effort to reestablish wetland habitat destroyed as a consequence of site remediation. The ponds were fed by contaminated ground water from the site. Colorado River flooding during the late spring and early summer of 1995 mostly destroyed the eight ponds.

6.2.1.2 Ecological Chemicals of Potential Concern

Ecological COPCs were defined in the 1995 BLRA as those constituents that exceeded background concentrations (Table 6-4). The water quality of upgradient wells was considered to be representative of background conditions (DOE 1995a). Two categories of surface water were defined: Colorado River water and water in ponds constructed as part of a wetlands mitigation project. Colorado River COPCs were those constituents with higher concentrations downstream of the millsite than upstream. COPCs in the wetlands mitigation ponds were determined by comparing concentrations in the ponds and in the upgradient ground water wells (DOE 1996d). Sediment COPCs were determined by comparing data from Colorado River sediment sampled upstream, downstream, and adjacent to the site (DOE 1995a).

6.2.1.3 Potential Adverse Effects

The 1995 BLRA evaluated the following potential exposure using data available at the time:

- Plant uptake of ground water
- Use of ground water to water livestock or irrigate crops
- Exposure of aquatic life in Colorado River water and sediments

- Livestock and terrestrial wildlife ingestion of surface water from ponds fed by site ground water
- Exposure of aquatic life in ground-water-fed ponds
- Use of pond water for crop irrigation

Table 6–4. Summary of Ecological Chemicals of Potential Concern in Ground Water, Surface Water, and Sediments

Constituents Above Background in Ground Water	COPC in Ground Water	Ecological COPC in Colorado River Water	Ecological COPC in Water in Wetlands Mitigation Ponds	Ecological COPC in Colorado River Sediment
Ammonium		X		
Arsenic	X		X	
Cadmium	X		X	
Cobalt	X		X	
Copper		X		
Fluoride	X		X	
Iron	X	X	X	
Manganese	X		X	
Molybdenum	X		X	X
Nickel	X		X	
²²⁶ Ra	X	X	X	
Selenium				X
Strontium	X			X
Sulfate	X		X	X
Uranium	X	X	X	X
Vanadium	X	X	X	
Zinc	X		X	

Phreatophytes, plants that have the potential to root into contaminated ground water, were not sampled. Concentrations of COPCs in plant tissue were estimated using published soil-to-plant concentration ratios (DOE 1995a). The potential for adverse effects was evaluated by comparing the tissue estimates to published benchmark concentrations that can result in phytotoxicity (Will and Suter 1994). HIs were calculated by dividing the plant tissue concentration by the benchmark concentration; an HI greater than one indicates a possible phytotoxic effect. HIs for arsenic, manganese, vanadium, and zinc ranged from 3.5 to 34. HIs for cobalt and copper were only slightly greater than one (DOE 1996d).

Ground water pumped from the most contaminated area of the plume may be toxic if used to water livestock or wildlife or to irrigate crops. Sulfate and TDS concentrations may be toxic if ingested by livestock or wildlife. Comparisons of ground water concentrations with toxicity benchmarks indicate that cobalt, fluoride, iron, manganese, molybdenum, vanadium, and zinc exceed levels that may have adverse effects on irrigated crops.

Contaminant concentrations in the two wetlands mitigation ponds at the southwestern edge of the site were higher than concentrations in nearby upgradient ground water wells (DOE 1996d). For example, in 1995 the uranium concentration in surface water of the westernmost pond was 0.473 mg/L, and the concentration in ground water 200 ft (60 m) upgradient (well 1000) was 0.096 mg/L. The higher concentration in the pond was attributed to evaporation. Water chemistry

data for samples taken from the wetlands mitigation ponds before they were destroyed by floods, when compared to water quality standards, indicate that cadmium, manganese, and vanadium concentrations exceeded chronic toxicity benchmarks for aquatic life; and manganese, molybdenum, sulfate, and vanadium concentrations exceeded toxicity benchmarks for livestock watering, crop irrigation, and ingestion by wildlife.

6.2.2 BLRA Update

The 1998 ecological investigation (Section 4.4) was conducted to provide the following data to update the 1995 BLRA:

- Characterization of current plant communities overlying contaminated ground water and projections of the future plant ecology of the area given land-use scenarios.
- Selection and characterization of the plant ecology of a reference (background) area.
- Comparison of ecological COPC concentrations in vegetation, sediment, and surface water, on site and in the reference areas, with ecotoxicity benchmarks.
- Screening assessment of ecological risks associated with irrigation ponds constructed at the botanical gardens since publication of the BLRA.

The results of the 1998 ecological sampling and analyses (Appendix I) indicate generally low levels of a few COPCs in sediment, surface water, and plant tissues. The occurrences of significantly elevated concentrations coincide with sampling locations that are known to be either remnants of the wetlands mitigation ponds or ponded areas that receive little or no regular surface water flushing.

Based on sample size and variability, the strongest line-of-evidence factors for basing risk conclusions are the surface water and sediment results. In spite of necessarily smaller sample sizes, the biota data serve as an additional but significant line of evidence. Tissue results show that for the majority of the analytes, Grand Junction site concentrations are the same as or less than the reference area concentrations.

The majority of the data indicate no significant differences between Grand Junction site and reference area mean analyte concentrations in both abiotic and biotic media. To maintain a conservative approach, the following constituents were retained as COPCs even though their occurrences appear to be isolated. In most cases, the occurrences coincide with Grand Junction site location 1228. On the basis of an initial evaluation of the analytical data for the 1998 ecological sampling, it is recommended that the following COPCs be retained:

- Ammonia in surface water
- Nickel in surface water
- Uranium in surface water
- Vanadium in surface water
- Arsenic in reed canarygrass stems
- Vanadium in reed canarygrass stems
- Manganese in cattail stems
- Molybdenum in cattail stems

- Molybdenum in cattail roots

One of the objectives of the 1998 field investigation was to collect data from areas that might have the highest contaminant levels. The highest values were obtained from ponded areas (locations 1226, 1228, and 1235, see Figure 4–15) where the Colorado River provides little or no natural flushing.

Because the occurrences are localized, elevated concentrations of ammonia and some metals in surface water and vegetation at these locations probably do not present an unacceptable ecological risk. Although unlikely, the possibility remains that an isolated effect or mortality could be associated with these locations; however, no negative ecological effects have been observed.

Location 1226 (Figure 4–15) is located at the Botanical Gardens pond. This pond is small, fenced, and provides no significant ecological habitat. The ecological sampling for surface water at this location did not include all parameters listed on the State of Colorado agricultural standards (Colorado Department of Health, Water Quality Control Commission, *The Basic Standards for Ground Waters*, Section 3.11.0, amended April 1996). For those analytes that were included on this list, only the pH value of 9.07 was elevated over the recommended maximum value of 8.5. Based strictly on the surface water results for the ecological sampling event, there is no indication that this pond should not be used to irrigate the plants in the arboretum.

The other ponded areas (Figure 4–15, locations 1228 and 1235) are very small and are located on a braided portion of the river. Their small size (estimated to be no more than 1,000 square feet each) restricts the numbers and types of ecological receptors that rely solely on them for surface water, forage, or prey species. In addition, wildlife receptors typically utilize a variety of prey or forage items.

Manganese concentrations in cattail stems averaged 860 mg/kg at the Grand Junction site and 300 mg/kg at the reference area. Before the bioaccumulation factors for manganese were calculated, the plant tissue concentrations were plotted against the sediment concentrations to detect a linear correlation. A correlation coefficient of 0.77 was obtained for the manganese data, and an r^2 of 0.6 was calculated for the linear regression trend line. Bioaccumulation factors were obtained by dividing the maximum co-located tissue concentration by the minimum co-located sediment concentration. Bioaccumulation factors calculated for manganese were approximately equal for the Grand Junction site and reference area (4.5 and 3.9, respectively). The manganese sediment concentrations for the Grand Junction site and reference area locations did not differ significantly and were all between 200 and 300 mg/kg. The screening benchmark for terrestrial plant phytotoxicity is given as 500 mg/kg in soil (ORNL 1996). A mature leaf tissue manganese concentration range of 200 to 1,000 mg/kg (dry weight) was cited as toxic in the BLRA (Kabata-Pendias and Pendias 1992, cited in DOE 1995a). Manganese appears to bioaccumulate in cattail stems to a significant level at both the millsite locations and the reference area.

According to Kabata-Pendias and Pendias (1992), “the Mn compounds are known for their rapid oxidation and reduction under variable soil environments, and thus oxidizing conditions may greatly reduce the availability of Mn and associated micronutrients, whereas reducing conditions may lead to the ready availability of these elements even up to the toxic range.”

Therefore, it is possible that under stagnant conditions manganese may become highly bioavailable to cattails, thereby producing a high concentration such as that observed at Location 1226 (914 mg/kg wet weight). Reducing conditions at the other two Grand Junction site locations (1231 and 1235) might also account for the elevated manganese concentrations in cattails. It is noteworthy that most elevated concentrations of metals in biota occurred at generally stagnant ponded areas that represent the remnants of the mitigation wetlands ponds, especially locations 1228 and 1235.

Since the data evaluation did not indicate an unacceptable ecological risk at the Grand Junction site, the ecological risk assessment concludes with the analysis phase (See Appendix I). Exposure estimates and stress-response profiles were not calculated, and no risk characterization was performed.

Some residual milling-related constituents apparently persist at the Grand Junction site, as shown by the occasional elevated concentrations of metals and ammonia in surface water and biota. Based on a review of the analytical data and screening criteria, these isolated occurrences are not likely to present significant ecological risks.

Natural flushing is expected to diminish ground water COPC concentrations to background levels and prevent bioaccumulation of contaminants through phreatophytes growing in the terrestrial habitat. This situation depends on the future land use at the millsite.

Elevated concentrations of COPCs in surface water, sediment, and biota are expected to diminish over time as a result of natural ground water flushing. The sediment concentrations do not indicate site-related contamination, although elevated concentrations in some of the biota suggests that some degree of bioaccumulation is occurring. Constituent concentrations in sediment and biota are likely to persist for a longer period of time. Periodic flooding of the Colorado River adjacent to the site will tend to disperse these contaminants and remove the remaining boundaries of the wetlands ponds.

7.0 Ground Water Compliance Strategy

7.1 Process

The proposed ground water compliance strategy for the Grand Junction site is illustrated in [Figure 7-1](#); the figure is based on the compliance strategy selection framework described in Section 2.1 of the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project* (DOE 1996c).

Three compliance strategies are available in the selection framework:

- **No remediation.** Application of the no-remediation strategy would mean that compliance with EPA ground water protection standards would be met for a particular constituent without altering the ground water or cleaning it up in any way. This strategy could be applied at sites where chemicals of potential concern are below the MCL or background, or at sites that have contamination above MCLs or background levels but qualify for supplemental standards or ACLs.
- **Natural flushing.** Natural flushing relies on natural ground water movement and geochemical processes to decrease contaminant concentrations to levels within regulatory limits in a given time period. This strategy could be applied at sites where ground water compliance would be achieved with natural flushing in 100 years, where effective monitoring and institutional controls could be maintained, and where the ground water is not currently and is not projected to be a drinking water source.
- **Active ground water remediation.** Active ground water remediation requires the application of engineered ground water remediation methods such as gradient manipulation, ground water extraction and treatment, and in situ ground water treatment to achieve compliance with EPA ground water protection standards.

7.2 Site-Specific Compliance

To achieve compliance with Subpart B of 40 CFR 192 at the Grand Junction site, the DOE proposed action is no remediation and application of supplemental standards based on the criteria for limited use ground water (40 CFR 192.21[g]). For ground water to be classified as limited use, at least one of three criteria must be met:

- TDS concentrations are at least 10,000 mg/L.
- Widespread ambient contamination not due to ore-processing activities exists that cannot be cleaned up using treatment methods reasonably employed in public water supply systems.
- The quantity of water reasonably available for sustained continuous use is less than 150 gallons per day.

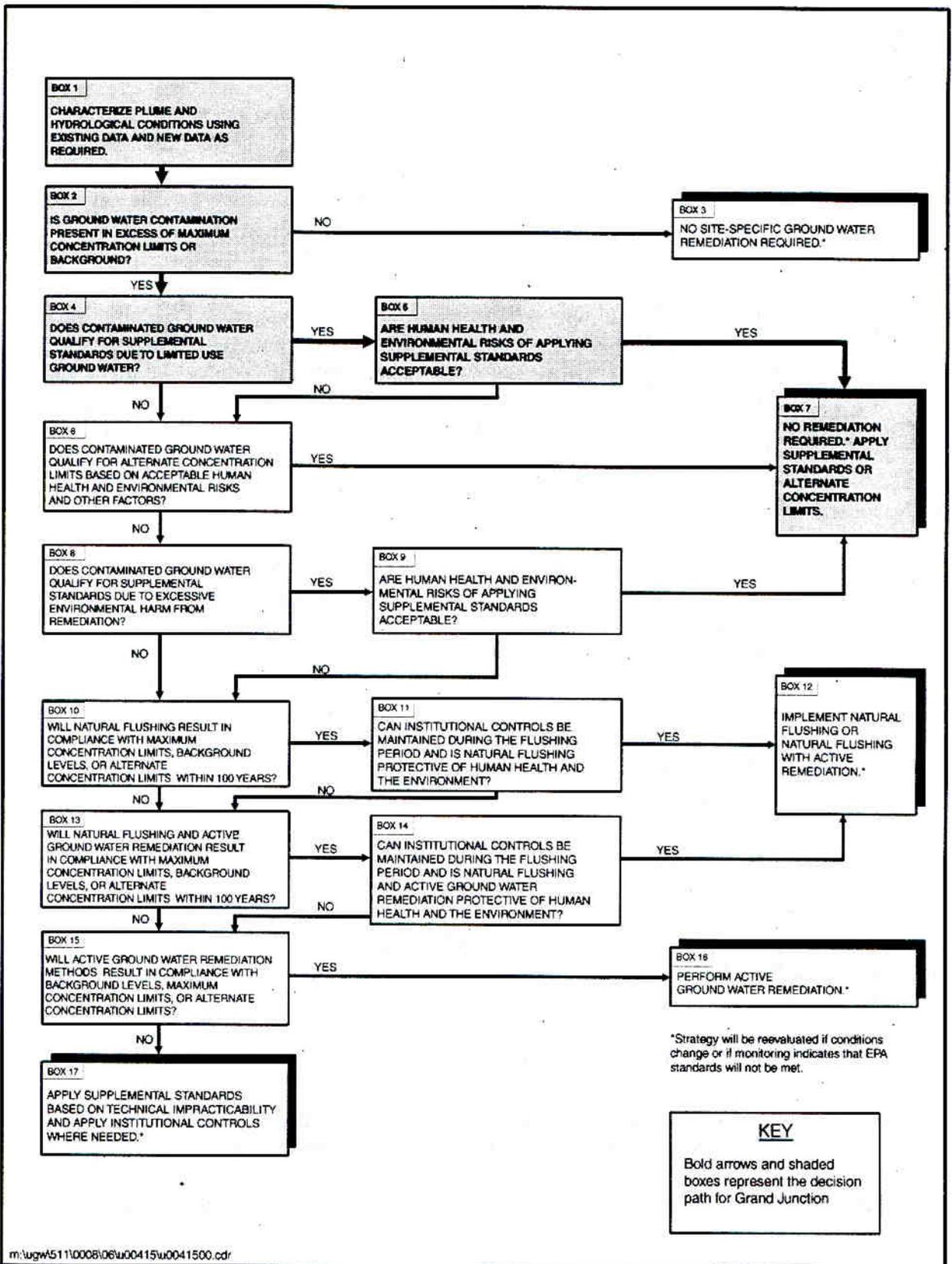


Figure 7-1. Compliance Selection Framework for the Grand Junction Site

The second criterion applies to alluvial ground water at the Grand Junction site and is the basis for the classification of limited use. Ground water in the uppermost aquifer is not a current or potential source of drinking water.

The applicability of supplemental standards at the Grand Junction site is described in this section, and the potential risk to human health and the environment was addressed in the BLRA (DOE 1995a) updated risk information is presented in Section 6 of this document. This proposed action was determined by applying the compliance strategy selection framework shown in Figure 7-1.

7.2.1 Assessment of Environmental Data

7.2.1.1 Background

The original SOWP (DOE 1996d) indicated that the criterion of widespread ambient contamination in the alluvial aquifer of the Grand Valley might be justified. This premise was based on the following evidence:

- Naturally occurring levels of molybdenum, selenium, and uranium in upgradient and regional ground water exceed UMTRA Project MCLs or national primary drinking water standards. A study of northwestern Colorado municipal water systems, which did not include Grand Junction specifically, concluded that ground water with types and levels of contaminants similar to those in the alluvial aquifer would not be adequately cleaned up for human consumption using reasonably available treatment systems. From discussions with U.S. Bureau of Reclamation personnel, it was learned that water would continue to leak out of unlined canals upgradient of the site and leach naturally occurring constituents from the Mancos Shale, further contributing to widespread ambient contamination.
- The BLRA concluded that alluvial ground water quality in the area is naturally poor, was not currently being used, and that local institutional controls required new developments to hook up to city water. Water that was being discharged into the Colorado River did not appear to represent unacceptable risks to human health or the environment.

7.2.1.2 Hydrologic Assessment

The first step in the decision process was an assessment of both historical and new environmental data collected to characterize hydrogeologic conditions and the extent of ground water contamination related to uranium-ore processing at the site. The three main hydrogeologic units beneath the Grand Junction site are the unconfined alluvial aquifer, the underlying aquitard composed primarily of shale units in the Cretaceous Dakota Sandstone, and the confined aquifer in sandstones of the Dakota Sandstone. The alluvial aquifer is considered the uppermost aquifer at the site. Surface components of the hydrologic system in the area include the Colorado River along the south boundary of the site and irrigation canals and ditches north of the site.

The alluvial aquifer is composed of unconsolidated clays, silts, sands, gravels, and cobbles. Ground water is unconfined in the alluvial aquifer; depth to the water table ranges from zero near the river to approximately 20 ft (6 m) at the northern end of the site. The saturated thickness of the aquifer ranges from 5 to 20 ft (1.5 to 6 m). Ground water generally flows to the southwest toward the Colorado River at a horizontal gradient of approximately 0.004. The alluvial aquifer

is recharged by infiltration of precipitation directly on the site, leakage from upgradient irrigation canals and ditches in the area, and infiltration of river water during spring runoff in the Colorado River. Seasonal fluctuations in water levels beneath the site range from 2 to 5 ft (0.6 to 1.5 m) in response to changes in river stage. Limited amounts of recharge also occur as upward leakage of ground water from the underlying Dakota Sandstone aquifer. Ground water discharge is primarily limited to drainage into the river during low stage. Some discharge also occurs as evapotranspiration from vegetation growing in areas of shallow ground water depth near the Colorado River. Hydraulic conductivity in the alluvial aquifer ranges from 20 to over 200 ft/day, based on aquifer pumping tests in several monitor wells. The variability is a result of lateral and vertical facies changes typical of alluvial depositions and from other boundary conditions in the vicinity. The average linear ground water velocity beneath the site is 2.0 ft/day, based on an estimated average hydraulic conductivity of 100 ft/day, a hydraulic gradient of 0.004, and an effective porosity of 0.20.

Underlying the alluvial aquifer is a shale aquitard composed of low-permeability shale units in the Dakota Sandstone. Thickness of the shale aquitard in the Dakota may be as much as 50 ft; depths to the top of the aquitard range from less than 10 ft to more than 75 ft below the ground surface. Although the shale unit is regarded as an aquitard, wells completed within the unit indicate that it is saturated with ground water. Horizontal hydraulic conductivity for the aquitard is variable depending on the degree of weathering of the unit, but the lower end of the range for unweathered material may be as low as 0.02 ft/day. Previously collected data indicate that vertical hydraulic gradients are generally upward, with a few exceptions noted during high water levels in the alluvial aquifer associated with high river stages.

The confined aquifer in sandstones of the Dakota Sandstone underlies the shale aquitard. This aquifer has not been extensively characterized during site investigations because of the presence of the overlying aquitard and vertical upward hydraulic gradients that minimize the potential for any infiltration of contamination from the alluvial aquifer. Recharge to the Dakota Sandstone occurs as infiltration of precipitation on outcrops to the south. Ground water flow direction in the Dakota beneath the site likely follows regional gradients, which vary between a northwest and a northeast orientation. Sparse information on hydraulic conductivity for this unit indicates a range from 0.02 to 0.13 ft/day.

7.2.1.3 Ground Water Contaminants

The second step in the decision process was to compare the list of ground water contaminants to MCLs or to concentrations in background ground water. A modified list of COPCs identified in the 1995 BLRA was evaluated using 1998 sampling data. Potential risks calculated using the recent data for a residential scenario indicated that the major risk contributors were uranium, ammonia, iron, manganese, molybdenum, and vanadium. Although there is no consensus as to what concentration of sulfate is acceptable in drinking water, concentrations detected in the site ground water are sufficiently high to be of probable concern. A discussion of COPCs is presented in section 6.1.2, and data are presented in Table 6-1.

7.2.1.4 Applicability of Supplemental Standards

The third step in the decision process determines whether contaminated ground water qualifies for supplemental standards on the basis of limited use ground water. Ground water in the unconfined alluvial aquifer is of limited use because of widespread, elevated concentrations of naturally occurring uranium and selenium.

Background Concentrations

Uranium values for background ground water average 0.047 mg/L (the MCL is 0.044 mg/L). Activity concentrations for $^{234}\text{U} + ^{238}\text{U}$ average 42 pCi/L, well above the 30 pCi/L MCL. Analytical data for the background ground water quality are shown in [Table 7-1](#) and Appendixes D and H.

Background selenium values average 0.04 mg/L; the UMTRA MCL is 0.01 mg/L. Selenium concentrations are high in some wells and not detected in others. The population is bimodal; if the nondetect values are assumed to be the detection limits, the average of 0.04 mg/L is above the MCL of 0.01 mg/L. Previous studies by the U.S. Geological Survey found concentrations of selenium in valley ground water up to 0.88 mg/L (Butler et al. 1994).

The source of uranium and selenium in background ground water is thought to be the dark marine shales in the Mancos Shale (discussed in Section 5.1.2.2). Black shales are known to contain unusually high concentrations of uranium (Levinson 1980), and Late Cretaceous marine shales, such as the Mancos, are known to have high concentrations of selenium (USGS 1997). These shales underlie most of the valley and are leached by ground water moving to the south and southwest.

Other constituents in background ground water that have concentrations above the secondary drinking water standards in the Safe Drinking Water Act include chloride, iron, manganese, sulfate, and TDS (Table 7-1). Although the secondary drinking water standards are not enforceable, they do indicate that the background ground water is of poor quality. The mean TDS concentration for background ground water is 5,238 mg/L, which is below the 10,000 mg/L that defines a limited-use aquifer, but still elevated. The data for uranium and selenium concentrations support the use of the criterion of widespread ambient contamination in the alluvial aquifer.

Reasonableness of Ground Water Treatment

Ground water from the alluvial aquifer 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. Ground water from the alluvial aquifer has no current use, and there is no historical record of wells completed in this unit beneath or downgradient of the site. Future use of ground water from the alluvial aquifer is unlikely based on historical information and the planned future development of a park and recreational facilities in the area. Therefore, the current and reasonably projected uses of site-affected ground water would be preserved with the application of supplemental standards.

Table 7-1. Summary of 1998 Alluvial Ground Water Quality

Contaminant	Maximum mg/L	Mean mg/L	MCL mg/L	SMCL mg/L	RBC mg/L
Ammonia (as NH ₄)					
Plume	233	71.4			0.20 (as NH ₃)
Background	0.321	0.093			
Arsenic					
Plume	0.0349	0.005	0.05		0.001N
Background	0.0014	n/a			0.000045C
Chloride					
Plume	1,160	796		250	
Background	991	437			
Fluoride					
Plume	7.57	1.93	4	2	2.2N
Background	1.62	0.895			
Iron					
Plume	21.2	3.88		0.3	11N
Background	3.13	0.552			
Manganese					
Plume	4.54	2.82		0.05	1.7N
Background	2.22	1.4			
Molybdenum					
Plume	0.299	0.101	0.1		0.18
Background	0.124	0.0587			
Selenium					
Plume	0.016	n/a	0.01		0.18
Background	0.137	0.036			
Sulfate					
Plume	3,700	3,154		250	
Background	3,720	2,566			
²³⁴ U & ²³⁸ U					
Plume	1,668	215.3	30 pCi/L		
Background	57	42			
Uranium (total)					
Plume	2.5	0.304	0.044		
Background	0.0662	0.0469			
Vanadium					
Plume	0.832	0.0857			0.26
Background	0.0049	0.0019			
Total Dissolved Solids					
Plume	7,840	6,525		500	
Background	7,400	5,238			

NOTE: SMCL—secondary maximum contaminant level
RBC—risk based concentration (human health)
N—noncarcinogenic risk
C—carcinogenic risk

Even though ground water has no current or projected use, a study was performed to test how reasonable the costs would be to treat contaminated ambient ground water for municipal potable

use. The study addressed the criterion in 40 CFR 192.11(e)(2) that the water cannot be treated by “methods reasonably employed in public water systems.” Appendix J describes the results of this study, which was based on information provided by contractor personnel and guidance in *Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy* (EPA 1988). The study shows that the cost of producing potable water from the alluvial aquifer is conservatively estimated at \$680 per household per year. This value exceeds the threshold of \$300 per household per year provided by the EPA 1988 guidelines; adjusted for inflation of 3 percent per year, which results in a current threshold of \$400 per year, the cost is still well above the threshold. The three sources of municipal water in the Grand Valley are Grand Junction city water, Clifton water, and Ute water. Mr. Terry Franklin, Grand Junction Water Superintendent, provided average private household domestic costs for local water. The average household uses about 8,000 gallons per month; therefore the cost for each is

- Grand Junction: \$222 per year per household
- Clifton water: \$222 per year per household
- Ute water: \$216 per year per household

These amounts are about one-third the estimated cost of treating alluvial ground water.

7.2.1.5 Human Health and Ecological Risks

The fourth step in the decision process considers whether the human health and environmental risks of applying supplemental standards are acceptable. Assessment of site conditions and consideration of potential effects on environmental resources indicate that supplemental standards will be protective of human health and the environment.

The BLRA (DOE 1995a) and the update presented in this SOWP indicate that residential use of ground water, mainly as drinking water, presents the only unacceptable pathway for exposure to ground water at the site. If site ground water were used exclusively for residential consumption, risks would exceed EPA’s acceptable level of 1×10^{-6} for carcinogens and a total HI of 1 for noncarcinogens. The largest contribution to noncarcinogenic risks from site ground water would be from uranium, ammonium, arsenic, fluoride, iron, manganese, molybdenum, and vanadium. Uranium would also produce the largest carcinogenic risk (see Table 6–2). Table 7–2 lists the COPCs discussed in the 1995 BLRA and presents a summary of the rationale for retaining them in or deleting them from the 1998 update.

Although risks calculated for use of site ground water in a residential setting are unacceptably high, no risks currently exist at the site because no pathways for human use of ground water are complete at this time. Risks associated with ground water at the site will continue to be acceptable in the future as long as no significant changes in ground water use occur. Because institutional controls on site ground water are in place and are likely to continue (see Section 7.3.1), current and future human health risks are acceptable.

Table 7-2. Human Health and Ecological Risk COPC Update Summary

COPC	UMTRA MCL mg/L	Updated COPC for Human Health Risk ^a	Update COPC for Ecological Risk ^b	Comments and Rationale for Retaining as a COPC HR: Human Health Risk ER: Ecological Risk
Ammonia ^c		Y	Y	HR: HI ^d > 1 for inhalation in residential setting ER: One surface water concentration exceeded RBC ^e
Arsenic	0.05	Y	N	HR: Risks higher than acceptable; MCL not exceeded
Cadmium	0.01	N	N	HR: Insignificant contribution to total risk
Cobalt		N	N	HR: Insignificant contribution to total risk
Fluoride		N	N	HR: No evidence of use at millsite
Iron		Y	N	HR: HQ ^f > 1
Manganese		Y	Y	HR: HQ > 1
Molybdenum	0.10	Y	Y	HR: HQ > 1 ER: Concentration in cattail stems 2 to 3 times greater in site area than in reference area
Nickel		N	N	HR: Insignificant contribution to total risk
Nitrate	44	N	N	HR: Plume concentrations are within background range
²²⁶ Ra	5 pCi/g	N	N	HR: Plume concentrations are within background range
Sulfate		Y	N	HR: Toxicity data are currently under evaluation by EPA, but concentrations are high enough to be of probable concern
Uranium	0.044	Y	Y	HR: Primary carcinogenic and noncarcinogenic risk contributor ER: Concentration in one surface water sample exceeded EPA's Ecotox threshold and lowest chronic value
Vanadium		Y	Y	HR: Concentrations exceed RBC but have decreased two orders of magnitude from historical values ER: Concentration in one surface water sample exceeded EPA's Ecotox threshold and lowest chronic value
Zinc		N	N	HR: Insignificant contributor to total risk

NOTE: Boldface type indicates COPCs that were retained in 1998 update of BLRA

^aIdentified as a COPC if concentrations exceeded the calculated acceptable risk for a hypothetical residential exposure scenario.

^bIdentified as a COPC if concentrations exceeded an ecological benchmark or threshold.

^cScreened out as a COPC in the original BLRA through evaluation of ground water ingestion only; retained here for evaluation through inhalation pathway.

^dHI = Hazard index

^eRBC = Risk-based concentration (EPA 1998a)

^fHQ = Hazard quotient

Ecological Risk

Ecological risk assessments evaluate the likelihood that adverse ecological effects are occurring or might occur as a result of exposure to a physical, chemical, or biological entity. Section 6.2 and Appendix I describe the collection and evaluation of information from surface water, sediment, and vegetation to determine risks to the environment. Samples were collected from the plume area and from a reference area located in an ecologically similar environment about 3 miles (5 km) east (upgradient) along the Colorado River.

Results of this sampling indicate generally low levels of a few COPCs in sediment, surface water, and plant tissues. Some residual levels of millsite-related constituents still remain in ponded areas along the Colorado River that receive little or no regular surface water flushing. Nearly all the data indicate no significant differences between the Grand Junction site and the reference area for concentrations of COPCs in biotic and abiotic media. Because isolated maximum values for some constituents exceeded threshold values, it is recommended that ammonia in surface water, uranium in surface water, vanadium in surface water, vanadium in reed canarygrass stems, manganese in cattail stems, and molybdenum in cattail stems be retained as COPCs. Because data evaluation did not indicate an unacceptable ecological risk for the Grand Junction site, no further ecological risk assessment was performed. Table 7–2 lists the COPCs discussed in the 1995 BLRA and presents a summary of the rationale for retaining them in or deleting them from the 1999 update.

7.2.1.6 Compliance Strategy Selection

The fifth and final step in the decision process is the selection of an appropriate compliance strategy to meet the EPA ground water protection standards. The selected strategy is no remediation and application of supplemental standards based on the criterion of limited use ground water (40 CFR 192.21[g]). Ground water in the uppermost aquifer is not a current or potential source of drinking water because “widespread, ambient contamination not due to activities involving residual radioactive materials from a designated processing site exists that cannot be cleaned up using treatment methods reasonably employed in public water systems...” (40 CFR 192.11[e][2]).

7.3 Implementation of Supplemental Standards

7.3.1 Institutional Controls

7.3.1.1 On-Site Controls

The State of Colorado, through the Colorado Department of Public Health and Environment (the Grantor), transferred the Climax millsite property to the City of Grand Junction (the Grantee) via two quitclaim deeds recorded in the Mesa County Courthouse, Book 2320, pages 882 to 886, on March 29, 1997. As part of the agreement, the City agrees “not to use ground water from the site for any purpose, and not to construct wells or any means of exposing ground water on the property unless prior written approval of construction plans, designs and specifications is given by the Grantor and the U.S. Department of Energy.”

7.3.1.2 Downgradient Controls

Several controls are in place for private landowners downgradient of the millsite. The question of institutional controls has been investigated in the past.

Considerable research found no evidence that anyone was drinking water from the alluvial aquifer in the area of the millsite (see Appendix J). This conclusion resulted from inquiries with the Colorado State Engineer's Office for well permits, the City of Grand Junction water service records, visual physical inspections, and contact with about 40 percent of the landowners in the affected area.

As of 1998 the State Engineer's Office has no records of wells installed in the alluvial aquifer on or downgradient of the site. The nearest alluvial wells are south of the Colorado River on Orchard Mesa, which is not in the flow path of ground water from the alluvial aquifer.

Although the City of Grand Junction will not prevent someone from drilling a well, it does require citizens to hook up to municipal water lines for potable water.

The Western Colorado Botanical Gardens has a sump near the Colorado River for pumping water to the ponds on the western side of their property. Water from the lowermost and largest pond is used for watering the gardens but not for human consumption. The pond is lined to prevent surface water from contacting ground water and is fenced to prevent access. Analysis of pond water indicates uranium levels are below the MCL.

7.3.1.3 Public Involvement Plan

A Public Involvement Plan (MAC-GWGRJ 11.6.2) was prepared for the Grand Junction site. The plan describes the history of the UMTRA Project legislation and scope, a brief history of the Climax mill, Phase I (surface remedial action) at the site, the reasons for soliciting public involvement, and a summary of results from information gathered for this study. It also describes the types of public responses that were recorded at the public meeting conducted June 22, 1995. The public comments received at the meeting are included in Volume II of the PEIS (DOE 1996c).

A meeting was held in March 1999 with the City Council, other representatives from the city and county, the State Engineer's Office, CDPHE, and the public (see [Table 7-3](#)). Discussions included information gathered for this study, risks to human health and the ecology, and the supplemental standards compliance strategy based on the classification of limited use ground water. The purpose of the meeting was to inform the public about decisions that affect the community and to solicit comments for consideration during planning of the final compliance strategy.

Table 7-3. Public Participation Activities To Be Conducted Before Completion of the Environmental Assessment, SOWP, and Compliance Strategy

Activity	Scheduled Date
Send letter describing the proposed compliance strategy to: City Council County Commissioners Planning Commission State Engineer's Office	February 19, 1999
Send letter to adjacent property owners	February 26, 1999
Make presentation to City Council during regularly scheduled meeting. (D. Metzler, DOE-GJO)	March 3, 1999
Press releases (as needed)	July 15, 1999
Publish public notice in the Daily Sentinel twice a week for two months before issuing the Finding of No Significant Impact (FONSI)	July 15, 1999
Public meeting	To Be Determined

The Public Involvement Plan also provides a schedule for producing the Environmental Assessment and the Finding of No Significant Impact and for holding any meetings deemed necessary during this process (see [Table 7-4](#)). These documents are planned for completion in fiscal year 1999.

Table 7-4. Scheduled Public Participation Activities for Preparing the Environmental Assessment of Ground Water Compliance at the Grand Junction UMTRA Project Site

Activities	Scheduled Date
Review of draft Environmental Assessment by the State of Colorado	April 1999
Notification of Environmental Assessment availability : • News release • Federal Register notice (not required)	May 1999
Transmit draft Environmental Assessment to interested stakeholders, other agencies, public (upon request)	June 1999
Place copies of Environmental Assessment in public locations: • Mesa County Library • DOE-GJO Reading Room • Other	June 1999
Hold public meetings	As Needed
Comments received from stakeholders	July 1999
Comments addressed	July 1999
News release of Finding of No Significant Impact (FONSI) approval	August 1999
Final Environmental Assessment and Finding of No Significant Impact issued to the public, stakeholders, and agencies	September 1999
Place copies of Environmental Assessment in public locations: • Mesa County Library • DOE-GJO Reading Room • Other	September 1999

7.4 Future Activities and Contingencies

Future activities for the site will include verification of institutional controls to ensure continued protection of human health and the environment. Verification will be conducted annually for the next 5 years and will consist of consultation and documentation of discussions with the Grand Junction City Engineering Department, the State Engineer's Office, and the local office of the Colorado State Water Quality Division. If no changes are found or if no issues arise that might compromise established institutional controls, contacts will subsequently be made every 5 years for the next 20 years. Documentation of the contacts will consist of telephone logs sent to the UMTRA Ground Water Project file for the Grand Junction site. All future activities will be conducted through the Long-Term Surveillance and Monitoring Program.

Limited ground water monitoring is proposed as a best management practice to determine when concentrations of site-related constituents are at a level that certain uses of ground water may no longer be restricted. Determination of concentration levels and potential uses of ground water will be made on a case-specific basis by DOE, the State of Colorado, and the City of Grand Junction. Monitoring locations will include on-site monitor wells 1014 (the well with highest contaminant levels) and 1001 (directly downgradient from 1014), off-site and downgradient monitor well 590, background monitor well 745, and surface water location 427 (Colorado River downgradient from the millsite). Analytes will include ammonia (as NH_4), molybdenum, and uranium. Samples will be collected and analyzed annually for the first 5 years by the Long-Term Surveillance and Monitoring (LTSM) Program. If concentrations in ground water are steady or decreasing after this time, samples will be collected and analyzed every 5 years. If analyte concentrations are consistently below MCLs or baseline values during these 5-year intervals, the analyte list may be modified. Monitoring will continue for 5-year increments and be evaluated at these times until all analytes are below MCLs or baseline values, or until the monitoring program is modified or terminated.

Natural flushing is expected to decrease the concentrations of site-related constituents (ammonia, molybdenum, and uranium) in the alluvial aquifer over time. Natural processes such as dilution, dispersion, and sorption are the mechanisms that reduce contaminant concentrations in ground water. Since natural flushing was not part of the compliance strategy for ground water protection at the Grand Junction site, the collection of data and level of activity necessary to support a quantitative modeling study was not warranted. However, in a qualitative sense, it is estimated that natural flushing processes in the alluvial aquifer should significantly reduce site-related contaminants in ground water within a 100-year period. This estimation is based on an average hydraulic conductivity of 100 ft/day, a horizontal gradient of 0.004, and an effective porosity of 20 percent, which gives an average linear ground water velocity of 2 ft/day (730 ft/yr). Based on this linear ground water velocity, contaminant particles at the upgradient end of the area of site-related contamination would take approximately 8 years to traverse the 6,000 ft downgradient (southwest) to the discharge point in the Colorado River. If it were to conservatively take 10 pore volumes of ground water to flush significant amounts of contaminants from the aquifer, ground water quality would likely be approaching background levels in 80 to 100 years. Uranium in ground water beneath the site is relatively mobile, as predicted by the measured K_d , which has a value of approximately 1.0. A number of physical and chemical factors enter into the processes and affect the actual time required for changes to take place in the aquifer. For example, upgradient ground water migrating on site has naturally elevated concentrations of certain constituents. Evaluation of decreasing concentration levels and potential future uses of ground water in the vicinity of the Grand Junction site will be made by DOE, the State of Colorado, and

the City of Grand Junction in conjunction with the best management practice of limited ground water monitoring.

End of current text

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