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Rev. 1

# Final Site Observational Work Plan for the UMTRA Project Site at Mexican Hat, Utah

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# Acronyms and Abbreviations

| | |
|---|---|
| ac | acre(s) |
| ACL | alternate concentration limit |
| cm/s | centimeters per second |
| CFR | U.S. Code of Federal Regulations |
| DOE | U.S. Department of Energy |
| EA | environmental assessment |
| Eh | oxidation-reduction potential |
| EPA | U.S. Environmental Protection Agency |
| FR | Federal Register |
| ft | foot (feet) |
| ft/day | feet/day |
| gal | gallon |
| gal/hr | gallons per hour |
| gal/minute | gallons per minute |
| L | liter |
| MAP | Management Action Process |
| MCL | maximum concentration limit |
| mg/L | milligrams per liter |
| mi | mile |
| $mi^2$ | square miles |
| mm | millimeters |
| NEPA | National Environmental Policy Act |
| NRC | U.S. Nuclear Regulatory Commission |
| pCi/L | picocuries per liter |
| PEIS | Programmatic Environmental Impact Statement |
| RAP | remedial action plan |
| RRM | residual radioactive material |
| S | second |
| SEE | Site Environmental Evaluation database |
| 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 |
| USC | U.S. Code |
| $yd^3$ | cubic yards |

# Executive Summary

This Site Observational Work Plan addresses ground water compliance (Subpart B) for the UMTRA Ground Water Project Mexican Hat processing site. Surface cleanup at the site is complete. Associated mill tailings and contaminated former mill buildings from the Mexican Hat site and the nearby Monument Valley UMTRA site have been consolidated in the Mexican Hat disposal cell.

The requirements for ground water compliance for Uranium Mill Tailings Remedial Action (UMTRA) Project sites, including the Mexican Hat processing site, are stated in the Uranium Mill Tailings Radiation Control Act (42 USC §7901 *et seq.*) and in the U.S. Environmental Protection Agency's "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings" (40 CFR 192, Subpart B).

The processing/disposal site is underlain by the upper and lower units of the Permian Halgaito Formation. Scattered, ephemeral ground water occurs in fractures and in perched zones in the upper unit; ground water under confined and semiconfined conditions occurs in the lower unit (which is the uppermost aquifer).

Ground water contamination in the upper unit of the Halgaito Formation at the Mexican Hat site is the result of uranium milling operations. Uranium was concentrated from 2.2 million tons of ore using the acid-leaching process. Waste water associated with the milling process and water used to place the mill tailings in the disposal cell contain process products and byproducts and are the primary sources of water in the upper unit of the Halgaito. The extent of this residual process water is limited to the upper unit of the Halgaito. Water in the upper unit of the Halgaito Formation is not considered a significant resource because of limited recharge, relatively low hydraulic conductivity, generally low yield from monitor wells completed in the unit, and minimal areal extent. Water quality is not particularly good, resulting both from natural characteristics and contamination introduced during the uranium mill operations. It appears that the upper unit of the Halgaito was predominantly unsaturated before milling operations and is returning to this state. The lower unit of the Halgaito Formation (uppermost aquifer) is not affected by uranium processing activities because of an upward hydraulic gradient and the presence of an overlying confining unit (the deeper aquifers are protected by hydrogeologic isolation). The perched water in the upper unit of the Halgaito Formation is not a ground water resource because of its limited yield.

Ground water in the upper and lower units of the Halgaito is not a current or potential source of drinking water. The nearby San Juan River and two water supply wells provide all the water needs for the area. There are no current threats to human health and the environment in the area. There are, however, seeps issuing from the upper unit of the Halgaito where contaminated water is exposed at land surface. The seeps create potential exposure pathways for plants and wildlife, but it appears that there is no risk to the environment. These seeps (248, 249, 251, 253, 254, 255, 256, 261, 922, 923, and 924) are being monitored quarterly as part of the Long Term Surveillance and Maintenance project.

The ground water compliance strategy for the site is no remediation, because the ground water in the lower unit of the Halgaito Formation (uppermost aquifer) has not been contaminated by uranium processing activities (NRC 1996) and there are no threats to human health and the environment.

# 1.0 Introduction

The purpose of the Mexican Hat, Utah, Uranium Mill Tailings Remedial Action (UMTRA) Project Site Observational Work Plan (SOWP) is to (1) provide a summary of all existing characterization data and (2) propose a site-specific ground water compliance strategy that meets the U.S. Environmental Protection Agency (EPA) ground water standards in Title 40, Part 192, Subpart B of the *U.S. Code of Federal Regulations* (40 CFR 192, Subpart B) at this UMTRA Project site.

The SOWP also summarizes site conditions, presents a site conceptual model based on existing characterization data, and identifies the proposed compliance strategy. The site conceptual model describes the sources of the contaminants of potential concern, defines the current conditions, and evaluates environmental and human health risks.

Section 2.0 of this SOWP describes the requirements for meeting standards at UMTRA Project sites. Section 3.0 summarizes site-specific data and provides the site conceptual model. Section 4.0 provides justification for the recommended ground water compliance strategy for the Mexican Hat site. Section 5.0 provides a list of the references cited. The appendices include data on monitor well construction, aquifer lithology, and analytical results of ground water and surface water sampling.

## 1.1 Ground Water Compliance Strategy

The proposed ground water compliance strategy for the Mexican Hat site is no remediation and continued monitoring of seeps and the Halgaito Formation ground water. Site data indicate that the uppermost aquifer (the lower unit of the Halgaito Formation) beneath the processing site has not been contaminated by uranium milling activities. Beneficial use of ground water from the uppermost aquifer is protected because the contaminated zone is hydrogeologically isolated. Contamination introduced from uranium processing is only present in the perched, ephemeral ground water system at a higher stratigraphic level in the Halgaito Formation. Water in this system emerges as seeps downgradient of the site along North Arroyo and Gypsum Creek. Based upon data from the seeps closest to the disposal cell, 249 and 251, it appears concentrations of contaminants may be decreasing. It is believed that contamination in the seeps will decrease over time; therefore, monitoring of contaminant concentrations in the seeps will continue in order to verify that concentrations are decreasing.

## 1.2 UMTRA Project Programmatic Documents

The programmatic documents that guide the SOWP include the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailing Remedial Action Ground Water Project* (PEIS) (DOE 1996a), the *Technical Approach to Groundwater Restoration* (TAGR) (DOE 1993b), and the *UMTRA Ground Water Project Management Action Process* (MAP) document (DOE 1998). The PEIS provides an objective programmatic decision-making framework for conducting the UMTRA Ground Water Project, assesses the potential programmatic impacts 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 (42 USC §4321 *et seq.*). The TAGR provides technical guidance for conducting the ground water program. The MAP states the mission and objectives of the UMTRA Ground Water Project and provides a technical and managerial approach for conducting the project.

## 1.3 Relationship to Site-Specific Documents

The surface remedial action plan (RAP) (DOE 1993c) provides site characterization information. This information is updated for the SOWP to formulate the site conceptual model. If a ground water compliance strategy requiring remedial action is selected for this site, a draft and final Ground Water Compliance Action Plan will be prepared; otherwise a page modification to the surface RAP will suffice.

This document and others identify the potential public health and environmental risks at the site. Potential risks are considered in this SOWP to ensure that the proposed compliance strategy is protective of human health and the environment.

After identification of a proposed compliance strategy in the final SOWP, a site-specific NEPA document (e.g., environmental assessment [EA]) will be prepared to determine the potential effects, if any, of implementing the proposed compliance strategy.

## 1.4 SOWP Revisions

The SOWP is a multiyear process of sequenced document preparation and field data collection activities consisting of two versions: Revision 0 (draft) and Revision 1 (final).

The draft SOWP was prepared in 1995 and included all previous information about the site, presented a proposed compliance strategy, and defined additional data needs.

This final SOWP presents the additional data collected since 1995, correlates the data to previous information, updates the site conceptual model, and recommends a final compliance strategy based on the updated site conceptual model.

# 2.0 Regulatory Framework

This final SOWP proposes a ground water compliance strategy for the Mexican Hat site that achieves compliance with Subpart B of the EPA ground water standards applicable to Title I UMTRA Project processing sites. This section identifies the relationship of the Uranium Mill Tailings Radiation Control Act (UMTRCA), EPA compliance standards, the cooperative agreements, and NEPA to the UMTRA Ground Water Project.

## 2.1 Uranium Mill Tailings Radiation Control Act

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

UMTRCA has three titles that apply to uranium processing sites. Title I designates 24 inactive processing sites that will undergo remediation, directs EPA to promulgate standards, mandates remedial action in accordance with standards prescribed by EPA, directs the U.S. Nuclear Regulatory Commission (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 UMTRA Amendments Act (42 USC §7922 *et. seq.*), authorizing DOE to extend without limit the time needed to complete ground water remediation at the processing sites.

### 2.1.1 Ground Water Protection Standards

UMTRCA requires EPA to promulgate standards for protecting public health and the environment from hazardous constituents associated with the processing of uranium and the resulting residual radioactive materials (RRM). On January 5, 1983, EPA published standards (40 CFR 192) for the disposal and cleanup of RRM. The standards were revised and a final rule was published on January 11, 1995 (60 FR 2854).

The standards address two ground water contamination scenarios: future ground water contamination that may occur from tailings piles after disposal, and cleanup of contamination that occurred at the processing sites before disposal of the tailing piles (40 CFR 192). Protection of ground water at the disposal sites is addressed under the UMTRA Surface Project with the design of disposal cells and the long-term surveillance plans. The UMTRA Ground Water Project addresses residual contamination at the processing sites and is regulated by Subparts B and C of 40 CFR 192.

Subpart B, "Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites" (40 CFR 192), requires that remedial action at processing sites be conducted to ensure that concentrations of RRM in ground water meet one of the following three criteria:

- Background levels—concentrations of constituents in nearby ground water not contaminated by processing activities.
- Maximum concentration limits (MCLs)—EPA's maximum concentration of certain hazardous constituents in ground water, as proposed for the UMTRA Project (see Table 2–1).
- Alternate concentration limits—an alternate concentration limit (ACL) for a hazardous constituent that does not pose a substantial present or potential hazard to human health and the environment, as long as the limit is not exceeded. An ACL may be applied after considering options to achieve background levels or MCLs.

*Table 2–1. Maximum Concentrations of Inorganic Constituents for Ground Water Protection at UMTRA Project Sites (40 CFR 192)*

| Constituent | Maximum Concentration[a] |
|---|---|
| Arsenic | 0.05 |
| Barium | 1.0 |
| Cadmium | 0.01 |
| Chromium | 0.05 |
| Lead | 0.05 |
| Mercury | 0.002 |
| Molybdenum | 0.1 |
| Nitrate (as N) | 10.0[b] |
| Selenium | 0.01 |
| Silver | 0.05 |
| Combined radium-226 and radium-228 | 5 pCi/L |
| Combined uranium-234 and uranium-238 | 30 pCi/L[c] |
| Gross alpha-particle activity (excluding radon and uranium) | 15 pCi/L |

[a]Milligrams per liter (mg/L), unless otherwise noted.
[b]Equivalent to 44 mg/L nitrate as nitrate.
[c]Equivalent to 0.044 mg/L.

pCi/L = picocuries per liter.

Under certain conditions, DOE may apply supplemental standards to contaminated ground water in lieu of background levels, MCLs, or ACLs (40 CFR 192).

Subpart B also provides for selecting natural flushing as a means to meet the proposed standards. Natural flushing allows natural ground water processes to reduce the contamination in ground water to acceptable standards (background levels, MCLs, or ACLs). Natural flushing must allow the standards to be met within 100 years. In addition, ground water must not be a current or projected source of drinking water during the period of natural flushing. Institutional controls (measures that restrict access to contamination and retain beneficial uses of ground water) that protect human health must be established and maintained during the period of natural flushing.

Subpart C, "Implementation," provides guidance for implementing methods and procedures to reasonably ensure that standards of Subpart B are met. Subpart C requires that the standards of

Subpart B are met on a site-specific basis using information gathered during site characterization and monitoring. The plan to meet the standards of Subpart B must be stated in a site-specific ground water compliance action plan. The plan must contain a compliance strategy and a monitoring program, if necessary (40 CFR 192.12[c]).

### 2.1.2 Cooperative Agreements

The UMTRCA requires that remedial action include full participation of the states and Indian tribes that own land containing uranium mill tailings. UMTRCA also directs DOE to enter into cooperative agreements with the states and Indian tribes.

## 2.2 National Environmental Policy Act

Implementation of UMTRCA represents a major federal action subject to the requirements of NEPA of 1969 (42 USC §4321 *et seq.*). The Council on Environmental Quality's regulations that implement NEPA are codified in 40 CFR 1500–1508. The regulations require that each federal agency develop its own implementing procedures (40 CFR §1507.3). DOE-related NEPA regulations are contained in 10 CFR 1021, "National Environmental Policy Act Implementing Procedures." DOE guidance is provided in *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements* (DOE 1993d).

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

# 3.0 Site Background

The Mexican Hat UMTRA site is within the Navajo Reservation in San Juan County, Utah, east of U.S. Highway 163, between the towns of Halchita and Mexican Hat, approximately 18 miles (mi) southwest of Bluff, Utah, and 10 mi north of the Arizona border (Figure 3–1). A uranium processing mill operated at the site from 1957 until 1965, and a sulfuric acid plant operated from 1957 to 1970. An overview of the site's physical setting and climate, a history of the former milling operation, and a summary of previous investigations is presented in the following sections.

## 3.1 Physical Setting and Climate

The Mexican Hat site is within the Colorado Plateau physiographic province that covers approximately 114,000 square miles ($mi^2$) in Utah, Arizona, Colorado, and New Mexico. Major topographic features in the area are the deeply entrenched San Juan River to the north and prominent Raplee Ridge to the northeast. The elevation of the site is approximately 4,300 feet (ft) above mean sea level.

The climate in the area is arid with widely ranging daily and annual temperatures. Winters are cold (night time temperatures below freezing prevail from November through March), and summers are hot; high temperatures range from 90 to 105 °F. Average annual precipitation is approximately 6 inches. Precipitation is fairly evenly distributed throughout the year. Snowfall is usually light. Mexican Hat received an annual average of 3.3 inches of snow from 1951 through 1980.

The area is sparsely vegetated by desert shrubs and grasses and the land around the site is used for limited residential purposes and livestock grazing.

## 3.2 Site History

The mill at Mexican Hat was constructed and operated from 1957 to 1963 by Texas-Zinc Minerals Corporation. Atlas Corporation purchased the mill in 1963 and operated it until it was closed in 1965. The mill was built on land leased from the Navajo Nation; control of the site reverted to the Navajo Nation after the Atlas Corporation lease expired in 1970. The designated Mexican Hat UMTRA Project site covered 235 acres (ac) (DOE 1996b).

Much of the ore processed at the Mexican Hat site came from the White Canyon area of Utah and contained a considerable amount of copper sulfide and other sulfide minerals. The ore was crushed, ground, and treated by froth flotation. The flotation concentrates and tailings were acid leached separately to recover both copper and uranium. During its operation, the mill processed 2.2 million tons of ore and produced 5,700 tons of uranium concentrate. In addition to the milling operation, a sulfuric acid manufacturing plant operated at the site until 1970 (DOE 1996b).

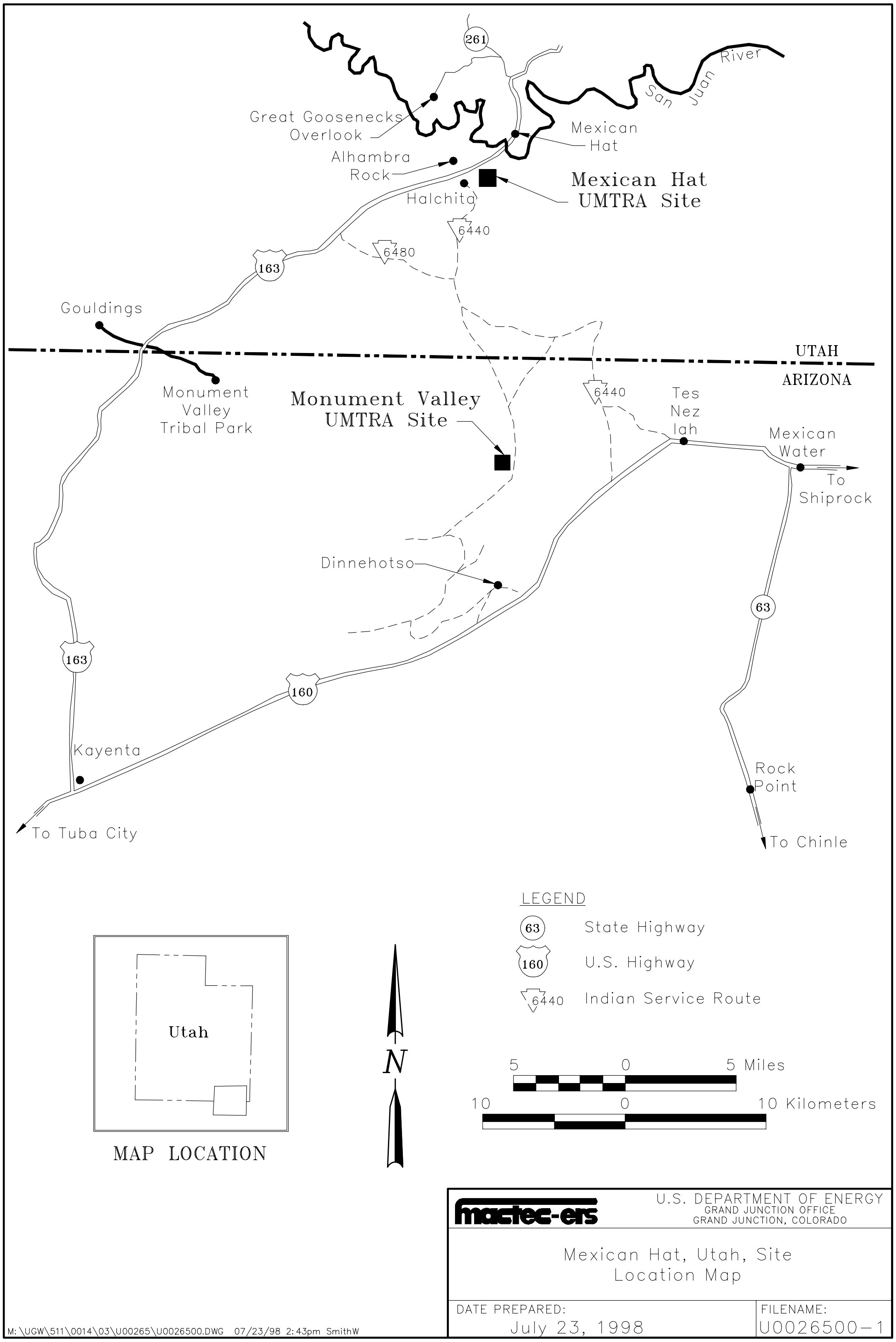


Figure 3–1. Mexican Hat, Utah, Site Location Map

The waste solids or tailings from milling of the ore were transferred to two tailings piles. The upper tailings pile covered approximately 24 ac and had an average thickness of 20 ft. Dispersion of the tailings by wind and water erosion contaminated 162 ac of land adjacent to the tailings piles and outside the designated site boundary. Another 19 ac within the designated site were contaminated by activities around the mill buildings and in the former ore storage area. The total volume of RRM, including the tailings and soils beneath and around the tailings, was estimated to be 2,654,000 cubic yards ($yd^3$) (DOE 1996b).

At the time of the remedial action, the concrete pad for the mill building and several associated buildings and structures (e.g., scale house, office building, and tanks) remained. One or two of the smaller buildings appeared to be used for storage, and the Navajo Tribal Utility Authority operated a small electrical substation and sewage system (three lagoons) at the site. Access to the site was not restricted; however, the Navajo Environmental Protection Administration had discouraged any activity at the site since 1978 (DOE 1996b).

The Mexican Hat site is also the repository for RRM from the Monument Valley, Arizona, UMTRA site. The total volume of RRM at the Monument Valley site, including tailings, soils beneath and around the tailings, and other contaminated materials, was estimated to be 983,300 $yd^3$. The Monument Valley site RRM was transported to the Mexican Hat site and placed on top of the Mexican Hat RRM in the disposal cell (DOE 1996b).

### 3.2.1 Surrounding Land Use

The town of Mexican Hat had an estimated population of 259 in 1990 (DOC 1990). The population of Halchita was estimated at 500 in 1985, roughly equivalent to the 1980 population (DOE 1987). There are no residences in the area of the disposal cell, between the disposal cell and seeps, or in the area of contaminated seeps. Land use near the tailings site is controlled by the Utah Navajo Development Corporation and is limited to livestock grazing.

### 3.2.2 Surrounding Water Use

There are no recorded uses of ground water within a 2-mi radius of the former mill site, based on results of a well inventory (DOE 1993c). Water in the upper unit of the Halgaito Formation contaminated by the former uranium mill is not used as a drinking-water resource, and there is no evidence of any effect on community water supplies. Small amounts of contaminated water from the upper part of the Halgaito could potentially seep into the nearby arroyos and eventually drain into the San Juan River. However, no effect would be expected, because contaminant concentrations will decrease with time and any water draining into the river would be substantially diluted resulting in concentrations of hazardous constituents less than background or MCLs. Analytical results of water samples show that the quality of water in the San Juan River is unaffected by the Mexican Hat UMTRA site (DOE 1993c). Based on sampling results, ground water in the lower Halgaito Formation (uppermost aquifer) has not been contaminated by processing activities at the former millsite.

The water supply for the community of Halchita is from a treatment plant that obtains water from the San Juan River. The community of Mexican Hat derives its water supply from the San Juan River and two water supply wells northwest of the San Juan River (Avery 1986) (Plate 1). The two water supply wells at a surface elevation of approximately 4,080 ft were installed by the San Juan Association. The wells, drilled to 57 and 54 ft (water depths of 19 and 11 ft respectively), derive water from fractures in the lower unit of the Halgaito Formation. The San Juan River is between the site and the water supply wells, so no flow paths exist between the contaminated water from the site and the water supply wells.

### 3.2.3 Contaminant Sources

The Mexican Hat UMTRA site contamination was caused by the discharge of waste water and tailings from uranium milling, and construction water due to tailings consolidation during material compaction. Contamination is present in this residual process water within the upper part of the Halgaito Formation. Although in operation for a longer period of time, the sulfuric acid plant probably contributed little additional contamination when compared to the uranium mill. Contaminant sources did not exist before plant startup in 1957 because the site was vacant land.

Mill tailings are the fine-grained materials (sand, silt, and clay) resulting from the uranium removal process. Because the uranium represented only a small portion of the ore, the volume of tailings is approximately equal to the amount of ore processed (i.e., approximately 2.2 million tons). The tailings were mixed with water from the San Juan River and waste water from the chemical concentration process. The tailings and water mixture was pumped through pipes to the upper and lower tailings piles a short distance from the processing plant (the former upper tailings pile and former millsite are shown on Figure 3–2). The current disposal cell is located at the former lower tailings pile.

A standard acid-leach process for uranium concentration was used at the Mexican Hat site. Process materials contributing to site contamination were uranium ore, sulfuric acid, nitric acid, magnesium hydroxide, manganese, ammonium nitrate, and ammonia. Constituents resulting from the process materials and byproducts were copper, vanadium, molybdenum, ammonium, sulfate, nitrate, magnesium, calcium, and uranium.

The removal of copper from the ore and the operation of the sulfuric acid plant were important components of the uranium milling process. Because of the relatively high copper content and its interference with the uranium concentration process, copper was removed from the ore before uranium. Sulfuric acid was produced from sulfur trucked to the site from Wyoming.

Waste products from the copper and sulfuric acid operations were similar to the uranium mill waste products. The waste produced from these operations is assumed to be included in the overall waste water generated from the mill.

Waste water was produced from the mill at a rate of 1 to 5 tons for every ton of ore processed (Merritt 1971). Therefore, from 2.2 to 11 million tons of waste water was produced during the 8 years of operation. This is equivalent to between 71 and 350 million cubic feet ($ft^3$) or from 0.53 to 2.6 billion gallons (gal) of waste water. Waste water was disposed of with the tailings.

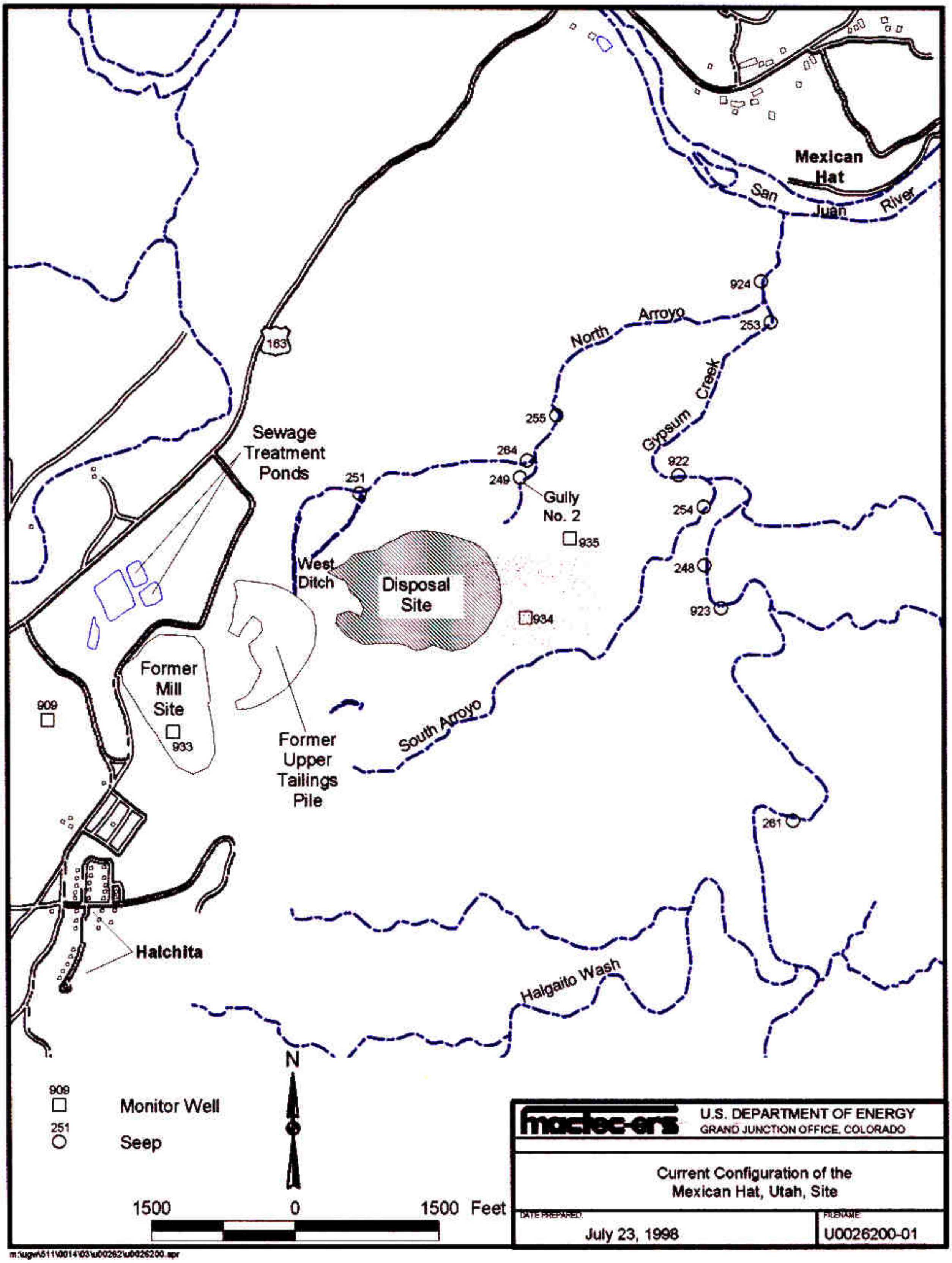


*Figure 3–2. Current Configuration of the Mexican Hat, Utah, Site*

An estimated 250 million gallons per year of waste water was produced over the 8 year period of operation; this totals approximately 2.0 billion gallons. Much of this water has evaporated—the annual evaporation rate in the area is 84 inches (DOE 1993c). A certain amount of the water infiltrated into the upper Halgaito Formation during the 8 years of operation and discharged from the seeps into the adjacent arroyos. During the 33 years since the cessation of milling operations, the amount of contaminated water initially introduced into the upper Halgaito by the milling operations has substantially decreased. Small amounts are still present, however, as evidenced by several of the seeps that still indicate elevated concentrations of constituents related to the processing activities. The amount of recharge to the upper Halgaito is limited to precipitation (average annual precipitation is approximately 6 inches), possible contribution from the sewage settling ponds updip from the disposal site, and potential transient drainage from the disposal cell (which would be minimal and continuously decreasing).

Mill tailings and the former mill buildings from the Monument Valley UMTRA site were relocated to the disposal cell at the Mexican Hat UMTRA site in January 1994. Because the processes and ore used at the former mills were similar, the characteristics of the Monument Valley wastes are similar to those at the Mexican Hat site. The addition of the Monument Valley wastes adds to the size of the disposal cell and to the amount of water that will temporarily drain from the cell but does not influence the chemical characteristics of the tailings or tailings pore fluids.

### 3.2.4 Site Status

The site was leased from the Navajo Nation by the site operators from 1957 until 1970 when the lease expired. Control of the site and all structures and materials then reverted to the Navajo Nation (DOE 1993c).

Remedial action at the Mexican Hat disposal site was completed in 1995. Approximately 3.6 million $yd^3$ of RRM were stabilized in a disposal cell at the location of the lower tailings pile. The former mill office building and sewage lagoons were left intact. The roughly pentagonal-shaped disposal cell covers approximately 68 ac and the fenced disposal site encompasses approximately 119 ac (DOE 1996b).

## 3.3 Previous Investigations

Pre-milling site conditions, construction of the mill, and mill processes were described by Banks (1959). Additional details regarding the process of uranium concentration, mill byproducts, and process waste streams are provided in Merritt (1971).

Site hydrogeologic conditions are described in detail in the RAP (DOE 1993c) and the Technical Evaluation Report prepared by NRC (NRC 1996). Additional information was obtained through a review of geologic and hydrologic reports cited in the RAP, an examination of monitor well completion reports, and water chemistry data in the UMTRA Project Site Environmental Evaluation database (SEE UMTRA). The SEE UMTRA system contains results from laboratory and field analyses of water samples collected as part of the UMTRA Project.

# 3.4 Geology and Hydrology

## 3.4.1 Physical Setting

The site is approximately 1 mi south of the San Juan River, on the northern boundary of the Navajo Uplands section of the Colorado Plateau physiographic province. The topography of the Navajo Uplands section has been influenced primarily by erosion from the Colorado River and its tributaries, which include the San Juan River (DOE 1987).

The disposal site is on a relatively flat mesa at an elevation of about 4,300 ft. Surface drainage from the site and surrounding areas is to the San Juan River, which is at an elevation of about 4,055 ft at a point nearest the site (Plate 1). Bounding the mesa to the north and east are North Arroyo and Gypsum Creek, which are ephemeral drainages (surface water flow is present only after significant rainfall). The arroyo and creek are relatively narrow with near vertical walls 30 to 100 ft deep. South of the site is a ridge that rises about 100 ft above the site; west of the site the topography is similar to the North Arroyo and Gypsum Creek areas, relatively flat but with deeply incised arroyos (Plate 1).

## 3.4.2 Geology

The geologic unit exposed at ground surface is the Halgaito Formation, the basal part of the Permian Cutler Group. Although previously called the Halgaito Shale, the term Formation has recently been used in the literature to imply that several lithologic types are present (Lowe 1996). The most common lithology in the Halgaito is siltstone, with shale, very fine grained to fine-grained sandstone, and thin, lenticular limestone present but less common. In this report, the Halgaito is informally divided into the upper and lower units; the lower unit is classified as the uppermost aquifer in the vicinity of the site. Soil is thin to nonexistent in the area due to the extremely dry climate. Beneath the Halgaito Formation is the Honaker Trail Formation, which is the upper part of the Pennsylvanian Hermosa Group. The Honaker Trail Formation was not characterized during this investigation.

Correlation of units in this area and placement of the boundary between the Pennsylvanian and the Permian is somewhat subjective because of disagreement in the literature (O’Sullivan 1965). In general, the contact between the Pennsylvanian and the Permian is a pervasive limestone unit (the McKim Limestone) that contains marine fossils and lies atop the Honaker Trail Formation. The McKim Limestone crops out approximately 0.5 mi west of the site and forms the cap of the ridge that rises to the west. North-northeast of the site along the San Juan River, the McKim dips eastward and passes below the level of the river at an elevation of approximately 4,050 to 4,055 ft. If this elevation is projected south-southwest along formation strike, it agrees closely with the elevations projected for the Halgaito/Honaker Trail contact in the area just west of Gypsum Creek near monitor well 935. The McKim Limestone is overlain by the fluviatile siltstones of the Halgaito Formation. The lithologies of respective units in this area have been adequately described by O’Sullivan (1965) and in other literature from the area. Lithologic descriptions below are derived from drill cuttings from the monitor wells installed at the site. For the purposes of this report, these descriptions are sufficient for defining the local geology and stratigraphy.

The lithologic descriptions in the borehole logs from wells installed at the Mexican Hat site indicate the presence of coarser grained material in the Halgaito; this is partly a result of the drilling technique (often much of the finer grained materials are not retained in the drill cuttings) and partly a result of the site geologists interpretation of lithology in the drill cuttings. Fracturing occurs in the Halgaito but is not extensively discussed because core from five of the boreholes was destroyed before being logged in detail. Qualitative information on the orientation and spacing of joints indicates that the predominant trend is east-northeast, the dip is vertical, and the spacing is approximately 2 ft. The descriptions below are based on the borehole lithologic logs (provided in Appendix A).

The upper unit of the Halgaito Formation consists primarily of siltstone interbedded with silty sandstone and shale. Calcareous, well-cemented beds alternate with less-cemented beds. A few thin, lenticular beds of limestone and conglomerate are also present (DOE 1993c). The conglomerate consists of siltstone and limestone pebbles in a silty matrix. The upper unit is up to 215 ft thick near the site, based on lithologic logs from 16 wells drilled for the UMTRA Project (Plate 1). Well logs are presented in Appendix A. Two sets of nearly vertical fractures (trending east-west and northeast-southwest) and fractures along bedding planes (which dip gently to the east) are present in the upper portion of the Halgaito at the site (Plate 1). The presence and size of the fractures decrease significantly with depth (DOE 1993c).

The lower unit of the Halgaito Formation consists of siltstone interbedded with limestone, shale, and sandstone. Chert and limestone nodules are present throughout the siltstone beds. The limestone units are predominantly fine to very fine grained and crystalline. The sandstone units are very fine to fine grained. The contact between the Halgaito and the Honaker Trail Formations is marked by the McKim Limestone, a fossiliferous marine limestone (typically 3 to 5 ft thick) with a strong chemical odor (like that of hydrogen sulfide) when penetrated, which is at the top of the Honaker Trail Formation. The base of the lower unit of the Halgaito is at a depth of 181 ft in monitor well 908, and 158 ft in monitor well 909 (Plate 1).

### 3.4.3 Ground Water Hydrology

#### *Upper Unit of the Halgaito Formation*

The upper unit of the Halgaito Formation is predominantly unsaturated but has some scattered ephemeral ground water in fractures and as perched water overlying finer grained zones. Because of the fine-grained nature of the sediments and the presence of intergranular calcium and silica cement, the unit exhibits very little primary hydraulic conductivity. Although there are a few conglomerate zones within the Halgaito, the hydraulic conductivity of those zones is also low because of the fine-grained matrix and cementation. Fracture-related hydraulic conductivity of the unit decreases with depth because of a decrease in the number and size of the fractures. Lenticular (or continuous) limestone beds in the lower unit of the Halgaito function as a confining unit. A water table map for the upper unit of the Halgaito was not constructed because of the limited extent of water and because water is contained predominantly in fractures or is perched. However, the orientation of the nearly vertical fractures and the fractures along the bedding planes that control the ground water flow direction have been adequately identified to determine that the direction of ground water flow is generally downdip toward the seeps in Gypsum Creek and North Arroyo.

Hydraulic conductivity of the upper and lower units of the Halgaito Formation was estimated based on packer tests and slug tests. The horizontal hydraulic conductivity of the upper unit of the Halgaito Formation, based on packer tests, is between 0.75 and 0.19 ft/day in the upper portion and 0.014 ft/day in the lower portion (DOE 1993c). Therefore, the lower portion of the upper unit of the Halgaito is a very effective confining unit and significantly limits the vertical exchange of water between the upper and lower units of the Halgaito Formation. The estimated hydraulic conductivity of the upper unit of the Halgaito, based on slug tests in three monitor wells (912, 934, and 935), ranged from 0.002 to 0.26 ft/day. Calculations of hydraulic conductivity are presented in Appendix B.

Current sources of potential recharge to the upper unit of the Halgaito Formation include precipitation, seepage from the sewage settling ponds updip from the disposal site, leakage from the aqueduct that supplies water from the San Juan River treatment plant to Halchita, and possibly some transient drainage from the disposal cell. Recharge resulting from precipitation is limited by low annual rainfall (6 inches) and high evaporation (84 inches) (DOE 1993c). Annual evaporation exceeds precipitation every month except January, when average rainfall is 0.5 inch and evaporation is 0.35 inch. Seepage from the sewage ponds would be minimal because it is a point source with a relatively small volume of water over time; that volume is also decreased by evaporation. These sewage ponds, however, may be a source of some of the nitrate detected in water in the nearby seeps. Transient drainage from the disposal cell should be minimal and continuously decreasing (because of the design of the cell). A substantial amount of water was introduced into the system during the 8-year period of uranium milling operations from 1957 through 1965 (see Section 3.2.3) and during construction of the disposal cell. Residual water related to this process is still in the system and may be part of the contaminated water discharging from the seeps in North Arroyo and Gypsum Creek. A certain amount of natural regional recharge occurs, as evidenced by some variation in water levels in monitor well 934 over time, and discharge from a noncontaminated seep (261) in Gypsum Creek.

Ground water discharges from the upper unit of the Halgaito Formation through fractures and on low permeability beds as water travels toward the seeps in North Arroyo and Gypsum Creek. Water in some of the seeps contains constituents indicative of contamination related to the processing site. Some of the water may infiltrate downward but then preferentially flows along the top of thin limestone beds scattered through the upper part of the Halgaito, discharging in the form of seeps, or possibly discharging into the San Juan River. A qualitative water balance for the area shows that the current rate of recharge from precipitation and other man-made sources (sewage pond) to the upper unit is minimal, and residual water from the uranium processing activities has most likely dissipated over the 33 years since cessation of milling operations. Transient drainage from the base of the disposal cell is considered to be minimal based on design criteria. Therefore, only a small amount of water will infiltrate into the upper unit of the Halgaito; that water will ultimately discharge into the seeps in North Arroyo and Gypsum Creek.

Characterization of water in the upper unit of the Halgaito Formation is based on limited information from four borings (905, 906, 911, and 912). Of the four borings, ground water was not found in one (905), and monitor wells were only installed in the remaining three boreholes. Of the three monitor wells, two have gone dry since installation (906 and 911). The remaining well (912) had sufficient water for sampling, but contained a limited water column (approximately 6 ft), which would inhibit any potential use as a water resource well.

The methods employed for drilling within the upper unit of the Halgaito (air rotary and air hammer) are appropriate for evaluating the presence of ground water and are typically used for installation of water-supply wells in the region of the site. Some of the borings/wells were dry even when drilled below the depth where the zone of saturation was expected. Others were drilled shallow to provide geotechnical information. Water levels initially recorded in some wells have decreased over time. This may be attributable to water introduced during drilling that gradually dissipated. The overall result of the drilling program in the upper unit of the Halgaito, combined with records of water-level measurements, provides an indication of the probable limited extent and low potential yield of ground water from the upper unit of the Halgaito Formation in the vicinity of the disposal site. These factors, along with the presence of residual contamination in the available water, minimize the potential of this unit as a viable water resource in the area. This is offset by availability of potable water from the San Juan River and deeper aquifers, and the indication that anticipated growth in the area in the foreseeable future will not require additional water resources from such marginal sources as those in the upper unit of the Halgaito.

Ground water in the upper unit of the Halgaito Formation is not considered a significant resource because of limited recharge, relatively low hydraulic conductivity, low yield from monitor wells completed in the unit, and minimal areal extent. The poor quality of the water results both from natural characteristics and contamination introduced during the uranium milling operations. A small amount of water has always infiltrated from precipitation, causing some seepage at points along North Arroyo and Gypsum Creek (as evidenced by vegetation along Gypsum Creek appearing in aerial photographs from 1946, and eyewitness accounts before World War II, which provide evidence for the presence of seeps 922, 923, and 248 before the start of milling operations in 1957). Some of the water presently contained in the Halgaito is a result of former milling operations (discharge of process water and water used to place the tailings) and, to a lesser extent, transient drainage from the disposal cell. Information to support the source of the water as primarily from former milling operations is presented in Section 3.5.

### *Lower Unit of the Halgaito Formation*

The lower unit of the Halgaito Formation is classified as the uppermost aquifer beneath the site. The aquifer is isolated from ground water in the upper unit of the Halgaito by thin lenticular to continuous limestone beds in the lower unit that act as a confining layer limiting vertical water movement. There also is an upward hydraulic gradient in the lower unit, preventing ground water in the upper unit from entering the lower unit of the Halgaito. Water levels in the lower unit of the Halgaito are above water levels in the upper unit, and, in one instance, ground water flowed at the ground surface (monitor well 907) (Plate 1).

Ground water in the lower unit of the Halgaito Formation flows east toward the San Juan River at an average gradient of 0.45 (Plate 1). The estimated hydraulic conductivity of the lower unit of the Halgaito, based on slug tests in three monitor wells (908, 909, and 930), ranged from 0.11 to 0.86 ft/day (calculations of hydraulic conductivity are presented in Appendix B). The potentiometric surface map for the lower unit of the Halgaito was based on ground water elevations measured during 1985 because that was the time of maximum data availability and areal coverage. Recharge to the unit is limited and may occur as rainfall in areas to the west where the unit is closer to or exposed at ground surface. A certain amount of natural regional recharge occurs, as evidenced by some variation in water levels in monitor well 909 over time. The discharge area for ground water in the lower unit is the San Juan River.

Although ground water is not contaminated from the uranium milling activities, the natural water quality of the lower unit of the Halgaito in the vicinity of the site is likely unsuitable for human consumption. Three of the monitor wells (910, 932, and 936) showed the presence of hydrogen sulfide during drilling. Two of these wells (932 and 936) were abandoned due to the potential health hazard of the hydrogen sulfide gas. Well 910 was completed and screened at a depth of 140 to 180 ft. Naturally occurring petroleum was also present in wells 908, 910, 931, 932, and 936 (see well logs in Appendix A). A small amount of oil is produced from the Honaker Trail Formation in the nearby Mexican Hat oil field (located in and near the town of Mexican Hat).

### 3.4.4 Surface Water Hydrology

The disposal cell is located within an arroyo that originally drained northeastward to Gypsum Creek. Drainage channels were constructed upslope and downslope from the disposal cell, and other local drainages were improved, to divert surface water away from the cell. The surface drainage pattern is shown on Plate 1.

Surface water is sometimes present in unlined ponds west of the tailings pile. The ponds were originally constructed as sewage treatment ponds for the mill community and now serve the same purpose for the community of Halchita. Waste water either evaporates or infiltrates into the Halgaito Formation and discharges to an unnamed arroyo that drains to the northwest into the San Juan River. Seepage from the ponds does not affect site-related seeps in the North Arroyo or Gypsum Creek, since the ponds are in a drainage basin separate from the site drainage basin. Because they are in a separate drainage basin and are unaffected by site activities, water from these ponds has not been sampled.

Ground water and surface water interactions are limited to the small amount of recharge to the upper unit of the Halgaito Formation from rainfall events. The lack of surface water in North Arroyo and Gypsum Creek show that these surface water features do not act as ground water discharge areas, except for the small amount of seep water that discharges to them from the walls of the arroyos. The San Juan River acts as a regional ground water recharge and discharge area.

Under normal conditions (i.e., between rainfall events), discharge from the seeps represents the total contribution to surface water in the creek and arroyo. Seep discharge is not sufficient to support a continuous flow of surface water. Significant rainfall events can cause relatively large but short-term flow in the creek and arroyo. During these high-flow periods, the contribution of seep flow to total flow is insignificant.

The zone of contamination within the upper unit of the Halgaito Formation is not affected by the San Juan River. The deeply incised walls of the arroyo and creek act as ground water divides, isolating the contaminated portions of the upper unit of the Halgaito from connection with the river and limiting the areal extent of contamination by intercepting seep flow.

### *North Arroyo Seeps*

Three seeps in North Arroyo were identified and evaluated during construction of the disposal cell. These are identified as seeps 249, 251, and 255. As shown in Plate 1, seep 251 is on the south bank of North Arroyo about 400 to 500 ft north of the disposal cell. Seep 249 is at the base of the southeast bank of Gully No. 2 about 800 ft northeast of the toe of the disposal cell and 100 ft upslope from the confluence of the gully with North Arroyo. Seep 255 is farther downgradient in North Arroyo about 1,300 ft from the disposal cell. Seep 255 is directly below a runoff retention dam constructed as part of the remedial activities. As noted below, flow in these three seeps is continually decreasing and is expected to cease in the future.

Seep 251 was first noticed in December 1989 during the first phase of remediation involving the relocation of the upper pile materials to the lower pile. A french drain was installed in February 1990 to collect water samples and measure flow rates (MKES 1990). The flow rate was measured at 4 gal/hour. The flow decreased over the next several months until it stopped in May 1990. In November 1997 the flow was measured at approximately 2 gal/hour. In May 1998 this seep once again was not flowing. Although there was no evidence of a seep at this location during the site characterization before remediation, dense green vegetation noted in aerial photographs taken as early as 1974 provided evidence of the earlier occurrence of near-surface water at this location. The seep was observed to be flowing when samples were collected during the final phase of the surface remediation in May 1994. Based on the historical performance of this seep, it is expected that the seep eventually will cease flowing.

Flow rates at seep 249 were measured at 0.5 gal/minute in March 1990 and decreased to 0.35 gal/ minute in July 1990. The flow rate in November 1997 had decreased to approximately 0.26 gal/minute and by May 1998 was less than 0.1 gal/minute. A spring in this area was documented and sampled in 1968 (Snelling 1971). There is no documentation that the seep has ever fully stopped since the relocation of the upper tailings pile to the lower tailings pile. The seep was observed to be flowing when samples were collected during the final phase of surface remediation in May 1994.

Water has been observed flowing at the location of seep 255 as far back as March 1976. The seep was observed from 1988 through 1990 and was observed to be flowing when samples were collected during the final phase of remediation in May 1994. The flow rate in November 1997 was approximately 0.26 gal/minute and in May 1998 was less than 0.1 gal/minute.

### *Gypsum Creek Seeps*

Locations of six seeps in Gypsum Creek near the disposal cell have been identified. As shown in Plate 1, seep 922 is about 2,000 ft upstream from the confluence with North Arroyo and approximately 2,200 ft northeast of the disposal cell. Seep 923 is approximately 3,200 ft upstream from the confluence with North Arroyo and about 2,500 ft east of the disposal cell. Seep 924 is about 250 ft downstream from the confluence of Gypsum Creek and North Arroyo, 750 ft upstream from the San Juan River, and 3,800 ft northeast of the disposal cell. Seep 248 is about 500 ft downstream from seep 923, and 2,100 ft east of the disposal cell. Seep 261 is 2,250 ft upstream from seep 923 and approximately 3,750 ft southeast of the disposal cell. Seep 253 is about 250 ft upstream from the confluence of Gypsum Creek and North Arroyo and 3,700 ft northeast of the disposal cell.

All six seeps have been in existence for several years, with five locations (922, 923, 924, 248, and 261) being documented in existence since before World War II. In May 1998, flow rates from these seeps ranged from less than 0.1 gal/minute to 2 gal/minute. The flow rates in these seeps have decreased since first being measured in November 1997.

## 3.5 Geochemistry

Water samples were collected from 14 surface water and 9 ground water locations from 1985 to 1997 (Plate 1); no samples were collected in 1986, 1987, or 1996. Table 3–1 presents dates of sampling for all surface and ground water locations. Locations of all existing and decommissioned wells and seeps are presented in Plate 1. A table on Plate 1 presents surface elevation, total depth, depth of screened interval, zone of completion, and depth to the top of the Honaker Trail Formation for all wells.

Both filtered and unfiltered samples were collected and analyzed for millsite-related constituents. Tailings leachate were collected from four suction lysimeters located within the tailings piles. Analytical results were used to determine background water quality and the distribution of residual process water in the Halgaito Formation. All data are provided in Appendix E.

### 3.5.1 Uranium Processing and Process Solutions

As discussed in Section 3.1, the milling process produced solutions containing nitrate, ammonium, sulfate, manganese, magnesium, calcium, and several metals and nonmetals leached from the ores, including vanadium, selenium, copper, and uranium. Lysimeter samples from the tailings (collected at four locations in 1990 and 1991) displayed a wide variation in pH (from 3 to 6.5), which indicated a mix of neutralized raffinates and acid tailings. All the constituents related to the ores and process solutions listed above were identified in the tailings solutions. In addition, several constituents derived from leaching of the ore were found, including aluminum, iron, boron, arsenic, cadmium, cobalt, fluoride, and nickel. Nitrate was at notably low concentrations in the tailings solutions (less than 0.2 to 6.5 mg/L) when compared to concentrations in the contaminated ground water below the tailings (less than 1 to 286 mg/L), suggesting that the nitrate-bearing process solutions were disposed of in limited areas within the tailings piles, such as the pond once located at the north end of the lower tailings pile. Another significant source of nitrate would be the biotransformation of the ammonium ion.

| Location Id | Years Sampled[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1985** | **1988** | **1989** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1997** |
| ***Surface Locations*** | | | | | | | | | | |
| 248 | | | | Apr., Jun., Oct. | Apr., Aug., Dec. | | Jun | Apr., Dec. | Apr., Nov. | Apr., Nov. |
| 249 | | | | Apr., Jun., Oct. | Apr. | | | May, Dec. | | Nov. |
| 251 | | | | Apr., Oct. | Apr. | | Feb. | | Apr. | Nov. |
| 253 | | | | | May, Aug. | | Jun. | Dec. | Apr., Nov. | Apr., Nov. |
| 254 | | | | Oct. | May | | Jun. | Apr., Dec. | Apr. | |
| 255 | | | | | Apr., Aug., Dec. | Aug., Nov. | Jun. | May | | Apr., Nov. |
| 256 | | | | Oct. | Jun., Aug., Dec. | Aug. | Jun. | | Apr., Nov. | |
| 261 | | | | Jun., Aug., Oct. | May, Dec. | | | Dec. | Apr., Nov. | Apr., Nov. |
| 922 | Apr., Jul. | Jun., Aug. | | Jun., Oct. | Apr., Aug., Dec. | Nov. | Jun. | Apr., May, Dec. | Apr., Nov. | Apr., Nov. |
| 923 | Jul. | Jun. | | | Apr. | Aug., Nov. | Jun. | | Apr., Nov. | |
| 924 | Jul. | Aug. | | | | | | | | Nov. |
| 925 | | Jun., Aug. | | | | | | | | |
| 938 | Nov. | | | | | | | | | |
| 939 | Nov. | | | | | | | | | |
| ***Ground Water Locations*** | | | | | | | | | | |
| 907 | Apr., Jul | Aug. | | | | | | | | |
| 908 | Apr., Jul. | Aug. | | | | | | | | |
| 909 | Apr., Jul. | Aug., Nov. | | | Apr., Aug., Dec. | Aug., Nov. | Jun. | Apr., Dec. | Apr., Nov. | |
| 910 | Jul. | Aug. | | | | | | | | |
| 911 | Apr. | | | | | | | | | |
| 912 | Apr., Jul. | May, Aug. | | | | | | | | |
| 930 | Oct. | May, Aug., Nov. | | | | | | | | |
| 934 | Nov. | Aug., Nov. | Jun., Nov. | Jun., Oct. | Apr., Aug., Dec. | Aug. | | | | Apr., Nov. |
| 935 | Nov. | | | | | | | | | |

[a]No samples were collected in the years 1986, 1987, or 1996.Table 3–1. Sampling Locations and Frequencies

*Table 3-1. Sampling Locations and Frequencies*

### 3.5.2 Background Ground Water Quality

Background ground water quality was determined for two hydrogeologic units at the site, the upper and lower units of the Halgaito Formation. Background ground water quality data for the lower unit of the Halgaito was collected from monitor well 909, located off site and upgradient from the tailings piles (Plate 1).

Because the upper unit of the Halgaito contains only minor amounts of naturally occurring ephemeral water in fractures and in perched zones, monitor wells could not be used to establish background ground water quality. Updip monitor wells that would normally define background ground water quality were dry. Instead, two seeps were used to define background ground water quality in the Honaker Trail Formation and the upper unit of the Halgaito. One seep is located in Halgaito Wash 2.5 mi upgradient from the site (location 256). This seep issues from a zone in the upper part of the Honaker Trail Formation. The second seep is in Gypsum Creek, upstream and on the southeast side of the creek (location 261). This seep issues from alluvium atop and adjacent to the upper unit of the Halgaito. Water quality from both seeps is very similar and does not indicate contamination from the uranium-ore processing. Both seeps are isolated from site-related contamination.

Both the upper and lower units of the Halgaito Formation appear to contain calcium sulfate (as the mineral gypsum), which has been identified in outcrops of the upper unit of the Halgaito. Background ground water from both units contains relatively high concentrations of sulfate as the dominant anion (1,980 to 3,652 mg/L) balanced by nearly equal concentrations of sodium, calcium, and magnesium. The pH of waters from both units is slightly alkaline, and limited Eh measurements, as well as the general presence of sulfate, demonstrate that the water in both units is oxidizing. Total dissolved solids (TDS) in both units ranges from 2,990 to 5,910 mg/L (Tables 3–2 and 3–3). Background ground water quality in both units is generally similar because both units are lithologically similar and contain the same minerals.

Several other constituents commonly found in the processing solutions are also naturally present in the background seeps. The concentrations of these constituents, however, are at levels below those in the tailings solutions. In the background seeps, naturally occurring constituents that are also found in the process solutions include ammonium, boron, magnesium, manganese, molybdenum, nitrate, silica, sulfate, and uranium (Table 3–2).

### 3.5.3 Nature and Extent of Contamination

Major element concentrations and TDS are not useful as indicators of site-related contamination in ground water at Mexican Hat because the levels are similar to or only slightly greater than background levels. Three parameters that are useful as indicators of site-related contamination are nitrate, uranium, and sulfur isotopes. Figure 3–3 illustrates the differences in these three parameters in background and contaminated ground water. The extent of contamination in groundwater has not been plotted because of the lack of continuity in a fracture flow and perched ground water system.

| Constituent | Tailings Lysimeters[a] | Halgaito[b] Below Tailings | Downgradient North Arroyo[c] Seeps | Gypsum Creek[d] Seeps | Background Seeps[e] |
|---|---|---|---|---|---|
| Alkalinity | 8 – 240 | 294 – 1124 | 111 – 820 | 53 – 583 | 185 – 359 |
| Aluminum[f] | 0.2 – 24 | <0.1 – 0.4 | <0.1 | <0.008 – 1.4 | <0.05 – 17 |
| Ammonium[g] | 7 – 102 | 3.8 – 54 | <0.1 – 35 | <0.1 – 22.5 | <0.1 – 0.5 |
| Antimony | <0.003 – 0.04 | <0.003 – 0.005 | <0.001 – 0.02 | <0.001 – 0.04 | <0.02 |
| Arsenic[f] | <0.01 – 5.4 | <0.01 – 0.03 | <0.01 | <0.05 | <0.01 – 0.02 |
| Barium | <0.1 | <0.1 | <0.1 | <0.01 – 0.3 | <0.002 – 0.2 |
| Beryllium | <0.005 – 0.009 | NA | <0.01 | <0.01 | <0.005 |
| Boron | 0.1 – 1.8 | 0.1 – 1.3 | 0.038 – 0.9 | 0.1 – 1.3 | 0.2 – 0.5 |
| Bromide | 0.1 – 0.4 | <2 | 0.3 – 1.1 | 0.4 – 1.1 | 0.5 – 0.9 |
| Cadmium[f] | <0.001 – 0.11 | <0.001 | <0.001 | <0.001 – 0.002 | <0.001 |
| Calcium[g] | 410 – 596 | 530 – 640 | 263 – 640 | 108 – 656 | 410 – 745 |
| Chloride | 22 -46 | 76 – 100 | 90 – 537 | 12 – 273 | 109 – 358 |
| Chromium[f] | <0.01 – 0.13 | <0.01 – 0.16 | <0.01 | <0.003 – 0.12 | <0.01 |
| Cobalt[f] | 0.93 – 3.9 | <0.05 | <0.03 | <0.03 – 0.04 | <0.03 |
| Copper[f,g] | <0.01 – 14 | 0.02 – 0.05 | <0.01 – 0.03 | 0.006 – 0.04 | <0.01 – 0.03 |
| Fluoride | 0.2 – 5.1 | 0.4 – 0.7 | 0.3 – 1.1 | 0.3 – 0.8 | 0.4 – 2.2 |
| Iron[f] | <0.03 – 732 | <0.03 – 0.21 | <0.03 – 1.59 | <0.002 – 1.05 | <0.03 – 9.37 |
| Lead | <0.005 – 0.037 | <0.01 – 0.02 | <0.01 | <0.001 – 0.02 | <0.005 |
| Lead-210 (pCi/L) | NA | 1.1 – 1.3 | 0.2 – 1.2 | 0.0 – 1.1 | 0.0 – 1.0 |
| Magnesium[g] | 167 – 362 | 348 – 550 | 157 – 580 | 75.2 – 880 | 44 – 390 |
| Manganese[f,g] | 26 – 136 | 0.4 – 27 | <0.01 – 2.54 | <0.001 – 1.59 | <0.01 – 0.76 |
| Mercury | <0.0001 – 0.0003 | <0.0002 – 0.0006 | <0.0002 | <0.0002 | <0.0002 |
| Molybdenum[f,g] | <0.01 – 0.18 | <0.01 – 0.15 | 0.01 – 0.45 | <0.01 – 0.14 | <0.01 – 0.04 |
| Nickel[f] | 0.73 – 2.6 | 0.08 – 0.25 | 0.02 – 0.14 | <0.004 – 0.29 | <0.04 |
| Nitrate[g] | <0.2 – 6.5 | <1 – 286 | 30 – 800 | <1.0 – 994 | <1.0 – 8.9 |
| pH | 3.0 – 6.6 | 6.2 – 7.7 | 6.4 – 8.51 | 6.7 – 8.6 | 7.1 – 8.0 |
| Phosphate[f] | 0.1 – 2.8 | <0.1 – 0.2 | <0.1 – 0.1 | <0.049 – 0.1 | <0.049 – 0.1 |
| Polonium-210 (pCi/L) | NA | 0.0 – 0.4 | 0.0 – 0.1 | 0.0 – 0.2 | 0.5 – 0.7 |
| Potassium | 9.8 – 48.3 | 20 – 28 | 3.45 – 25.5 | 2.5 – 28 | 6 – 25.7 |
| Radium-226 (pCi/L) | NA | 0.2 – 1.1 | 0.0 – 0.65 | 0.0 – 1.6 | 0.0 – 3.95 |
| Radium-228 (pCi/L) | NA | 0.0 – 0.6 | 0.0 – 4.8 | 0.0 – 7.8 | 0.0 – 6.0 |
| Selenium | <0.03 | <0.05 | 0.005 – 0.025 | <0.005 – 0.31 | <0.03 |
| Silica[f] | 32 – 125 | 26 – 36 | 19 – 39.3 | 13 – 49.6 | 10.1 – 46 |
| Silver[f] | <0.01 – 0.08 | <0.01 | <0.01 | <0.01 | <0.01 |
| Sodium | 90 – 145 | 340 – 600 | 270 – 542 | 77 – 1520 | 270 – 780 |
| Strontium | 3.3 – 7.5 | <0.1 | 8.28 – 14.6 | <0.1 – 15.1 | 10 – 13 |
| Sulfate[g] | 498 – 4330 | 3040 – 3910 | 1770 – 3812 | 2300 – 4840 | 2120 – 3652 |
| Sulfide | <0.8 | <0.1 | <0.1 – 28 | <0.1 – 27 | <0.1 – 7.1 |
| Thallium | <0.03 | NA | <0.01 | <0.01 | <0.03 |
| Thorium-230 (pCi/L) | NA | 0 – 7.2 | 0.0 – 0.2 | 0.0 – 0.5 | 0 – 1.7 |
| Tin | <0.005 – 0.224 | <0.005 | <0.005 – 0.07 | <0.005 – 0.069 | <0.05 |
| Total dissolved solids | 3300 – 6500 | 2000 – 6700 | 2980 – 6680 | 4300 – 7780 | 3700 – 5910 |
| Uranium[f,g] | 0.005 – 1.5 | 0.60 – 0.78 | 0.101 – 1.29 | 0.012 – 0.81 | 0.01 – 0.09 |
| Vanadium[f,g] | <0.01 – 0.67 | <0.01 – 0.40 | <0.01 – 0.06 | <0.01 – 0.4 | <0.01 – 0.05 |
| Zinc[f] | 0.4 – 45.3 | 0.03 – 0.06 | <0.005 – 0.092 | <0.005 – 1.19 | <0.005 – 0.12 |

[a]Lysimeters HAT-01-241, -242, -243, and -244; 1990-1991 data.
[b]Monitor wells HAT-01-911 and -912; 1985 and 1988 data.
[c]Seeps HAT-01-249, -251, and -255; 1990-1997 data.
[d]Seeps HAT-01-248, -253, -254, -922, -923, and -925; 1985-1997 data.
[e]Seeps HAT-01-256 and -261; 1990-1997 data.
[f]Dissolved constituents in the tailings that are more than 5 times background levels and probably derived from dissolution of the ore.
[g]Constituents known to have been present in processing solutions or uranium ores. All data in mg/L unless noted as pCi/L.

NA - not applicable.
Values given as less than (<) are below the minimum detection limit for the analysis.

Table 3–2. Comparison of Water Quality in the Tailings to Contaminated and Background Water Quality in the Halgaito Formation, 1985–1997 Data

*Table 3–3. Summary of Water Quality in Upgradient and Downgradient Wells*

| Constituent | Upgradient[a] | | Downgradient |
|---|---|---|---|
| | Well 909 | Well 930[b] | Wells 907 and 908[c](mg/L) |
| Alkalinity | 133 – 159 | 34 – 61 | 92 – 137 |
| Aluminum | <0.1 – 0.3 | <0.1 – 0.2 | <0.1 – 0.4 |
| Ammonium | <0.1 – 0.4 | <0.1 – 0.3 | <0.1 – 0.1 |
| Antimony | <0.001 – 0.006 | <0.003 | <0.003 – 0.007 |
| Arsenic | <0.001 – 0.02 | <0.01 – 0.02 | <0.01 – 0.05 |
| Barium | <0.01 – 0.1 | <0.1 – 0.2 | <0.1 – 0.2 |
| Boron | 0.1 – 1.0 | 0.5 | 0.1 – 4.7 |
| Cadmium | <0.001 – 0.005 | <0.001 | <0.001 |
| Calcium | 266 – 445 | 153 – 173 | 410 – 600 |
| Chloride | 85.8 – 110 | 35 – 45 | 210 – 260 |
| Chromium | <0.01 – 0.09 | <0.01 – 0.06 | <0.01 – 0.10 |
| Cobalt | <0.05 | 0.07 | <0.05 |
| Copper | <0.01 – 0.04 | <0.02 | <0.02 – 0.05 |
| Fluoride | 1.3 – 1.5 | 1.2 – 1.4 | 1.1 – 1.5 |
| Iron | <0.03 – 0.14 | <0.03 – 0.04 | 0.13 – 0.24 |
| Lead | <0.01 | <0.01 | <0.01 – 0.03 |
| Magnesium | 137 – 190 | 47 – 62 | 163 – 200 |
| Manganese | <0.01 – 0.02 | 0.01 – 0.02 | 0.03 – 0.15 |
| Mercury | <0.0002 | <0.0002 | <0.0002 – 0.0008 |
| Molybdenum | <0.01 – 0.20 | 0.03 – 0.05 | <0.01 – 0.2 |
| Nickel | <0.04 – 0.11 | <0.04 – 0.06 | <0.04 – 0.20 |
| Nitrate | 0.8 – 12.4 | <1.0 | <0.1 – 2.0 |
| pH | 7.0 – 7.4 | 9.1 – 10.2 | 7.3 – 7.8 |
| Phosphate | <0.1 – 0.1 | <0.1 – 0.1 | <0.1 – 0.2 |
| Polonium-210 (pCi/L) | 0.0 | 0.0 | 0.0 – 0.3 |
| Potassium | 5.4 – 23 | 3.0 – 5.6 | 8 – 11.1 |
| Radium-226 (pCi/L) | 0.0 – 1.2 | 0.1 – 1.2 | 0.7 – 4.8 |
| Radium-228 (pCi/L) | 0.0 – 8.5 | 0.0 – 2.3 | 0.0 – 1.4 |
| Selenium | <0.005 – 0.04 | <0.005 | <0.005 |
| Strontium | <0.1 – 9.2 | 0.4 | <0.1 |
| Silver | <0.01 | <0.01 | <0.01 |
| Silica – $SiO_2$ | 13 – 17 | 15 – 22 | 12 – 14 |
| Sodium | 397 – 516 | 291 – 350 | 922 – 1320 |
| Sulfate | 1980 – 2800 | 1180 – 1240 | 3420 – 4090 |
| Sulfide | <0.1 – 64.4 | <0.1 | <0.10 |
| Thorium-230 (pCi/L) | 0.0 – 1.4 | 0.0 – 1.6 | 0.0 – 0.40 |
| Tin | <0.005 | <0.005 | <0.005 |
| Total dissolved solids | 2990 – 3880 | 1810 – 1920 | 5570 – 6580 |
| Total organic carbon | <1 – 31 | 32 | 16 – 25 |
| Uranium | 0.04 – 0.06 | <0.003 – 0.01 | 0.001 – 0.004 |
| Vanadium | <0.01 – 0.49 | <0.01 – 0.19 | <0.01 – 0.60 |
| Zinc | <0.01 – 0.03 | <0.005 | <0.01 – 0.20 |

[a]Data collected from 1985 – 1998.
[b]Upgradient monitor well 930 data provided; however, pH values of 9 to 10 in this well suggest the well is grout-contaminated. Monitor well data for 909 are therefore considered to be more representative of background. Well 930 data collected in 1985 and 1988.
[c]Data collected in 1985 and 1988.

Note: All data in mg/L unless noted as pCi/L.

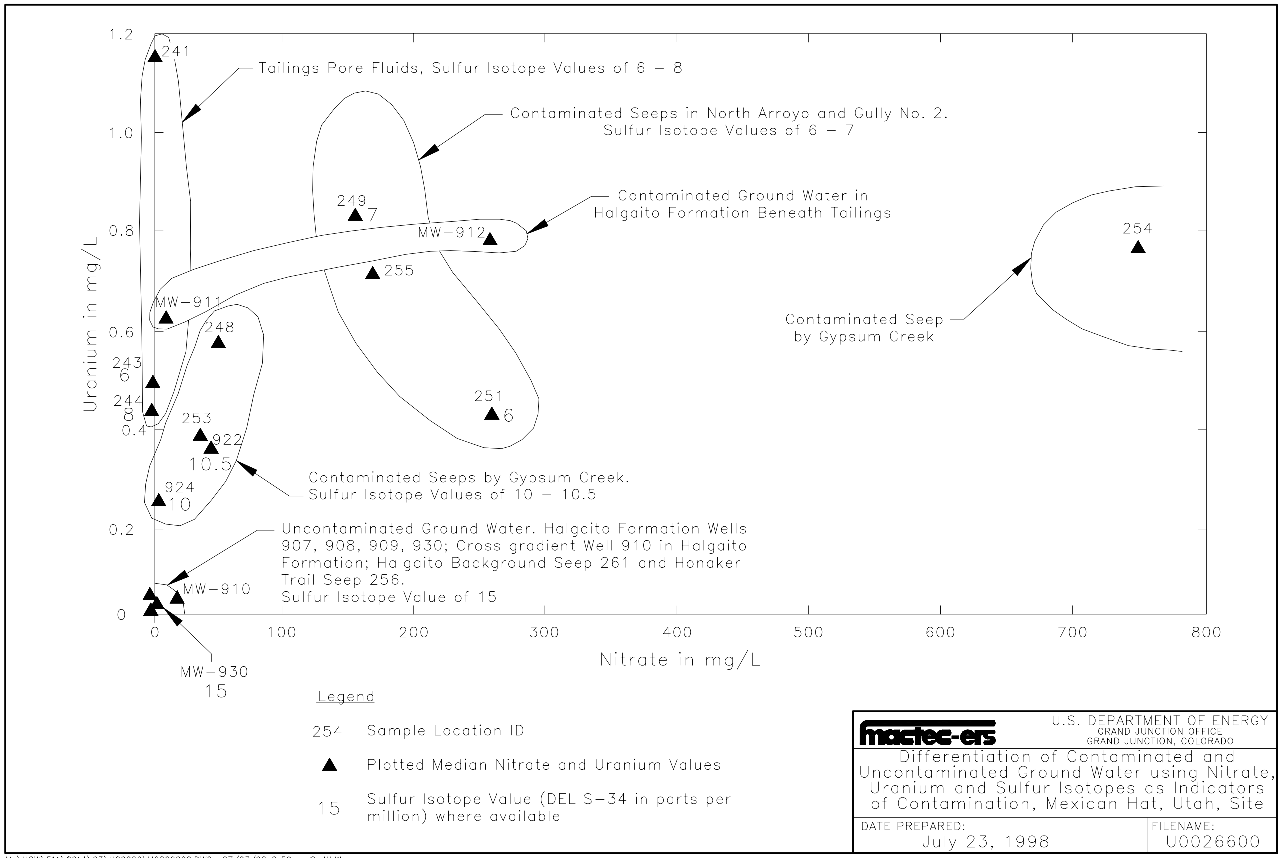


*Figure 3-3. Differentiation of Contaminated and Uncontaminated Ground Water*

Background and other uncontaminated ground water in both the upper and lower units of the Halgaito Formation have relatively low nitrate and uranium concentrations (generally less than 20 and 0.05 mg/L, respectively) and relatively high values for sulfur-34 isotopes (about 15). On a graph of nitrate versus uranium these uncontaminated ground waters plot near the origin (Figure 3–3).

Contaminated ground water is distinct from background (Figure 3–3) with higher concentrations of uranium (more than 0.2 mg/L) and, in most cases, nitrate (ranging from <1 to more than 750 mg/L), but with relatively low sulfur-34 isotope values (ranging from 6 to 10.5). Evaluation of water quality data indicates that ground water in the lower unit of the Halgaito (the uppermost aquifer) is not contaminated. However, contaminated ground water does occur in the overlying upper unit of the Halgaito and issues from seeps along North Arroyo and Gypsum Creek (Plate 1). A detailed discussion of these results is presented below.

The lower unit of the Halgaito Formation is isolated from site-related contamination by an upward vertical hydraulic gradient. Geochemical data support this. Specifically, no concentrations of uranium or nitrate in excess of background (monitor well 909) were detected in samples from any monitor wells completed in the lower unit of the Halgaito, including downgradient monitor wells 907 and 908 (Table 3–3, Figure 3–3, and Plate 1).

Water sampling records for the period 1985 through 1988 document that the three monitor wells in the upper unit of the Halgaito (wells 906, 911, and 912) produced some water after completion. However, two of these (wells 906 and 911) were capable of producing only small amounts (less than 16 gal) of muddy water before being bailed dry.

In downgradient monitor well 934, which is completed in the lower Halgaito Formation at a depth of 188 to 198 ft, the initial pH of 7 climbed to 11 during the first five samplings, indicating contamination of the well by water from grouting. The initial nitrate concentration in this well (62 mg/L) might suggest some contamination in this downgradient area (Plate 1) but all subsequent data fell within the range of background. However, possible grout contamination makes all data from this well suspect.

Monitor well 910, also completed in the lower Halgaito Formation at a depth of 140 to 180 ft, which is possibly cross gradient from the site (Plate 1), produced only a few liters of muddy water at a depth of about 167 ft during one round of sampling. Nitrate concentrations (18 mg/L) and uranium (0.03 mg/L) suggest little if any contamination in this area (Figure 3–3).

Only one monitor well in the upper unit of the Halgaito, monitor well 912 completed directly beneath the tailings, produced significant amounts of water at a depth of 74 ft. The chemistry of this water (up to 286 mg/L nitrate and about 0.8 mg/L uranium) indicates that the water was tailings solution. Monitor well 911, also completed directly beneath the tailings, produced a small amount of water at a depth of 93 ft before being bailed dry. Uranium concentrations (0.6 mg/L) indicate that this was also tailings solution at this depth (Figure 3–3). Data from these two wells are summarized in Table 3–2.

Chemical data, in conjunction with sampling records on the amount of water produced, demonstrate that the upper unit of the Halgaito is capable of producing very little natural ground water. Where significant amounts of water do exist (e.g., monitor well 912), they are from the uranium recovery operations.

The geochemical data for the seeps issuing from the upper unit of the Halgaito also support the conclusion that zones of saturation in the upper unit were created by uranium recovery operations. Seeps issuing from the upper unit of the Halgaito into North Arroyo, located north of the tailings pile, have a geochemical signature indicating that these are essentially pure tailings solutions (Figure 3–3). Uranium and nitrate concentrations are about the same as those found within or directly beneath the tailings, ranging up to 1.37 mg/L of uranium and up to 911 mg/L of nitrate (Table 3–2). Table 3–2 provides the concentrations of constituents in these seeps as compared to the same constituents in background seeps. Figures 3–4 through 3–9 present data for uranium and nitrate concentrations at seeps in Gypsum Creek, North Arroyo, and background.

Sulfur isotopes also indicate that the North Arroyo seeps are similar to tailings solutions. Sulfur isotopic data collected from the lower tailings pile show that dissolved sulfate in the tailings solutions is depleted in sulfur-34 (5.8 to 8.1 parts per million; DOE 1990). In contrast, natural sulfate from both the lower unit of the Halgaito ground water and the upper unit of the Halgaito that contains some bedded gypsum deposits is relatively enriched in sulfur-34 (values of 15.1 and 14.6, respectively). Sulfur-34 isotopes in the North Arroyo seeps had values of 5.7 to 6.8 per million, indicating that water in these seeps are similar to tailings solutions without any component of natural sulfate (Figure 3–3).

Downgradient water discharged at seeps in Gypsum Creek also have elevated concentrations of nitrate and/or uranium relative to background, indicative of contamination (Figure 3–3 and Table 3–2). The locations of the contaminated seeps in Gypsum Creek is consistent with the eastward movement of contaminant water along both the dip of bedding and the strike of the major fracture system affecting the upper unit of the Halgaito Formation.

However, sulfur isotopic data indicate that approximately 60 percent of the dissolved sulfate in the Gypsum Creek seeps is derived from the tailings. The remaining 40 percent is derived from natural sulfate sources (gypsum). Thus the geochemical data demonstrate that ground water in the upper unit of the Halgaito is primarily due to saturation by tailings solutions.

Constituents in the Gypsum Creek seeps, determined to be above background at the 0.05 level of significance, are listed in Table 3–4. These include several of the constituents known to be associated with process solutions and ore, including ammonium, magnesium, manganese, molybdenum, nitrate, selenium, sulfate, uranium, and vanadium. Other constituents, which were identified as being above background and which are probably the result of dissolution of the ore, are boron, nickel, potassium, silica, and sodium.

*Table 3–4. Statistical Comparison of 1990–1998 Water Quality in Downgradient Seeps with Background Levels*

| Constituent[a] | Background level[b] | Downgradient seeps in North Arroyo[c] | Downgradient seeps in Gypsum Creek[d] |
|---|---|---|---|
| Ammonium | <0.1 – 0.5 | <0.1 – 35 | <0.1 – 22.5 |
| Boron | 0.2 – 0.5 | 0.38 – 0.9 | 0.1 – 1.3 |
| Magnesium | 44 – 390 | 157 – 883 | 75 – 880 |
| Manganese | <0.01 – 0.76 | <0.01 – 2.54 | <0.01 – 1.59 |
| Molybdenum | <0.01 – 0.04 | 0.01 – 0.45 | <0.01 – 0.12 |
| Nickel | <0.04 – 0.011 | <0.04 – 0.14 | <0.04 – 0.29 |
| Nitrate | <0.22 – 8.9 | 30 – 911 | <1 – 994 |
| Potassium | 6 – 25.7 | 3.45 – 43.1 | 2 – 28 |
| Selenium | <0.03 | 0.005 – 0.046 | <0.005 – 0.31 |
| Silica | 10.1 – 46 | 19 – 39 | 13 – 50 |
| Sodium | 270 – 780 | 270 – 542 | 77 – 1520 |
| Sulfate | 2100 – 3652 | 1530 – 4810 | 2500 – 4840 |
| Uranium | 0.01 – 0.09 | 0.10 – 1.37 | 0.01 – 0.81 |
| Vanadium | <0.01 – 0.05 | <0.01 – 0.06 | <0.01 – 0.4 |

[a]Constituents determined to be, on average, above background levels (at the 0.05 level of significance).
[b]Seeps 256 and 261.
[c]Seeps 249, 251, and 255.
[d]Seeps 248, 253, 254, 922, and 923
Note: All values are in milligrams per liter.

### 3.5.4 Contaminant Fate and Transport Mechanisms

Most constituents in the contaminated water seeps within the upper unit of the Halgaito Formation are at levels that are at the same order of magnitude as background. Major (tenfold or greater) decreases in constituent concentrations are not expected to occur with transport or with time. This is true of boron, magnesium, molybdenum, nickel, potassium, silica, sodium, sulfate, and vanadium. These constituents are all naturally present and naturally equilibrated to processes of precipitation, rock-water reactions, adsorption, and cation exchange. These processes will have little effect on the slightly greater concentrations present in the tailings solutions migrating through fractures in the upper unit of the Halgaito.

Nitrate (up to about 110 times background), selenium (up to about 10 times background), and uranium (up to about 16 times background) are present in the contaminated water seeps at concentrations greater than ten times background. These three constituents are mobile and stable under the relatively oxidizing, slightly alkaline water conditions at the site and will probably persist in the tailings solutions within the upper unit of the Halgaito.

Ammonium is also present at concentrations greater than ten times background in North Arroyo seeps. This constituent is unstable in oxidizing environments because of biological nitrification (conversion to nitrogen by naturally occurring bacteria in soils). Ammonium also tends to be exchanged for sodium, calcium, or magnesium present in clays. Thus, ammonium is generally not construed to be a mobile constituent. This explains why ammonium is present at much lower concentrations in the Gypsum Creek seeps than in the North Arroyo seeps. With time, ammonium concentrations in all seeps will decrease due to biological nitrification.

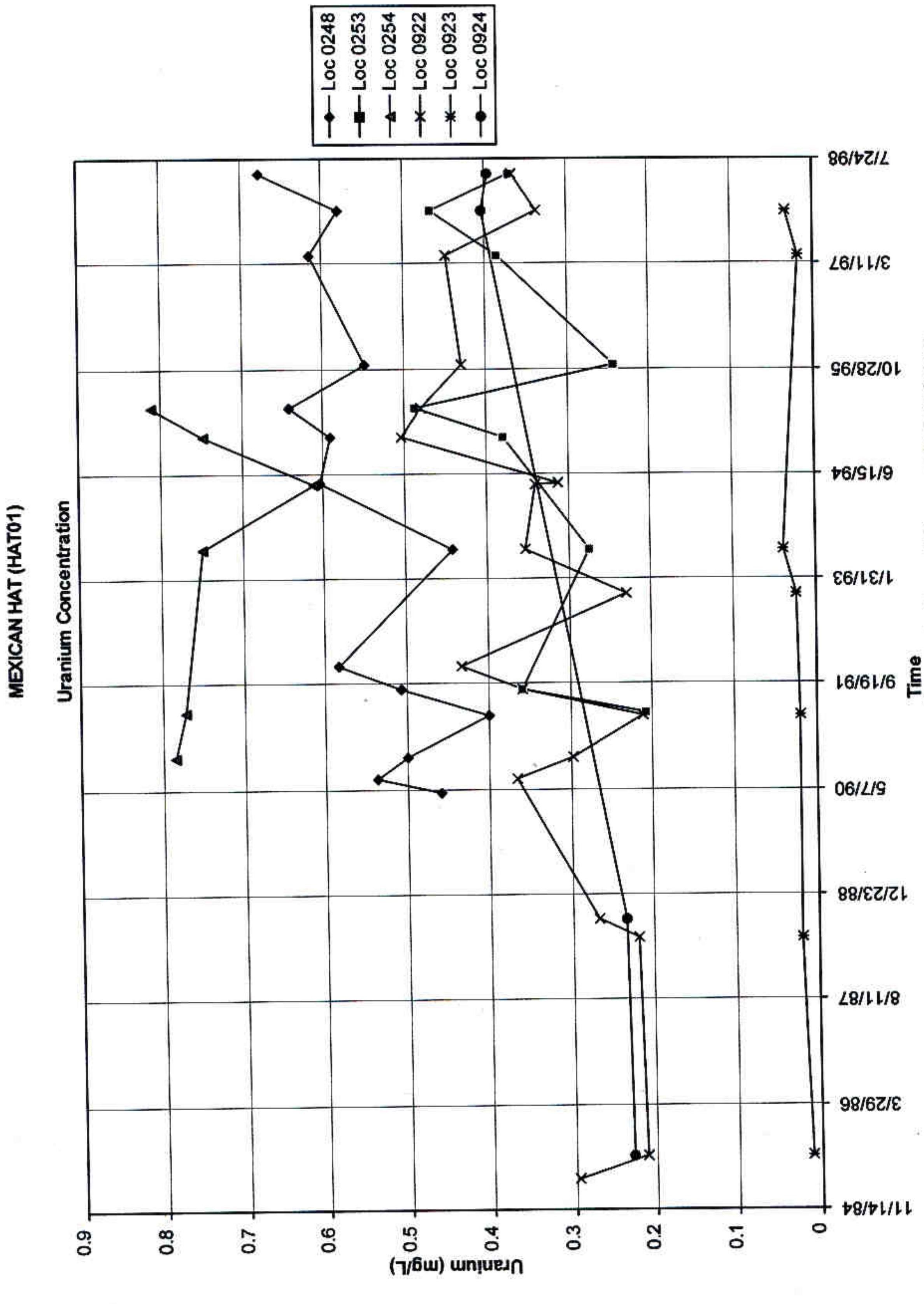


*Figure 3–4. Uranium Concentrations at Gypsum Creek Seeps*

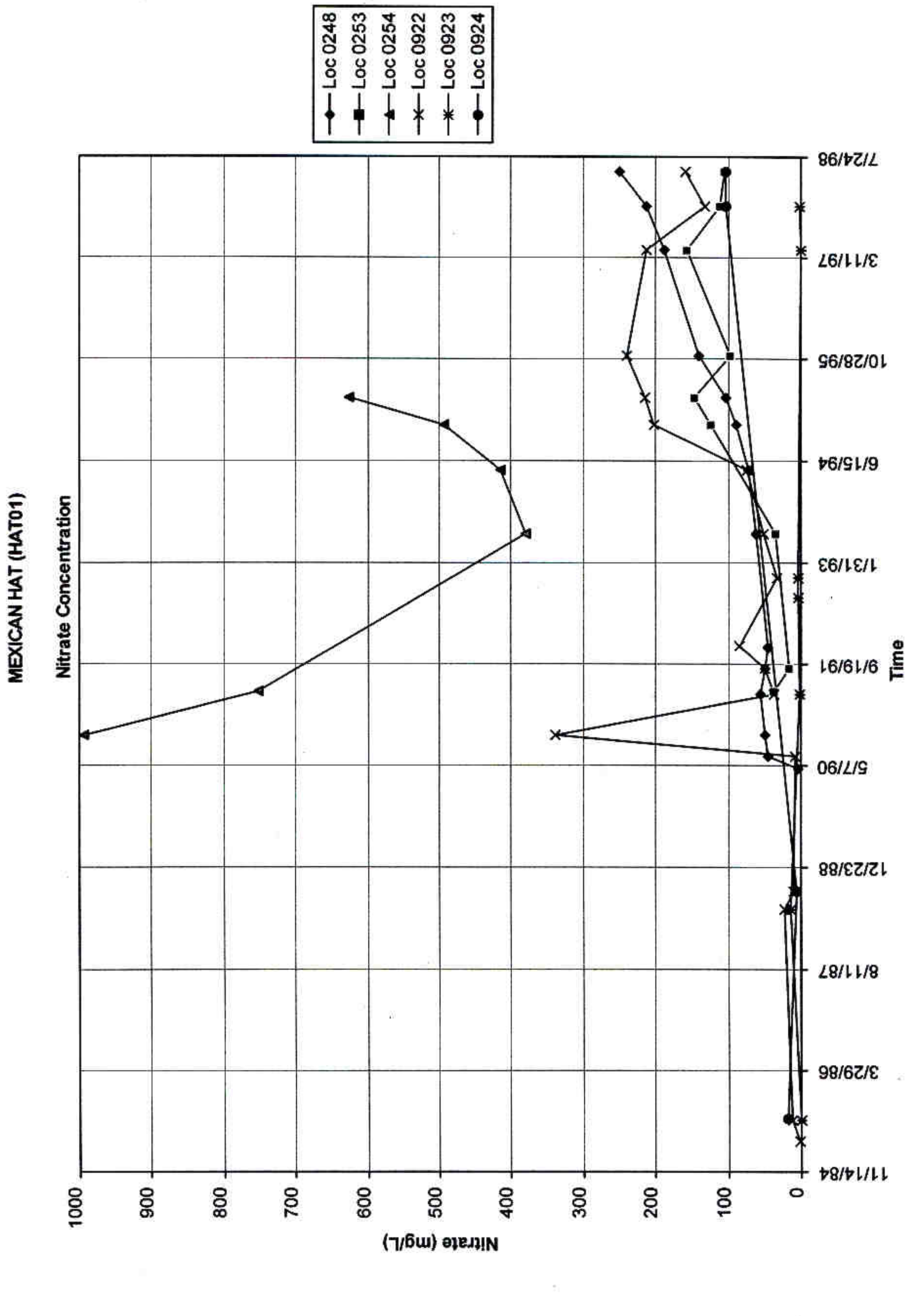


*Figure 3–5. Nitrate Concentrations at Gypsum Creek Seeps*

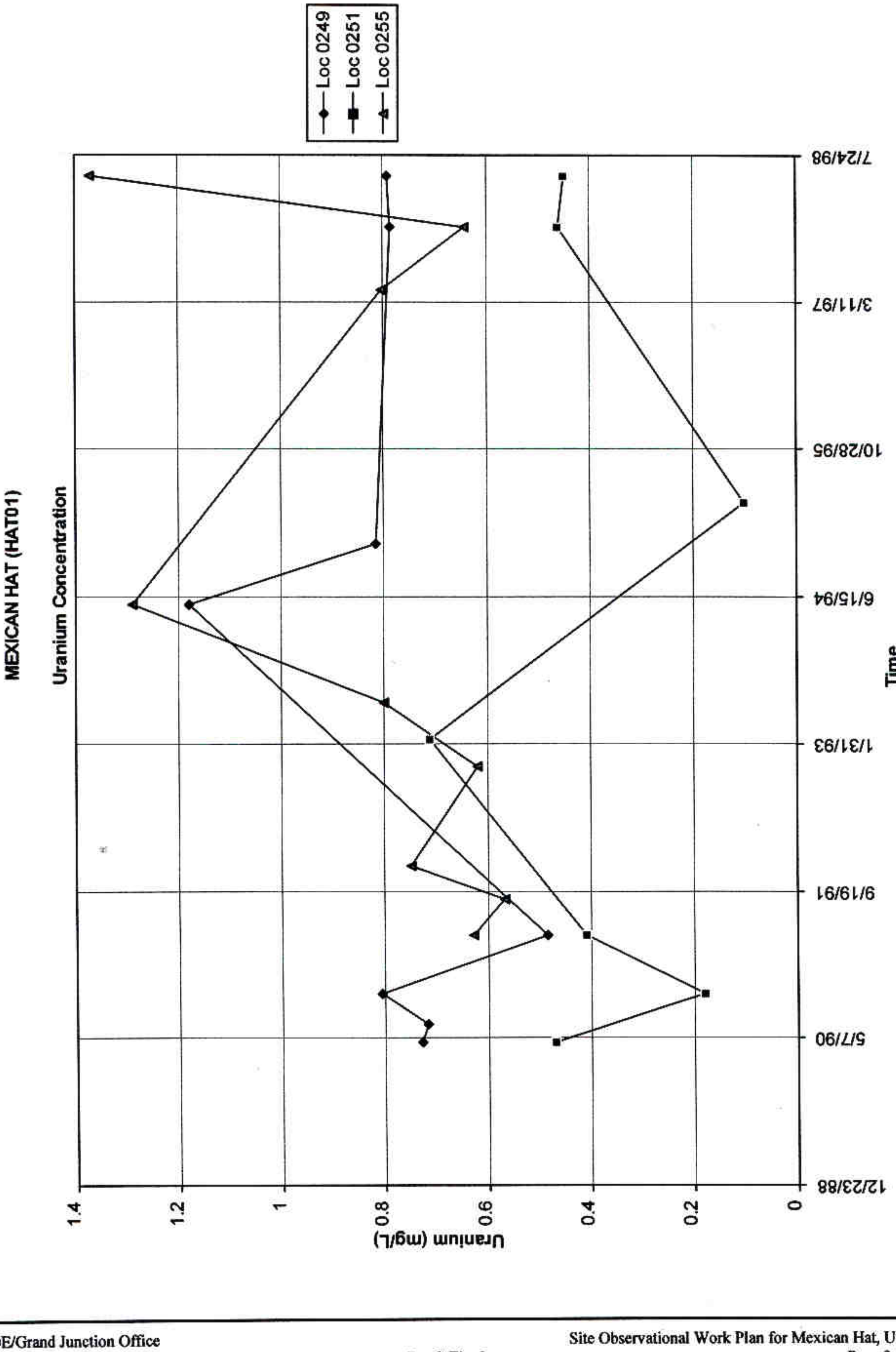


*Figure 3–6. Uranium Concentrations at North Arroyo Seeps*

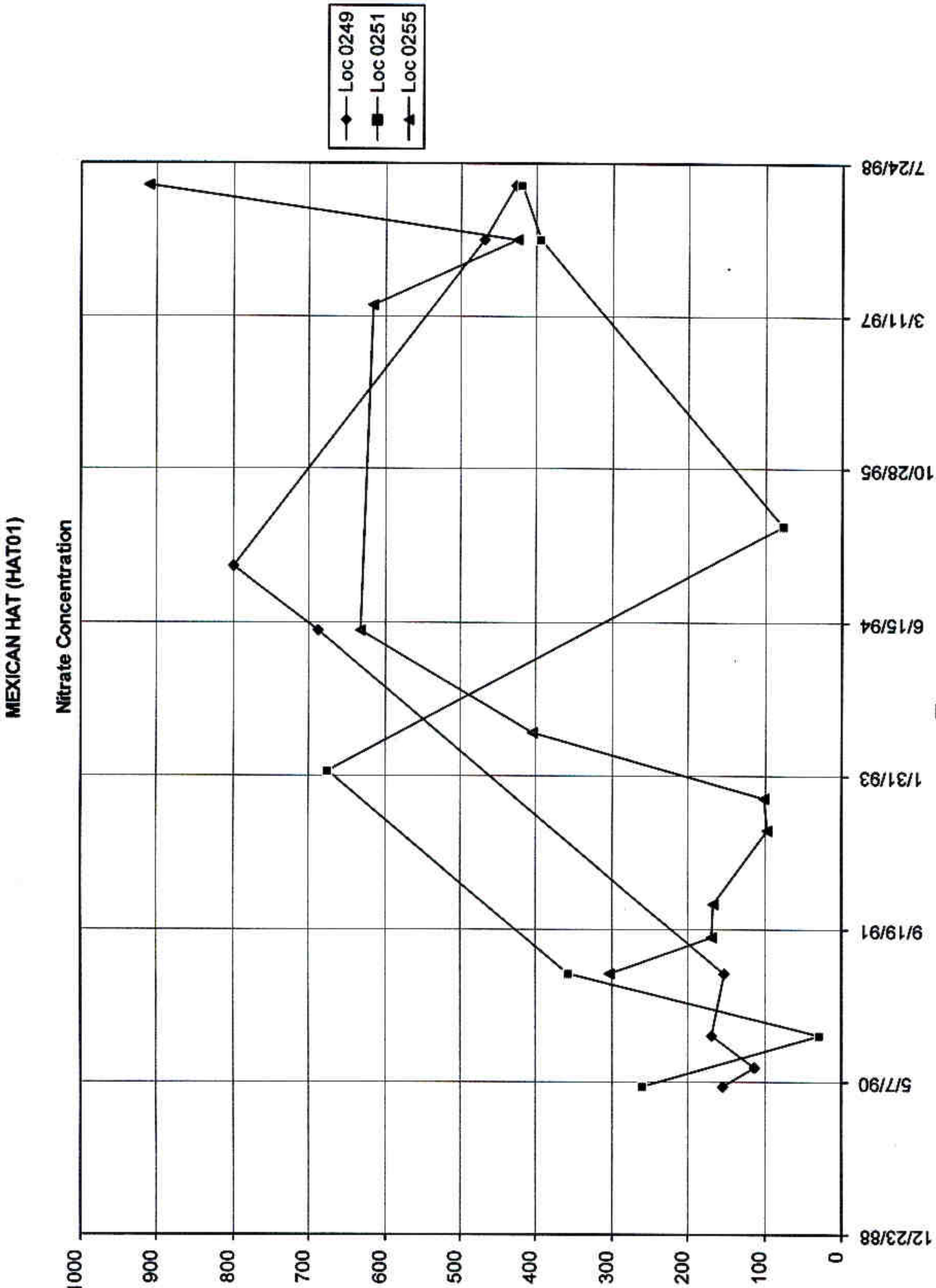


*Figure 3–7. Nitrate Concentrations at North Arroyo Seeps*

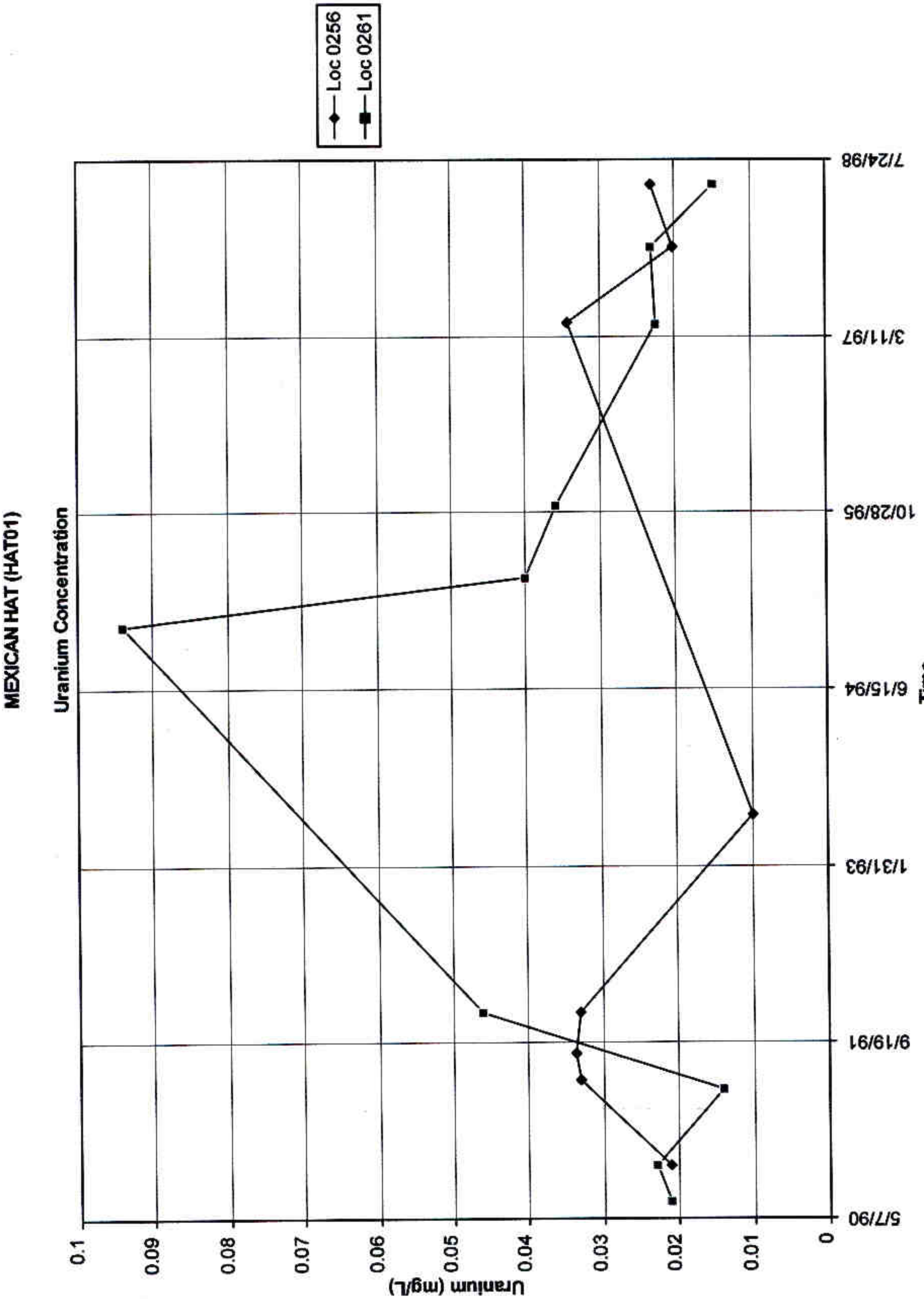


*Figure 3–8. Uranium Concentrations at Background Seeps*

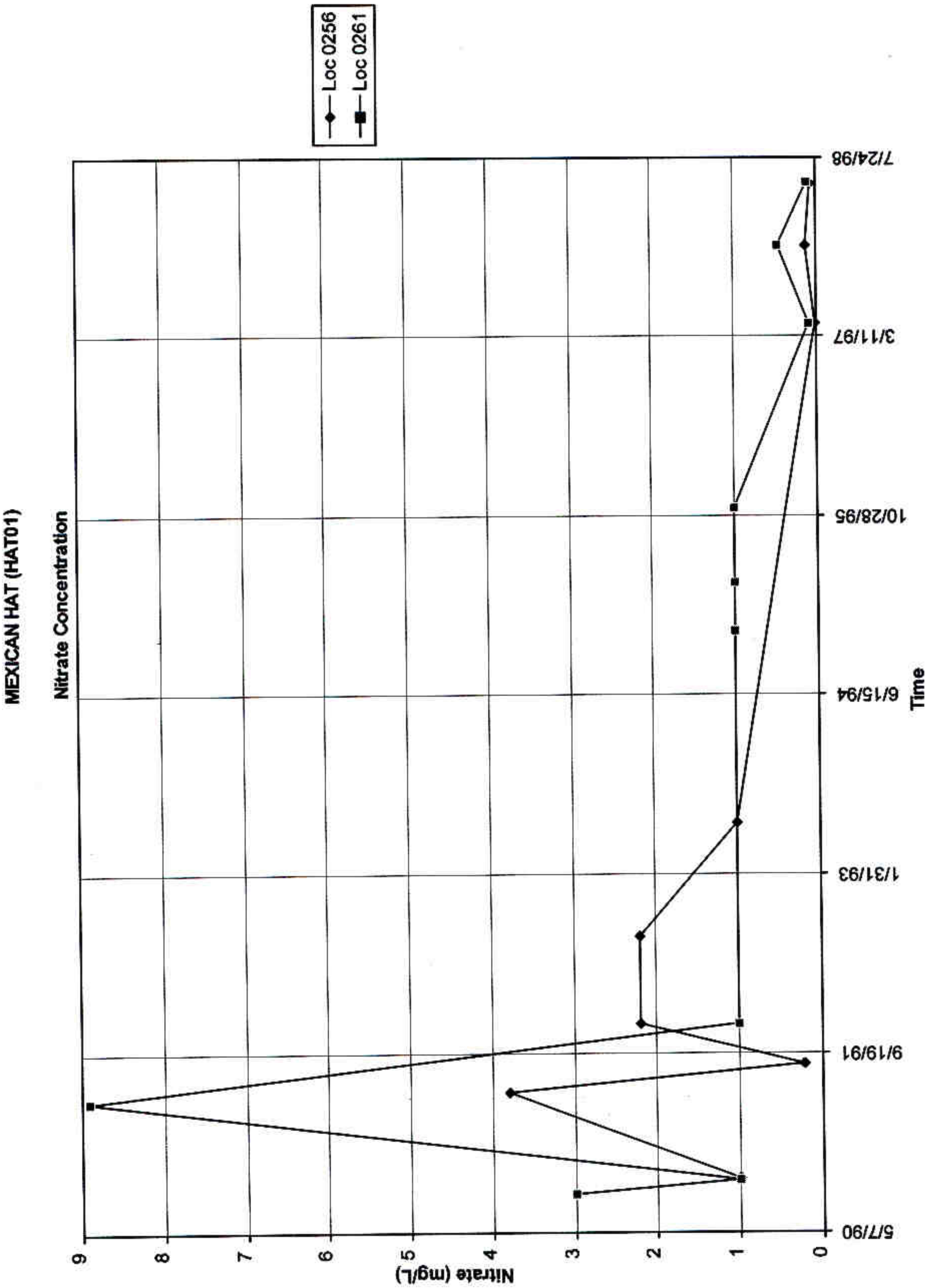


*Figure 3–9. Nitrate Concentrations at Background Seeps*

## 3.6 Risk Evaluation

A screening-level risk evaluation was conducted for the seeps at the Mexican Hat site to determine whether potential exposure to the seep water poses risks to humans, livestock, and wildlife. Constituents considered in the human health evaluation included inorganics and radionuclides. The data considered for the evaluation of potential adverse effects to livestock and wildlife focused only on inorganics. The radionuclide data were not considered for animals because of the paucity of information on the effects of ionizing radiation on relatively short-lived organisms such as the wildlife species that occur, or potentially occur, in the vicinity of the site.

The evaluation conducted for this SOWP is based on the results of two previous risk assessments (JEG 1990; Duncan et. al. 1994) and on site-specific exposure pathway information collected in June and July of 1994. The screening-level risk assessment (Duncan et. al. 1994) used worst-case exposure scenarios for the preliminary risk calculations for humans, livestock, and wildlife. Based on recently collected site-specific information, several of the input parameters, such as frequency of exposure, have been revised in this document to provide a reasonable evaluation of potential risks to humans and livestock.

The data used in this evaluation were from filtered seep water samples collected during 1990–1993 from seeps 248, 249, 251, 253, 254, 255, 261, 922, and 923 (Plate 1). Seep 924 was not sampled during this period. The data were divided into three components based on their location: background (seep 261), North Arroyo (seeps 249, 251, and 255), and Gypsum Creek (seeps 248, 253, 254, 922, and 923). As a conservative measure, maximum detected constituent concentrations were used to evaluate potential adverse effects to humans, livestock, and wildlife.

A botanical survey was conducted in May 1998 at the seeps in Gypsum Creek and North Arroyo. This survey was performed to determine the extent of coverage at the seeps of plants used for Navajo medicines and ceremonies. Table 3–5 presents Navajo cultural uses for certain plant species (Mayes and Lacy 1989), and Table 3–6 presents the coverage density of these plants at each of the seeps.

### 3.6.1 Contaminants of Potential Concern

The seep water data were screened in accordance with EPA guidance (EPA 1989a and 1989b) to develop the list of the contaminants of potential concern for the assessment of human, livestock, and wildlife health.

*Table 3–5. Navajo Cultural Uses of Plants Growing near Seeps at the Mexican Hat Site*

| Plant Name[a] | Cultural Uses[a] |
|---|---|
| Gad ni'eełii bílátah łichí'ígíí (juniper with red flowers)<br>Tamarisk<br>*Tamarix ramosissima* | Medicinal: Gad ni'eełii bílátah łichí'ígíí is a naturalized adventive from Eurasia that looks like juniper, and although it is only remotely related, it is sometimes used as a substitute for juniper in certain healing tonics and smoke treatments. Leaves are sometimes boiled to make a tea to alleviate symptoms of the common cold.[b] |
| K'ai'łibáhígíí (gray willow)<br>Coyote willow<br>*Salix exigua* | Medicinal: The leaves of K'ai'łibáhígíí are soaked in water and used to induce vomiting.<br>Ceremonial: K'ai'łibáhígíí is used in the Lightning Way and the Big Star Way ceremonies as a medicine and as tobacco. It is also used to make ceremonial equipment for the Lightning Way. |
| Lók'aa' (Reed)<br>Common Reed<br>*Phragmites australis* | Medicinal: Lók'aa' is one of several emetic plants used for stomach and skin problems.<br>Ceremonial: Lók'aa' is used for ceremonial equipment, and for prayersticks in all ceremonies. |
| Teeł nitsaaígíí (big cattail)<br>Southern Cattail<br>*Typha domingensis* | Ceremonial: At one time, the pollen of Teeł nitsaaígíí was preferred in Navajo ceremonies. Now corn pollen is used. Its leaves are used for ceremonial necklaces and wristbands in the Male Shooting Way ceremony. Teeł nitsaaígíí is also one of the emetics used in the five- and nine- night ceremonies.<br>Household: It is said that male and female mats made of Teeł nitsaaígíí leaves were once hung in hogans to keep the hogan and the livestock safe from lightning. |
| Tl'oh nitłizí (brittle grass)<br>Western Wheatgrass<br>*Agropyron smithii* | Ceremonial: Tl'oh nitłizí is burned for incense in the Enemy Way ceremony, and other ceremonies. |
| Zéé'iilwo'ii (god's plume)<br>Cheatgrass brome<br>*Bromus tectorum* | Medicinal: Zéé'iilwo'ii, a native of Eurasia but now circumboreal, arrived in the Four Corners area in the late Nineteenth Century. It has since been incorporated in several ceremonies: as plumage in the Night Way chant, as a blackening in the Evil Way and Hand Trembling Way, and as a medicine in the Night Way and Plume Way. |

[a]Mayes and Lacy 1989.
[b]Charley 1998.

*Table 3–6. Coverage Density of Plants at Mexican Hat Seeps*

| Taxonomic Name | Seep Numbers | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 248 | 249 | 251 | 253 | 254 | 255 | 261 | 922 | 923 | 924 |
| Shrubs | | | | | | | | | | |
| *Salix exigua* | | | | | | | + | | | |
| *Tamarix ramosissima* | 5 | 1 | 5 | | | 2 | 1 | 2 | 5 | 3 |
| Grasses/Grass like plants | | | | | | | | | | |
| *Bromus tectorum* | | | | | 1 | | | | | |
| *Hordeum jubatum* | | 1 | | | 1 | | | | | |
| *Phragmites communis* | | | | | | 1 | 5 | 5 | | 3 |
| *Scirpus americanus* | | 2 | | | | + | + | | | 2 |
| *Typha latifolia* | | 2 | | | | 3 | | | | |
| *Pascopyrum smithii* | | | | | | | + | | | |
| Herbs | | | | | | | | | | |
| *cf. Solidago sp.* | | | | | | | + | 1 | | |
| *Kochia scoparia* | | | | | 2 | 2 | | + | | |
| *Malcomia africana* | + | | | | 1 | 2 | | | | |
| Unknown *Asteraceae* | + | | | | | 2 | 1 | | | |

Cover Classes:
(+) = <1%
(1) = 1 to 5%
(2) = 5 to 25%
(3) = 25 to 50%
(4) = 50 to 75%
(5) = 75 to 100%

The following were identified as contaminants of potential concern in North Arroyo for the human health assessment: ammonium, antimony, bromide, chloride, lead-210, manganese, molybdenum, nitrate, radium-226, radium-228, silica, sulfate, sulfide, thorium-230, elemental uranium, and uranium-238. This same list of contaminants of potential concern, plus cobalt and selenium, was developed for Gypsum Creek.

For the ecological assessment, the contaminants of potential concern are aluminum, ammonium, antimony, barium, beryllium, boron, bromide, cadmium, chloride, chromium, cobalt, copper, cyanide, fluoride, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, nitrate, potassium, selenium, silica, silver, sodium, strontium, sulfate, sulfide, tin, uranium, vanadium, and zinc.

### 3.6.2 Potential Risk to Humans

A schematic diagram of potential human exposure pathways is shown on Figure 3–10. Three potential exposure pathways were identified for humans: (1) direct exposure by ingestion of seep water; (2) indirect exposure by eating meat from sheep and cattle watered with seep water; and (3) indirect exposure by drinking milk from dairy cattle watered with seep water. No sediment or soil data have been collected at the seeps. For the indirect exposure pathways it is assumed that the livestock drink contaminated seep water and eat plants which may have accumulated the constituents through root uptake, growing in the vicinity of the seep. The screening-level risk assessment (Duncan et. al. 1994) assumed, as a worst-case scenario, that humans and livestock would use the contaminated seeps every day, 365 days per year, to obtain all of their drinking water (humans and livestock) and all of their food (livestock only). As described below, these assumptions are not reasonable and were revised on the basis of information collected during recent site visits.

Direct, long-term exposure to seep water in either North Arroyo or Gypsum Creek through use as a drinking water source is considered highly unlikely for the following reasons: (1) the nearest residence is in Halchita, which is over 1 mi away; and (2) all drinking water for the residents in the town is supplied by the municipal system. It is unreasonable to assume that someone would travel over a mile to obtain water from the seeps when potable water is available in their homes. For these reasons, ingestion of seep water was not considered a complete exposure pathway for humans and was not evaluated further.

Risk calculations for ingestion of meat from sheep and cattle and ingestion of milk from dairy cattle indicate that the risk levels associated with potential noncarcinogenic and carcinogenic effects are below acceptable guidelines established by EPA. Thus, ingestion of meat and milk from livestock exposed to the constituents in the seep water is not expected to result in adverse health effects in humans. The risk calculations are presented in Appendix C, Tables C.1 through C.4.

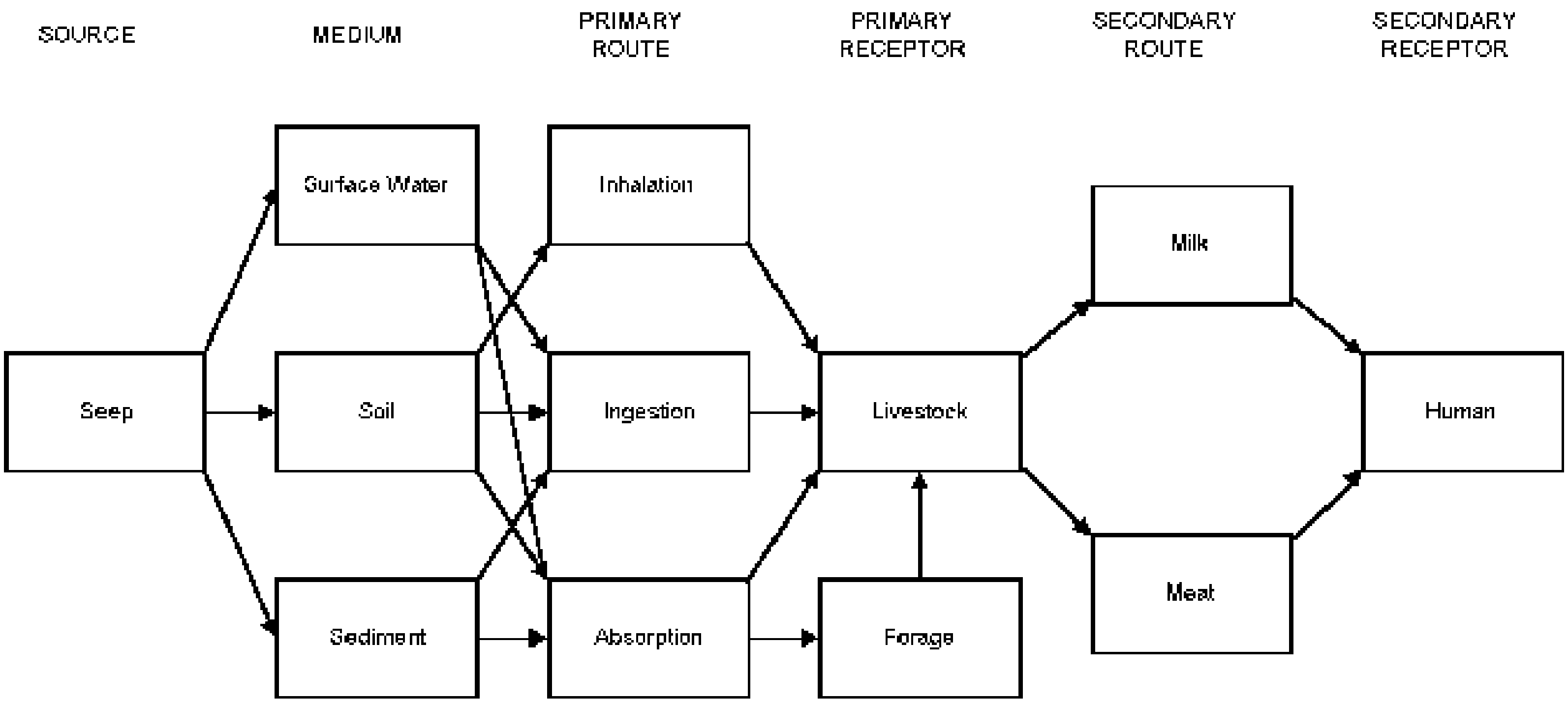


*Figure 3-10. Human Health Conceptual Site Model*

### 3.6.3 Potential Risk to Livestock

Risks to livestock (sheep and cattle) that drink the contaminated seep water and eat plants that may have accumulated constituents in the seep water were evaluated (Jacobs 1990). The site-specific exposure pathway information (e.g., area of contaminated seeps relative to potential foraging area; how often livestock might use the contaminated seeps), described in Section 3.6.2, was incorporated into the risk calculations.

Livestock sometimes graze in the vicinity of the site and have been observed in North Arroyo and Gypsum Creek in the past. However, during the June 1994 and May 1998 site visits, no livestock were seen. No recent signs (tracks, scat) were observed at any of the seeps with the exception of seep 922 in Gypsum Creek. Livestock in North Arroyo and Gypsum Creek could accumulate the constituents in their meat and milk by ingesting seep water and associated vegetation. Using these livestock for food would create an exposure pathway for humans. This exposure pathway was quantitatively evaluated in accordance with EPA risk assessment guidance (EPA 1989a).

Livestock would not be exposed to vegetation at the seeps on a daily basis due to the limited areal extent of the seeps. The total areas of the contaminated seeps (including the vegetated areas) in North Arroyo and Gypsum Creek are conservatively estimated to be 2.5 ac and 5 ac respectively. For the type of rangeland that exists in the vicinity of the site, it would require approximately 60 to 240 ac per year for a cow and 12 to 48 ac per year for a sheep to obtain adequate forage (Curtis 1994; Carling 1994; Hanson 1994). It was assumed for the risk calculations that livestock would roam an area of approximately 1 $mi^2$ over the course of a year in search of forage. A value of 600 ac (200 ha) was used for the potential foraging area. This acreage represents the approximate area of the major drainages in the site vicinity (DOE 1993c). Based on information collected during the November 1993 and June 1994 site visits, the predominant vegetation growing in the vicinity of the seeps (salt cedar) is not a suitable forage for livestock. It is estimated that the amount of forage suitable for livestock (grasses) is less than 0.5 ac and less than 1 ac at the contaminated seeps in North Arroyo and Gypsum Creek, respectively. Thus, livestock could not derive their entire diet from vegetation potentially contaminated by the seeps; they would require food from a variety of other sources.

In terms of water intake, the variable flow of the seeps precludes the possibility for year-round exposure. Also, for most of the seeps where ponding occurs, the amount of water is not sufficient to meet the daily water requirements of livestock. The nearby San Juan River, a perennial water body, represents an important source of water for livestock. For purposes of the risk evaluation, it was assumed that livestock would drink water and eat vegetation affected by the contaminated seeps 1 day per week, 52 weeks per year. This is considered a reasonable assumption because more frequent grazing pressure might result in damage to the vegetation (e.g., defoliation, physical trauma).

The results of the risk calculations indicate that exposure to the water and vegetation potentially affected by the seeps would not result in adverse effects to sheep or cattle. The risk calculations are presented in Appendix C, Tables C.5 through C.10.

### 3.6.4 Potential Risk to Wildlife

Several potential exposure pathways to the contaminants in the seep water exist for aquatic and terrestrial organisms (Figure 3–11). For aquatic organisms, direct ingestion and absorption of seep water and sediments is a potential exposure pathway. Algae and riparian plants could be exposed through root uptake and absorption of contaminants in water and sediment. The aquatic foodweb is also another potential exposure pathway. Aquatic herbivores, such as macroinvertebrates, may eat plants, such as algae, that have bioconcentrated constituents. These herbivores then may be eaten by predators that may be eaten by still other predators. The net effect of bioaccumulation through the foodweb may be significant.

Potential exposure pathways for terrestrial wildlife are similar to those for aquatic organisms (Figure 3–11). Contaminants may be ingested and absorbed if exposure to water, sediment, and soil occurs. Bioaccumulation in the terrestrial foodweb may be important, as for aquatic organisms.

All the potential exposure pathways discussed above were evaluated, with the exception of exposure to sediment and soil. Because no sediment or soil data are available, only pathways associated with seep water were evaluated. However, the contribution of these media to potential risks would be less than risks from exposure to seep water for most animals because exposure (e.g., ingestion) to sediments and soil would be incidental.

Several species of aquatic organisms which were observed or could occur in the seep water pools, include macroinvertebrates, beetles, toad tadpoles, and algae. No fish have been observed, which is not surprising considering the variable nature of seep flow and the shallow water depth. The only suitable habitat for fish is near the confluence of Gypsum Creek and the San Juan River during periods when the river water backs up into Gypsum Creek.

Several key receptor species were chosen for use in evaluating potential risks to terrestrial wildlife. The species were chosen on the basis of ecological importance and protected status and included coyote, desert bighorn, desert cottontail, spotted bat, and southwestern willow flycatcher. These species have been observed in the site vicinity or they could potentially occur in the site vicinity based on habitat characteristics.

A few terrestrial wildlife species (birds, lizards, and ground squirrels) were observed in the vicinity of the seeps during the November 1993, June 1994, and May 1998 reconnaissance-level surveys of North Arroyo and Gypsum Creek. It is likely that additional species would be identified if more detailed surveys were conducted. Also, no visual evidence of adverse ecological effects was noted during these visits.

Based on the results of the screening-level risk assessment (Duncan et al. 1994), which used worst-case exposure pathway assumptions (e.g., wildlife obtain all their water from the contaminated seeps and their food contains contaminants from the seeps), the potential exists for adverse effects to aquatic and terrestrial receptors in both North Arroyo and Gypsum Creek. This

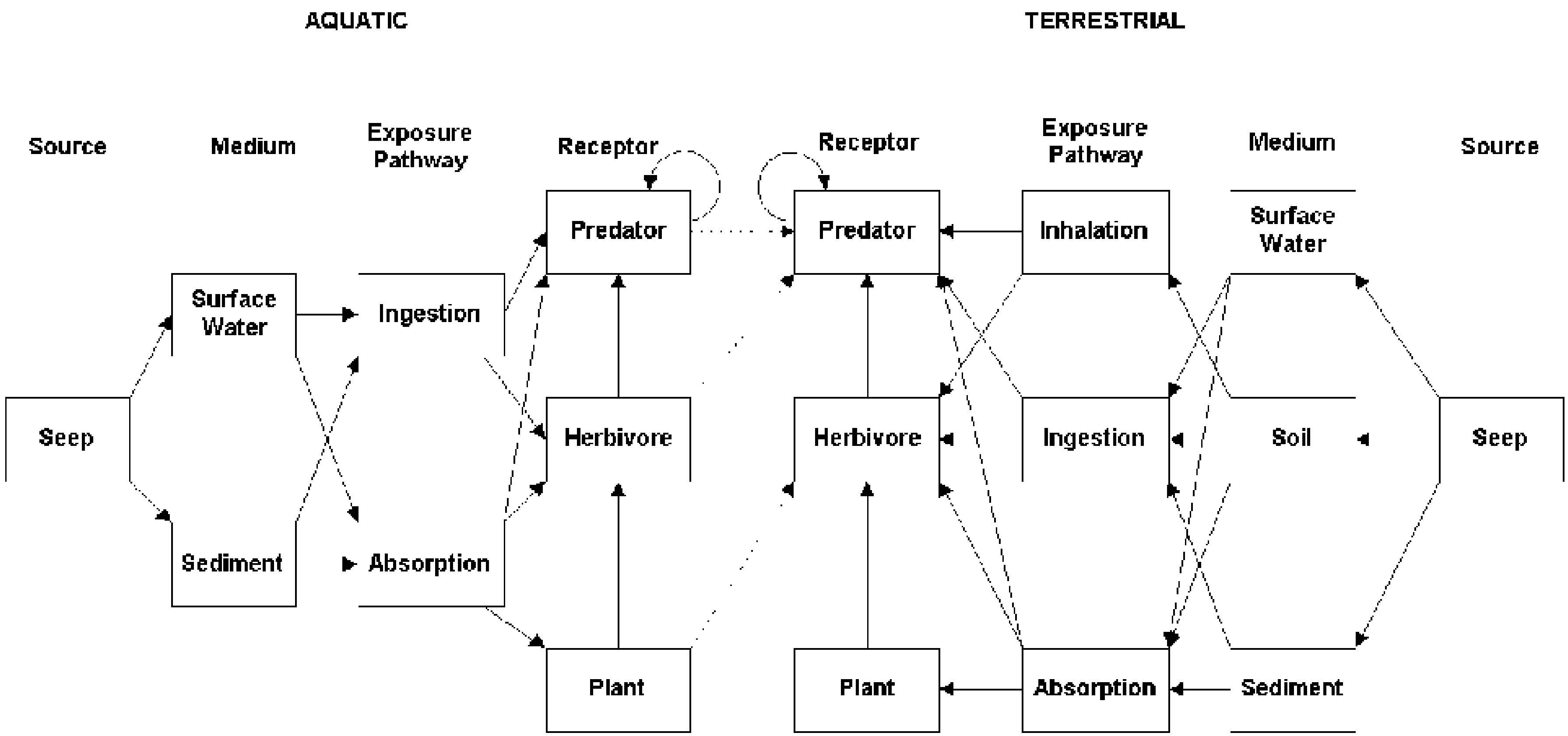


*Figure 3–11. Potential Conceptual Site Model*

preliminary risk assessment also screens out analytes that pose little or no ecological risk and identifies areas where additional information is required to more accurately evaluate ecological risks. The seep water constituents that were determined to pose little or no ecological risk to aquatic organisms are antimony, arsenic, barium, and thallium; and for terrestrial organisms are aluminum, arsenic, bromide, cadmium, calcium, chromium, fluoride, iron, lead, nickel, phosphate, silver, thallium, vanadium, and zinc. The risk calculations are presented in Appendix C (Tables C.11 and C.12 for aquatic organisms and Tables C.13 through C.22 for terrestrial organisms).

### 3.6.5 Limitations of the Risk Evaluation

Inherent in any risk evaluation are the uncertainties associated with the quantification and analysis of its components. Several factors may have resulted in overestimation or underestimation of the risks associated with the seeps at the Mexican Hat site. This section provides a brief discussion of the more important limitations associated with this risk evaluation, which include the following:

- The use of maximum detected concentrations as surrogate values of the actual watershed concentrations lead to overestimation of the potential risk posed by some contaminants. Maximum concentrations were used to maintain a high degree of conservatism.
- The risk evaluation assumed that the contaminants were totally bioavailable to the organisms. Bioavailability, and therefore toxicity, is dependent upon the chemical properties of the environmental media (e.g., water, sediment) and the contaminants.
- The most important limitation is the lack of sufficient toxicity data to calculate ecological risk from several contaminants of potential concern. For aquatic organisms, these contaminants are ammonium, bromide, calcium, fluoride, magnesium, nitrate, phosphate, potassium, silica, sulfate, sulfide, and tin. For terrestrial birds, constituents of potential concern are ammonium, antimony, barium, beryllium, chloride, nitrate, potassium, silica, sodium, sulfate, and sulfide. For mammals, contaminants of potential concern are ammonium, bromide, chloride, cyanide, magnesium, sodium, and sulfide.

An in-depth discussion of the limitations and uncertainty factors is presented in the draft screening-level risk assessment (Duncan et al. 1994).

### 3.6.6 Summary of the Risk Evaluation

A summary of the risk evaluation, which includes the receptors, potential exposure pathways associated with contaminants in the seep water, and whether the risks for each exposure pathway are within EPA's acceptable risk guidelines, is presented in Table 3–7.

*Table 3–7. Risk Evaluation Summary*

| Receptor | Potential exposure pathway | Is exposure pathway complete? | Are risks within EPA's acceptable guidelines? |
|---|---|---|---|
| Humans | Ingestion of seep water | No | Not Applicable |
| | Ingestion of meat and milk from livestock | Yes | Yes |
| Livestock | Ingestion of seep water and vegetation | Yes | Yes |
| Aquatic organisms | Direct exposure to seep water (ingestion/dermal absorption) | Yes | No |
| Terrestrial organisms | Ingestion of seep water and ingestion of food (plants and animals) | Yes | No |

## 3.7 Conceptual Site Model

The communities of Mexican Hat and Halchita are within 3 mi (5 km) of the site and derive their water supplies from the San Juan River and two water supply wells northwest of the San Juan River. These water sources currently provide and are anticipated to continue to provide the total water demand for the area. Contaminated water from the former uranium mill does not affect the community water supplies and the ground water resource. Therefore, site-related risks to human health from ingestion of contaminated ground water do not exist.

All contaminated solid materials have been encapsulated into a disposal cell and isolated them from direct human and animal contact. Current exposure to site-related contaminants potentially exists through direct contact with residual process water discharging from seeps and through ingestion of vegetation or animals that may have accumulated some of the contaminants. Although these potential exposure pathways exist, livestock are not threatened because the nearby San Juan River provides an adequate supply of good quality water, and the seeps are found in only a small portion of the total area used for grazing.

Water in the upper unit of the Halgaito Formation is not considered a significant resource because of limited recharge, relatively low hydraulic conductivity, generally low yield from monitor wells completed in the unit, and minimal areal extent. The poor quality of the water results both from natural characteristics and contamination introduced during the uranium milling operations. It appears that the upper unit of the Halgaito was predominantly unsaturated before milling operations.

The uppermost aquifer is contained within the lower unit of the Halgaito Formation. Site contaminants have not affected, and will not affect, ground water in the lower unit of the Halgaito due to the upward hydraulic gradient and the confining properties in the lower portion of the upper unit. These physical properties provide hydraulic isolation. In addition, the presence of naturally occurring petroleum and high levels of hydrogen sulfide in the lower unit of the Halgaito likely cause ground water within the unit to be unfit for consumption.

Contaminated water does not pose a risk to human health, is not anticipated to cause risks in the future, and will not affect current or beneficial uses of a deeper, isolated aquifer. The potential for risks to plants and wildlife has been identified.

## 3.8 Evaluation of Interim Remedial Action

Interim remedial action is not required for the protection of human health and livestock because the estimated risks for these receptors are within EPA's acceptable levels.

# 4.0 Ground Water Compliance Strategy Selection

This section defines the ground water compliance strategy options, identifies the most likely ground water compliance strategy for the Mexican Hat site, explains the application of site-specific data to the ground water compliance selection framework, and analyzes deviations, contingencies, and decision rules.

## 4.1 Ground Water Compliance Strategies

The Ground Water Project PEIS (DOE 1996a) presents a selection framework (Figure 4–1) for determining the appropriate strategy for achieving compliance with EPA standards. The three compliance strategies for protecting ground water in the uppermost aquifer beneath the processing site specified in the compliance selection framework are:

- No remediation—Application of the no-remediation strategy would mean that compliance with the standards would be met without altering the ground water or cleaning it up in any way. This strategy could be applied at sites that have no contamination above MCLs or background levels or at sites that have contamination above MCLs or background levels, but qualify for supplemental standards or ACLs as described in Section 2.1.1.

- Natural flushing—Natural flushing allows for the natural ground water movement and geochemical processes to decrease the contaminant concentrations to levels within regulatory limits within a given time period. This strategy could be applied at sites where the application of natural flushing would achieve ground water compliance within 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 would require 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 the standards.

## 4.2 Site-Specific Ground Water Compliance Strategy

The ground water compliance strategy for the Mexican Hat UMTRA site is no remediation. This is because ground water in the uppermost aquifer (lower unit of the Halgaito Formation) beneath the processing site has not been contaminated by uranium milling activities, and therefore, remediation is not applicable (Sections 3.4.3, 3.5.2, 3.5.3 of this document). The compliance strategy was selected through application of site conditions to the compliance selection framework (Figure 4–1). Analysis of ground water quality in the uppermost aquifer (lower unit of the Halgaito Formation) has shown that no site-related contamination is present (Box 2 on Figure 4–1). Therefore, no site-specific ground water remediation is required (Box 3 on

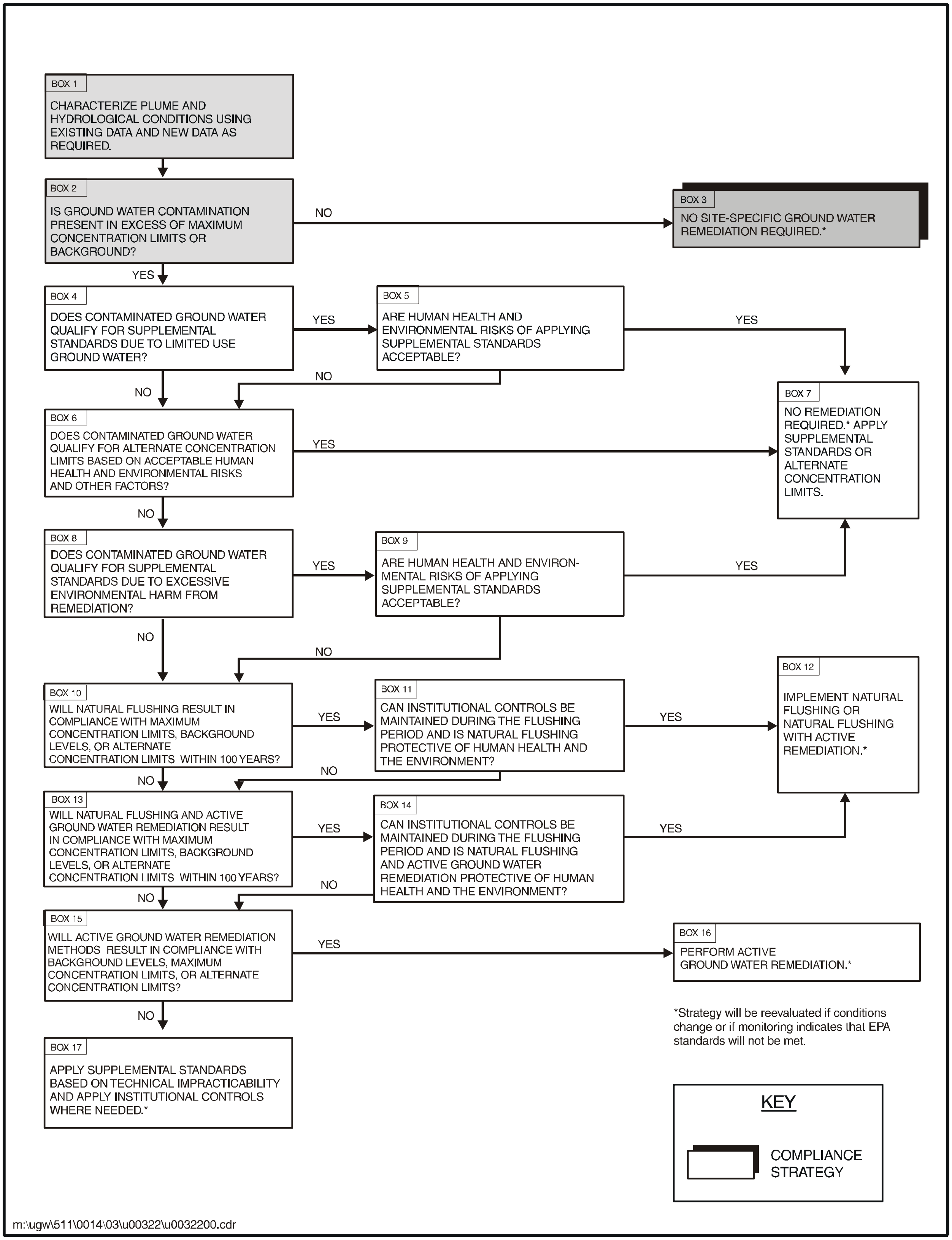


*Figure 4–1. Compliance Selection Framework, Mexican Hat, Utah, Site*

Figure 4–1). At this time, there are no known risks to human health and the environment by applying this compliance strategy.

Site-related contamination is present in sporadic ephemeral ground water in the upper unit of the Halgaito Formation beneath and downgradient from the processing/disposal site. Although it is not regulated since it is not part of the uppermost aquifer, DOE will monitor water discharging from seeps 248, 249, 251, 253, 254, 255, 256, 261, 922, 923, and 924 on a quarterly basis. Analyses will be performed for the following constituents: aluminum, ammonium, antimony, arsenic, cadmium, calcium, chloride, chromium, gross alpha, iron, lead, magnesium, manganese, molybdenum, nickel, nitrate, phosphate, potassium, radium-226, radium-228, selenium, sodium, sulfate, sulfide, total dissolved solids, total organic carbon, uranium, and vanadium. A program for seep monitoring to evaluate disposal cell performance has been discussed in Section 5.2 of the Long-Term Surveillance Plan (DOE 1996b). The seep monitoring will also be used to assess processing site conditions and will be a combined effort for evaluating ground water conditions in the upper unit of the Halgaito for both Subparts A and B of 40 CFR 192.

## 4.3 Deviations, Contingencies, and Decision Rules

The ground water compliance strategy of no remediation is based on lack of site-related ground water contamination in the uppermost aquifer (lower unit of the Halgaito Formation). In addition, adverse effects to human health or livestock are not expected to occur from site-related contamination in the upper unit of the Halgaito (i.e., the contaminated seeps in Gypsum Creek and North Arroyo).

The hydrogeologic portion of the site conceptual model is based on and supported by regional and site-specific data. Therefore, significant deviations from the hydrogeologic model are not expected. Information used for the human health and livestock risk evaluation scenarios is reasonable; therefore, significant deviations are not expected.

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