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U.S. Department of Energy

UMTRA Ground Water Project

Work Plan for Characterization Activities at the Shiprock UMTRA Project Site

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Acronyms

AEC	U.S. Atomic Energy Commission
BLRA	Baseline Risk Assessment
cfs	cubic feet per second
COPCs	contaminants of potential concern
DOE	U.S. Department of Energy
DOE–AL	DOE-Albuquerque
DOT	U.S. Department of Transporation
DQO	data quality objective
EHPA	di(2-ethylhexyl)phosphoric acid
EPA	U.S. Environmental Protection Agency
FR	Federal Register
ft	feet (foot)
ft/day	feet per day
ft^2/day	square feet per day
GJO	Grand Junction Office
gal/day	gallons per day
gpm	gallons per minute
HA	health advisory
HQ	hazard quotient
IDW	investigation-derived waste
in.	inch(es)
Kd	distribution coefficient
km	kilometers
MACTEC–ERS	MACTEC Environmental Restoration Services
MCL	maximum concentration limit
µm	micrometers
mg/L	milligrams per liter
mi^2	square miles
mL	milliliter
NECA	Navajo Engineering and Construction Authority
NEPA	National Environmental Policy Act
NTUA	Navajo Tribal Utility Authority
pCi/L	picocuries per liter
PEIS	Programmatic Environmental Impact Statement
PPE	personal protective equipment
PVC	polyvinyl chloride
QC	quality control
RCRA	Resource Conservation and Recovery Act
RRM	residual radioactive material
SOWP	Site Observational Work Plan
TDS	total dissolved solids
UMTRA	Uranium Mill Tailings Remedial Action (Project)
USGS	U.S. Geological Survey
VCA	Vanadium Corporation of America

1.0 Introduction

1.1 Purpose and Scope

The Shiprock Uranium Mill Tailings Remedial Action (UMTRA) Project site is on the Navajo Indian Reservation (Navajo Nation) in northwestern New Mexico, approximately 1 mile (1.6 kilometers) (km) south of Shiprock, New Mexico, and about 30 miles (48 km) west of Farmington, New Mexico (Figure 1S1). The UMTRA site at Shiprock consists of a stabilized disposal cell that covers approximately 76 acres (31 hectares). The disposal cell was completed in 1986.

Ground water affected by uranium ore processing at the Shiprock UMTRA site contains constituents in concentrations that exceed the ground-water protection standards established in Title 40, Part 192 of the *U.S. Code of Federal Regulations* (40 CFR 192). Affected ground water is on a terrace south of the San Juan River and also within an alluvial aquifer in the floodplain below that is hydraulically connected to the San Juan River. In the *Site Observational Work Plan for the UMTRA Project Site at Shiprock* (SOWP) (DOE 1995), the two compliance strategies considered appropriate for cleanup of the two ground-water systems are: (1) For the terrace system, no remediation and the application of supplemental standards based on classification of the terrace ground water system as limited-use ground water, and (2) for the floodplain system, active remediation using one or more remediation techniques currently under evaluation.

The purpose of this document is to develop a plan for investigating the extent of ground-water contamination in the terrace system, evaluate the hydraulic interconnection between the terrace and alluvial ground-water systems, evaluate the hydraulic interconnection between the alluvial ground water and the San Juan River, and collect data to help select a corrective action for the site. This work plan proposes that additional characterization data be collected to complete the evaluation of active technologies and to prepare a preliminary design of the potential treatment system. A discussion of the additional data needs is presented in Sections 2.0 through 5.0. A site conceptual model for the site is summarized in Section 6.0. Data quality objectives are defined in Section 7.0. The specific procedures that will be used to satisfy the data requirements are presented in Section 8.0. After completion of field work at the site, the results of this additional characterization and recommended techniques for ground-water remediation will be presented in Revision 1 of the final SOWP.

1.2 Site Background

The U.S. Atomic Energy Commission (AEC) established a uranium ore buying station at the Shiprock site in January 1952. An AEC contractor, American Smelting and Refining Company, operated the station until November 1954 when construction on the mill was completed and Kerr-McGee Oil Industries, Inc., assumed operation of the facility (Albrethsen and McGinley 1982). Kerr-McGee operated the mill until it was sold in March 1963 to the Vanadium Corporation of America (VCA). During the Kerr-McGee operation, about 80 percent of the processed uranium and vanadium ore came from company-controlled mines in northeastern

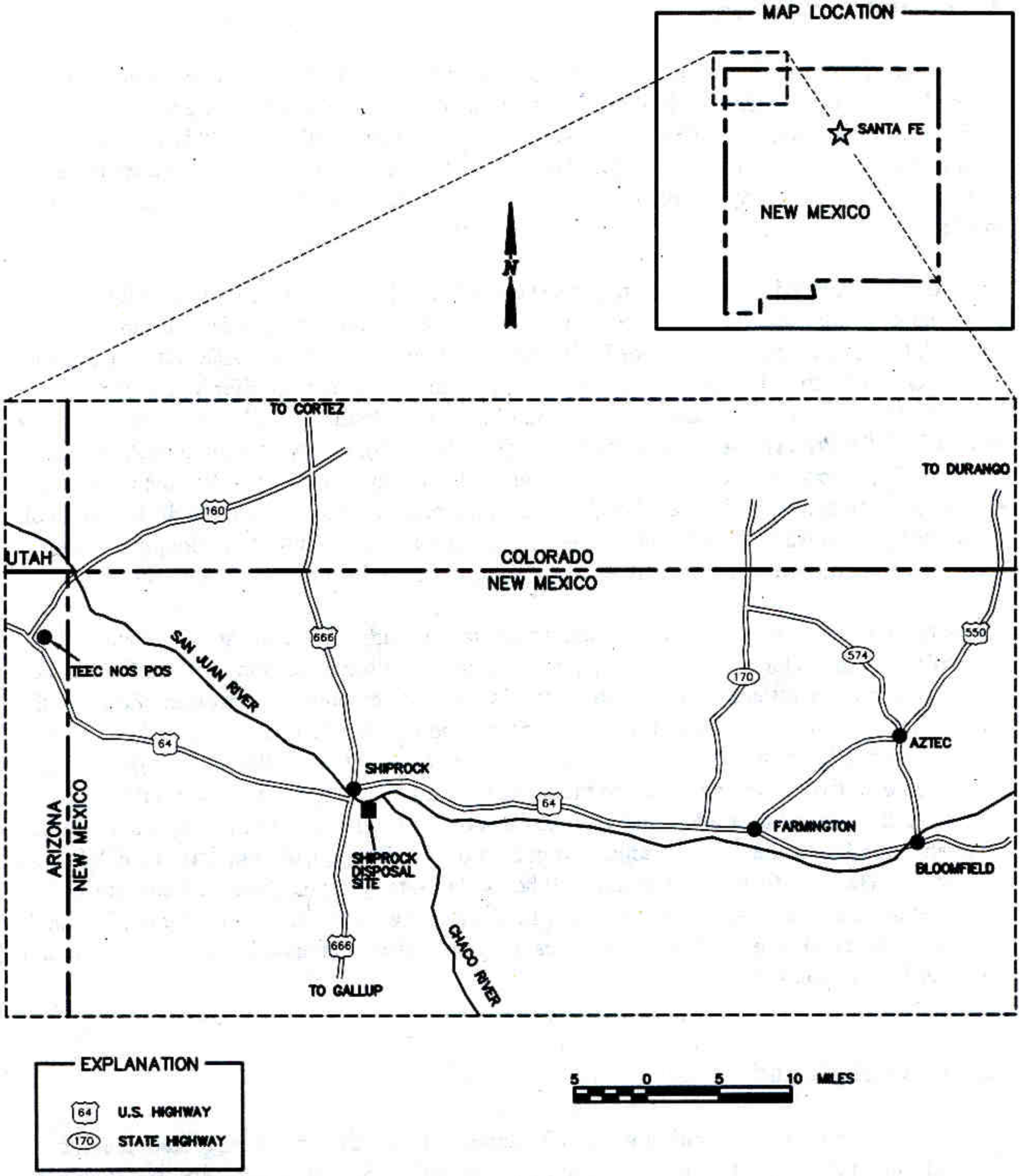


Figure 1–1. Location of the Shiprock Site

Arizona. The remaining ore came from other small mines mainly in northeastern Arizona and northwestern New Mexico. Ore was mainly sandstone that contained carnotite as the primary ore mineral.

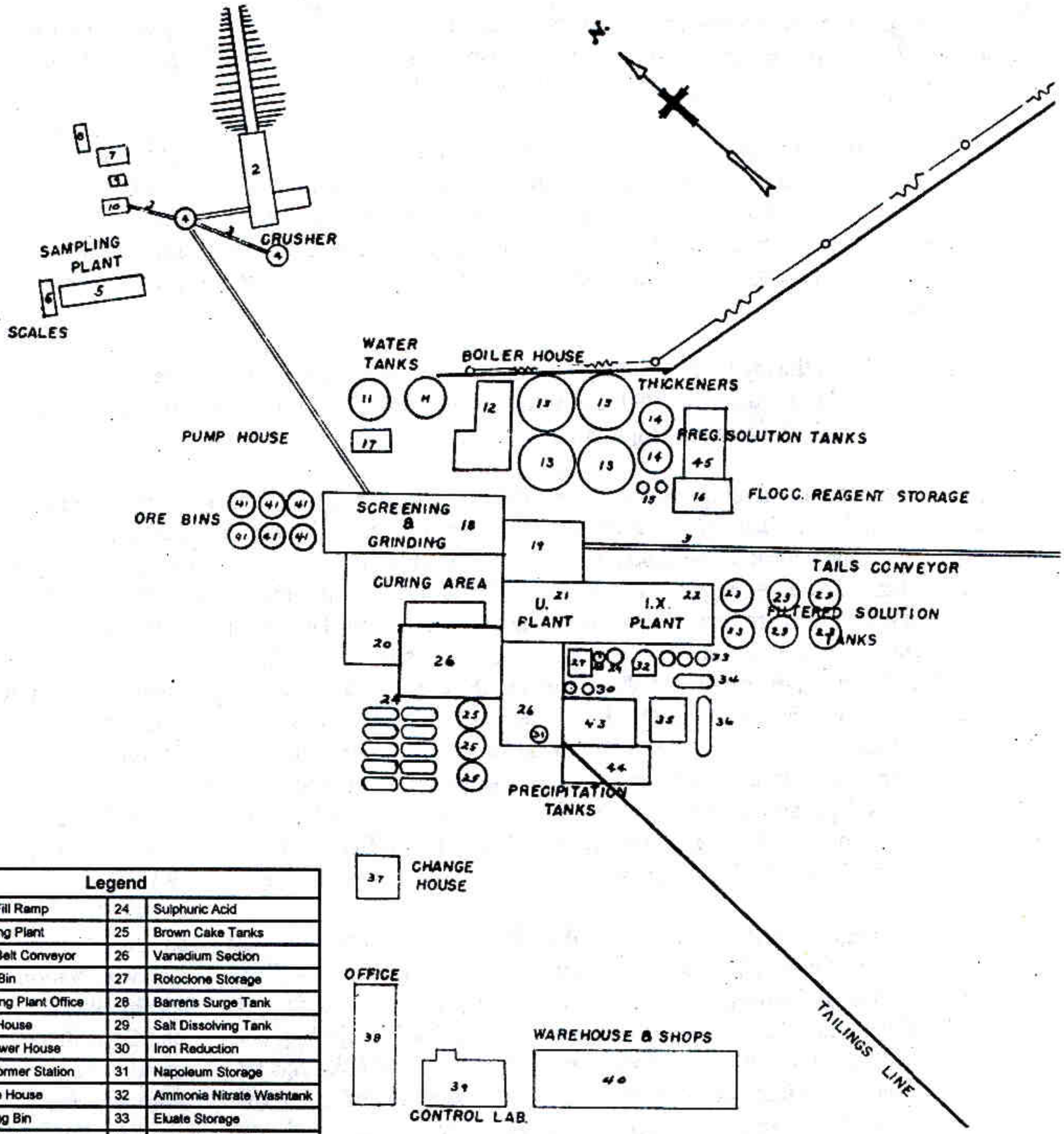
VCA operated until August 1967 when the company merged with Foote Mineral Company, which continued operation until milling ended in May 1968. During the VCA and Foote operation, more than half of the ore supply came from the Uravan Mineral Belt in southwestern Colorado. Another source of feed to the mill was the dried slime concentrates and chemical precipitates produced by VCA’s concentrating plants near the Monument No. 2 mine at the Monument Valley, Arizona, site.

Figure 1**S**2 shows the layout of buildings during milling operations; Figure 1**S**3 is a photograph showing the buildings and raffinate lagoons to the southeast. An aerial view of the millsite and surrounding area is shown in the high-altitude photograph in Figure 1**S**4.

The procedure for processing ore at the site called for the ore to be crushed and ground to less than 35 mesh. It was then fed into a sulfuric acid leaching circuit. Leaching occurred in two stages; the strong acid solution produced in the second stage was recirculated to the first stage for partial neutralization by the entering ore slurry. The high concentration of acid in the second stage was necessary to maintain profitable vanadium extraction. The bulk precipitate from the Monument Valley concentrator and upgrader was added ahead of the first leaching stage. Following leaching, the sands and slimes entered the countercurrent washing system in which the sands were washed in classifiers and the slimes were washed in thickeners. Uranium and vanadium were extracted from the pregnant liquors by means of liquid organic solvents. The organic compounds thought to be used in the solvent extraction process were di(2-ethylhexyl)phosphoric acid, tributyl phosphate, kerosene, and alcohol (DOE 1997). Tailings from the washing circuit were pumped to tailings ponds. Raffinate from the solvent extraction operation was disposed of by evaporation in separate holding ponds (Figures 1–3 through 1–5).

After milling ended in May 1968, much of the mill equipment was dismantled and some of the highly contaminated equipment and materials were buried with the tailings. The Navajo Nation was contracted for the decontamination and removal of the old main mill building. In 1973 the property reverted to the control of the Navajo Nation. The Navajo Engineering and Construction Authority (NECA) occupied the former plant office and shop buildings and operated a training school on the site to instruct Navajo students in the operation of earthmoving equipment. From 1974 through 1984 assessments were performed to develop stabilization alternatives for the surficial contamination at the Shiprock site. “Stabilization in place” became the chosen alternative; site stabilization was completed in 1986.

U.S. Nuclear Regulatory Commission staff reviewed the Shiprock Remedial Action Plan, Environmental Assessment, and supporting documents. On the basis of those reviews, the staff decided in June 1985 that the U.S. Department of Energy (DOE) proposed remedial action complied with water resource protection aspects of the U.S. Environmental Protection Agency (EPA) standards in 40 CFR 192, as they existed at that time, except for characterization and potential cleanup of the contaminated ground water in the floodplain alluvium north of the site. Since that time, DOE has further characterized the extent of ground-water contamination in the floodplain alluvium and assessed the need for control and cleanup of the contamination. No



Legend			
1	Earth Fill Ramp	24	Sulphuric Acid
2	Crushing Plant	25	Brown Cake Tanks
3	Open Belt Conveyor	26	Vanadium Section
4	Surge Bin	27	Rotoclone Storage
5	Sampling Plant Office	28	Barrens Surge Tank
6	Scale House	29	Salt Dissolving Tank
7	Old Power House	30	Iron Reduction
8	Transformer Station	31	Napoleum Storage
9	Grease House	32	Ammonia Nitrate Washtank
10	Trucking Bin	33	Eluate Storage
11	Water Tanks	34	Hydrochloric Acid Storage
12	Boiler House	35	Salt Storage
13	Thickeners	36	Ammonia Storage
14	Preg. Solution Tanks	37	Change House
15	Flocc. Reagent Storage	38	Office
16	Flocc. Storage	39	Control Lab
17	Pump House	40	Warehouse & Shops
18	Screening & Grinding	41	Ore Bins
19	Leaching Plant	42	
20	Curing Area	43	S.X. Plant
21	Uranium Plant	44	Chemical Warehouse
22	I.X. Plant	45	Iron Reduction
23	Filtered Solution Tanks		

Figure 1–2. Layout of Buildings at the Shiprock Millsite

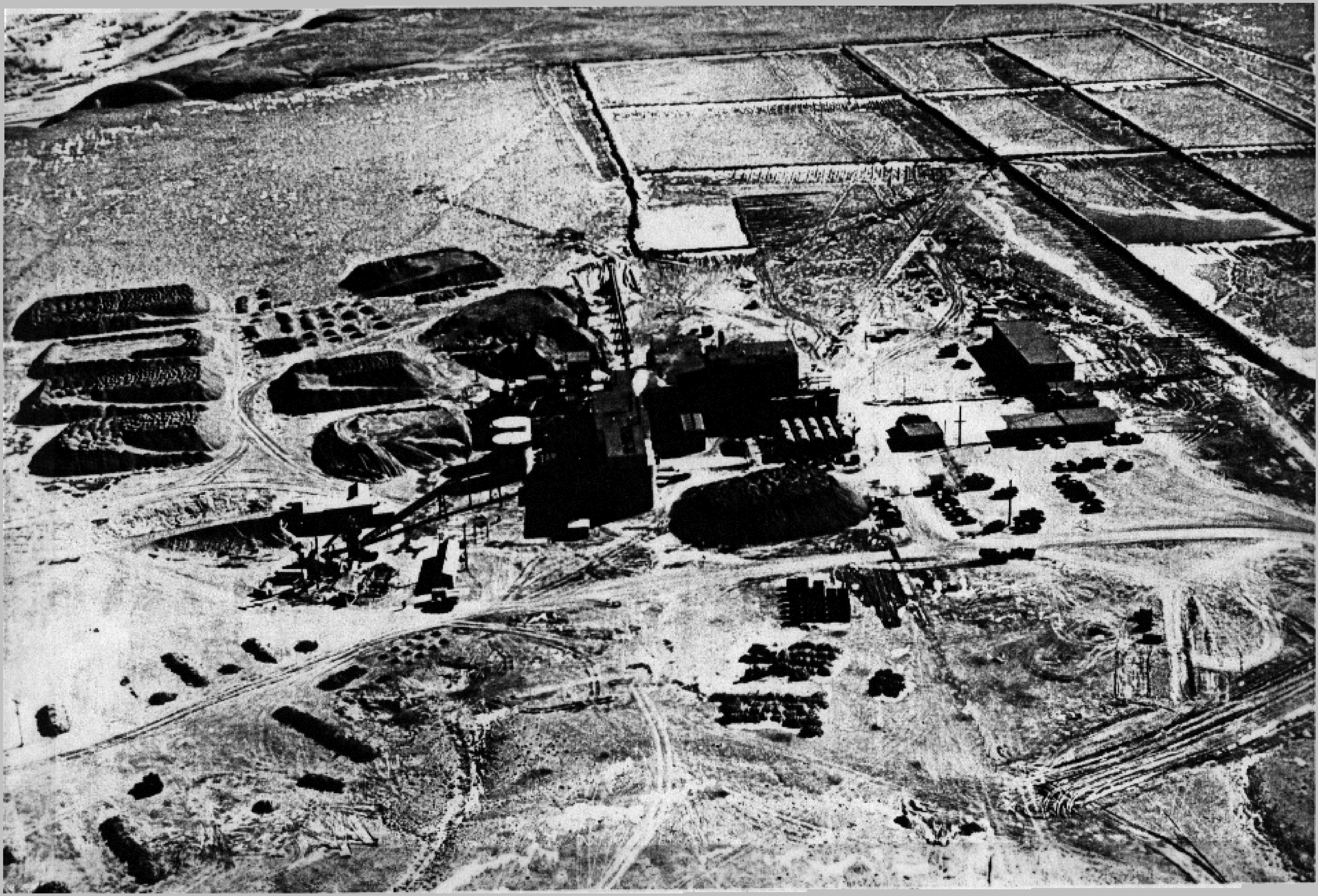


Figure 1–3. View Southeast of the Shiprock Millsite in Operation in the Late 1950s

Figure 1–4. Aerial View of the Shiprock Millsite and Adjacent Area

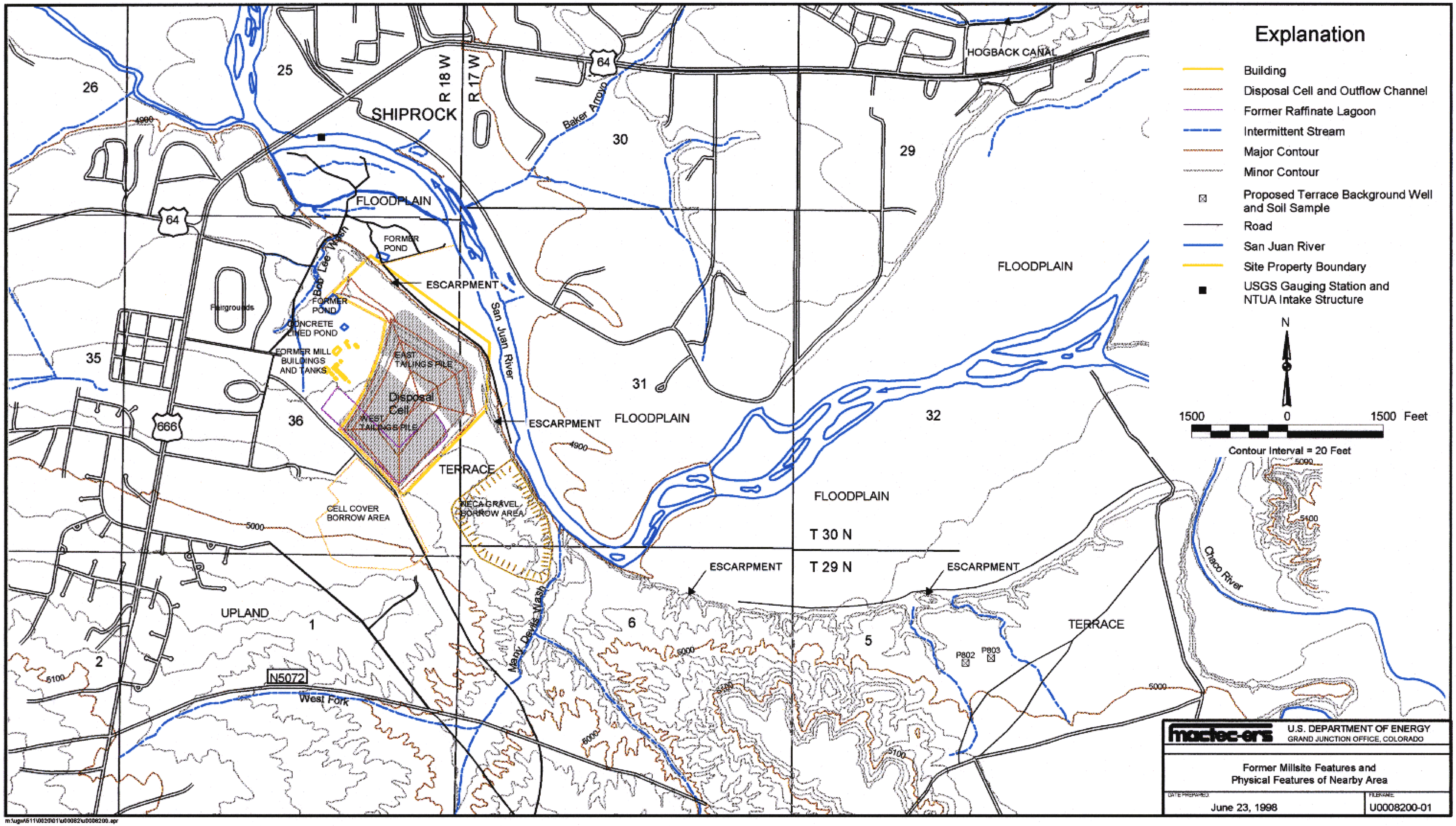


Figure 1–5. Former Millsite Features and Physical Features of Nearby Areas, Shiprock Site

significant effort was undertaken to characterize the terrace ground-water system because the water in that system was thought to have originated from seepage of tailings liquor from mill tailings impoundments and not to be contributing to contamination of any currently or potentially useful aquifer (60 FR 2866, January 11, 1995). However, the notion that the terrace represents a potential source of ground-water contamination in the alluvial aquifer, and the uncertainty over whether the terrace is a limited ground-water resource, are important stakeholder concerns.

1.3 Sources of Ground-Water Contamination from Milling Operations

Estimates of water used during the milling process are provided in Merritt (1971) and are also summarized in the SOWP (DOE 1995). These sources indicate that Kerr-McGee had two water withdrawal permits, NM2807 and NM2875, for 500 and 700 acre-feet (446,000 gallons per day [gal/day] and 625,000 gal/day), respectively, from the San Juan River. The water was used for processing operations and as cooling water. The process water was used at a rate of 720 to 1,200 gallons per ton of ore processed during acid-leach operations. At an ore processing rate of 400 tons per day and an assumed water use rate of 960 gallons per ton, water use at the Shiprock mill would have been about 384,000 gal/day. All process water used at the site was discharged to tailings piles as a tailings slurry and to unlined raffinate ponds. The discharged water either evaporated from the tailings piles and from the raffinate ponds, or it infiltrated into the ground water. Mill cooling water was used at a rate of approximately 187,000 gal/day. This water was discharged to Bob Lee Wash, which drains north to the San Juan River floodplain, on the west side of the mill (Public Health Service 1962). The cooling water was at times contaminated because of overflow of process waters. Surface contamination in Bob Lee Wash was remediated during the tailings stabilization process, which was completed in 1986.

Infiltration into the ground from the tailings slurry and the raffinate ponds was the principal source of ground-water contamination at the Shiprock site. The infiltration occurred from 1954 to 1968, a period of 14 years. Much of the infiltration occurred on the terrace. Water from the slurry and the raffinate ponds entered the ground and flowed vertically downward through terrace gravel and the weathered and fractured portion of the Mancos Shale. Upon reaching the base of the weathered Mancos Shale, it is believed the water spread radially due to mounding and either flowed to the escarpment at the edge of the terrace, where it issued forth as springs and seeps, or flowed as surface water from the watersheds of either Many Devils Wash or Bob Lee Wash (Figure 1–5). The discharge rate from these seeps, springs, and washes was measured at the land surface to be about 227,000 gal/day (Public Health Service 1962). The water from these sources probably seeped into the floodplain alluvium and carried with it dissolved inorganic constituents that are now a source of the present contamination.

Infiltration over the 14-year period created a ground-water mound in the terrace ground-water system. During the 30 years after milling ended, ground-water in the terrace system has probably subsided to its initial elevation. As part of this investigation, a detailed water balance will be developed to account for the water used during processing and to account for present water conditions.

1.4 Target Compliance Strategy

A framework for determining the appropriate strategy for achieving compliance with EPA's ground-water protection standards is presented in the *Final Programmatic Environmental Impact Statement for the Uranium Mill Tailings Remedial Action Ground Water Project* (PEIS) (DOE 1996b). This framework was used in the Shiprock SOWP (DOE 1995) to select the two ground-water compliance strategies targeted for the Shiprock site. One strategy is developed for the terrace ground-water system and the other is developed for the floodplain alluvial aquifer. The recommended final compliance strategies will depend on results of the additional characterization proposed in this work plan and will be presented in the final SOWP, Rev. 1, after completion of the field work.

The most likely compliance strategy presented in the SOWP for the terrace ground-water system is no remediation and the application of supplemental standards, based on the classification of the terrace system as limited-use ground water. This work plan identifies the field activities that will determine the sustained yield of the terrace ground-water system. Milling-related sources of past recharge to the terrace system no longer exist. Therefore, the saturated area in the terrace system is expected to decrease over time and return to its premilling condition of little-to-no saturation. Also, it is suspected that human activities (leaking water-supply and sewer/septic systems) provide recharge to the terrace system from the west and southwest. This human-induced contribution to the terrace system will also be evaluated as part of characterization activities to determine if a condition of widespread ambient contamination is present, further supporting a limited-use designation.

For the floodplain alluvial aquifer, the compliance strategy is to pursue active remediation for constituents that pose a potential risk or exceed EPA standards. Eleven contaminants of potential concern (COPCs) in the ground water at the Shiprock site were identified in the *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site Near Shiprock, New Mexico* (BLRA) (DOE 1994). The 11 COPCs are antimony, arsenic, cadmium, magnesium, manganese, nitrate, selenium, sodium, strontium, sulfate, and uranium.

2.0 Geologic Setting

The Shiprock disposal site is at an elevation of approximately 5,000 feet (ft) along the south side of the San Juan River in the arid southeastern part of the Colorado Plateau. The site is in the northwest part of the San Juan Basin on the Four Corners Platform, a part of the basin where bedrock formations are of Late Cretaceous age and are nearly flat lying. East of the site about 8 miles at the edge of the Four Corners Platform is the Hogback Monocline where rocks dip steeply eastward into the central part of the San Juan Basin. Ship Rock, about 10 miles southwest of the site, is a prominent volcanic neck composed of basaltic rock of mid-Tertiary age.

The disposal cell and adjacent NECA operation sit on a terrace elevated about 60 ft above the San Juan River floodplain. Unconsolidated Quaternary deposits consisting of sand, silt, gravel, and cobbles laid down by the ancestral San Juan River cover the terrace in the area of the disposal cell, where these deposits are 10 to 30 ft thick. Similar Quaternary deposits about 20 ft thick cover the floodplain. Bob Lee Wash and Many Devils Wash bound the terrace portion of the site to the northwest and southeast, respectively (Figure 1–5). These north-draining washes cut through the terrace material into the underlying Mancos Shale bedrock.

South of the disposal cell, the terrace surface rises gradually to a subtle upland area (Figure 1–5) and a low ridge at an elevation of about 5,060 ft. South of this ridge is a small east-draining (dry) tributary of Many Devils Wash. On the north flank of the ridge, about 1,500 to 2,000 ft south of the disposal cell, weathered Mancos Shale bedrock is exposed. Between the exposed bedrock and the disposal cell, the unconsolidated San Juan River deposits are present, but they are covered by a wedge of wind-deposited loess composed of fine-grained sand and silt. The loess thickens southward from the disposal cell and attains a thickness of up to 30 to 40 ft just north of the exposed bedrock on the upland area.

Underlying the Quaternary material in all of the site area is bedrock of Mancos Shale, which is of Late Cretaceous age. Weathered Mancos Shale is exposed in the upland area south (and for many miles farther south) of the disposal cell and in the escarpment that separates the San Juan River floodplain from the terrace.

2.1 Stratigraphy

Mancos Shale and overlying unconsolidated Quaternary material (loess, terrace material, and floodplain alluvium) are shown in a north-south cross section (A–A' in Figure 2–1) through the site in Figure 2–2. Figure 2–1 also shows the status of monitor wells and the sample locations for the site.

Drilled from October 1960 to February 1961 as an oil and gas test, artesian well 648 west of Bob Lee Wash (Figure 2–1) produces water from the Morrison Formation of Late Jurassic age through a perforated zone from 1,482 to 1,777 ft in depth. A lithologic and well completion log for this well is shown in Figure 2–3. This well penetrates deep sandstone units that contain ground water under artesian pressure; the confined ground water will not be affected by site-related contaminants.

Characteristics of the shallow geologic units that could be affected by site activities—Mancos Shale and the overlying unconsolidated Quaternary material—are described below.

2.1.1 Quaternary Material

Unconsolidated Quaternary material at the site consists of alluvium deposited by the San Juan River in its present floodplain, terrace material (situated about 60 ft above the floodplain) deposited by the ancestral San Juan River, and loess deposited by prevailing southerly winds on the lee side of Mancos Shale uplands.

Alluvium in the crescent-shaped floodplain area, which ranges in elevation from about 4,895 ft at the southeast and to about 4,885 ft at the northwest end, consists of two lithologic types. As described in the SOWP (DOE 1995) and in the study of the floodplain by Tsosie and others (1997), the two types are (1) a lower coarse unit composed mainly of sand, gravel, and cobble-sized material overlain by (2) a finer unit consisting mainly of clay, silt, sand, and minor gravel. Both types are poorly sorted and are gray-brown to yellow-brown. The average thickness of this alluvial material is about 15 ft but may be as much as 20 ft. Individual thicknesses of the two lithologic types are also variable, ranging from several feet to as much as 12 ft (see Figure 2–2).

Variation in the bedrock surface topography accounts for some of the thickness variation of the overlying alluvial material. The contoured bedrock surface and fence diagram of alluvial material in the SOWP (Figures 3.6 and 3.7, DOE 1995) and cross sections of the floodplain alluvial material by Tsosie and others (1997) show ridges and swales in the bedrock surface indicative of lateral migration of ancestral river channels. These low areas may be localizing and restricting movement of contamination in the lower part of the alluvial aquifer. Additional depth-to-bedrock data were collected during geophysical refraction surveys conducted on the floodplain in February 1996 to locate bedrock depressions (DOE 1996c). Additional boreholes and wells in the floodplain and vertical profiling of contamination would help in the understanding of contaminant distribution related to bedrock lows (swales).

The disposal cell sits on a terrace or bedrock bench about 60 ft above the San Juan River floodplain. Capping the terrace is a layer typically 10 to 20 ft (but as much as 30 ft) thick of generally clast-supported gravel and cobbles having a silty and sandy matrix. This terrace material is mapped along the San Juan River as "Q6" by Ward (1990), who indicates the material is glacial outwash deposited during Pleistocene time. In the site area the terrace-capping sand and gravel extends from the top of the escarpment south and west to the disposal cell area, beyond which it is covered by younger loess material. Most of the terrace sand and gravel has been removed from the NECA gravel borrow area (Figure 2–1) southeast of the disposal cell. The terrace sand and gravel is present in the subsurface at well 604–2, where it attains a thickness of nearly 30 ft; several hundred feet south of well 604–2, the extent of terrace gravel ends along the edge of a Mancos Shale hill (Figure 2–2). It is thought that the south edge of the terrace material ends abruptly in a similar manner south of the site along the Mancos Shale upland area. This

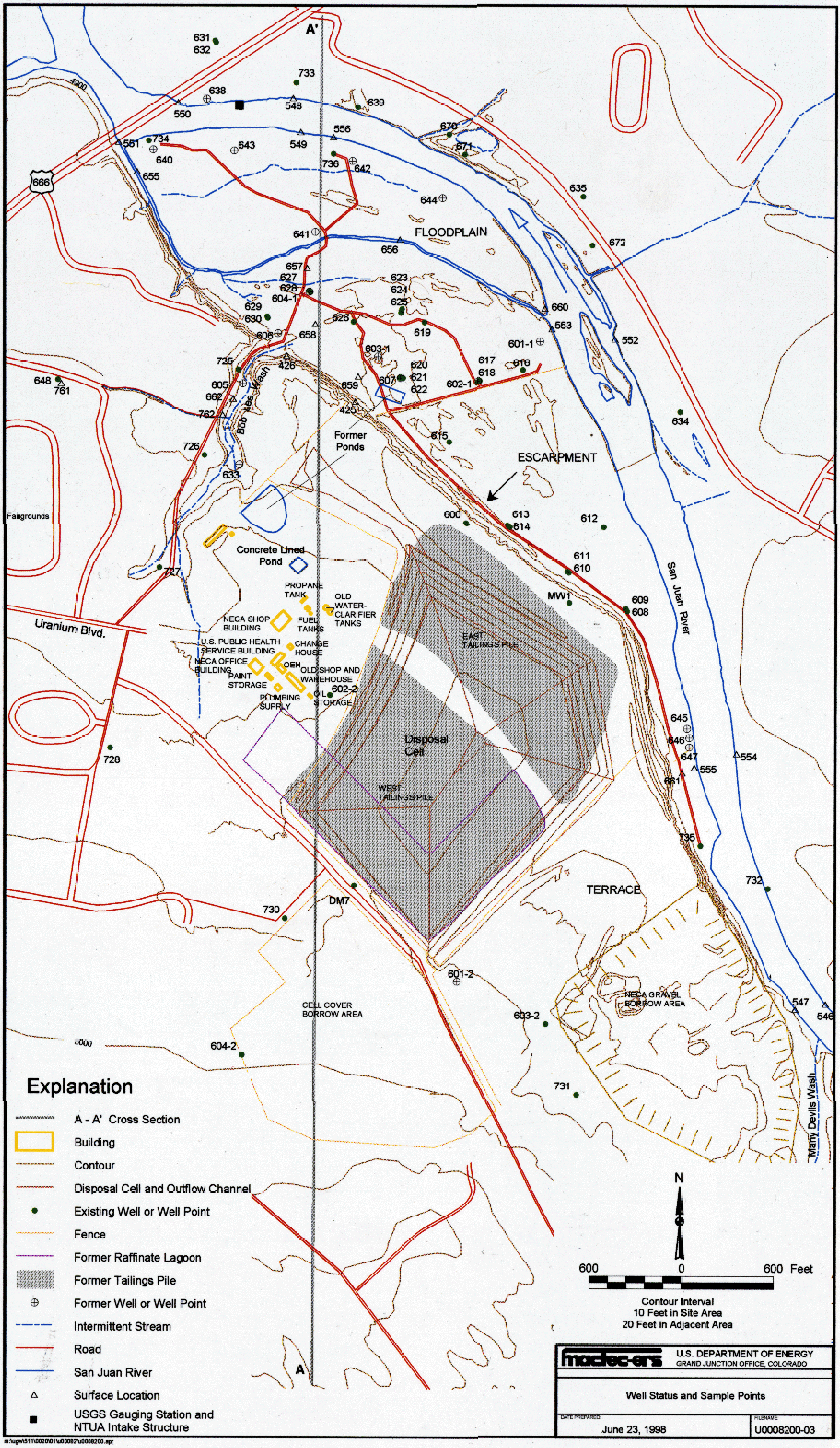


Figure 2–1. Monitor Wells and Sample Points, Shiprock Site

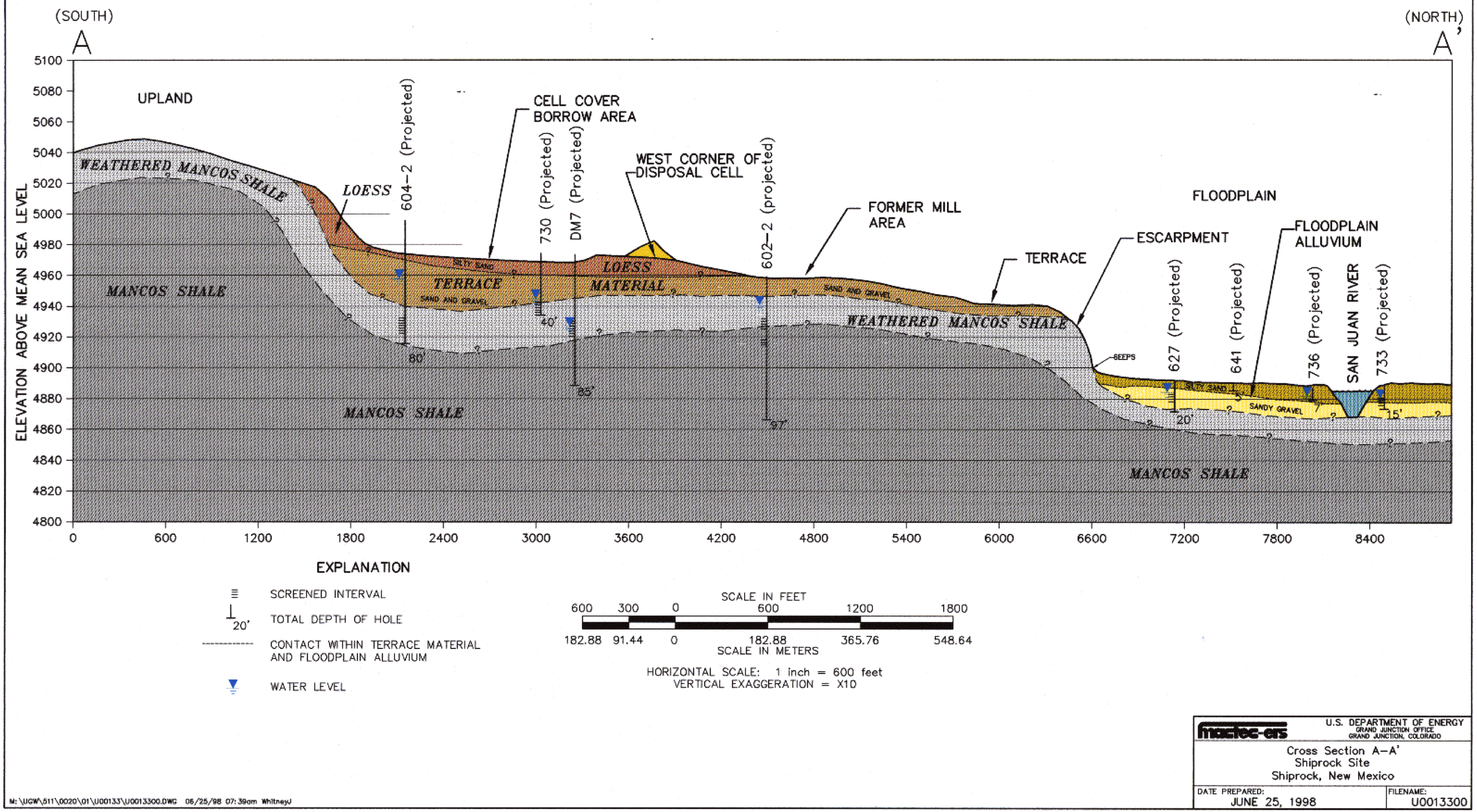


Figure 2–2. Geologic Cross Section A–A', Shiprock Site

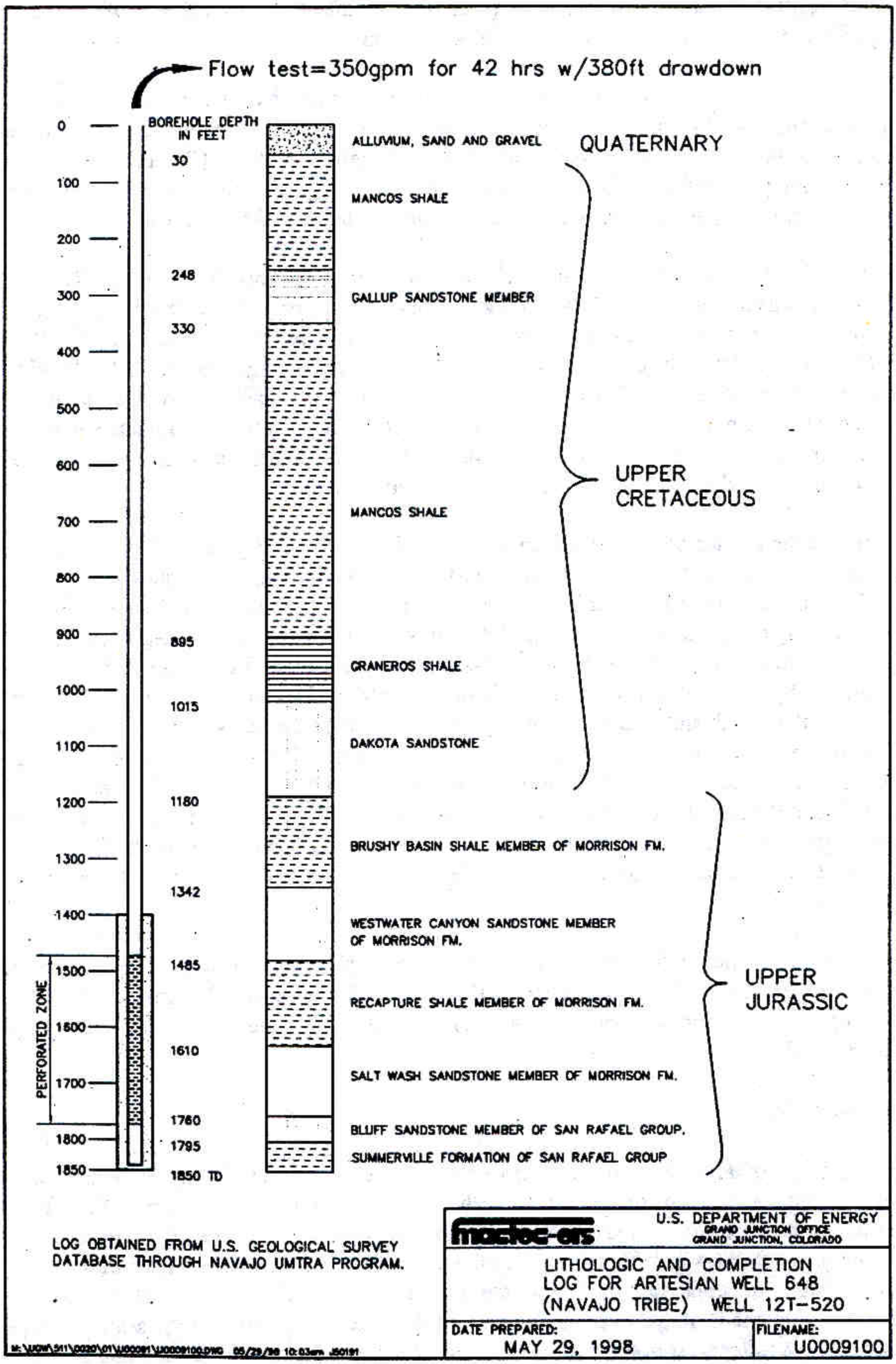


Figure 2–3. Lithologic and Completion Log for Artesian Well 648 (Navajo Tribal Well 12T–520),

abrupt edge of the Pleistocene terrace material is likely similar to the abrupt edge of the present floodplain alluvium against the Mancos Shale escarpment.

The ground-water surface is in weathered Mancos Shale over much of the terrace area where the terrace sand and gravel material is exposed. Farther south, where the terrace material is covered by loess, the ground-water surface rises and is within the terrace material (Figure 2–2). Additional boreholes in the area south and southwest of the disposal cell are necessary to further evaluate the extent of the terrace material that contains contaminated ground water.

Because the sand and gravel terrace material was deposited by the ancestral San Juan River in a similar manner as the floodplain alluvium, the contoured top of bedrock surface in the terrace area shows erosional swales and ridges oriented roughly eastward (Figure 3.5 in the SOWP, DOE 1995) and is also reflective of the process of lateral channel migration. As in the floodplain, a concern on the terrace is that low areas (paleochannels) may be localizing and restricting movement of contaminated ground water. Additional boreholes and wells south and southwest of existing monitor wells would help in delineating the extent, thickness, and composition of the terrace material and the vertical distribution of contaminants.

Loess covers the surface of the site area in a band southwest of the disposal cell extending to the north edge of the upland area where weathered Mancos Shale is exposed. As shown in Figure 2–2, the loess increases in thickness southward (to nearly 30 ft in well 604–2). This material, mainly of eolian origin, is composed of grayish-brown and yellowish-gray clay, silt, and very fine grained sand and is mapped and described generally as Tsegi Alluvium of Holocene age by Ward (1990). The loess is dissected by Many Devils Wash where distinctive exposures at the mouth and along lower parts of the wash stand vertically as classic examples of loess deposition. Loess from a large area just south of the disposal cell and east of well 604–2 (cell cover borrow area in Figure 2–1) was removed for use in the radon barrier during construction of the disposal cell. Deposition of the loess appears to have been in low areas along ancestral drainages in locations on the lee side of prevailing southerly winds, particularly in a thick accumulation along the north side of the Mancos Shale upland area in an ancestral San Juan River channel.

Water-level information indicates that the ground-water surface in the area where loess is present is below the loess and in the terrace material (Figure 2–2). The extent of the loess will be determined in conjunction with the delineation of the extent of ground water in the underlying terrace material.

2.1.2 Mancos Shale

Approximately 1,000 ft of Mancos Shale underlies the site area (Figure 2–3). The Mancos is mainly an open marine mudstone deposited in the Late Cretaceous Western Interior Seaway. The part of the Mancos exposed in the site area is composed of gray to dark gray, gypsiferous and calcareous shale with several thin (up to 1 ft thick), resistant, siltstone beds. This part of the Mancos is within the upper part of the formation (Ward 1990), which is separated into an upper and lower part by the Gallup Sandstone (a coastal sandstone representing a regression of the sea) exposed about 8 miles west of the site. The Gallup Sandstone, present to the west and south, pinches out several miles to the southwest of Shiprock (Molenaar and others 1996). Northeast of the pinchout is a thin, discontinuous sandstone interval that has been called the "Stray" sandstone; more recently, this interval has been named the Tocito Sandstone Lentil. This sandstone interval crops out about 4 miles west of the site along the San Juan River. It is this sandstone interval that is present in the subsurface of the site at a depth of about 250 to 330 ft and is shown in Figure 2–3 as the Gallup Sandstone Member in the lithologic log of well 648. Ground water that may be present in this sandstone would be under artesian conditions and not subject to contamination by milling activities at the site.

Exposures of Mancos Shale in the site area are best observed along the escarpment, in the lower part of Many Devils Wash, and in the cliffs along the San Juan River just upstream and downstream from the wash. A prominent, resistant, thin, siltstone bed exposed in the escarpment north of the disposal cell underlies the terrace area of the site. This marker bed indicates that the dip of the strata is toward the east or southeast at only 1 or 2 degrees. Also noticeable in the exposed Mancos in the escarpment is an orthogonal system of vertical joints. The principal set trends southeast to east-southeast and a secondary set trends north-northeast.

In Mancos Shale surface exposures and in shale immediately below the Quaternary material, a weathered zone 10 to 30 ft thick is present. In some areas, as on the upland area south of the site, the exposed weathered Mancos is soft with little recognizable bedding and has a colluvium-like appearance. This weathered zone is fractured and may be somewhat permeable to ground-water movement vertically or along horizontal bedding planes. Vertical fracturing may also extend downward into unweathered Mancos, which is considered relatively impermeable to horizontal ground-water movement. An effort was made to detect significant fracturing in the Mancos by conducting an EM34 conductivity survey during the geophysical survey in February 1996 (DOE 1996c); results indicated few fractures and none of importance.

Ground water is present in much of the weathered Mancos Shale where it is overlain by Quaternary terrace material or floodplain alluvium. On the terrace where only river deposits of sand and gravel overlie the Mancos, the ground-water surface is usually in the weathered Mancos Shale. This ground water travels toward the escarpment, down through fractures and along relict bedding planes, and appears as seeps near the escarpment base. The thin siltstone bed in the escarpment may act as a barrier to downward ground-water flow; perched ground-water may flow downdip to the east along the top of this siltstone bed. Unweathered competent Mancos Shale does not appear to contain significant amounts of ground water and is expected to behave as an aquitard. Additional borehole drilling and sampling will further characterize the ground water present in the weathered and unweathered Mancos Shale.

Also to be evaluated is the degree of ground-water communication through weathered Mancos Shale from the terrace material to the floodplain alluvial aquifer.

2.2 Summary of Data Needs

Geologic data needs summarized below are needed to refine the site conceptual model and to provide parameters for use in ground-water remediation.

Surface geologic mapping will identify the contact of weathered Mancos Shale bedrock and Quaternary material along the north side of the upland area. Also, surface geologic investigation will measure the orientation and spacing of joints (fractures) in the escarpment area of well-exposed Mancos Shale.

Descriptions of cuttings from the proposed boreholes will improve understanding of bedrock topography and thicknesses of the geologic units in both the floodplain and terrace areas. Descriptions of core from the deep boreholes into weathered and unweathered Mancos Shale will characterize degree of fracturing and relative amounts of ground water held in this bedrock.

3.0 Hydrology

This section contains a brief description of the hydrology of the Shiprock site and describes the data required for additional site characterization. The surface-water hydrology and ground-water hydrogeology of the site have been described in the SOWP (DOE 1995) and in the preamble to the ground-water protection standards (FR, Jan 11, 1995, p. 2863).

3.1 Surface Water

The San Juan River has a drainage area of approximately 12,900 square miles (mi^2) upstream from the town of Shiprock. Discharge records for the San Juan River at Shiprock are nearly continuous since February 1927. A river stage recorder (09368000) operated by the U.S. Geological Survey (USGS) is located in Shiprock about 300 ft east (upstream) of the U.S. Highway 666 bridge along the north side of the river (Figure 1–5). The river gauge was established at this location in 1995; formerly, the gauge was located about 3 miles west (downstream) of Shiprock. Data from the river gauge indicate that before 1963, extreme low and high flows ranged from less than 8 cubic feet per second (cfs) to about 80,000 cfs, respectively. After construction of the Navajo Reservoir (located 78 river miles upstream of Shiprock) was completed in 1963, the extreme low and high flows moderated to about 80 cfs and 15,000 cfs, respectively. Average flow in the San Juan River at Shiprock is 2,175 cfs (Stone and others 1983).

The Chaco River drains more than 4,000 mi^2 and empties into the San Juan River about 2 miles east of the Shiprock site. It drains many areas in the San Juan Basin containing coal and uranium resources (Stone and others 1983). The lower reaches of the Chaco River contain perennial flow amounts ranging from 10 to 30 cfs during non-storm flow periods. Much of the flow is reported to be effluent from the Four Corners Power Plant, about 12 miles southeast of the Shiprock site (Stone and others 1983).

Residents of Shiprock rely almost exclusively on San Juan River water for municipal, industrial, and agricultural needs. Most of this water is diverted near The Hogback, about 8 miles east of Shiprock, and conveyed to town via the Hogback Canal (Figure 1–5). Irrigation users divert water from the Hogback Canal both upstream and downstream of the town of Shiprock. During the irrigation season, municipal and industrial water for the community of Shiprock is drawn from the Hogback Canal and treated at the Navajo Tribal Utility Authority (NTUA) water treatment plant. During the winter months, when water is not diverted into the Hogback Canal, the NTUA obtains municipal and industrial water from an intake structure about 300 ft east of the U.S. Highway 666 bridge (Figure 1–5). The water intake structure on the north side of the San Juan River is a wet well from which water is pumped directly from the river.

Water-quality standards have been promulgated by the Navajo Nation for surface waters within the reservation. The San Juan River is classified as a domestic water supply suitable for primary and secondary human contact, for livestock and wildlife watering (including migratory birds), for irrigation, and for a cold-water fishery. Consequently, stringent water-quality standards are applicable to the San Juan River at Shiprock. Water quality is monitored by the USGS at river gauge 09368000, the location of which is now shared with Shiprock’s water intake structure. The water is also monitored by the NTUA in conjunction with requirements of the Safe Drinking Water Act. DOE monitors the San Juan River, both upstream and downstream of the Shiprock millsite under the auspices of the UMTRA Project.

Table 3–1 presents results of the quarterly water-quality monitoring performed by USGS. These results indicate that, for the varied flow rates reported, concentrations of the selected analytes are below the water quality standards for domestic and primary human-contact designated uses in the proposed water quality standards of the Navajo Nation (Navajo Nation 1998). In conjunction with the analytical results of DOE monitoring, the results also indicate that millsite-related contaminants do not pose an immediate threat to the quality of the water supply at Shiprock.

Table 3–1. Surface Water Quality Parameters for Selected Analytes Monitored at U.S. Geological Survey Gauge 09368000 at Shiprock

Date	Discharge (cfs)	Sulfate (mg/L)	TDS (mg/L)	Nitrogen as $NO_2 + NO_3$ (mg/L)	Arsenic (µg/L)	Uranium (µg/L)
Nov 17, 1994	996	170	410	0.410	2	2.2
Mar 02, 1995	1,460	170	392	0.390	Not Analyzed	Not Analyzed
May 03, 1995	4,210	65	199	0.090	2	0.68
Aug 08, 1995	1,280	100	260	<0.050	Not Analyzed	Not Analyzed

Seeps 425 and 426 along the escarpment just east of Bob Lee Wash (Figure 2–1) contribute a small amount (combined flow of less than 1 gallon per minute [gpm]) of surface water to wet areas on the San Juan River floodplain. Seep 425 has greater flow than seep 426. Water from the seeps is contaminated by constituents associated with uranium-ore processing, particularly nitrate, selenium, and uranium, which are present in concentrations that exceed maximum concentration limits (MCLs) (DOE 1991). Flow rates and contaminant concentrations in the seeps are continually measured as part of routine site water sampling.

3.2 Ground Water

Compared to the surface-water resources in the Shiprock area, ground water is a much scarcer resource. For example, records obtained from the Navajo Department of Water Resources database (Foley, personal communication, 1997) indicate that five (nonculinary) ground-water wells are within a 5-mile radius of the town of Shiprock (Table 3–2). Well-completion data indicate that the water is drawn from depths of approximately 2,000 ft below the land surface and that the water is produced from the Morrison Formation. Confining pressures are significant at this depth and several flowing artesian wells are known to occur near Shiprock. Navajo tribal well 12T–520 (also known as UMTRA well 648), located north of the Shiprock fairgrounds (Figure 2–1), is the closest flowing artesian well to the site; it is capable of flowing at a sustained rate of about 90 gpm. The next closest well to the site is Navajo tribal well 12K–300A, which is reported to be 2,170 ft deep. Its location could not be verified in the field, but its state-plane coordinates place it near the mouth of Many Devils Wash. Because of the upward-directed

Table 3–2. Summary of Water Wells within 5 Miles of Shiprock[a]

Well No.	UTM [b] East Location Coordinate (meters)	UTM North Location Coordinate (meters)	Date Drilled	Depth (ft)
12K–300A	707400	4073780	Sept 26, 1928	2,170
12T–520 (UMTRA Well 648)	705856	4072361	Feb 7, 1961	1,850
12T–627	701788	4065345	Unknown	Unknown
12T–630	711059	4065688	Nov 2, 1977	2,300
12T–663	706190	4073370	Unknown	Unknown

[a] Courtesy of the Navajo Department of Water Resources
[b] Universal Transverse Mercator

pressures in the Morrison Formation, there is no hydraulic potential for the Shiprock UMTRA site to affect the artesian water supply.

Shallow ground water exists in two hydrostratigraphic units at the Shiprock site: the floodplain alluvial aquifer and the Mancos Shale aquitard. This work plan describes the information that will be collected to evaluate the validity of the compliance strategies proposed for each of the ground-water systems.

3.2.1 Floodplain Alluvial Aquifer

The floodplain alluvial aquifer is in the floodplain area between the San Juan River and the base of the escarpment north of the mill tailings disposal cell. The aquifer consists of an unconsolidated sandy gravel layer that is in direct hydrologic communication with the San Juan River. The gravel fraction is composed of detrital material that was transported from Quaternary glacial moraines and outwash derived from the San Juan Mountains. Borehole evidence indicates that the sandy gravel unit is overlain by a layer of silty sand several feet thick. Both the sandy gravel and silty sand layers appear to be laterally continuous.

The hydrostratigraphy of the floodplain alluvial aquifer can be described using a simple depositional facies model. The basal gravel (or channel gravel) was deposited as the river migrated northward from the base of the escarpment to its present position. During its migration, older alluvial sediments to the north were eroded and a new layer of coarse sediment was deposited. This resulted in a continuous layer of channel gravel, sand, and silt that was deposited on a scoured bedrock surface. Periodic flood events later deposited sand and silt on top of the gravels, resulting in the present alluvial stratigraphy. This depositional model is similar to the fluvial-floodplain facies model of Mackin (1937, p. 826), which was later described in Leopold and others (1964, p. 323). According to this depositional model, the unstratified channel gravel is the coarsest material that moved along the stream channel. Since the channel material is uniformly coarse grained, directional and spatial contrasts in hydraulic conductivity are expected to be relatively minor.

Figure 3–1 shows the locations of monitor wells completed in the floodplain alluvial aquifer at the Shiprock site. Based on the 21 wells completed in the alluvium, the average thickness of the alluvium is 14.7 ± 3.3 ft, and the average saturated thickness is 12.8 ± 3.8 ft. The hydraulic conductivity of the alluvial aquifer is unknown but was estimated to be about 35 feet per day (ft/day) in a previous numerical modeling study (Henry 1995). The hydraulic gradient in the floodplain aquifer ranges from approximately 0.002 to 0.004. On the basis of these values, the specific discharge in the floodplain aquifer is estimated to range from 0.07 to 0.14 ft/day. Based on an average saturated thickness of 12.8 ft, the discharge per unit width is estimated to be 0.9 to 1.8 square feet per day (ft^2/day).

Boundaries to the ground-water flow system may be described as time-varying head where the alluvium contacts the San Juan River, and limited-flux to no-flux where the alluvium contacts the base of the bedrock cliffs. Surface water enters the floodplain alluvial aquifer at the mouth of Bob Lee Wash, as long as artesian discharge from well 648 continues uninterrupted. Vertical flow between the alluvial aquifer and the underlying Mancos Shale aquitard is relatively minor. One objective of the hydrologic investigation will be to obtain estimates for the magnitude and direction of the flow between the aquitard and the alluvial aquifer.

3.2.2 Mancos Shale Aquitard

The Mancos Shale was named by Cross (1899) for outcrops in the Mancos Valley around the town of Mancos in Montezuma County, Colorado, approximately 45 miles north of Shiprock. The Mancos Shale underlies most of the area around Shiprock and consists mainly of gray marine shale with a few sandy zones, siltstone beds, and some chalky shale (Lohman 1965).

Regionally, the Mancos Shale is considered an aquitard. If water does occur in the Mancos Shale it might be found as confined ground water within sandy beds. The source of the confined ground water can result from human activities. For example, leaking irrigation ditches are documented as being a source of recharge to confined ground water occurring in sandstone beds within the Mancos Shale in the Grand Valley, Mesa County, Colorado (Schneider 1975). Sections of the “Stray” sandstone or Tocito Sandstone Lentil, an eastward extension of the Gallup Sandstone, which divides the Mancos Shale into upper and lower parts (Ward 1990), are recharged 5 to 10 miles west of Shiprock where the Gallup Sandstone is exposed, and produce confined ground water at a depth of 250 to 330 ft near the Shiprock site (see the lithologic log for well 648 in Figure 2–3). Ground water in the “Stray” sandstone (or Tocito Sandstone Lentil) is under artesian pressure and is not in danger of being contaminated by site-related activities.

Unconfined ground water may be found in places from either the weathered zone of the Mancos or the alluvium filling former arroyos within the Mancos, but the water is usually of very poor quality owing to the high content of sodium sulfate and bicarbonate. The high content of salt in the Mancos is borne out by the many white efflorescent patches of alkali in both unirrigated and irrigated surfaces, and the abundance of salt grass and salt cedar along drainages (Lohman 1965). Near the Shiprock site, unconfined ground water may also be found in the axes of drainages. For example, Many Devils Wash receives runoff from an area of about 5 mi^2, and water appears to concentrate and infiltrate along its axis. The baseflow component discharging into the San Juan River observed in February 1998, however, is estimated to be less than 1 gpm. Rattlesnake

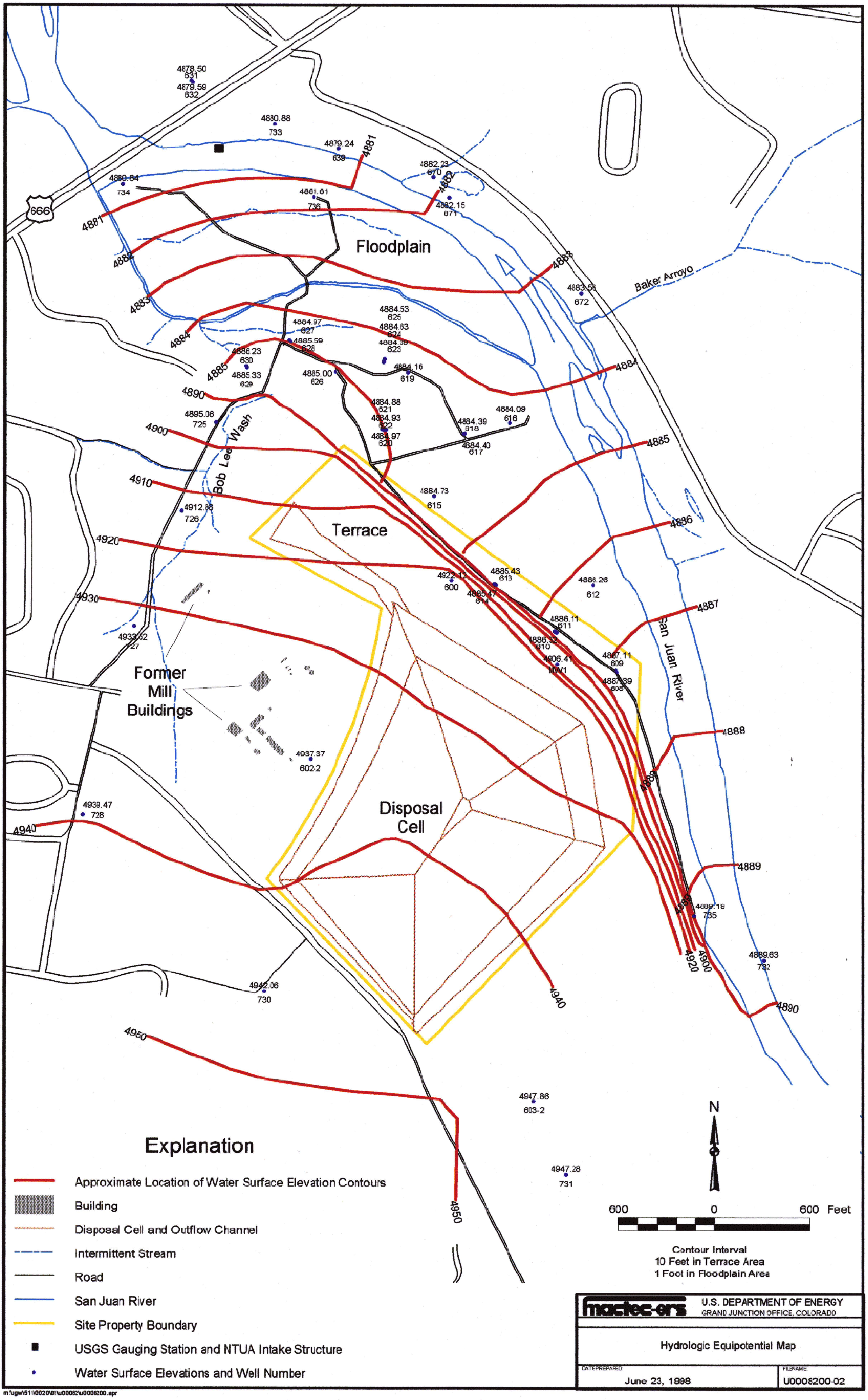


Figure 3–1. Ground-Water Surface Map, Shiprock Site

Wash, an even larger watershed about 1.5 miles west of the town of Shiprock, also has a low basin yield.

Unconfined ground water may also occur along a zone where terrace gravels of the ancestral San Juan River overlie the Mancos Shale. The terrace material is present mainly as a band along the margin of the escarpment. The band is about 0.5 mile in width and in places up to several tens of feet in thickness. The contact between the terrace material and the weathered bedrock is disconformable and undulating because of scouring of the bedrock surface by the ancestral river.

In the areas where terrace gravels overlie the Mancos Shale the source of ground water is likely anthropogenic. The Shiprock millsite, for example, was a considerable source of unconfined ground water during the time of mill operation. Much of the ground water from the milling process has by now discharged to the alluvial aquifer, but residual contamination remains in unconfined ground water near the site. The source of the present ground water near the site is probably a combination of a leaking water supply system, sewer pipes, and private septic system return flow. Natural precipitation contributes only a minor component of recharge to the unconfined flow system where the Mancos Shale is overlain by the terrace gravel. On the basis of this conceptual model and data gathered thus far under the UMTRA program, hydraulic head in the Mancos Shale near the site is believed to rise gradually toward the south, reaching a local maximum near the topographic divide about 0.5 mile south of the disposal cell. If ground water exists south of the topographic divide, it probably drains eastward within the subbasin formed by the west fork of Many Devils Wash.

The shapes of the equipotential contours on the terrace appear to be regular and continuous, which suggests that ground-water flow is not occurring in large discrete fractures, but rather in a weathered zone consisting of numerous fractures overprinted by weathering. Thus, the flow system in the weathered bedrock is believed to behave according to a porous-medium equivalent flow system (ASTM 1995) rather than a discrete-fracture or a dual-porosity system.

Preliminary data from a ground-water recovery test on well 726 suggests that the transmissivity in the unconfined ground-water system is about 0.1 ft^2/day. These data were collected during the ground-water sampling in January 1996. The total volume of water extracted during this test was 14 gallons over a duration of 145 minutes. The resulting pumping rate was less than 0.1 gpm.

3.3 Summary of Data Needs

Additional hydrologic data will be used to refine the site conceptual model, to determine the relationship between the two ground-water systems (Mancos Shale aquitard and floodplain alluvial aquifer), and to help select and evaluate proposed remedial action procedures for ground-water cleanup.

3.3.1 Surface Water

Surface water stage in the San Juan River will be recorded using a new stilling well. The water level of the river at the stilling well location will be measured using land surveying methods. A data logger will be installed at the stilling well to monitor the changes in river elevation. These data will be used to compare changes in river stage to water levels in monitor wells in the floodplain alluvial aquifer.

3.3.2 Floodplain Alluvial Aquifer

Records will be reviewed of slug tests conducted in wells within the floodplain alluvial aquifer during 1986. These data were recorded on 30- to 60-second time intervals and, depending on their value, may need to be confirmed before use.

Stage recorders will be placed on at least four wells in the contaminated part of the floodplain alluvial aquifer. Data from these recorders will be used in conjunction with the San Juan River-stage data to evaluate the hydraulic diffusivity of the floodplain aquifer using methods similar to those employed by Pinder and others (1969) and Grubb and Zehner (1973). The hydraulic diffusivity is a lumped parameter that represents the transmissivity divided by the storativity, or specific yield in the case of an unconfined aquifer.

Aquifer transmissivity and storativity will be obtained from two short-term pumping tests performed in uncontaminated parts of the floodplain aquifer. One of the tests will be performed in a background area, on the south side of the river, about 1 mile east of the contaminated floodplain aquifer. The storativity value thus derived will be used with the diffusivity values obtained in the contaminated parts of the floodplain aquifer to solve for transmissivity. It is assumed that the pumping-test-derived storativity will be representative of the entire aquifer because (1) the depositional facies model that describes the basal gravel of the floodplain suggests that the gravel is relatively homogeneous and isotropic, and (2) the scale of a pumping test measurement is similar to the scale of a wave-propagation test; therefore, it is expected that data quality of both measurements in terms of transmissivity and storativity will be comparable.

The amount of recharge entering the floodplain aquifer from ground water in the Mancos Shale aquitard will be estimated by installing a series of nested piezometers screened at equal elevations within the Mancos Shale in both the floodplain and terrace areas. Hydraulic head measurements and chemical sampling data obtained from these nests will enable the vertical and horizontal components of flow and contaminant transport to be evaluated.

The amount of ground water entering the floodplain from Bob Lee Wash will be measured either at the mouth of the wash or simply at artesian well 648, which contributes practically all of the outflow from Bob Lee Wash.

3.3.3 Mancos Shale Aquitard

The Mancos Shale aquitard has been described as being a limited-use ground-water system (FR January 11, 1995, p. 2863). Because of this classification, the ground-water compliance strategy for the terrace has been to apply for supplemental standards based on limited use. The technical basis for the limited-use designation has been sparse and has relied mainly on qualitative geologic reasoning. No concerted effort has been made thus far to test the limited-use designation.

Well-production data will be collected to evaluate the limited-use designation. Test wells will be located both near the disposal cell and in the background area on the terrace about 2 miles east-southeast of the disposal cell. In the area of the disposal cell, existing observation wells completed in the terrace ground-water system will be pumped to determine if the terrace system represents a resource capable of delivering more than 150 gal/day. It is predicted that the aquifer will yield more than 150 gal/day in this area because piping, septic tank return flow, and other sources of water recharge the unconfined ground water in this area.

Two new wells will be sited on the bench covered by terrace gravels in the background area about 1.5 miles east-southeast of the disposal cell to evaluate the well yield of the unconfined system where the effects of human activity are less evident. The well yield from the unconfined ground-water system will also be evaluated at locations south of the contact between the terrace material and loess and the Mancos Shale, approximately 2,000 to 3,000 ft south-southwest of the disposal cell. It is considered likely that the yield from the unconfined ground water in both these regions will be less than 150 gal/day.

4.0 Geochemistry

DOE collected ground-water quality data from the processing site and vicinity from 1985 through early 1998. Existing wells are currently being sampled annually. Information used to assess ground-water and surface-water quality was obtained from the sampling round in January 1997 and from previous sampling; the site was sampled again in February 1998.

4.1 Contaminants of Potential Concern

COPCs are contaminants that could cause adverse health effects if taken into the body. To select COPCs for the Shiprock site, chemical constituents were first screened to see if they exceeded background. If the maximum detected concentration of a constituent was within the acceptable nutritional requirement level, it was not retained as a COPC. If the maximum detected concentration was in the high end of the dietary range but was of low toxicity, it was not retained. The eleven constituents considered to be COPCs after this evaluation conducted as part of the BLRA (DOE 1994) include antimony, arsenic, cadmium, magnesium, manganese, nitrate, selenium, sodium, strontium, sulfate, and uranium. UMTRA MCLs for arsenic, cadmium, nitrate (as NO_3^-), selenium, and uranium are 0.05, 0.01, 44, 0.01, and 0.044 milligrams per liter (mg/L), respectively (Table 4–1). None of the other COPCs have UMTRA MCLs; however, antimony and strontium have health advisories of 0.015 and 25 mg/L, respectively. Ground water used as a sole source of drinking water was determined to be the exposure pathway of greatest potential risk. Uranium, sulfate, and nitrate are the most significant contaminants detected in ground water at the site. The high concentrations of nitrate represent the most significant health hazard.

Table 4–1. MCLs, Health Advisories for 10-kg Child (10-Day Exposure), and Maximum Concentrations Detected in Alluvial Ground-Water Samples

Constituent	UMTRA MCL (mg/L)	Health Advisory (HA)	Maximum Concentrations (mg/L)[a]
Antimony	no MCL	0.015	0.093
Arsenic	0.05	no HA	0.05
Cadmium	0.01	0.04	0.057
Magnesium	no MCL	no HA	2,690
Manganese	no MCL	no HA	68.8
Nitrate (as NO_3^-)	44	44	3,190
Selenium	0.01	no HA	0.607
Sodium	no MCL	no HA	3,780
Strontium	no MCL	25	14.1
Sulfate	no MCL	no HA	16,400
Uranium	0.044	no HA	2.24

[a] Results are from the January 1997 sampling round.

4.2 Contaminant Source Areas

Processing waters from the acid milling and solvent extraction circuits have entered the ground water at the site. The mill operated on the terrace, and most of the mill effluent was placed in tailings and raffinate ponds on the terrace (Figures 1–3 through 1–5). Some of the mill fluids apparently either spilled over the terrace or were placed in one or more ponds on the floodplain. A small pond on the floodplain just north of the escarpment is shown in the aerial photograph in Figure 1–4. The amount of contaminated material that went into the floodplain ponds is unknown. However, it is likely that most of the contamination has entered the ground-water system from pond seepage on the terrace.

Water from wells 642, 643, 644, and 736 has elevated concentrations of uranium and other contaminants. These wells are in the outer part of the floodplain near the San Juan River. Although no tailings are known to have been placed on the floodplain, high concentrations of nitrate, sulfate, and uranium in these wells indicate that milling-related material may be present. These wells are north of the area surveyed for radionuclides during the site characterization (Allen and others 1983).

All of the COPCs are derived either from the ores or the compounds used in the milling. Antimony, arsenic, cadmium, selenium, strontium, and uranium are constituents of the ores. Nitrate was used to strip uranium from the ion exchange agents. Some nitrate may have been derived from the microbial breakdown of ammonia, which was used to adjust the pH of the mill liquors. Sulfate was generated from sulfuric acid used to partially dissolve the ores. Magnesium and strontium were probably derived from dissolution of Ca-Mg-Sr cements present in the ores. Manganese is a major component of many rocks, including ores, and will become mobile if the ground-water is chemically reducing.

4.3 Contamination in the Floodplain Alluvial Aquifer and Terrace Ground Water

The floodplain alluvial aquifer and terrace ground water are contaminated. Figure 4–1 shows the locations of wells and the ground-water system in which they are completed; five wells are screened in Mancos Shale bedrock, which may be weathered or unweathered. Figures 4–2 through 4–12 show the distribution of COPCs (arranged alphabetically). Several of the wells are screened across the contact between unconsolidated material and bedrock and extend up to several feet into the underlying weathered Mancos Shale. Because the unconsolidated material and upper weathered Mancos are hydrologically connected, wells that are screened across this contact are shown in the concentration maps as being screened in unconsolidated material.

High concentrations of uranium, sulfate, nitrate, total dissolved solids (TDS), and other contaminants are present in the unconsolidated material of both the terrace and the floodplain. Well 600 is the only sampling location between the tailings disposal cell and the floodplain. Contaminant concentrations are slightly lower in terrace well 600 than in wells 614 and 615, which are in the floodplain just below well 600 (Table 4–2). If contamination on the floodplain is due to ground water from the terrace flowing directly into floodplain alluvial gravels, the concentrations in well 600 would be expected to be the same or higher than those in the nearby

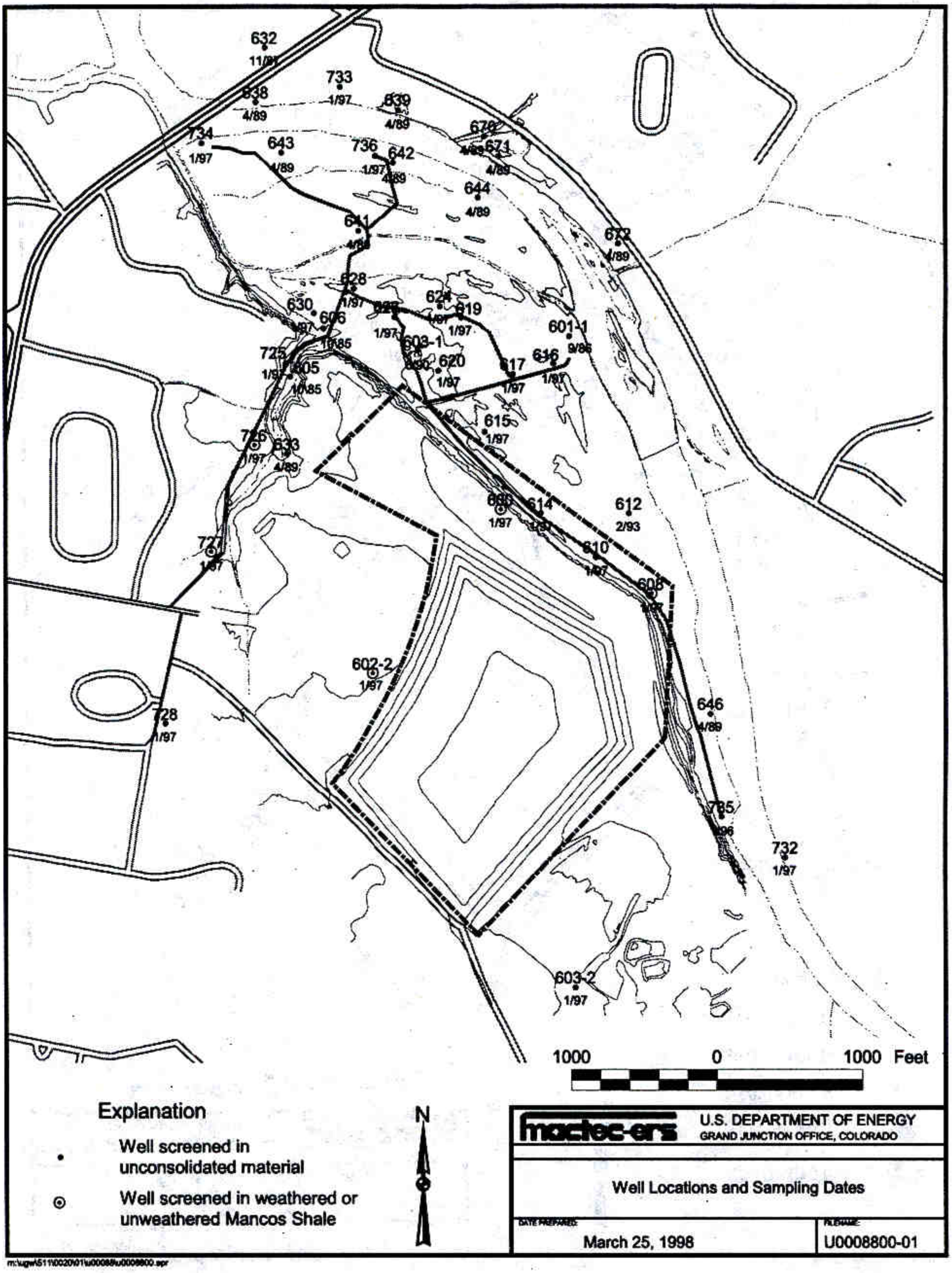


Figure 4–1. Well Locations and Sampling Dates, Shiprock Site

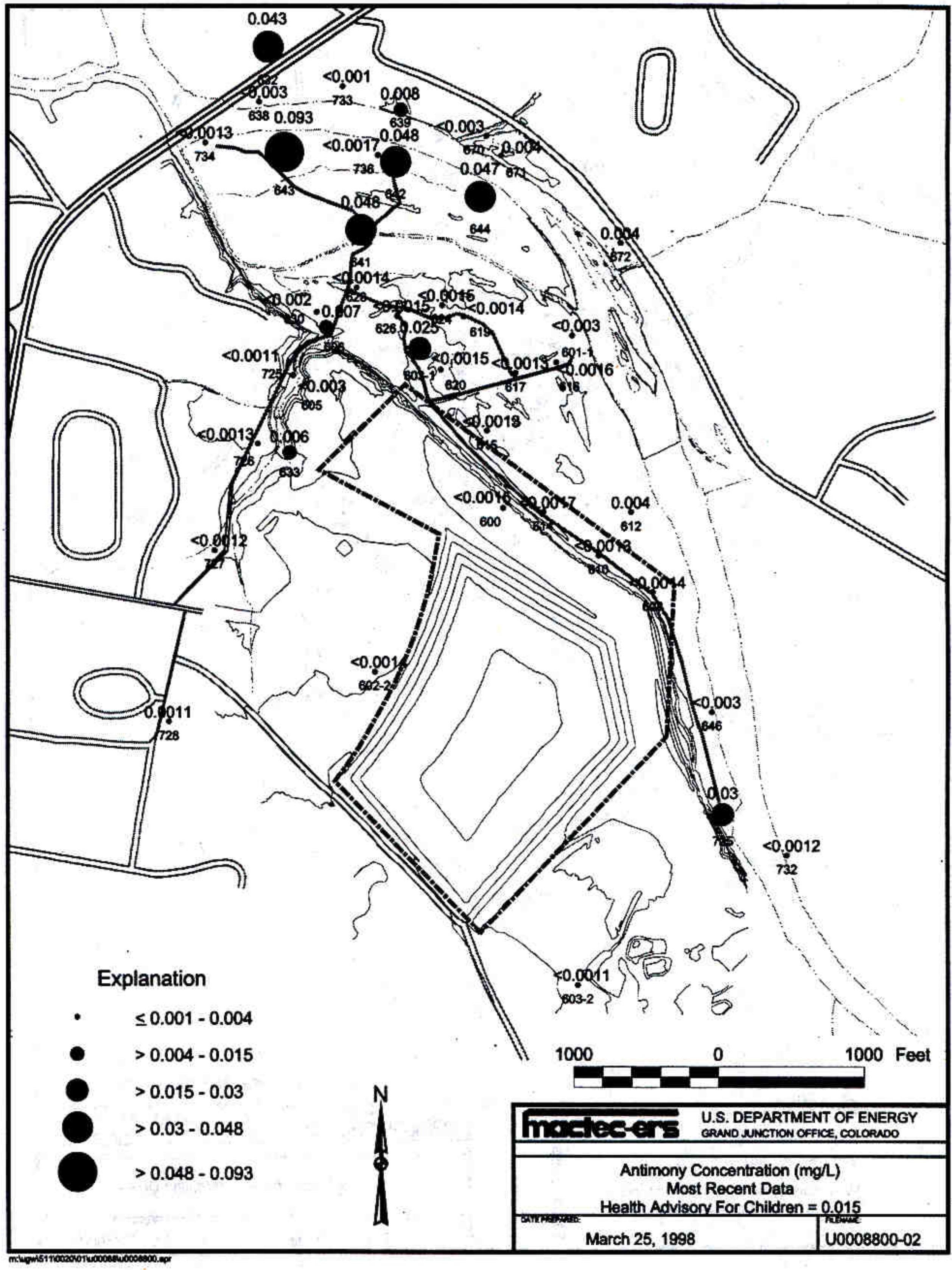


Figure 4–2. Antimony Concentrations at the Shiprock Site

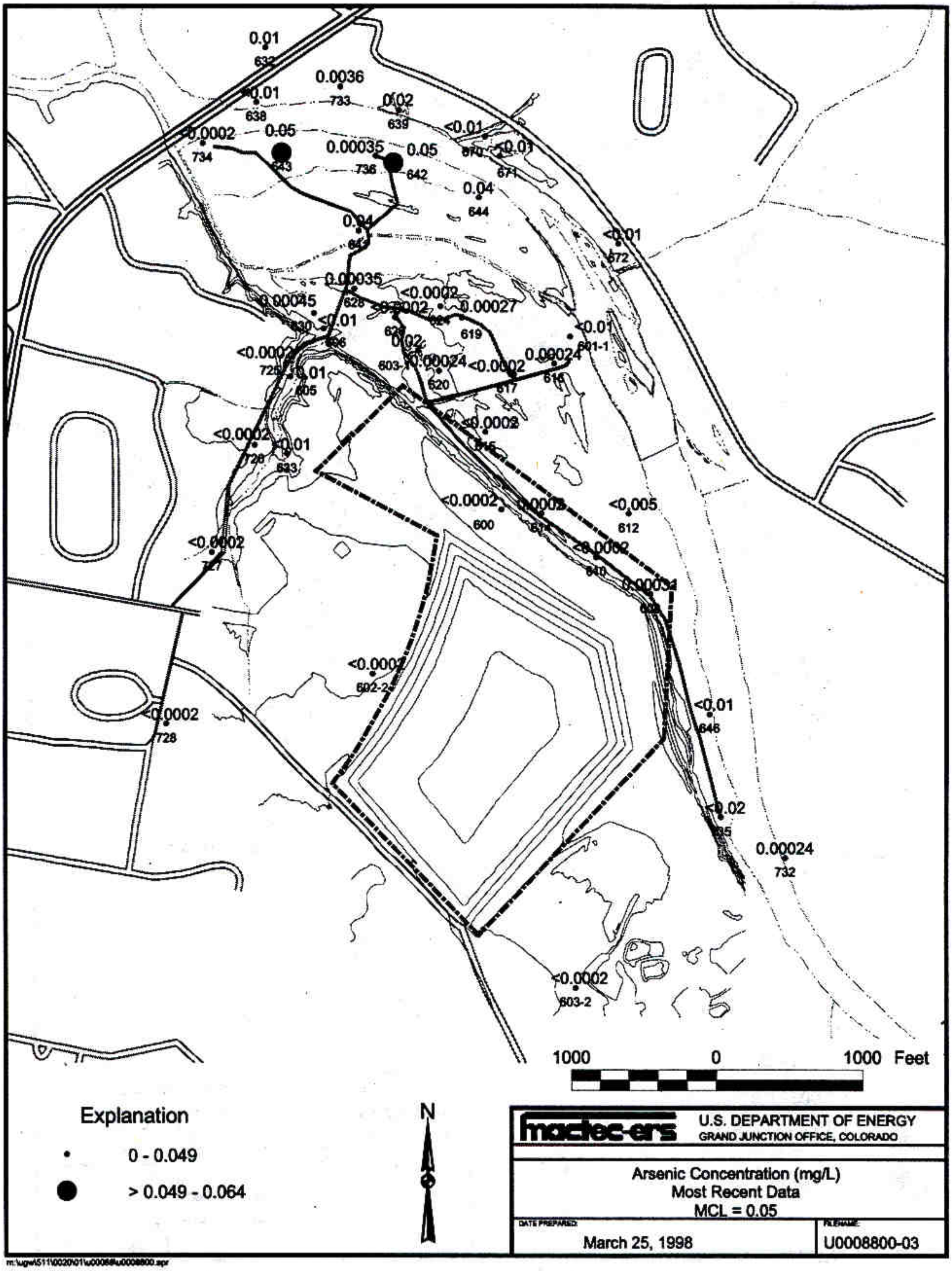


Figure 4–3. Arsenic Concentrations at the Shiprock Site

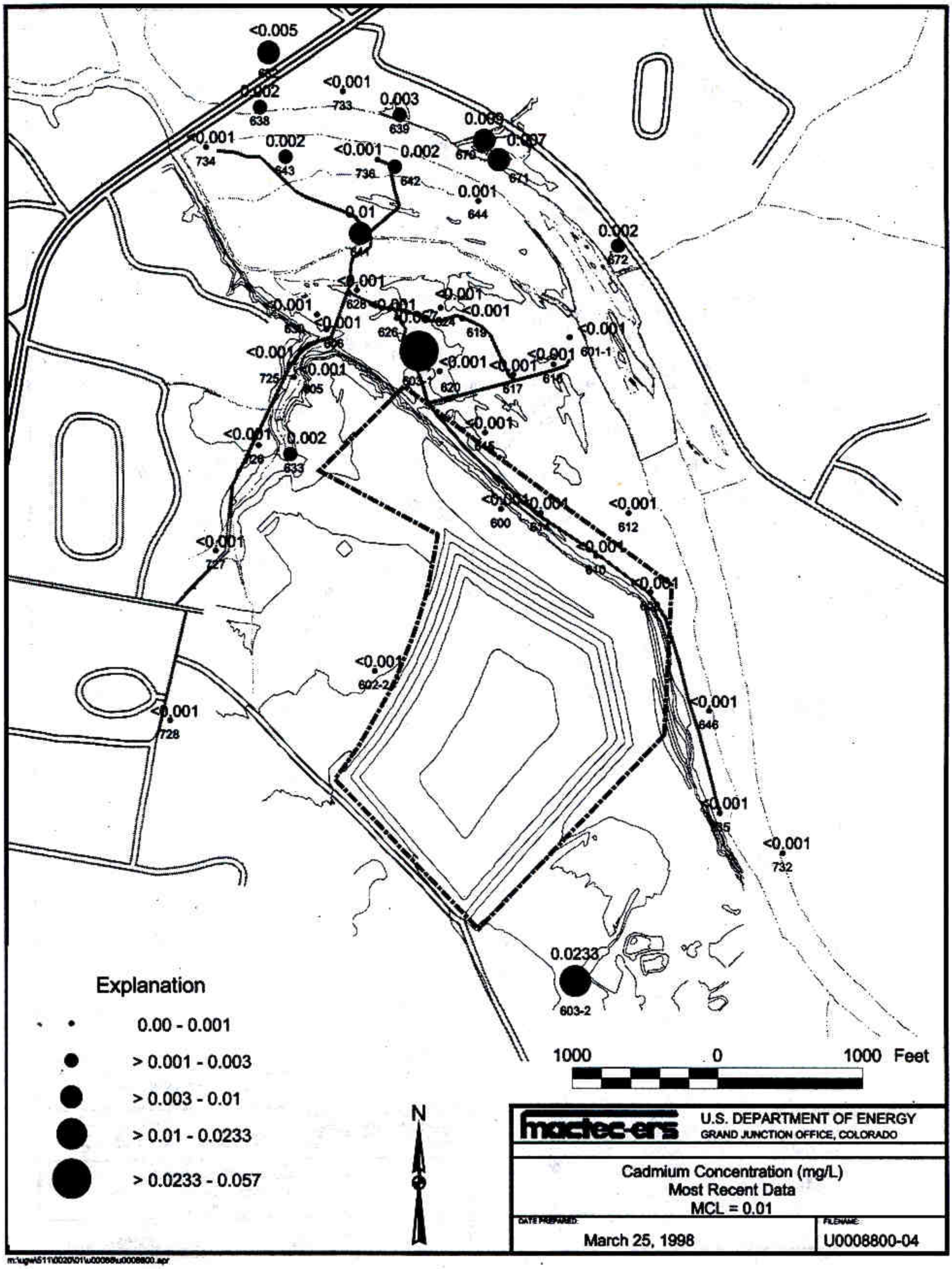


Figure 4–4. Cadmium Concentrations at the Shiprock Site

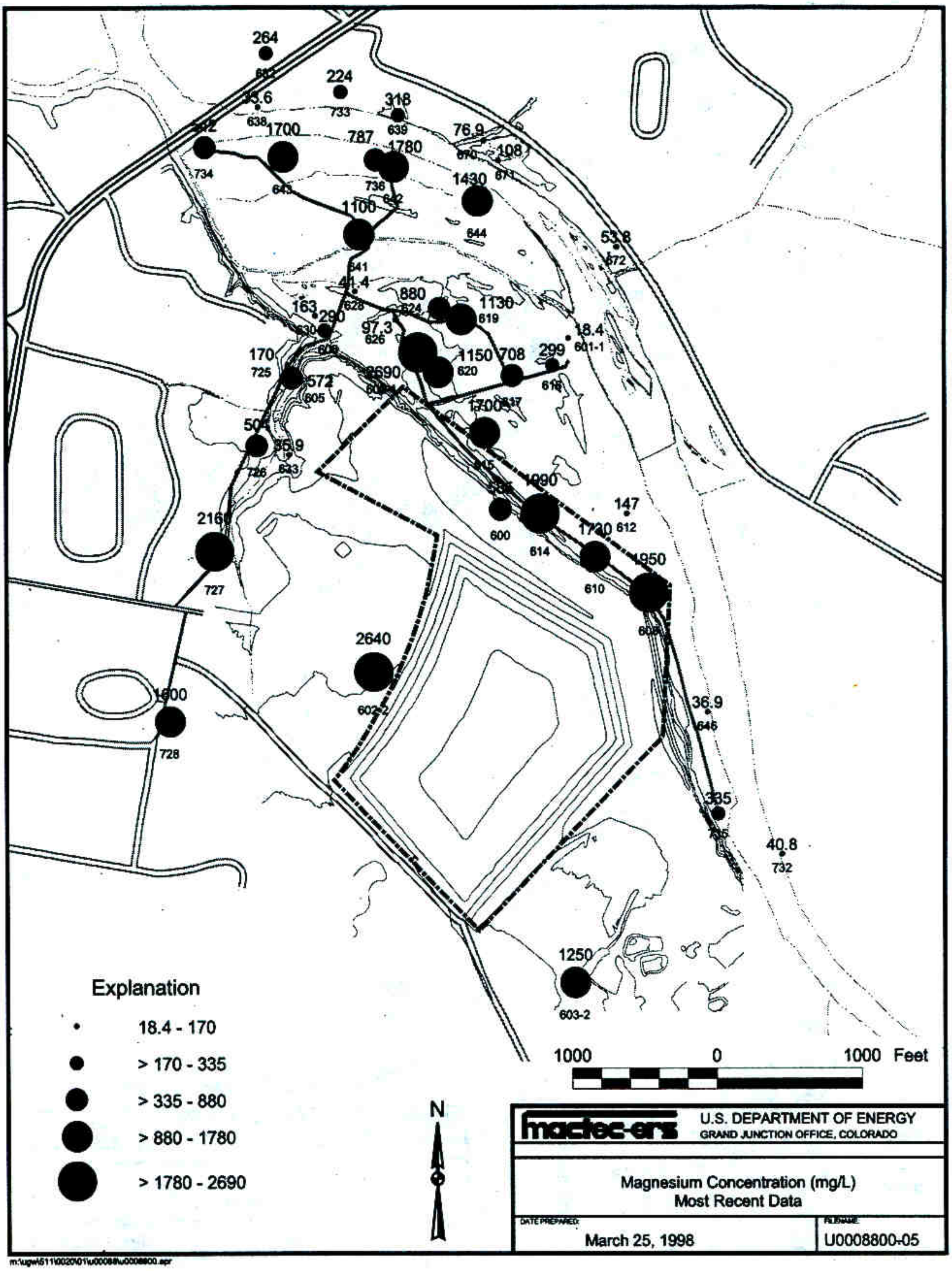


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Figure 4–5. Magnesium Concentrations at the Shiprock Site

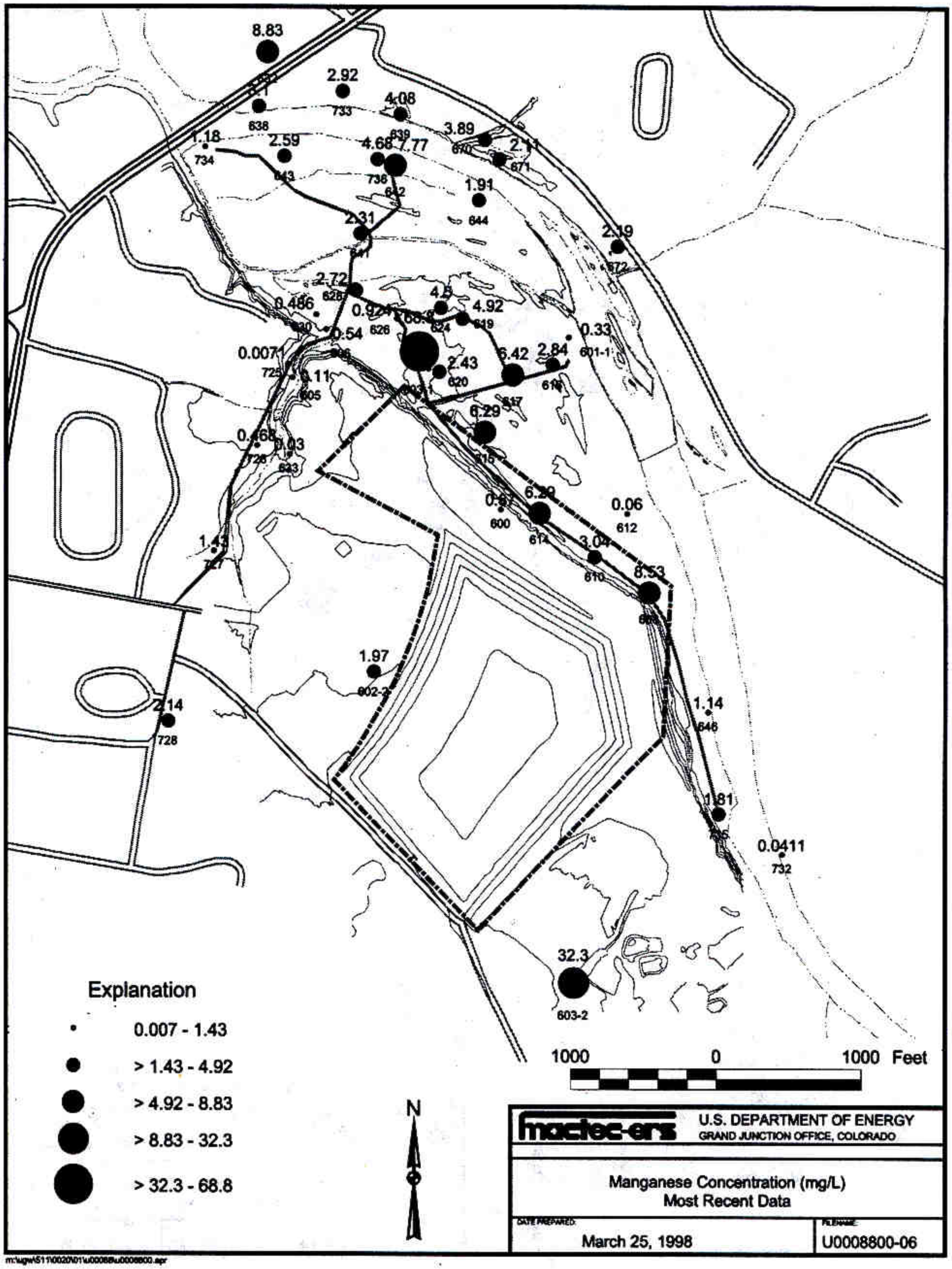

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Figure 4–6. Manganese Concentrations at the Shiprock Site

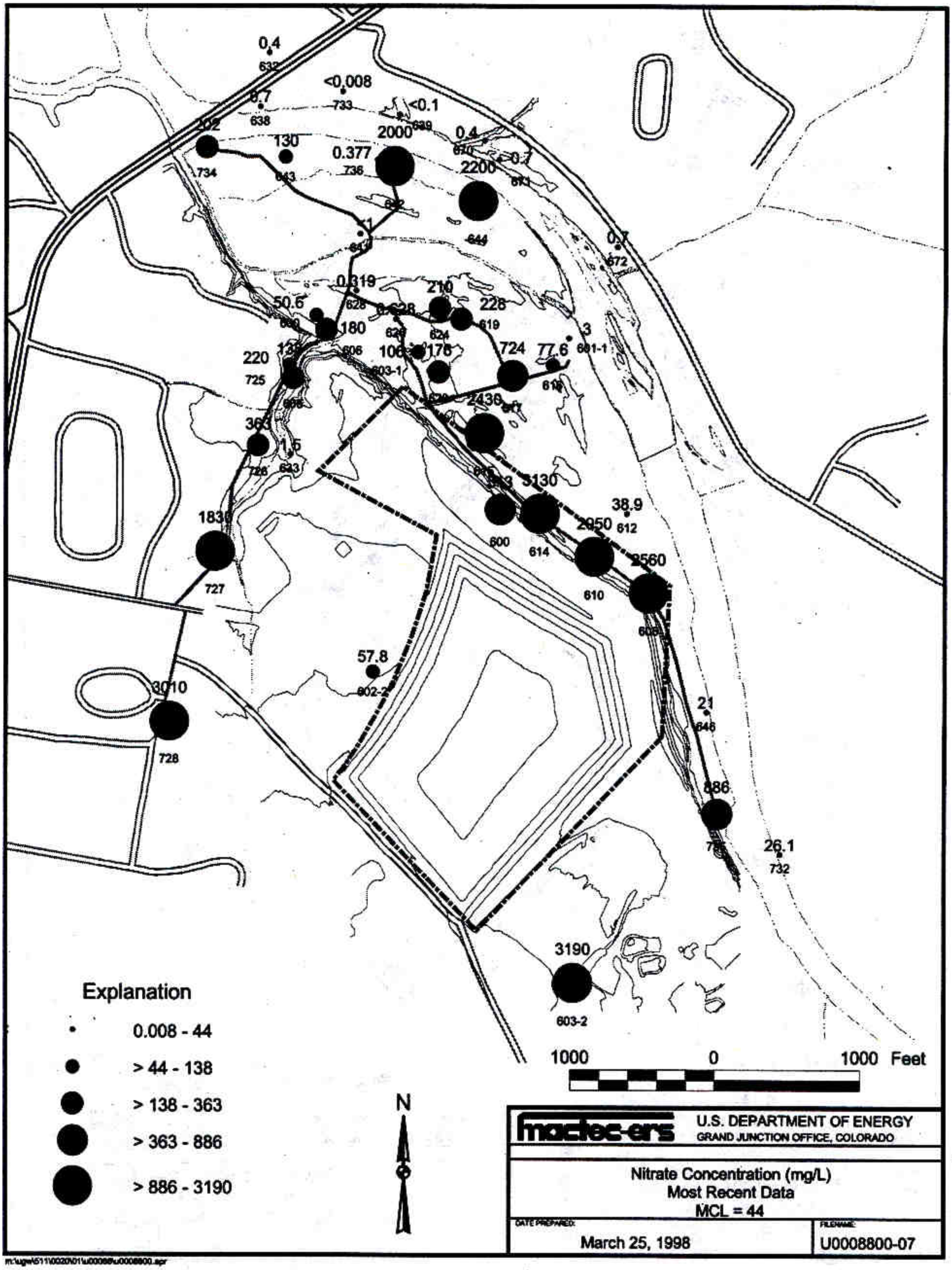


Figure 4–7. Nitrate Concentrations at the Shiprock Site

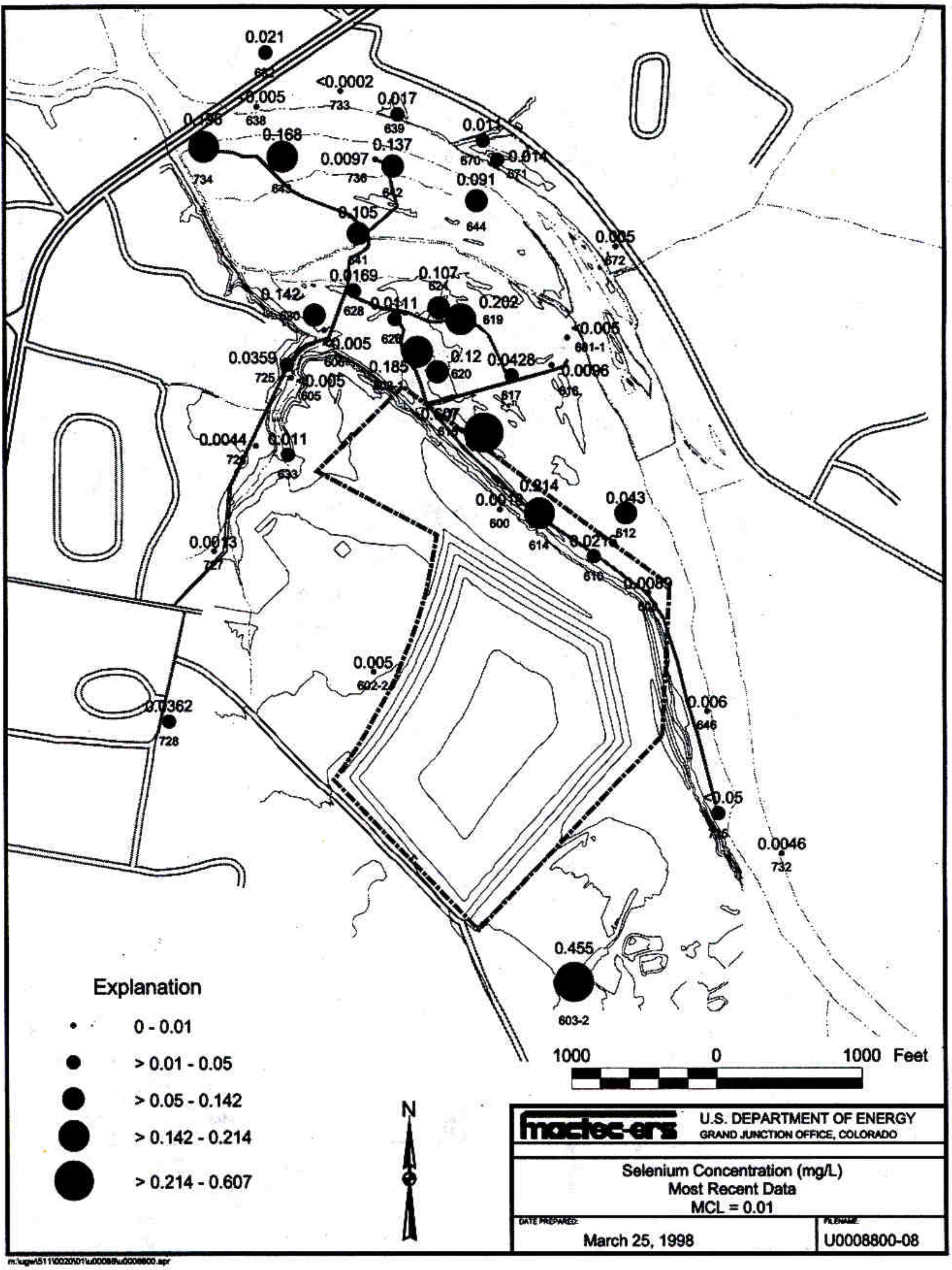


Figure 4–8. Selenium Concentrations at the Shiprock Site

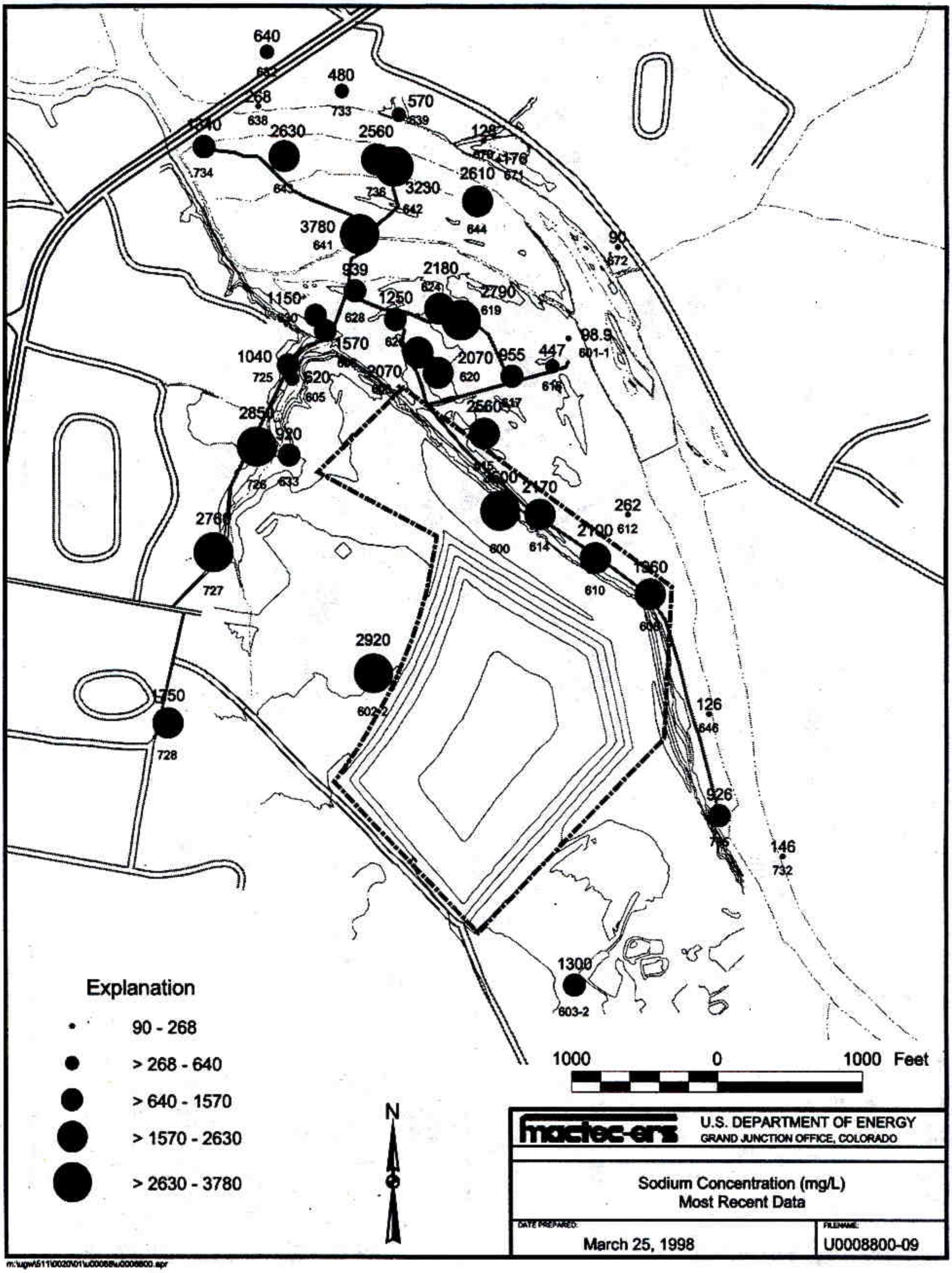


Figure 4–9. Sodium Concentrations at the Shiprock Site

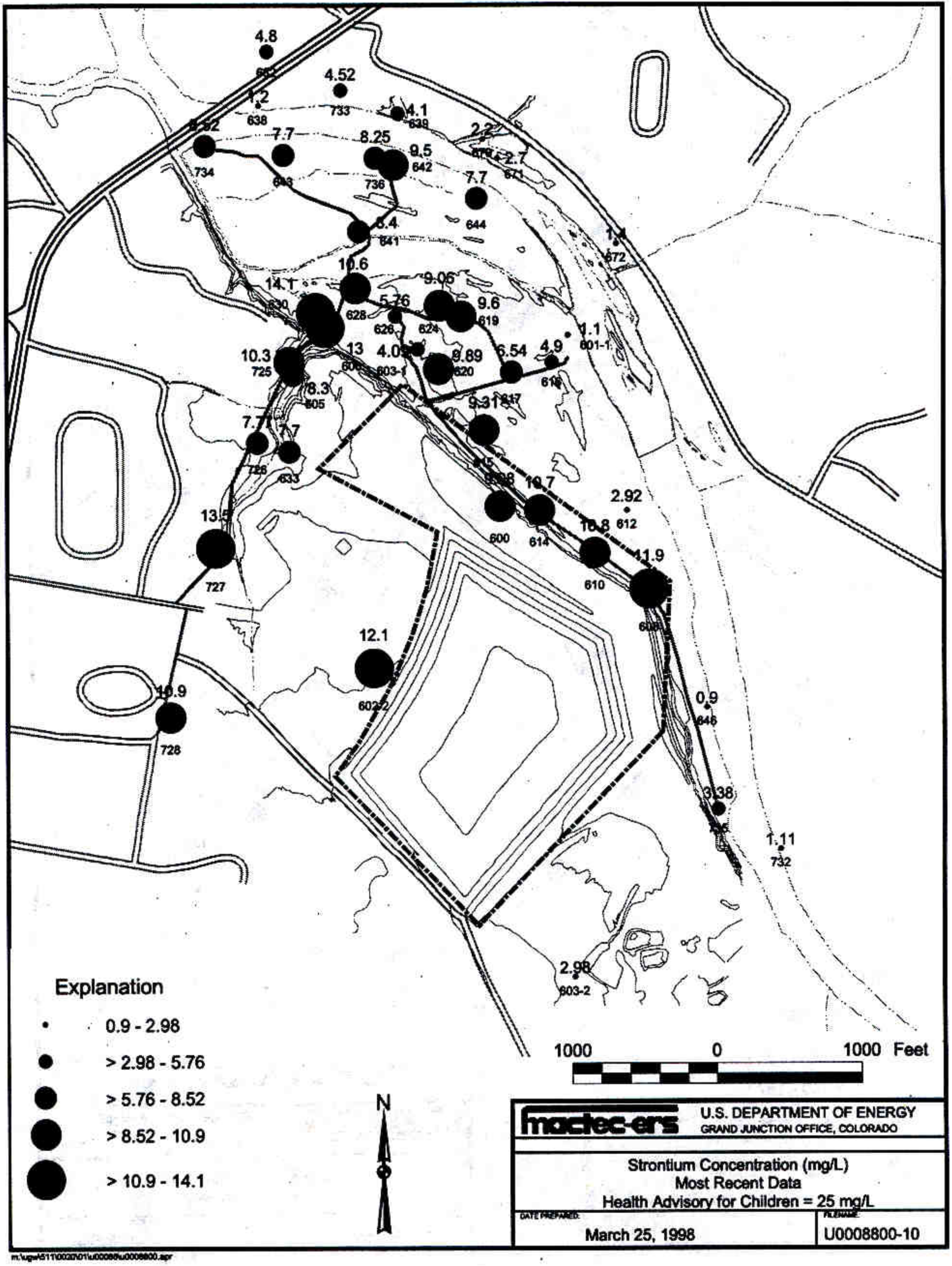


Figure 4–10. Strontium Concentrations at the Shiprock Site

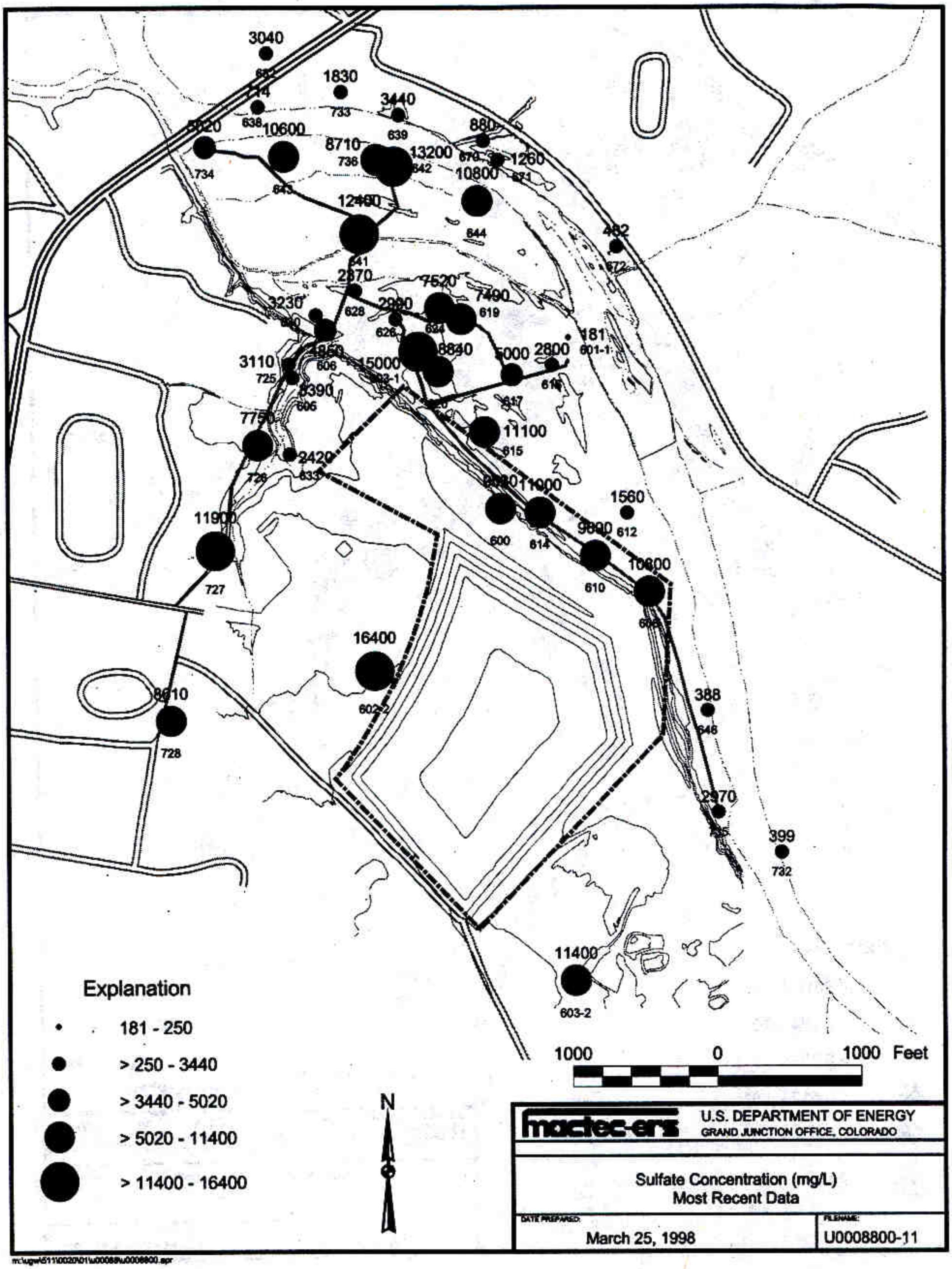


Figure 4–11. Sulfate Concentrations at the Shiprock Site

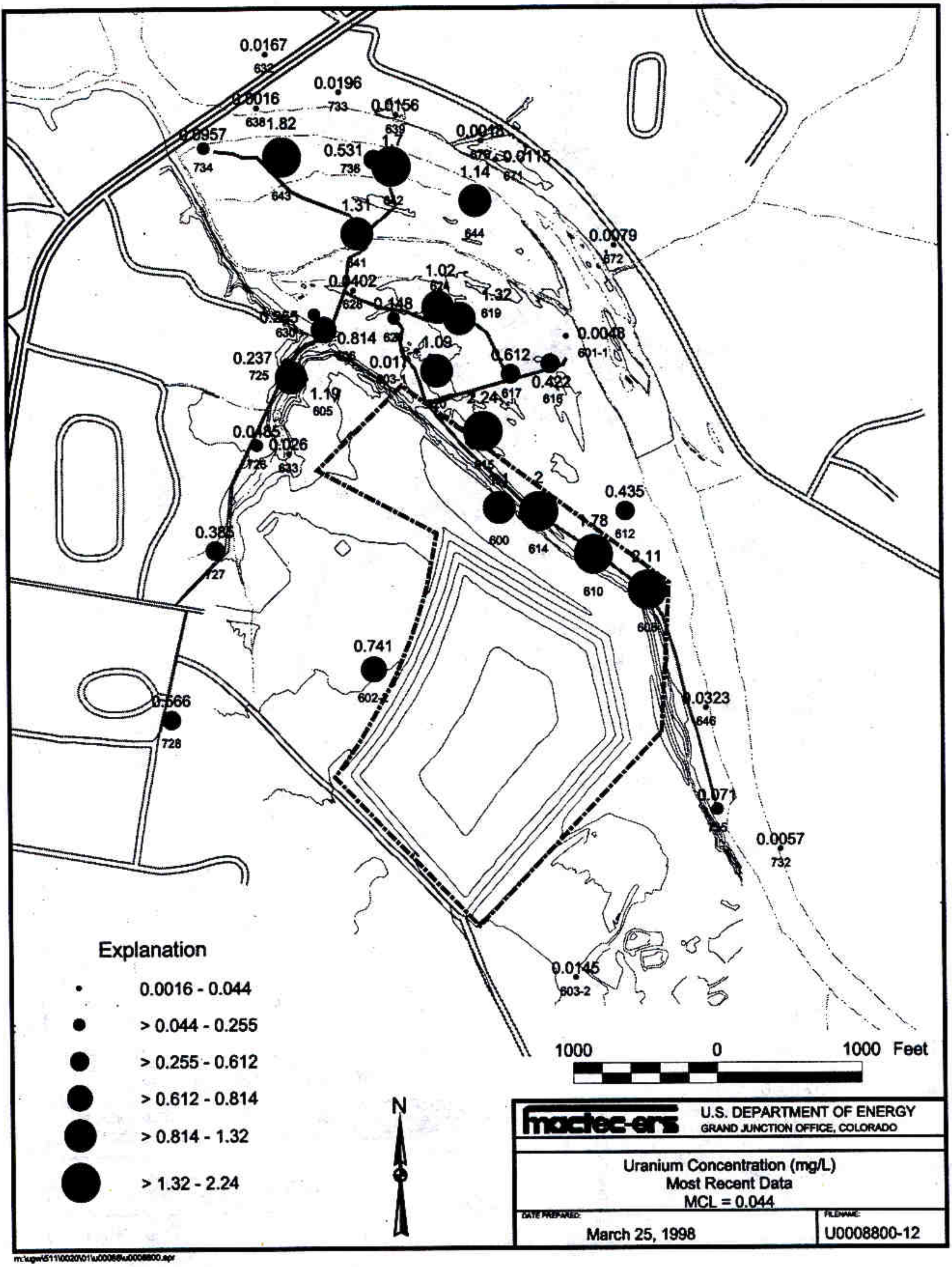


Figure 4–12. Uranium Concentrations at the Shiprock Site

floodplain. This does not appear to be the case, based on the data in Table 4–2. Contaminant concentrations in well 600 may be lower because the well is screened in Mancos Shale rather than unconsolidated terrace material, or perhaps the contaminants have already moved through the terrace system. More well control is needed to evaluate the pathways through which terrace ground water enters the floodplain.

Table 4–2. Comparison of a Terrace Well in Mancos Shale to Floodplain Alluvial Aquifer Plume Concentrations

Contaminant[a]	**Terrace Well 600**	**Floodplain Well 615**	**Floodplain Well 614**
Uranium	1.10	2.24	2.0
Sulfate	9,030	11,100	11,000
Nitrate	513	2,430	3,130
TDS	15,900	20,800	21,200

[a] Concentrations are in mg/L; analytical results are from the January 1997 sampling.

Concentrations of some COPCs (most notably nitrate, sulfate, and uranium) that greatly exceed MCLs or background levels are present over the entire floodplain. COPC concentrations in four wells (608, 610, 614, and 615) that border the terrace are typically higher than in most other floodplain wells. Wells near the San Juan River (642, 643, 644, and 736) also have concentrations of some COPCs that greatly exceed MCLs or background levels despite their greater distance from the terrace.

The distribution of contaminants in ground water on the terrace is not well known because of the sparse number of monitor wells. From the data that are available, the terrace appears to have COPCs in concentrations that greatly exceed MCLs or background levels. For example, nitrate and sulfate concentrations in terrace wells are higher than in any of the floodplain wells. Thus, the interpretation that contaminated ground water flows from the terrace to the floodplain is consistent with the existing ground-water quality data. The spatial distribution of each COPC in the terrace ground water and the floodplain alluvial aquifer is discussed below.

4.3.1 Antimony

Although there is no MCL for antimony, the health advisory (HA) for children is 0.015 mg/L. Antimony concentrations in seven wells (603–1, 632, 641, 642, 643, 644, 735) exceed the 0.015 mg/L HA (Figure 4–2). The highest concentrations are in wells bordering the San Juan River. One of the wells (632) in which antimony concentration exceeds the HA is north of the San Juan River and thus was not affected by the tailings site. Of the seven wells in which antimony concentrations exceeded the HA, only one (735) was sampled since 1990. It is possible that the high concentrations in previous analyses can be attributed to analytical uncertainty. The concentration (0.03 mg/L) in well 735 was the detection limit. Concentrations of antimony in wells 734 and 736, which are near wells 642, 643, and 644 and were sampled in 1997, are less than 0.0013 and 0.0017 mg/L, respectively. These observations suggest that antimony concentrations are currently below the HA for children. No additional wells are needed to determine the distribution of antimony.

4.3.2 Arsenic

The MCL for arsenic is 0.05 mg/L. All arsenic concentrations measured on the most recent samples are at or below the MCL (Figure 4–3). Only two wells (642 and 643) have arsenic concentrations of 0.05 mg/L. These wells were last sampled in 1989. Wells 734 and 736, which are near wells 642 and 643 and were sampled in 1997, have arsenic concentrations of less than 0.0002 and 0.00035, respectively. These values indicate that arsenic concentrations probably do not currently exceed the MCL on the floodplain. No additional wells are needed to determine the distribution of arsenic.

4.3.3 Cadmium

The MCL for cadmium is 0.01 mg/L. Concentrations in samples from two floodplain wells (603–1 and 641) meet or exceed the MCL (Figure 4–4). Floodplain wells 603–1 and 641, last sampled in 1990 and 1989, respectively, are near wells that were sampled in 1997. Concentrations in samples from the more recently sampled wells are below the MCL. As a result of these values, it is likely that ground water in the floodplain is currently below the MCL for cadmium. No additional wells are needed to determine the distribution of cadmium on the floodplain.

Ground water in terrace well 603–2, sampled in 1997, had a concentration of 0.0233 mg/L (Figure 4–4). Because of the sparse distribution of wells on the terrace it is not possible to determine whether cadmium typically exceeds the MCL or if the concentration in well 603–2 was an isolated occurrence. Additional terrace monitor wells are necessary to better define the distribution of cadmium.

4.3.4 Magnesium

Although there is no MCL or HA, magnesium at elevated concentrations is known to be mildly toxic to humans. Magnesium concentrations in the alluvial aquifer are as high as 2,690 mg/L, whereas an average city water supply has about 6.5 mg/L (DOE 1994). Magnesium concentrations were above background levels in samples from both the terrace and the floodplain (Figure 4–5). Samples from wells on the opposite side of the San Juan River from the disposal cell (632, 733, 639, 670, 671, 672, and 732) had magnesium concentrations that range from 40.8 to 318 mg/L. Thus, there is a significant contribution of magnesium from the millsite to ground water. No additional wells are required for determining the distribution of magnesium; however, magnesium will be included in all future ground-water analyses.

4.3.5 Manganese

Although there is no MCL or HA, manganese at elevated concentrations is known to be toxic to humans. Manganese concentrations in the unconsolidated material of the terrace ground water and the floodplain alluvial aquifer are as high as 68.8 mg/L (Figure 4–6). There is no clear trend that relates manganese to tailings contamination; however, samples from several wells near the disposal cell (603–2, 614, 610, and 608) had concentrations above 3 mg/L. A sample from well 632, which is on the opposite side of the San Juan River from the disposal cell, had a manganese concentration of 8.83 mg/L. Like iron, manganese is a common constituent of rocks and sediments. Manganese mobility is largely a function of the oxidation potential of the ground water. Low oxidation potential will dissolve manganese minerals and mobilize manganese. If manganese is associated with the tailings, it may be related to a lower oxidation potential in the tailings rather than to a high manganese content of the tailings.

A wider distribution of samples is needed to determine if manganese concentrations are elevated due to tailings fluids or if the variation is due to natural fluctuations in the oxidation potential. Background concentrations of manganese need to be better quantified by examining ground water in settings similar to both the floodplain alluvium and the terrace material.

4.3.6 Nitrate

The MCL for nitrate is 44 mg/L. Nitrate concentrations are as high as 3,190 mg/L in the terrace ground water and as high as 3,130 mg/L in ground water of the floodplain (Figure 4–7). High nitrate concentrations in floodplain wells near the terrace (617, 614, 610, and 608) indicate a contribution from the millsite. Samples from wells 642 and 644, which are some distance downgradient of the terrace, also had elevated nitrate concentrations (2,000 and 2,200 mg/L, respectively, for the most recent sampling in 1989). A nearby well (736) had only 0.377 mg/L nitrate in 1997. Many of the wells show high variability in nitrate concentrations over time. For example, concentrations in well 734 increased from 1 mg/L in 1993 to 202 mg/L in 1997. From 1993 through 1997, nitrate concentrations in well 736 were variable and ranged from 0.377 to 5,450 mg/L. Such widely fluctuating values may be due to a combination of factors, including the nature of the ground-water flow paths and the influence of biodegradation. White efflorescent salt deposits on the surface of areas of the floodplain may contain some nitrate deposited along with soluble salts that could contribute to ground-water contamination.

Because nitrate represents the most significant health risk on the site, additional wells should be placed to better define the spatial distribution. Background concentrations of nitrate need to be better quantified by examining ground water in settings similar to those of the floodplain alluvium and the terrace material. Analysis of nitrate concentrations in soil samples would help to determine the potential for ground-water contamination attributable to leaching from the soil.

4.3.7 Selenium

The MCL for selenium is 0.01 mg/L. Selenium concentrations are as high as 0.455 mg/L in ground water in the terrace and as high as 0.607 mg/L in ground water in the floodplain. The high concentrations in wells 615 (0.607 mg/L) and 614 (0.214 mg/L), which are near the terrace, suggest that some selenium has come from the millsite. The Mancos Shale is known to contribute selenium to ground water and may cause concentrations to be elevated above the MCL without any contribution from the millsite. Lower values of selenium (although some are above the MCL) in wells on the opposite side of the San Juan River from the disposal cell suggest that the contribution from the Mancos is less than the contribution from the millsite. Additional monitor wells are needed to better define the distribution of selenium in the ground water in both the terrace and the floodplain.

4.3.8 Sodium

Sodium does not have an MCL or HA. High sodium concentrations in drinking water, however, may cause hypertension in humans. An analysis of water supply systems indicated that sodium concentrations varied from 1 to 402 mg/L. Sodium concentrations range up to 3,500 mg/L in the terrace ground water and up to 3,780 mg/L in floodplain ground water. High sodium concentrations in wells 600, 614, 610, 608, 603–2, and 602–2 near the disposal cell indicate that sodium is millsite-related (Figure 4–9). Samples from wells 632, 638, 733, 639, 670, 671, 672, and 732 on the opposite side of the San Juan River from the disposal cell had sodium concentrations ranging from 90 to 640 mg/L and probably reflect background levels. No additional wells are required for determining the distribution of sodium; however, sodium will be included in all future ground-water analyses.

4.3.9 Strontium

There is no MCL for strontium. Concentrations in all ground-water wells are below the 25 mg/L HA for children (Figure 4–10). Strontium concentrations are as high as 13.5 mg/L in the terrace ground water and as high as 14.1 mg/L in the floodplain ground water. Concentrations in ground water from the opposite side of the San Juan River from the disposal cell are lower, ranging from 1.11 to 4.8 mg/L, which indicates that some of the strontium in the ground water on the millsite side of the river is attributable to the former milling operation. No additional wells are required for determining strontium distribution.

4.3.10 Sulfate

There is no MCL or HA for sulfate. Ingestion of sulfate is known, however, to produce a laxative effect in adults and severe dehydration in infants. Sulfate concentrations in drinking water in the western United States in 1978 ranged from 0 to 820 mg/L and had a mean concentration of 99 mg/L (DOE 1994). Sulfate concentrations are as high as 16,400 mg/L in the terrace ground water and as high as 15,000 mg/L in the floodplain ground water. Higher concentrations in wells 600, 614, 610, 608, 602–2, and 603–2 near the disposal cell indicate that the millsite was a source of sulfate contamination in the ground water (Figure 4–11). Sulfate concentrations in wells on the opposite side of the San Juan River from the disposal cell range from 399 to 3,440 mg/L, which indicates that some sulfate may be naturally occurring. Sulfate occurs in gypsum, which is a common constituent of Mancos Shale. The white mineral precipitate that coats the ground surface in areas of the floodplain and in some areas on the terrace where the Mancos Shale is exposed is composed mainly of gypsum. These surface (or shallow subsurface) occurrences could be contributing to the sulfate in the ground water.

Additional wells are required on the floodplain and on the terrace to better define the distribution of sulfate contamination. Background concentrations of sulfate need to be better quantified by examining ground water in settings similar to those of the floodplain alluvium and the terrace system. Analysis of sulfate concentrations in soil samples would help to determine the potential for ground-water contamination attributable to leaching from the soil.

4.3.11 Uranium

The MCL for uranium is 0.044 mg/L. Uranium concentrations range up to 1.19 mg/L in the terrace ground water and up to 2.24 mg/L in the floodplain ground water. The elevated uranium concentrations are due to the milling process. Uranium concentrations in wells on the opposite side of the San Juan River from the disposal cell range from 0.0016 to 0.0196 mg/L. Concentrations above 0.01 mg/L from wells 671, 639, 733, and 632 (Figure 4–12) may indicate some contribution from the millsite. Uranium data from the terrace are sparse. On the floodplain, uranium concentrations are greater than one order of magnitude above the MCL in wells 615, 614, 610, and 608 near the terrace, in wells 620, 619, and 624 in the central portion, and in wells 643, 736, 642, and 644 near the San Juan River. These high concentrations in the wells near the river are surprising given the long distance from the terrace and the lower concentrations in some of the wells (e.g., 626, 628, 616, and 603–1) in the area between the terrace and the river.

Additional wells are required on the floodplain and on the terrace to better define the distribution of uranium contamination. Background concentrations of uranium need to be better quantified by examining ground water in settings similar to those of the floodplain alluvium and the terrace system. Analysis of uranium concentrations in soil samples would help to determine the potential for ground-water contamination attributable to leaching from the soil.

4.3.12 Organics

Although organics are not currently included in the list of COPCs, organic solvents that were used in the milling operations could have entered the ground water. Ground water has not been analyzed for organic solvents. Based on sampling and analyses at other UMTRA sites, organic contamination, if present, is probably not widespread in the ground water (DOE 1997c). Organic contamination at the Shiprock site would most likely be in ground water near the solvent extraction facilities or near solvent storage areas (Figure 1–2). Analysis of organic compounds in ground water sampled from a monitor well sited just downgradient of former solvent extraction facilities would determine if organic contaminants are present.

4.4 Surface-Water and Sediment Contamination

The San Juan River was sampled upstream and downstream of the site (seven sampling locations) on February 25, 1993. However, only two of the sample locations were on the same side of the river as the millsite. Downstream median concentrations of arsenic, nitrate, sodium, and sulfate were above median concentrations determined at the upstream locations (DOE 1994). Median concentrations of the remaining COPCs at downstream locations were similar to concentrations at the upstream locations. The river was flowing at about 3,000 cfs during this sampling; flows range from about 900 to 6,000 cfs during a typical season. Additional samples should be collected at a lower flow stage and at sample locations on the same side of the river as the millsite to determine the effect of ground water releases from the site on concentrations of COPCs in the river.

Only a small number of river sediment samples have been analyzed, and the results were inconclusive (DOE 1994). Thus, there is a need to determine if contamination from the site has concentrated in the sediment and presents a risk to human health or the environment.

4.5 Summary of Geochemical Data Needs

Additional monitor wells are needed on the floodplain and on the terrace to determine the nature and extent of ground-water contamination in the unconsolidated material in those systems. Wells are needed along the terrace-floodplain boundary to determine the extent of contaminated ground-water migration through the Mancos Shale. Ground-water samples selected near the possible sources of organic solvent contamination need to be analyzed for organic constituents specific to the milling process [di(2-ethylhexyl)phosphoric acid, tributyl phosphate, kerosene, and alcohol]. Background concentrations of contaminants need to be determined for ground water in the terrace and floodplain. Target analytes should include all COPCs and any other constituents that may present a risk to human health or the environment. Chemical data are needed from soils on the floodplain to determine if there is a continuing source of contamination that can enter the alluvial aquifer. San Juan River water needs to be sampled at low flow to determine the contribution of contaminants from the millsite. Sediment samples should be collected to determine if any contamination resides in the river sediment. Distribution coefficients (the equilibrium ratio of a chemical concentration in ground water to the concentration in the aquifer solid particles) for all COPCs in the floodplain alluvial gravels need to be determined.

5.0 Ecology

Characterization of the ecology of the former millsite at Shiprock and of surrounding areas is needed to complete the assessment of ecological risks associated with site-related contaminated ground water. A defensible ecological risk assessment will support the development of risk-based compliance strategies.

The purpose of any ecological risk assessment is to evaluate the likelihood that adverse ecological effects are occurring or may occur as a result of exposure to contamination or other stressors (EPA 1996). For ecological risks to occur at the Shiprock site, now or in the future, pathways must exist for exposure of biological receptors to contaminated ground water. A previous baseline assessment of ecological risks at the site evaluated COPCs, potential pathways, receptors, and adverse effects (DOE 1994). This section summarizes the results and recommendations of the baseline assessment and identifies ecological characterization activities needed to complete the assessment.

5.1 Summary of the Baseline Risk Assessment

The BLRA was a screening-level assessment that evaluated the potential exposure of terrestrial and aquatic organisms to contaminated ground water and to surface water or sediment contaminated by ground water (DOE 1994). Concentrations of ecological COPCs in ground water, surface water, and sediment were compared to toxicity standards and guidelines for various ecological receptors.

5.1.1 Ecological Contaminants of Potential Concern

Ecological COPCs were defined in the screening-level risk assessment as those constituents that exceeded background concentrations (Table 5–1). Background ground-water quality was defined as the quality of ground water in areas that were not affected by milling operations. Water quality in ground-water wells upgradient of the Shiprock site were considered to be representative of background conditions (DOE 1994; Section 3.3). Constituents in the alluvial aquifer were included in the list of ecological COPCs if on-site concentrations statistically exceeded background concentrations.

Two categories of surface water were defined: San Juan River water and water in Bob Lee Wash and associated wetland ponds. San Juan River COPCs were those constituents having higher median concentration values on site or downstream than upstream from the site. Ecological COPCs in San Juan River sediments were determined by comparing upstream with downstream sediments. A 2.5-acre wetlands area on the floodplain just north of the mouth of Bob Lee Wash receives a constant supply of water from an uncapped artesian well on the terrace. Water in the wetlands area flows through a ditch to the San Juan River. A small area with ponded water is fed by a seep (shown as seep 425 on Figure 2S1) at the base of the terrace escarpment approximately 300 ft east of Bob Lee Wash. Other ponds in depressions in the floodplain are associated with the fluctuating ground-water surface. Surface water and sediment in these floodplain ponds were analyzed but no comparison was made with background (reference) areas.

Table 5–1. Summary of Ecological Contaminants of Potential Concern in Ground Water, Surface Water, and Sediments

Constituents Above Background in Ground Water[a]	San Juan River Water[b]	San Juan River Sediments[b]	Floodplain Surface Water and Sediments[c]
Ammonium			
Antimony	X		
Arsenic	X	X	
Boron			
Cadmium			
Calcium			
Chloride			
Lead-210			
Magnesium	X		
Manganese			X
Nickel			
Nitrate			X
Phosphate			
Polonium-210			
Potassium			
Radium-226		X	
Selenium			X
Sodium	X		
Strontium	X	X	X
Sulfate	X		
Thorium-230	X		
Uranium		X	X
Zinc			

[a] Ground-water constituents that exceeded background at the 0.1 significance level.
[b] Ground-water constituents were excluded that were either not detected in surface water or sediment, or the median concentration adjacent to and downgradient from the site was less than concentrations upgradient of the site.
[c] Selection of constituents analyzed from floodplain pond water and sediment was not based on a comparison with reference areas.

5.1.2 Potential Receptors

This section summarizes information on ecological receptors that are potentially exposed to ecological COPCs (DOE 1994; Section 7.2). The information was derived from qualitative surveys and observations conducted on the floodplain and in Bob Lee Wash in the spring of 1993.

Potential Terrestrial Receptors

The BLRA identified four habitat types in the floodplain: dense salt cedar along the San Juan River, open salt cedar in the interior floodplain, wetlands, and disturbed ground.

A dense, tall stand of salt cedar (*Tamarix* sp.) with a few scattered Russian olive (*Elaeagnus angustifolia*) grow in a band along the bank of the San Juan River and along the canal or ditch that traverses the floodplain. The understory consists primarily of salt cedar litter and clumps of common reed (*Phragmites australis*) with patches of cheatgrass (*Bromus tectorum*) and saltgrass (*Distichlis spicata*). In the interior of the floodplain, salt cedar are shorter and more scattered. Woody plants are more diverse and consist of Russian olive, Fremont cottonwood (*Populus fremontii*), black greasewood (*Sarcobatus vermiculatus*) and fourwing saltbush (*Atriplex* *canescens*). Birds observed in the floodplain included mourning dove, brown-headed cowbird, red-winged blackbird, meadow lark, Gambel's quail, yellow-billed magpie, yellow warbler, common raven, spotted sandpiper, house finch, mallard, blue-winged teal, black-headed grosbeak, ring-necked pheasant, American gold finch, song sparrow, and killdeer.

A band of wetlands approximately 30 ft wide by 650 ft long occurs downstream from the point where water from artesian well 648 enters Bob Lee Wash to the mouth of the wash at the edge of the floodplain. The water was generally clear. Filamentous algae covered the majority of the bottom and were interspersed with a few submergent macrophytes. The plant community consists primarily of cattails (*Typhus* sp.), mannagrass (*Glyceria* sp.), salt cedar, and saltgrass. The 2.5-acre wetlands just north of the mouth of Bob Lee Wash contains a mixture of cattails, saltgrass, bulrushes (*Scirpus*), and open water. A few bullfrogs and garter snakes were observed in the wetlands.

Aquatic organisms were surveyed using dip-net collections near the mouth of Bob Lee Wash and in the drainage ditch downstream near surface water and sediment sampling locations 657 and 658 (DOE, 1994; Section 7.2.3). A diverse assemblage of organisms was observed. Water boatmen (Corixdae), backswimmers (Notonectidea), water striders (Gerridae), mosquito larvae, and unidentified cladocerans were observed. Many damselfly (Zygoptera) nymphs and a few dragonfly (Anisoptera) nymphs and lace-wing larvae (Chrysopidae) were also observed. Snails were observed grazing on periphyton, and diving beetles were common. Chrionomid larvae and nematode worms were observed in the bottom sediments. Some small fish, identified as *Gambusia* sp., were abundant. Many black tadpoles were observed in the ditch downstream of the wetlands. Ponded water in Bob Lee Wash above the floodplain contained the same types of aquatic organisms. Caddis fly larvae (Trichoptera) were observed in the flowing parts of the wash.

5.1.3 Potential Adverse Effects

The BLRA evaluated potential adverse effects of contaminated ground water in the terrace system and the floodplain system.

Terrace System

The BLRA concluded that nitrate, sulfate, and uranium levels were high enough to make the water from the terrace system unsuitable as drinking water for livestock. However, the BLRA concluded that the ecological risks in the terrace system could not be fully assessed until background ground-water quality for this system had been evaluated. Plant uptake of terrace system water is a potential pathway not addressed in the BLRA. Black greasewood, a phreatophyte, was observed growing on the terrace after the BLRA was completed. Phreatophytes can be adversely affected if exposed to contaminated ground water taken up through roots. Wildlife that ingest phreatophyte vegetation that bioaccumulate certain contaminants could also be adversely affected. Sampling of black greasewood and any other phreatophytes growing on the terrace is warranted to determine if phreatophyte tissue concentrations exceed phytotoxicity benchmarks.

Floodplain System

The following are potential exposure pathways for terrestrial and aquatic organisms residing in the San Juan River floodplain below the former millsite:

- Plant uptake of ground water.
- Exposure of terrestrial and aquatic life in seeps and ground-water-fed ponds and wetlands.
- Agricultural use of ground water or pond water.
- Exposure of aquatic life in San Juan River water and sediments.

Plant Uptake of Ground Water

Phreatophytes, including salt cedar and greasewood—plants that have the potential to root into the shallow ground water—inhabit the San Juan River floodplain. The BLRA attempted to evaluate the potential for phytotoxic effects by comparing estimates of contaminant concentrations in plant tissues with published values that have been shown to result in phytotoxicity (Kabata-Pendias and Pendias 1992). Plant tissue concentrations were estimated using soil-to-plant concentration factors. No soil data for the floodplain were available. Soil concentrations were estimated by multiplying the ground-water concentration by a soil/water distribution coefficient (Kd) (ORNL 1984). Because soil-to-plant concentration data were unavailable for many COPCs, the BLRA concluded that it was not possible with existing data to evaluate whether tissue concentrations could result in adverse effects to plants or to animals foraging on contaminated vegetation.

Terrestrial and Aquatic Life in Ponds and Wetlands

The BLRA concluded that seep-contaminated surface-water bodies existing on the floodplain form an incidental pathway to domestic animals and wildlife, and that levels of ecological COPCs in seep water and sediment may result in adverse effects to aquatic and terrestrial organisms that reside in the seep areas. Unfiltered surface water collected at the base of the escarpment directly below seep 425 (shown on Figure 2–1) contained the highest levels of nitrate and selenium anywhere on the floodplain. The BLRA also concluded that with the data available at the time, concentrations of ecological COPCs in surface water in the floodplain, excluding seep water, did not exceed federal water quality criteria for aquatic life. The BLRA did not evaluate exposure of organisms to sediment concentrations in surface-water bodies on the floodplain because of a lack of sediment quality criteria or benchmarks.

Agricultural Use of Floodplain Water

In the BLRA, water quality data for floodplain ground water and surface water were compared with available livestock drinking water criteria. The conclusion was that, with the exception of the wet area near seep 425, livestock could safely use these water bodies as a sole source of drinking water. However, the data represent only a snapshot in time and do not capture seasonal or annual variation expected in standing water, and therefore may not represent long-term conditions. A recommendation in the BLRA was to conduct additional monitoring of seasonal variations in water quality and sediment.

The BLRA evaluated the potential pumping of ground water for crop irrigation, for fish ponds, and for stock ponds. Water from the most contaminated wells in the aquifer contained levels of boron, manganese, selenium, sodium, and salinity that make it unsuitable for crop irrigation. Water from the most contaminated wells also would not be suitable for fish or as the sole source of drinking water for livestock.

Aquatic Organisms in San Juan River Water and Sediments

Concentrations of many ecological COPCs in San Juan River water and sediment were higher at sampling locations adjacent to and downstream of the former millsite than at upstream locations. However, the BLRA concluded that San Juan River water and sediment data were inadequate to evaluate whether concentrations represent a hazard to aquatic life in the river.

5.2 Summary of Ecological Data Needs

Data available for the BLRA were inadequate to evaluate whether adverse ecological effects could occur now or in the future with respect to (1) plants growing on the terrace or floodplain that root into the contaminated ground water, (2) seep water and alluvial ground water contaminating surface water and wetlands on the floodplain, and (3) potential use of alluvial aquifer water for livestock ponds or for crop irrigation. Pathways currently exist for the first two exposure scenarios. Phreatophytes grow on the terrace and on the floodplain. Seep water and alluvial aquifer water currently feed surface water and wetland areas on the floodplain that are inhabited by a variety of terrestrial and aquatic organisms. Contaminated ground water is not currently used for agriculture; however, there is considerable evidence that livestock and wildlife on the floodplain are drinking surface water that is potentially contaminated.

The following ecological characterization activities are needed to evaluate these exposure pathways:

- Meet with officials from the Navajo Nation Department of Agriculture and Grazing Management Program to determine current use of the floodplain for livestock and to enforce institutional controls already in place. Evaluate ecological risks of any other potential future land uses.

- Characterize the plant ecology of the terrace, Bob Lee Wash, seep habitat, and floodplain habitats. Identify phreatophyte species potentially rooted into areas with the highest contaminant concentrations. Project possible changes in plant ecology given possible future land-use scenarios.

- Establish geologic, hydrologic, and ecological criteria to select ecological reference areas for (1) phreatophytes growing on the terrace, in Bob Lee Wash, and on the floodplain; (2) seep habitat at the base of the escarpment; (3) surface water and wetland habitat on the floodplain; and (4) San Juan River water and sediment. Conduct a reconnaissance for reference areas. Characterize vegetation of reference areas.

- Establish geologic, hydrologic, and ecological criteria to select ecological reference areas for (1) phreatophytes growing on the terrace, in Bob Lee Wash, and on the floodplain; (2) seep habitat at the base of the escarpment; (3) surface water and wetland habitat on the floodplain; and (4) San Juan River water and sediment. Conduct a reconnaissance for reference areas. Characterize vegetation of reference areas.

- Conduct co-located sampling (same time and place as water and sediment sampling) of ecological COPCs in phreatophyte tissue taken from plants growing in the most contaminated ground water and surface water and from phreatophytes growing in reference areas. Calculate Incremental Hazard Quotients (HQs) and HQ ratios for toxicity to plants and animals (wildlife and livestock) that may ingest the contaminated vegetation.

- Sample and compare COPC levels in water and sediment in Bob Lee Wash, seeps at the base of the escarpment, in wetland areas, and in the reference areas. Calculate incremental HQs and HQ ratios for aquatic life. Characterize and sample aquatic life populations if the incremental risk is significant.

- Establish a monitoring program for water, sediment, and plant tissue in habitats where adverse ecological effects could potentially occur. Include reference areas in the monitoring program. Continue monitoring and continue institutional controls until environmental contamination drops below potential hazard levels.

6.0 Site Conceptual Model

Geologic, hydrogeologic, geochemical, and ecological characterization data for the Shiprock site and nearby area were evaluated and used to develop the site conceptual model. Details of the conceptual model and supporting information are presented in Sections 2.0 through 5.0. The model presented here is a synthesis of available site data. The model will be improved and refined as data needs are addressed by the proposed additional characterization.

Figure 6–1 presents a conceptual model for the Shiprock site and illustrates the pertinent geologic, hydrologic, and geochemical elements. The conceptual model illustrates how the disposal cell is located within the Bob Lee Wash subbasin, a hydrologic subbasin that is separate from the subbasin defined by the drainage of the west fork of Many Devils Wash. Ground-water recharge to the Bob Lee Wash subbasin enters the terrace ground-water flow system and flows north. As the ground water reaches the terrace margin, it either discharges to springs and seeps (Figure 6S1) at the base of the escarpment, or it discharges directly into the floodplain alluvial aquifer. The rate of these discharges is not known but will be estimated as part of the site characterization.

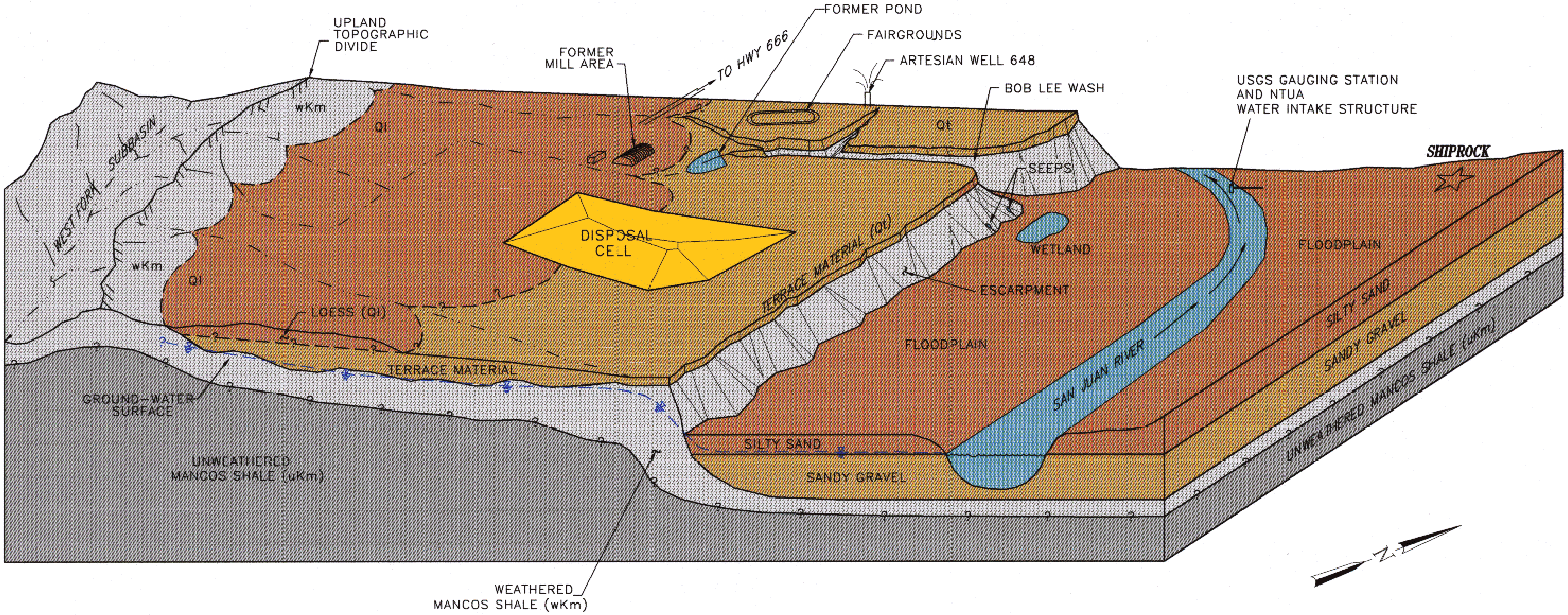
The floodplain alluvial aquifer is dynamic. Its northern boundary is defined by the San Juan River, and its southern boundary is the relatively impermeable Mancos Shale at the base of the escarpment bounding the floodplain. The aquifer receives most of its recharge from the San Juan River. Fluctuations in the stage of the river induce transient gradients on the floodplain alluvial aquifer. These transient changes in ground-water head along the boundary of the San Juan River must be taken into account in predictions of the effectiveness of ground-water management methods. In comparison to recharge from the San Juan River, only minor amounts of recharge enter from the south. The largest component of flow from the south is at the mouth of Bob Lee Wash, which obtains most of its flow from artesian well 648. The amount of water entering the floodplain alluvial aquifer from Bob Lee Wash will be gauged as part of this characterization.

Eleven COPCs in ground water at the Shiprock site were identified in the BLRA (DOE 1994) and consist of antimony, arsenic, cadmium, magnesium, manganese, nitrate, selenium, sodium, strontium, sulfate, and uranium. Ground-water contamination at the site resulted from processing ore from 1954 to 1968. During that period, water drained from stockpiled fine-grained material and from sandy tailings that were directed as a slurry into two tailings piles just east of the former mill and ore-storage areas. Inorganic contaminants from ore processing include nitrate, sulfate, strontium, and uranium. Trace levels of the remaining COPCs may have entered the ground water either as solubilized mineral constituents or as by-products of chemical processing.

The former ore-processing area at the site is shown in Figures 1–2 through 1S5. The ore-processing area was where the organic solvents di(2-ethylhexyl)phosphoric acid (EHPA) and tributyl phosphate suspended in kerosene were used for extraction of uranium and vanadium.

Quinn (1957) reports that the EHPA was pumped by hand from 55-gallon stainless steel barrels into the solvent mixing tank. Therefore, the potential for large leaks from voluminous solvent-storage tanks is considered to have been unlikely. To date, there has been no sampling for organic compounds at the Shiprock site; however, during the course of the field investigation, sampling and analysis will be performed to determine whether residual organics from ore processing are present beneath the former solvent extraction area.

Tailings from the ore processing were slurried into evaporation ponds; however, not all of the water evaporated. Some of it infiltrated into the ground and spread radially before flowing north. The infiltration is thought to have created a ground-water mound beneath the evaporation ponds. During the 30 years since processing stopped, the mounding is thought to have dissipated.



BLOCK DIAGRAM REPRESENTING THE SITE CONCEPTUAL MODEL AT SHIPROCK

mactec-ers

U.S. DEPARTMENT OF ENERGY
GRAND JUNCTION OFFICE
GRAND JUNCTION, COLORADO

Block Diagram Representing
the Site Conceptual Model
at Shiprock, New Mexico

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Figure 6–1. Block Diagram Representing the Site Conceptual Model at Shiprock

7.0 Data Quality Objectives

The Data Quality Objective (DQO) process is “a scientific and legally defensible data collection planning process to help users decide what type, quality, and quantity of data will be sufficient for environmental decision making. DQOs are qualitative and quantitative statements derived from the outputs of each step of the DQO process that (1) clarify the study objective; (2) define the most appropriate type of data to collect; (3) determine the most appropriate conditions from which to collect the data; and (4) specify acceptable levels of decision errors that will be used as the basis for establishing the quantity and quality of data needed to support the decision” (EPA 1993).

DQOs are governed by the decisions necessary to determine appropriate responses at the Shiprock site terrace and floodplain areas and will be achieved by using procedures specified in Section 8.0. Specific DQOs for this project are summarized in Tables 7–1 and 7–2. Proposed locations (indicated by a "P" prefix) for monitor wells, boreholes, sediment, soil, and water samples for the terrace and floodplain areas of the site are shown in Figure 7–1.

7.1 Data Quality Objectives for the Terrace Area

DQOs and data collection strategies for the terrace area of the Shiprock site are presented in Table 7–1. The rationale for each DQO is described in Sections 7.3.1 through 7.3.9.

7.2 Data Quality Objectives for the Floodplain Area

DQOs and data collection strategies for the floodplain area of the Shiprock site are presented in Table 7–2. The rationale for each DQO is described in Sections 7.3.1 through 7.3.9.

7.3 Rationale for Data Quality Objectives and Data Collection Strategies

The purpose of additional characterization at the Shiprock site is to collect the data required to (1) determine the extent of ground-water contamination in the terrace system, (2) determine the yield of the terrace ground-water system and whether it meets the criteria for limited-use ground water, (3) select alternate concentration limits for contaminants in the terrace ground-water system if supplemental standards is the compliance strategy, (4) evaluate the hydraulic connection between the terrace and floodplain alluvial ground-water systems; (5) evaluate the hydraulic connection between the floodplain alluvial aquifer and the San Juan River, and (6) select one or more active remediation technologies for the floodplain alluvial aquifer. The following subsections summarize the rationale for the DQOs and data collection strategies presented in Tables 7–1 and 7–2.

Table 7–1. Data Quality Objectives and Data Collection Strategies at the Terrace Area

Data Quality Objective—Terrace Area	Data Collection Strategy—Terrace Area
Characterize water quality of the terrace system (mainly Mancos Shale aquitard) to determine the lateral extent of the terrace plume.	• Use direct-push (Hydropunch or equivalent) sampling method (or small-diameter bailer) to collect ground-water samples for field measurements at up to 14 locations (see Figure 7–1). Ground-water samples (2 at each location) will be collected and analyzed in the field for uranium, nitrate, and sulfate according to the procedures in Sections 8.1 and 8.2. • Install 15 monitor wells (see Figure 7–1): —Two 4-inch (in.) upgradient background monitor wells (P802 and P803). —Thirteen 2 in. monitor wells (P804 through P816). • Collect and analyze ground-water samples after wells are developed according to the procedures in Sections 8.4 and 8.5.
Characterize stratigraphy and ground-water yield/conductivity in the Mancos Shale aquitard/Quaternary material system.	Determine the geologic and hydrologic properties of the terrace system: • Install two 4-in. monitor wells (P817 and P818, Figure 7**S**1) and two 4-in. background monitor wells (P802 and P803, Figure 1–5). —Advance boreholes by air rotary through Quaternary material several feet into weathered Mancos Shale. —Air core an estimated 30 to 40 ft through weathered Mancos into unweathered Mancos Shale to identify water-bearing zones. • As part of installation of three 2-in. wells in each of the two well nests (P820 through P822 and P823 through P825), air core each borehole from the top of competent Mancos Shale to total depth. • Conduct pumping tests in wells P817 and P818; use adjacent existing wells 602–2 and 604–2 as observation wells (see Figure 7–1). Conduct pumping tests in background wells; use adjacent background well as observation well. • Conduct tests to estimate transmissivity and storativity in the terrace system. —Conduct slug tests in up to 10 wells. —Conduct packer tests in the first (deepest) borehole drilled (P820 and P823) in each well nest (see Figure 7–1). • Describe the lithology of the unconsolidated Quaternary material and weathered Mancos Shale. —Collect one 2-ft split-barrel soil sample starting at a depth of 10 ft for each borehole. Collect additional representative split-barrel samples from each lithology (loess, terrace material, weathered Mancos Shale) penetrated in the borehole. Log all drill cuttings.
Determine if organic compounds from solvent extraction processing at the site are present in terrace system ground water.	• Install one 2-in. monitor well (P819) just downgradient of the former location of the solvent extraction operation (see Figure 7–1). —Air rotary through Quaternary material to the top of the bedrock. Air rotary through the upper 10 ft of the saturated zone. Set stainless steel screen across the water table. After well development, sample ground water and analyze for organic compounds.

Table 7–1 (continued). Data Quality Objectives and Data Collection Strategies at the Terrace Area

Data Quality Objective—Terrace Area	Data Collection Strategy—Terrace Area
Characterize contaminant sorption in the terrace system ground water.	Determine distribution coefficients (Kd) in saturated weathered and unweathered Mancos Shale. Kd determinations will be made on samples from background wells P802 and P803. Two samples will be collected from each well—one in weathered Mancos Shale and one in unweathered Mancos Shale. The samples will be taken either from split-barrel samples (most likely for the weathered Mancos) or from core (most likely for the unweathered Mancos).
Characterize ground-water flow directions and the location of the ground-water divide.	Determine the configuration of the potentiometric surface of ground water in the terrace system. • Measure water levels using data loggers in at least 10 wells every 4 hours for 1 year. • Take manual measurements of water levels in all permanent wells quarterly for 1 year. Determine the position of the ground-water divide (or edge of saturation) in the upland area south of the disposal cell. • Measure water levels either manually or using data loggers in 5 wells (P808 through P812) in the upland area.
Characterize the hydraulic communication between ground water of the terrace system and the floodplain alluvial aquifer.	• Install three 2-in. monitor wells in each of two well nests north of the disposal cell near the terrace edge (P820 through P822 in first nest and P823 through P825 in second nest; see Figure 7–1). The first borehole in each nest will be completed in unweathered Mancos Shale, the second in weathered Mancos Shale, and the third at 10 ft or less below the water table (possibly in Quaternary terrace material). —Air rotary through Quaternary material to the top of the bedrock and air core to total depth. Conduct packer tests over selected 5-ft intervals of bedrock in the first (deepest) borehole in each nest.
Characterize water quality from a basin that is recharged by the Mancos Shale aquitard.	• Collect a water sample (P889) from the lower reach of Many Devils Wash. The recharge area of Many Devils Wash is in weathered Mancos Shale, which is similar to the recharge area geology for Bob Lee Wash. —Analyze the water sample for the analytes listed for routine sampling of site monitor wells.
Characterize plant ecology and land use.	• Conduct a qualitative survey of the composition and abundance of riparian plant communities in the terrace and upland areas of the site. • Collect tissue samples of plants rooted in areas of highest contaminant concentrations in ground water; analyze samples for ecological COPCs (Table 5–1). • Identify and characterize vegetation of a terrace ecological reference area.

Table 7–2. Data Quality Objectives and Data Collection Strategies at the Floodplain Area

Data Quality Objective—Floodplain Area	Data Collection Strategy—Floodplain Area
Characterize water quality of the floodplain alluvial aquifer.	• Install seven monitor wells (see Figure 7–1): —Three 4-in. upgradient background monitor wells (P850 through P852). —Four 2-in. monitor wells (P853 through P856). • Collect and analyze ground-water samples after wells are developed according to the procedures in Sections 8.4 and 8.5.
Characterize stratigraphy and hydraulic properties of the floodplain alluvial aquifer.	Evaluate the geologic and hydrologic properties of the floodplain alluvial aquifer. • Collect split-barrel samples every 5 ft, starting at a depth of 5 ft, of unconsolidated alluvial material during drilling of each borehole on the floodplain (P850 through P864). • Conduct tests to estimate hydraulic conductivity in the floodplain alluvial aquifer. • Conduct slug tests at the three background wells and at selected new wells to be installed on the floodplain (up to 11 tests). • Conduct aquifer tests (transmissivity and storativity) using 2-in. wells P858 and P859 to be installed near well 612 in an uncontaminated area of the floodplain. • Determine the response of the alluvial aquifer to the stage of the San Juan River. —Take measurements from stilling well P899 (installed in April 1998) along the bank of the San Juan River. —Install 2-in. monitor well P857 and conduct diffusivity tests in conjunction with the stilling well and nearby wells 616 and 617.
Characterize contaminant sorption in the floodplain alluvial aquifer.	Obtain distribution coefficients (Kd) for saturated alluvial aquifer material. • Determine Kd on samples from background wells P850 through P852. • Collect two split-barrel samples from each well—one from shallower fine sand and silt material and one from deeper sand and gravel material.
Characterize ground-water flow directions in the floodplain alluvial aquifer.	Evaluate the configuration of the potentiometric surface of ground water in the alluvial aquifer. • Measure water levels using data loggers in at least 8 wells and one stilling well every 4 hours for 1 year. • Take manual measurements of water levels in all permanent wells quarterly for 1 year.

Table 7–2 (continued). Data Quality Objectives and Data Collection Strategies at the Floodplain Area

Data Quality Objective—Floodplain Area	Data Collection Strategy—Floodplain Area
Characterize the hydraulic communication between ground water of the terrace system and the floodplain alluvial aquifer.	• Install two 2-in. monitor wells in each of two well nests on the floodplain just below the well nests on the terrace above. Each nest will consist of three wells - the wells 615 and 608 are the existing alluvial aquifer wells in each nest (see Figure 7–1). The first of the two wells to be installed in each nest (P860 and P862) will be completed in unweathered Mancos Shale, and the second wells (P861 and P863) will be completed in weathered Mancos Shale. —Advance boreholes through alluvial material to top of bedrock. After setting and cementing casing into firm bedrock and pressure testing the seal of each borehole, core each hole to total depth. Packer testing will be conducted over selected 5-ft intervals of bedrock in the first (deepest) borehole in each nest.
Characterize leachability conditions of alluvial material in several contaminated areas of the floodplain.	Evaluate leaching characteristics of contaminated alluvial material in the floodplain under conditions of head-gradient manipulation. • Collect samples of alluvial material from split-barrel samples taken at three borehole locations in areas of contaminated ground water beneath the floodplain (P860 or P861 near well 615, P862 or P863 near well 608, and P864 near well 736). Samples will be leached in a column with simulated San Juan River water to mimic leaching conditions during head-gradient manipulation. The first leachate sample will be analyzed for all the COPCs and ammonium. Succeeding leachate samples will be analyzed only for U, NO_3, and SO_4 until sufficient number of pore volumes have passed through the sample so that analyzed values are less than prescribed values (MCLs in the case of U and NO_3).
Characterize soils as a source of continuing contamination.	Determine if millsite-related contamination is still present in the subsurface of the floodplain in several areas where former ponds or highly contaminated water may indicate the presence of a contaminant source. • Collect two soil samples of alluvial material from each of four locations (P864, P890 through P892). Analyze each pair of soil samples for selected COPCs (specific COPCs to be determined by water chemistry analyses in the area). —Collect soil samples at P890 through P892 by auger; collect soil samples at P864 by split-barrel sampling.

Table 7–2 (continued). Data Quality Objectives and Data Collection Strategies at the Floodplain Area

Data Quality Objective—Floodplain Area	Data Collection Strategy—Floodplain Area
Determine if millsite-related contamination has entered the San Juan River and affected its water and sediment.	Characterize contaminant concentrations in San Juan River sediments and water upstream and downstream of the site. • Collect water and sediment samples at six locations along the south side of the San Juan River (P893 through P898; see Figure 7–1). Sample locations include two downstream from the site, two upstream from the site, and two along the floodplain where millsite-related contaminants are likely to enter the river. Sampling should occur during low flow of the river, which is in late summer and fall. Analyze water samples for COPCs and for other analytes normally run in routine site water sampling. Sediment samples will be leached with 5 percent nitric acid and analyzed for COPCs and ammonium; these leachable COPC values will be compared to COPC and ammonium values for upstream samples.
Characterize effectiveness of contaminant flushing by gradient manipulation using water from well 648.	Construct a small intake structure in lower Bob Lee Wash to collect water mainly supplied by outflow from artesian well 648. Much of the water will be piped from the intake structure eastward to the floodplain and discharged through gated pipe in the contaminated area between wells 614 and 615 (see Figure 7–1). The intake structure and piping/discharge will be constructed after all new wells have been installed on the floodplain. Before construction, computer modeling will be used to evaluate engineering design parameters and hydrologic effects. Wells immediately downgradient of the discharge area will be sampled quarterly and analyzed for COPCs and ammonium to determine the effectiveness of the flushing.
Characterize plant ecology and land use.	• Conduct a qualitative survey of the composition and abundance of riparian plant communities in the floodplain areas of the site. • Collect tissue samples of plants rooted in areas of highest contaminant concentrations in ground water; analyze samples for ecological COPCs (Table 5–1). • Identify and characterize vegetation of a floodplain ecological reference area.

7.3.1 Ground-Water Quality

The extent of ground-water contamination in the terrace system south and west of the disposal cell is not known. Preliminary results of ground-water sample analyses from three wells (604–2, 730, and 731) sampled in February 1998 indicate that the milling-related contaminants nitrate, selenium, sulfate, and uranium occur to the south and west of the disposal cell. These three wells were added in February 1998 to the list of wells for annual sampling. The extent of contamination south and west of these wells is unknown. Preliminary results for ammonium, an analyte added in the February 1998 sampling, indicate that contamination extends south and west

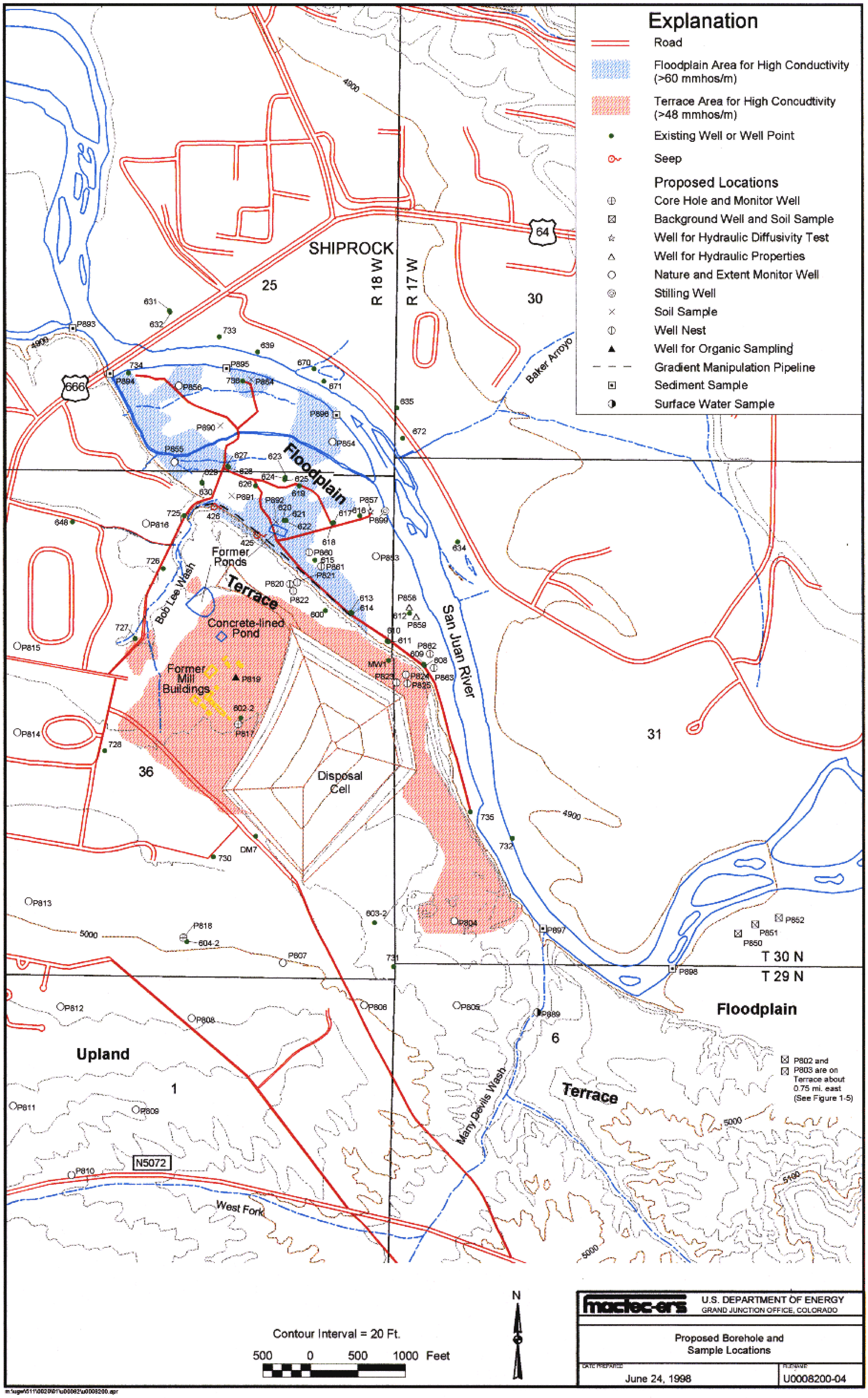

Figure 7–1. Proposed Locations for Monitor Wells, Boreholes, Sediment, Soil, and Water Samples, Shiprock Site

of the disposal cell at least to wells 603S2, 728, and 730. The high concentrations of ammonium may also be a product of anthropogenic factors (septic systems from numerous homes) southwest and west of the site. Organic compounds were used in solvent extraction processing of the ore during milling operations. The terrace system ground water has not been sampled for organic compounds immediately downgradient of the location of the former solvent extraction facility. Background water quality has not been established for the terrace system.

The extent of ground-water contamination in the floodplain alluvial aquifer is not known in several areas of the floodplain where high conductivity values (>60 millimhos/m, Figure 7S1) from a 1996 EM31 geophysical survey indicated that contamination may be present. Also, background water quality has not been established for the floodplain alluvial aquifer in an area of similar hydrogeologic environment upgradient from the site.

Terrace System

Eight permanent 2-in. monitor wells (P804 through P807 and P813 through P816) will be installed just beyond the estimated edge of millsite-related contamination in a clockwise direction from southeast to northwest from the disposal cell. The position of these wells will be determined from results of field measurements of uranium, nitrate, and sulfate in ground-water samples collected by Hydropunch or by a small-diameter bailer lowered through the drill string. Initially, each borehole will be drilled by air rotary at the locations shown in Figure 7–1. Ground-water samples will be collected in the first 5-ft interval below the water table. This interval may be in terrace material or weathered Mancos Shale, or both. After the borehole is advanced to 20 ft below the water table, a second ground-water sample will be collected in the next 5-ft interval. The two ground-water samples will be analyzed in the field for uranium, nitrate, and sulfate; results will be compared to respective MCL values for uranium and nitrate. Because sulfate has no MCL or HA value, a threshold concentration will be determined that will be used as a rough indication of background versus millsite-related contamination. If any of the MCLs or sulfate threshold value are exceeded in either of the samples, the borehole will be filled and abandoned, and a second borehole will be sited farther outward from the disposal cell. The drilling, sampling, and analysis will be repeated at this and succeeding borehole locations until sample analysis values are below MCLs and the sulfate threshold value. When this occurs, the borehole will be completed as a monitor well with a 10-ft screen. Up to six additional borehole locations are estimated for ground-water sampling before the extent of the contaminant plume is delineated.

Five additional wells (P808 through P812) in the upland area south of the disposal cell will be completed with a 10-ft screened interval in saturated weathered or unweathered Mancos Shale. These wells, along with the eight terrace wells described above, will be developed and sampled quarterly and analyzed for COPCs and ammonium. Analyses of water samples from these 13 wells will provide information on the amount of suspected anthropogenic (septic, sewer system, and water line leakage) contamination of the Mancos Shale aquitard that likely migrates northward into the terrace ground-water system.

One borehole (P819) will be drilled just downgradient of the location of the former solvent extraction facility that operated on the millsite. This borehole will be rotary drilled to the top of Mancos Shale and then to 10 ft below the water table. To complete the 2-in. well, a 10-ft stainless steel screen will be placed to intersect the water table. After well development, samples will be collected for analysis of light organic compounds that may be present at the top of the water column. This location is judged to be most likely to contain millsite-related organic contaminants (if they exist) on the site.

Background wells P802 and P803 will be installed at an upgradient location that is geologically similar to the terrace setting of the disposal cell, where terrace material overlies weathered Mancos Shale. The terrace site is unaffected by anthropogenic factors. These 4-in. production wells will be drilled by air rotary to the top of competent Mancos Shale and screened for 20 ft, starting at the water table. Coring from the top of competent Mancos to a total depth of 70 ft will identify water-bearing zones. After well development, sampling and analysis for COPCs and ammonium will provide background data for the terrace system.

Floodplain Alluvial Aquifer

Four permanent 2-in. monitor wells (P853 through P856) will be installed in areas of the floodplain where either information on ground water is lacking (P853) or high conductivity values from a geophysical survey conducted in 1996 indicate that contamination may be present. These boreholes will be drilled by a casing-advance method to bedrock and screened (5 ft) in the lower, coarse gravel of the alluvial aquifer. After development, these wells will be sampled and analyzed for COPCs and ammonium.

Vertical distribution of contaminants in the floodplain alluvial ground water will be characterized in five existing wells (614, 620, 624, 626, and 736). A multilayer ground-water sampling device will be used in each well to collect samples, which will be analyzed for the COPCs and ammonium.

Three background wells (P850 through P852) will be installed at upgradient locations about 0.75 mile southeast of the contaminated floodplain in a geologically and ecologically similar floodplain setting that has been unaffected by human activity. These boreholes will be drilled by a casing-advance method to bedrock (weathered Mancos Shale), screened for 5 ft in the lower, coarse gravel of the alluvial aquifer, and completed as 4-in. production wells. After well testing and development, sampling and analysis for COPCs and ammonium will provide background data for the floodplain alluvial aquifer.

7.3.2 Stratigraphy and Yield/Hydraulic Properties

The thickness and extent of the loess that overlies the terrace material on the terrace area south and southwest of the disposal cell is not known. At well 604–2, nearly 30 ft of loess is present and Mancos Shale bedrock is at a depth of 58 ft. Less than 1,000 ft south of this well, weathered Mancos Shale is at the surface. The position of the Mancos Shale–loess contact and the thickness of the loess should be determined for use in the site conceptual model.

Additional data on depth to bedrock in boreholes for both the terrace and floodplain areas will help define ancestral channels and other irregularities of the bedrock surface that may host contaminated ground water. Additional information in both the terrace and floodplain areas on the character of the weathered and unweathered Mancos Shale and features such as fracturing, jointing, and siltstone beds that influence ground-water flow will be gathered for use in the site conceptual model.

Yield of wells in the terrace ground-water system has not been determined. Aquifer pumping tests will be conducted for several terrace wells to evaluate if they represent a resource capable of delivering at least 150 gallons of water per day. If well yields are less than this, the terrace ground-water system may qualify for supplemental standards on the basis of limited use ground water. Well yield will also be determined for terrace ground water in a background setting.

Hydraulic conductivity, transmissivity, and storativity for the floodplain alluvial aquifer and the terrace system will be determined both on site and in background areas. These parameters are necessary to understand contaminant transport and to design remediation methods. Also, the response of the floodplain alluvial aquifer to variations in the stage of the adjacent San Juan River will be determined.

Terrace System

Additional stratigraphic information will be gained while drilling the boreholes, describing the cuttings, and collecting split-barrel samples and core. Rotary drill cuttings will be collected for each 5-ft interval in all boreholes. The cuttings will be described and recorded in a borehole lithologic log. Split-barrel samples 2-ft long will be collected in unconsolidated material and weathered Mancos Shale from each borehole starting at a depth of 10 ft. Additional split-barrel samples will be collected as the lithology changes. The deepest split-barrel sample in a borehole will be of weathered Mancos Shale. All split-barrel samples will be described and recorded in a borehole lithologic log.

Coring will be done in selected boreholes beginning in competent bedrock. Initially, the core in a given borehole may start in weathered Mancos Shale but will pass into unweathered Mancos Shale within a few feet. All core will be described and recorded in a borehole lithologic log. Coring will be conducted in Mancos Shale in wells P817 and P818 and in background wells P802 and P803. Coring will also be done in each of the three boreholes in the two well nests. The coring will allow identification and accurate description of the character of water-bearing zones in each borehole.

Pumping tests will be conducted in wells P817 and P818; adjacent existing wells 602–2 and 604–2, respectively, will be used as observation wells. If water is present in wells P808 through P812 in the upland area, a pumping test will be conducted at one or more of these wells to determine the yield of this area of the terrace system where weathered Mancos Shale is exposed. Pumping tests will also be conducted in background wells P802 and P803; the nearby background well will be used as an observation well.

Hydraulic conductivity will be determined by performing slug tests in up to ten of the new monitor wells. Wells selected for slug testing will reflect the range in hydrogeologic conditions in the terrace ground-water system and will include at least one of the background wells. Packer tests will be conducted in wells P820 and P823, which are the deepest boreholes in each of the two well nests (Figure 7–1). These holes, which will be drilled into unweathered Mancos Shale, will be packer tested over selected 5-ft intervals in weathered and unweathered Mancos Shale to determine hydraulic conductivity. The variation in hydraulic conductivity will be compared and related to the character of the bedrock as described in core from these boreholes.

Floodplain Alluvial Aquifer

Description of cuttings and split-barrel samples obtained during drilling of boreholes will add to the understanding of the floodplain alluvial stratigraphy. Cuttings and split-barrel samples will be collected and recorded in a borehole lithologic log, as stated in the previous section on the terrace system. In each borehole, split-barrel samples will be collected every 5 ft, starting at a depth of 5 ft below ground surface.

Hydraulic conductivity will be determined from slug tests conducted at the three background wells (P850 through P852) and at other selected new wells (up to a total of 11 tests). Tests of additional hydraulic properties (such as transmissivity and storativity) of the floodplain aquifer will be conducted around well 612. There, where the alluvial ground water is relatively uncontaminated, wells P858 and P859 will be installed and a short-term aquifer pumping test will be conducted. A short-term aquifer pumping test will also be conducted at one of the wells in the floodplain alluvial background cluster to determine aquifer properties.

The response of the floodplain alluvial aquifer to the varying stages of the adjacent San Juan River will be evaluated by measuring water levels in a stilling well along the river and in an observation well several hundred feet away on the floodplain. The stilling well (P899) was installed along the San Juan River bank in April 1998, and a data logger was placed in the well to record continuous river stage data. Well P857 will be installed as an observation well 100 to 200 ft west of the stilling well and about the same distance east of well 616. Measurements from the stilling well and the nearby wells to the west on the floodplain (P857, 616, and 617) will be used to determine the hydraulic diffusivity for the floodplain alluvial aquifer.

7.3.3 Contaminant Sorption

Interactions between ground-water contaminants and aquifer sediments need to be understood to evaluate the efficiency of natural flushing. Contaminants with high sorption potential are less likely to flush from the aquifer than are contaminants with low sorption potential. To evaluate solid phase-aqueous phase contaminant interaction, samples will be collected for analysis of sorption characteristics of the aquifer matrix, which includes floodplain alluvial material, terrace material, and weathered and unweathered Mancos Shale.

A distribution coefficient (Kd), the ratio of contaminant concentration in the aquifer matrix to contaminant concentration in water, is used to predict chemical interactions between ground water and the aquifer matrix. It is likely that pH and other chemical conditions will be reasonably constant for a period of active remediation involving induced flushing.

Kd values can vary for the same sample if different dissolved contaminant concentrations are used. The contaminants that have maximum concentrations in ground water that exceed the MCL by an order of magnitude or more (or are more than twice background values) include uranium, cadmium, selenium, and ammonium. These analytes will have Kd values determined for five aqueous solutions (5-point isotherm) for one sample collected of weathered Mancos Shale. The same procedure will be performed for one sample collected of unweathered Mancos Shale, of floodplain alluvial silty sand material, and of floodplain alluvial sand and gravel material. Succeeding or other samples of a given lithologic type will have Kd values determined from only the single-point isotherm (one solution). Concentrations to be used for the analyses will be determined after early data collection and analysis. Selection of either natural or synthetic ground water will also be made at that time.

Samples from the terrace system to be collected for Kd analysis will be from split-barrel or core samples taken from each of the background wells P802 and P803. The first sample, likely to be from a split-barrel, will be weathered Mancos Shale; the second sample will be unweathered Mancos Shale from a core. If boreholes P802 and P803 are dry, the samples will not be analyzed.

Samples from the floodplain alluvial aquifer to be collected for Kd analysis will be from split-barrel samples taken from each of the background wells P850 through P852. The first sample will be of silty sand material near or just below the water table; the second sample will be of sand and gravel in the lower part of the alluvial aquifer.

7.3.4 Ground-Water Flow Directions

Water-table (potentiometric surface) elevations will be measured on the site to determine ground-water flow directions and to estimate ground-water flow rates. Seasonal fluctuations in the San Juan River stage will be used to evaluate recharge from and discharge to the river. These data along with hydraulic conductivity data will be used as input parameters for ground-water modeling.

For all permanent wells in the floodplain and in the terrace area, manual measurements of water levels will be made quarterly for 1 year. Data loggers will record water levels in wells every 4 hours for 1 year. In the terrace area, at least 10 wells will have data loggers, and in the floodplain area, the stilling well and at least 8 wells will have data loggers.

The ground-water surface in the weathered Mancos Shale in the upland area south of the disposal cell is unknown. This surface possibly mimics the surface topography, but near the crest or divide of the upland, ground water may be absent. The configuration of this surface needs to be determined to evaluate the boundary conditions of the terrace system. To define this surface, water levels will be measured either manually or using data loggers in five wells (P808 through P812) in the upland area.

7.3.5 Hydraulic Communication Between the Terrace System and the Floodplain Alluvial Aquifer

The interrelationship between ground water in the terrace system and the floodplain alluvial aquifer will be evaluated by installing two pairs (4) of well nests. Hydraulic head measurements from these wells will allow the vertical and horizontal components of flow to be evaluated. Three 2-in. wells, completed in different lithologic units, will be in each nest. The nests in each pair will be less than 500 ft apart—one nest on the terrace and one directly below on the floodplain. The first borehole in the two terrace nests will be completed in unweathered Mancos Shale, the second well will be in weathered Mancos Shale, and the third at 10 ft or less below the water table (possibly in terrace material).

In the floodplain nests, the first wells exist (wells 608 and 615) and are completed in the alluvial aquifer. The second wells in each nest will be completed in unweathered Mancos Shale; the third wells will be completed in weathered Mancos Shale. In the new boreholes for the floodplain nests, the casing will be set and cemented in firm Mancos Shale, and the seal will be pressure tested before further drilling. Coring will then proceed for the first borehole in each nest (P860 and P862) into the unweathered Mancos Shale; the wells will be screened at the same elevations as the paired unweathered Mancos well from the terrace nest. The second holes (P861 and P863) will be completed in weathered Mancos Shale. Packer tests will be conducted in the deepest wells, P860 and P862, which will be tested over selected 5-ft intervals in weathered and unweathered Mancos Shale to determine hydraulic conductivity.

7.3.6 Surface Water and Sediment Quality

In the terrace area, recharge for the ground-water system is believed to be the weathered Mancos Shale to the south. Many Devils Wash, just east of the site and unaffected by anthropogenic contributions, drains a large area of weathered Mancos Shale. The drainage area of this wash is geologically similar to the recharge area of Bob Lee Wash. To evaluate surface flow from a weathered Mancos Shale drainage area, a water sample (P889) will be collected from the lower part of Many Devils Wash. The sample will be analyzed for constituents listed for the routine sampling of the site monitor wells.

Millsite-related contamination in the floodplain alluvial aquifer may have entered the San Juan River and affected its water and sediment. To address this concern, contaminant concentrations in San Juan River water and sediments upstream of the site, on site, and downstream of the site will be characterized. Water and sediment samples will be collected at six locations along the south side of the San Juan River (P893 through P898). Sample locations P893 and P894 are downstream locations, P895 and P896 are where millsite-related contaminants are likely to contact the river, and P897 and P898 are upstream locations.

Samples will be collected along the river during a low-flow period in late summer and fall (August and September). Water samples will be analyzed for COPCs and other analytes that are normally included in routine site water sampling. Sediment samples will be leached with 5 percent nitric acid in river water of high sediment content and analyzed for COPCs and ammonium; these values of leachable contaminants will be compared to contaminant values in upstream samples.

7.3.7 Possible Contaminant Source Areas in the Floodplain Alluvial Aquifer

Millsite-related contamination in the form of nonradioactive constituents may still be present in the subsurface of the floodplain. These materials may be a continuing source of ground-water contamination. Shallow soil that was radioactively contaminated was removed from the floodplain during remediation in the mid 1980s; however, removal criteria were based on a radiometric standard, and nonradioactive contamination may have been left in place.

Two areas in the west part of the floodplain may have contaminants in the subsurface. The first area is around monitor well 736 and former well point 642 (Figure 2–1). Water from well point 642 has had sulfate concentrations above background and COPC concentrations that exceeded MCLs, particularly for nitrate and uranium. Water from well 736 has had concentrations of sulfate that exceeded background and concentrations of most other COPCs, particularly uranium, that exceeded MCLs. The geophysical survey, in which an EM31 was used in the floodplain to measure conductivity, detected an area of high conductivity (possibly indicating the presence of nonradioactive contaminants) in the area of well 736 and former well point 642 (Figure 7–1). A second area just north of the escarpment and seep 425 is the site of a former pond. The pond appears in sketches of the millsite area and in aerial photographs taken in the 1960s during milling operations (Figure 1–4); it also appears in aerial photographs taken in the 1970s, but it was no longer present in photographs from the 1980s. This pond area held surface runoff from the millsite that drained down through the escarpment to the floodplain by way of a small arroyo (filled and no longer present). A high-conductivity area measured by the EM31 geophysical survey (Figure 7–1) also occurs in the area of the former pond.

Soil samples will be collected and analyzed for selected COPCs and other analytes in these areas. Specific COPCs and other analytes to be analyzed will be chosen by evaluating ground-water chemistry analyses from several nearby monitor wells. Two soil samples for analysis will be collected from 2-ft split-barrel samples at two depths from borehole P864 (Figure 7–1). The first sample will be from just below the water table at a depth of 5 to 10 ft and the second sample will be from the lower part of the alluvial material at a depth of 15 to 20 ft. Two soil samples from depths similar to P864 will be collected by auger at location P892, just north of the former pond.

Soil samples collected by auger at depths similar to the sample depths at P864 will be collected and analyzed for selected COPCs and other analytes at two additional locations. These locations (P890 and P891) are also in the western part of the floodplain in areas where no sample analyses are available and millsite contamination may be present.

7.3.8 Leachability Conditions and Gradient Manipulation of the Floodplain Alluvial Aquifer

Flushing of contaminants in the floodplain aquifer using water diverted from the San Juan River to manipulate the hydraulic gradient may be a feasible remediation method. Leachability characteristics of the contaminated alluvial material under conditions of head-gradient manipulation need to be determined to evaluate the feasibility of this method.

Leaching characteristics will be tested in alluvial soil sample from three areas of the floodplain where contaminated ground water is present. Samples for testing will be collected from split-barrel samples taken in the saturated zone at depths of about 10 to 12 ft at each of three boreholes (P860 or P861 near well 615, P862 or P863 near well 608, and P864 near well 736, Figure 7–1). The three samples will be repeatedly leached in a column with simulated San Juan River water. The first leachate sample will be analyzed for all the COPCs and ammonium. Succeeding leachate samples will be analyzed for only uranium, nitrate, and sulfate until a sufficient number of pore volumes (possibly 6 or 7) have passed through the sample so that analyzed values are less than prescribed values (MCLs in the case of uranium and nitrate). Results of these leaching tests will be used as input parameters for modeling the effectiveness of the gradient manipulation method of remediation.

The highest concentrations of milling-related contaminants in the floodplain aquifer are just north of the escarpment in the area from well 615 to well 608. About 400 ft north of the escarpment, water from well 612 shows much lower concentrations of contaminants. Well 612 is much closer to the San Juan River, and the lower concentrations of contaminants appears to have resulted from ground-water flushing attributable to inflow from the river. Contaminant concentrations in the area between wells 615 and 608 could be lowered by increasing ground-water flow to flush contaminants northeastward downgradient and closer to the San Juan River where natural flushing would further decrease contaminant concentrations.

A pilot-scale gradient manipulation experiment will be constructed using water from artesian well 648 to flush contaminants from the contaminated ground water in the area between wells 614 and 615. This system will serve to characterize the effectiveness of contaminant flushing by gradient manipulation that ultimately could be applied (if successful) at a larger scale using a larger amount of water diverted from the San Juan River.

Nonpotable artesian flow estimated at 70 to 80 gpm from well 648 currently is routed by ditch eastward and drains into the lower part of Bob Lee Wash, where it constitutes at least 95 percent of flow in the wash. Water from Bob Lee Wash flows onto the floodplain and contributes to the formation of a small (about 2.5 acres) wetland area just north of the escarpment. Flow of water from the wetland is northward and then westward through a series of ditches and eventually into the San Juan River.

Water for flushing a part of the floodplain will be collected from a small intake structure constructed about 200 ft upstream from the mouth of Bob Lee Wash. An irrigation headgate will control the flow of water from the intake structure into above-ground 6-in. diameter polyvinyl chloride (PVC) pipe that will transport the water approximately 1,000 ft along the base of the escarpment to the floodplain fence. Sufficient flow will continue down Bob Lee Wash below the intake structure to ensure the continued existence of the small wetlands area. From the floodplain fence, an additional 1,000 ft of pipe will extend southeastward to the area of well 614. This section of pipe will be gated to discharge the water into the floodplain alluvial material through an underlying shallow, gravel-filled trench.

The intake structure and piping/discharge will be constructed after the new wells have been installed on the floodplain. Before this system is constructed, computer modeling will be conducted to evaluate the engineering design and the hydrologic effects on the water table and wetlands. Wells immediately downgradient of the discharge area will be sampled quarterly and analyzed for COPCs and ammonium to evaluate the effectiveness of the flushing.

The BLRA (DOE 1994) developed for the Shiprock site was based on the contaminant concentrations and distributions that existed at the time of the assessment. A conclusion of the risk assessment was that the only unacceptable risk to humans was through use of alluvial ground water for drinking water. Surface water seeping out onto the floodplain contained high enough concentrations of nitrate to pose a risk to some sensitive animal species through prolonged ingestion. Calculations for the San Juan River showed that contaminant concentrations from ground-water discharge were negligible. If institutional controls are put in place to restrict ground water use, the gradient manipulation described here will presumably have a positive effect on ground water quality by accelerating flushing of contaminants from the system and restoring it to a usable quality more quickly. However, the effect of gradient manipulation on surface-water quality is less certain because of the interaction of surface and subsurface processes.

Data collected as part of the current characterization will ensure that risks associated with a gradient manipulation system can be adequately assessed, particularly with respect to surface water. Enhanced ground-water movement could result in increased contaminant concentrations in surface water, including the San Juan River. Data collected to better understand subsurface ground-water flow and interactions with surface water bodies will help in predicting potential effects of gradient manipulation. Ground-water flow and contaminant transport modeling results and ground- and surface-water monitoring results will be used to ensure that implementation of a gradient manipulation system does not create an unacceptable risk to humans or ecological receptors near the site and along the San Juan River. Benchmark values for COPCs (e.g., MCLs for ground water, aquatic criteria for surface water) will be used in conjunction with modeling results to optimize operating conditions of the gradient manipulation configuration while minimizing risk.

7.3.9 Plant Ecology and Land Use

To complete a screening-level risk assessment (Section 5.2) for the site, the following are needed: (1) characterization of present and potential land use in the floodplain and terrace areas; (2) characterization of plant communities in the floodplain and terrace areas; and (3) identification and characterization of plant communities in a floodplain and a terrace ecological reference area. Surface-water and ground-water sampling described in Tables 7–1 and 7–2 and the surface-water and ground-water routine sampling round for the site are sufficient for the ecological investigations.

The qualitative survey (see Tables 7–1 and 7–2) will focus on plant communities likely to inhabit the site in the future. Sample sizes for tissue analyses will be calculated to meet a relative precision level of ±20 percent of the mean at a confidence level of $a=0.10$.

8.0 Site Investigation Procedures

As described in Section 7.0, activities required to meet the DQOs include rotary and casing advance drilling, ground-water sampling, surface-water and sediment sampling, soil sampling, core sampling, soil leaching, determination of distribution coefficients, aquifer testing, land surveys, vegetation sampling, and chemical analyses. The following sections present the procedures that will be used to collect these data.

8.1 Hydropunch Sampling, Ground-Water Monitor Well Installation, and Field Analysis of Water Samples

Direct-push (Hydropunch) sampling, rotary and core drilling, casing advance drilling, and monitor wells will be used to obtain water-quality samples, ground-water elevation data, and river stage information. Installation procedures for these activities are described in this section. Terrace and floodplain areas will require different types of drilling and well installations.

8.1.1 Terrace Aquifer Sediments

Boreholes in the terrace area will be advanced by rotary and drilling through unconsolidated surficial material into weathered Mancos Shale and further into unweathered Mancos Shale. Ground water from 8 to 14 boreholes will be sampled by a direct-push device (Hydropunch or equivalent) to determine if MCLs for uranium and nitrate and a threshold value (indicative of background versus millsite-related contamination) for sulfate are exceeded. Water levels will be measured through the center of the rotary drill string. When the saturated zone is reached, a direct-push device will be advanced approximately 5 ft into the ground and a ground-water sample will be pumped through a small hose to the surface or collected with a small-diameter bailer inserted through the device. If a direct-push device cannot be pushed into the material, a small-diameter bailer will be lowered through the drill string to obtain a ground-water sample. The sample will be analyzed in a mobile field laboratory for uranium, sulfate, and nitrate. The hole will then be advanced 20 ft into the saturated zone and a second sample will be collected and analyzed in the same manner as the first. Hydropunch sampling locations will be south and west of the disposal cell (Figure 7–1). Analytical results of the direct-push ground-water sampling will be evaluated and integrated with existing data to update the site conceptual model on a near real-time basis. The updated site conceptual model will be used to establish the locations of the next boreholes and sampling. After analytical results of the Hydropunch samples are evaluated, the hole will either be abandoned as described in Section 9.0 or completed as a monitor well.

An estimated 24 permanent wells will be completed on the terrace area with 2-in. or 4-in. i.d., flush-joint, threaded, PVC casing and machine-slotted (2-in. wells) or wire-wrapped (4-in. wells) screen (Table 7–1). Well P819, to be installed for sampling organic compounds, will be completed with a 10-ft stainless steel screen. Two 4-in. background wells will be located about 1.5 miles east-southeast of the disposal cell as shown in Figure 1–5. For these and all 4-in. wells, a rotary hole will be advanced into the unweathered Mancos and screened across the upper 20-ft of saturated zone. Two-inch wells will also be rotary drilled into the upper 20 ft of saturated zone; screen will be set in unconfined ground water in the Mancos Shale. All wells will have filter packs (probably 20**S**40 mesh sand) that will consist of clean quartz. Above this will be 2 ft of clean, fine-grained quartz sand (likely 100 mesh), and a 3-ft bentonite pellet seal will be placed above the filter packs. Enviroplug, Volclay, or a similar grout will be used to fill the annular space above the bentonite pellet seal to within 3 ft of ground surface. Concrete will be used to fill the remaining annular space to the ground surface and will be continuous with a 3-ft diameter well pad. Construction details for typical monitor wells in the terrace are shown in Figure 8–1. All 4-in. background and production wells and 2-in. wells outside the contaminated area will have flush-mounted protective locking covers. Remaining 2-in. wells will be completed with minimum 6-in. diameter steel protective casings with locking, hinged, weatherproof covers.

Wells will be developed by surge-block bailing, pumping, or jetting after an initial flow rate is established. Surging is usually accomplished using a weighted piece of PVC, slightly smaller in diameter than the inside diameter of the well, that is attached to a line and slowly raised and lowered along the length of the screen. This period of agitation is continued for 15 to 30 minutes. Water is then bailed or pumped from the well and the process is repeated until the water clears and the flow rate is determined to be optimal. Pumping is simply pumping water from a well until it clears and until the flow rate reaches a maximum. Pumping rates can usually be increased as the well clears. Jetting involves forcefully pumping water from a tank (formation water, tap water, or river water) into a well and discharging it through a T-nozzle that has horizontal openings. The T-nozzle is raised and lowered along the length of the screen as the water jets through the openings and clears the screen. The well is allowed to equilibrate, usually for 24 hours, and is then pumped to observe flow rate and turbidity of formation water. The process is repeated until formation water clears and production is considered optimal.

8.1.2 Floodplain Aquifer Sediments

Floodplain aquifer sediments will be drilled using a truck-mounted casing-advance system. Two-inch holes will be advanced through the alluvial material to bedrock; a 5-ft machine-slotted screen will be set in the lower part of the alluvial aquifer. Eleven 2-in. i.d. wells (Table 7–2) will be installed with natural formation filter pack around the slotted screen and a 1-ft sump below the screen; wells will be completed with a minimum 6-in. diameter protective steel locking cover. A sieve analysis of the alluvial material (natural formation) will be conducted to determine the optimal screen-slot size (Driscoll 1986). Three 4-in. i.d. background wells will be installed east of the site and will also have natural formation filter pack around the screen (Figure 8–1). Both 2-in. and 4-in. wells will have 2 ft of medium-grained sand pack (likely 20–40 mesh) placed in the annular space above the natural sand pack and a 3-ft bentonite pellet seal will be placed above the sand. Enviroplug, Volclay, or a similar grout will be used to fill the annular space above the bentonite seal to within 3 ft of ground surface. Concrete will be used to fill the remaining annular space to the ground surface and will be continuous with a 3-ft diameter well pad. Construction details for floodplain monitor wells are presented in Figure 8–1. Four-inch wells will be completed with continuous-wrapped vee-wire screens with flush-joint, threaded, PVC casing and protected with flush-mounted locking covers. Well development will be accomplished as described in Section 8.1.1.

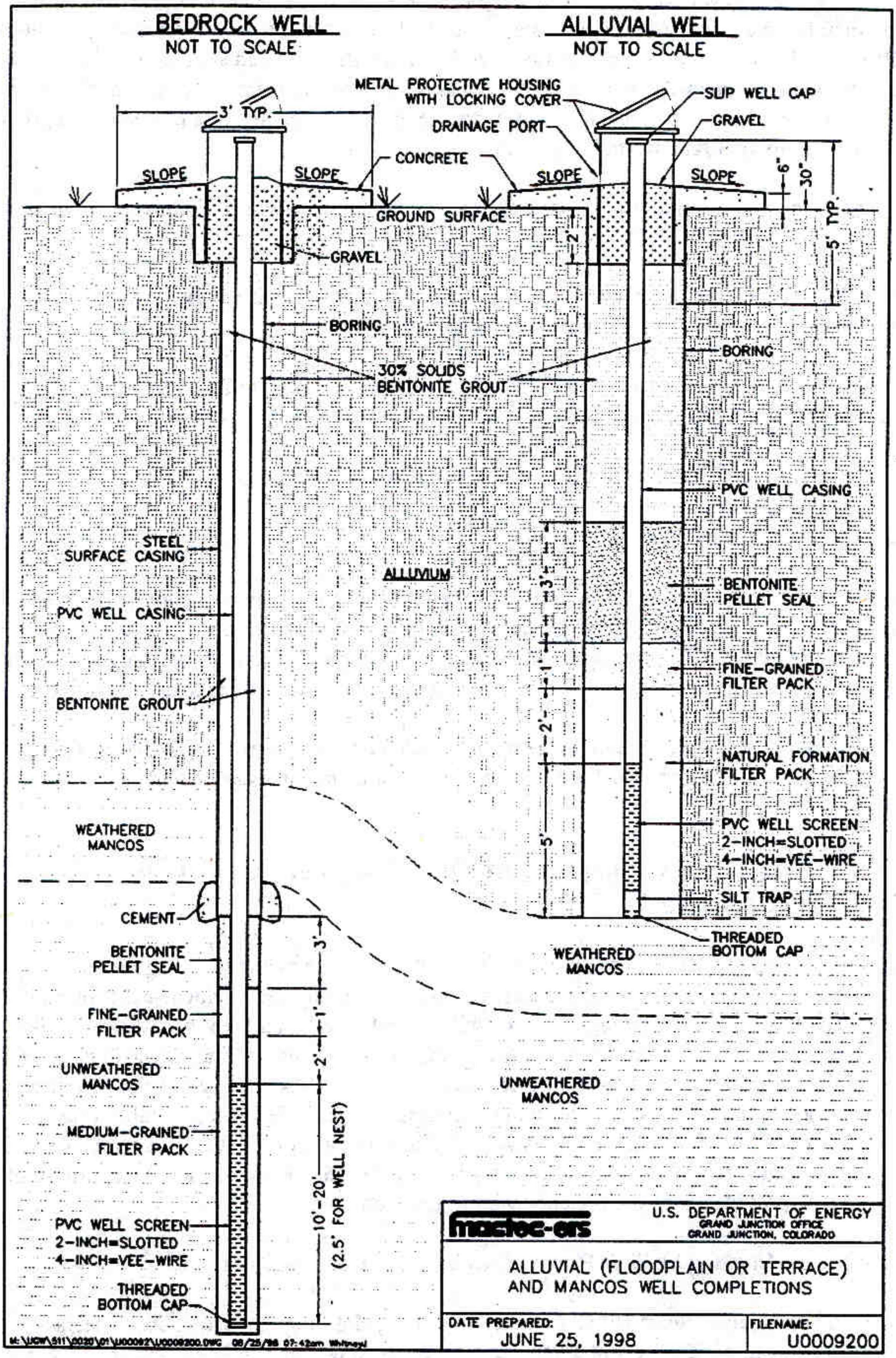

Figure 8–1. Alluvial (Floodplain or Terrace) and Mancos Well Completions, Shiprock Site

A stilling well (P899) was installed along the San Juan River in April 1998 to provide a means for continuous measurement of the river stage. The well consists of a pressure transducer housed in a PVC pipe buried along the edge of the river down into the river bed about 2.5 ft. The transducer cable extends westward up the bank and is set about 50 ft from the edge of the river. The cable is housed in PVC pipe and the data storage module is secured in a locked steel upright casing that sits about 3 ft above the floodplain.

Details of the procedures that will be used for monitor well installation are in the Environmental Procedures Catalog (GJO 1997):

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

- SL–9(P), "Technical Comments on ASTM D2113–83 (93)—Standard Practice for Diamond Core Drilling for Site Investigation."

- GN–13(P) "Standard Practice for Equipment Decontamination."

8.2 Field Analysis of Water

Field analyses of water will be performed using the Environmental Sciences Mobile Laboratory. The laboratory consists of a trailer with a spectrophotometer and radiometric instrumentation that will be transported to the site and operated during Hydropunch sampling. Field analytical results for uranium, sulfate, and nitrate will be performed by personnel trained in the use of equipment.

Procedures for these analyses are in the *Environmental Sciences Laboratory Procedures Catalog*; Section 1.3, "Nitrate Analysis;" Section 1.4, "Uranium Analysis;" and Section 1.5, "Sulfate Analysis."

8.3 Soil Sampling and Coring for Lithologic Logging, Kd Analysis, and Sediment Sampling

Soil and rock samples will be collected by split-barrel and coring methods during the installation of monitor wells. Samples will be collected for lithologic logging and chemical and geotechnical analysis of soils and rocks. Lithologic logging will be performed on all monitor well boreholes to develop and refine the site hydrogeologic model. Chemical analysis will include analyzing for Kd and mobile fractions of COPCs and other analytes. Both analyses will aid in characterizing subsurface contaminant transport. Geotechnical analysis will include a formal aquifer matrix grain-size analysis and filter-pack/well design as outlined in Driscoll (1986). The analysis will be performed as needed for wells in the alluvial aquifer and in wells on the terrace. The purpose of the design is to provide for high-efficiency well installations.

8.3.1 Lithologic Logging by Split Barrel, Cuttings, and Core Samples

Lithology of the Mancos Shale on the terrace will be logged during the installation of terrace monitor wells through the use of rotary and core rotary drilling. For boreholes that are not cored, weathered and unweathered Mancos Shale will be drilled by rotary methods, and cuttings will be described in the preparation of a lithologic log. Core samples will be collected using a core barrel according to procedure SL–9(P) (GJO 1997). Wells to be cored include background wells, nested wells, and all 4-in. production wells. A 2-ft split-barrel sample will be collected after the first 10 ft of drilling and each separate lithologic type will be sampled by a 2-ft split-barrel until unweathered Mancos Shale is reached. At that point, continuous coring will advance the corehole to the total depth of the well. Weathered Mancos Shale will be described according to descriptions in the Unified Soil Classification System and according to colors in the Munsell Soil Color Chart. Rock descriptions will be based on the standard rock nomenclature in Travis (1955) or equivalent descriptions. Color descriptions of rocks will be based on the Geological Society of America's Rock Color Chart.

Lithology of the floodplain aquifer material will be logged during alluvial well installation through the use of a split-barrel sampler. A 2-ft split-barrel sample will be collected every 5 ft, starting at a depth of 5 ft. Cuttings from the casing advance drilling will be described and logged. Two wells each from two sets of nested wells (4 wells) and background wells will be sampled by split-barrel sampling. Split-barrel sampling will be conducted using a truck-mounted rotary drilling rig centered over the sample location. The casing advance drill string is advanced to the desired sampling depth, and a 3-in. o.d. by 24-in.-long split-barrel sampler is lowered to the top of the interval to be sampled. A 140-pound drop hammer, or equivalent hydraulic driver, is then used to drive the sampler the required 2 ft or until penetration is less than 6 in. per 50 blows. The split-barrel sampler is then removed from the borehole, separated from the drive-rod assembly, and laid flat on an uncontaminated surface, where the head and drive shoe are removed. One-half of the split barrel is removed to expose the sample. The uppermost portion of sample in the split barrel is inspected for slough and the slough is discarded, if present. The split barrel is decontaminated according to procedure GN–12(P) (GJO 1997). The remaining sample is considered representative. The site geologist or designee will log the material using Unified Soil Classification System terminology in procedure SL–24(P) (GJO 1997).

All sediment and soil sampling will be performed in accordance with the following procedures from the Environmental Procedures Catalog (GJO 1997):

- SL–6(P), "Technical Comments on ASTM D 1452–80(90)—Standard Practice for Soil Investigation and Sampling by Auger Borings."

- SL–7(P), "Technical Comments on ASTM D 1586–84(92)—Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils."

- SL–9, "Technical Comments on ASTM D2113–83(93) Standard Practice for Diamond Core Drilling for Site Investigation."

- SL–19(P), "Technical Comments on ASTM D 2488–93—Standard Practice for Description and Identification of Soils."

- SL–24(P), "Technical Comments on ASTM D 2487–93—Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)."

- GN–8(P), "Standard Practice for Sample Labeling."

- GN–9(P), “Standard Practice for Chain-of-Sample-Custody Control and Physical Security of Samples.”

- GN–13(P), “Standard Practice for Equipment Decontamination.”

8.3.2 Distribution Coefficient (Kd)

Samples will be collected for Kd analysis from both terrace and floodplain wells. In the terrace wells, samples for Kd analysis will be collected from core-barrel samples from the weathered and unweathered Mancos Shale in the background wells. Samples from the floodplain aquifer material will be collected from split-barrel sampling from all background wells—one sample from just below the water table and one from the lower part of the alluvial material.

Laboratory Kd analyses will be performed according to ASTM procedure D4646–87 (ASTM 1996) for three COPCs (uranium, cadmium, and selenium) that exceed the MCL by an order of magnitude or more and for ammonium, present in concentrations that are more than twice background values.

8.3.3 Leachability of Alluvial Soils

Sediment splits will be collected from three boreholes in the contaminated part of the floodplain to determine how quickly constituents are leached. Locations are listed in Table 7–1. Samples will be placed in columns, leached with simulated San Juan River water, and analyzed in the Grand Junction Office (GJO) Environmental Sciences Laboratory. The process will be repeated until uranium and nitrate concentrations in the leachate are below UMTRA MCL values and sulfate concentration is below a number to be established on the basis of sulfate concentrations in ground water from the floodplain background wells. The amount of each constituent removed during each step and the total amount of each constituent will be calculated. Techniques used to analyze for these three constituents are listed in Section 8.2.

8.3.4 Alluvial Soils as a Source of Hot Spots

Several locations in the floodplain have waters, ponded or otherwise, that have contaminant concentrations that are higher than at other locations in the floodplain. Two soil samples will be collected from four locations by hand auguring or from split-barrel sampling (see Table 7–1 for details). Lithologic logs will be prepared for each sample location.

Samples will be collected in clean, doubled plastic bags and marked with the site name, hole number, date, sampling interval and analysis type and transported to the GJO Environmental Sciences Laboratory. Samples will then be air-dried (no oven heat). If the samples contain significant amounts of gravel larger than No. 4 sieve size (4.76 millimeters), they will be sieved using a No. 4 sieve to obtain grain sizes suitable for laboratory analysis. Because soil contaminants are likely to be in the fine-grained material, sieving may bias analytical results toward higher solid-phase concentrations than are actually present. If sieved, weight fractions of each fraction will be recorded.

Analytes are extracted from the samples according to the following procedure:

- Accurately weigh 2 grams of soil and place in a 100-milliliter (mL) centrifuge tube (or divide between two 50-mL tubes).

- Add 100 mL of 5-percent nitric acid and shake the contents on an end-over-end shaker for 4 hours.

- Centrifuge the contents to remove particles less than 2 micrometers (µm). Decant the supernatant into a 200-mL volumetric flask.

- Add additional 5-percent nitric acid (about 100 mL). Shake the contents for 15 minutes, centrifuge, and decant into the same 200-mL flask. This step will remove most of the constituents present in the residual fluid.

- Fill the 200-mL flask to volume with deionized water and filter through a 0.45 µm filter. Measure alkalinity, pH, and Eh. Preserve the remaining solution and send it to the GJO Analytical Laboratory for analyses. The laboratory will analyze all samples for selected COPCs and other analytes (determined from evaluating ground-water chemistry of nearby monitor wells.

8.3.5 Sediment Characterization Upstream and Downstream of Millsite-Related Contaminants Entering the San Juan River

To evaluate the extent of any contamination along the San Juan River downstream from where millsite-related contaminants may have entered the river, six sediment and water samples will be collected: two upstream, two downstream, and two in the area of the floodplain influenced by the mill (see Figure 7–1). Samples will be collected during low river flow. Sediment samples will be collected in double plastic bags, labeled appropriately, and sent to the GJO Environmental Sciences Laboratory. Sediment samples will be leached using the 5 percent nitric acid extraction method described in the previous section. Water samples will be collected near the sediment samples, according to procedures outlined in Section 8.4, and sent to the GJO Analytical Laboratory for analyses of COPCs and ammonium. Leachates from the sediment samples will be analyzed by the GJO Analytical Laboratory for the same suite of constituents as the water samples; analytical results will be compared to the results of upstream and downstream water analyses.

8.4 Ground-Water Sampling

Each new monitor well will be undisturbed for at least 40 hours after final completion before it is developed. Development will be performed according to the Drilling Statement of Work. Ground-water sampling will be performed in accordance with the *Sampling and Analysis Plan for the UMTRA Ground Water Project* (1998b), and the Environmental Procedures Catalog (GJO 1997). Ground-water samples will be collected from the new monitor well network and from all existing wells and submitted to the GJO Analytical Laboratory for analyses. At a minimum, samples will be collected once during high river flow (May–July) and once during low flow (October–February).

The following procedures from the Environmental Procedures Catalog (GJO 1997) will be used for ground-water sampling:

- GN–8(P), “Standard Practice for Sample Labeling.”
- GN–9(P), “Standard Practice for Chain-of-Sample-Custody and Physical Security of Samples.”
- GN–13(P), “Standard Practice for Equipment Decontamination.”
- LQ–2(T), “Standard Test Method for the Measurement of Water Levels in Ground-Water Monitor Wells.”
- LQ–3(P), “Standard Practice for Purging Monitor Wells.”
- LQ–4(T), “Standard Test Method for the Field Measurement of pH.”
- LQ–5(T), “Standard Test Method for the Field Measurement of Specific Conductance.”
- LQ–6(T), “Standard Test Method for the Field Measurement of the Oxidation-Reduction Potential (Eh).”
- LQ–7(T), “Standard Test Method for the Field Measurement of Alkalinity.”
- LQ–8(T), “Standard Test Method for the Field Measurement of Temperature.”
- LQ–9(T), “Standard Test Method for the Field Measurement of Dissolved Oxygen.”
- LQ–10(T), “Standard Test Method for Turbidity in Water.”
- LQ–11(P), “Standard Practice for Sampling Liquids.”
- LQ–12(P), “Standard Practice for the Collection, Filtration, and Preservation of Liquid Samples.”

8.5 GJO Analytical Laboratory Sample Analyses

Ground-water and surface-water samples will be submitted to the GJO Analytical Laboratory. All procedures will be checked for accuracy through internal laboratory quality-control checks (e.g., analysis of blind duplicates, splits, and known standards). Table 8–1 lists the analytical methods to be used for analysis of ground-water samples. Sample preservation will consist of storing the samples in an ice chest with Blue Ice (or equivalent) to cool samples during field sampling, packaging, and shipping. Samples will be analyzed for TDS, organic components of the solvents used in the extraction process, COPCs listed in Table 4–1, and ammonium. Analysis will include U-234 and U-238 activity concentrations in picocuries per liter (pCi/L) and mass (mg/L) for the first round of sampling. These analyses will be used to evaluate secular equilibrium. Sample handling, preparation, and analyses are described in the references shown in Table 8–1.

Table 8–1. GJO Analytical Laboratory Sample Requirements

Measurement Parameter	Analyte	Sample Container	Analytical Instrument/Method	Detection Limit
Ground Water	Total uranium	2 each 120 mL	ICP/MS EPA 6020	1.0 µg/L
	Other Inorganics and Organics	See *FY 1998 Sampling Frequencies and Analyses* (DOE 1997a), and *Sampling and Analysis Plan for the UMTRA Ground Water Project* (DOE 1998b).		

8.6 Hydrologic Tests

As described in Section 7.0, several types of hydrologic measurements are necessary to meet the DQOs. Procedures for collecting these data are presented in this section.

8.6.1 Measurements of Water Levels Using a Data Logger

During the water-level monitoring period, an absolute-pressure transducer will be set up to monitor changes in atmospheric pressure. Pressure transducers from In-situ, Inc. (or equivalent) will be used to measure water levels. The transducers will be positioned 5 ft above the bottom of the wells. Transducer setup parameters, installation depth, model, and serial number will be recorded in a field log book before the start of baseline data collection.

Water-level and barometric-pressure data will be recorded at 4-hour intervals by using the In-situ, Inc., HERMIT model data logger, or the In-situ, Inc. SENTINEL model, or the Geoguard Tuber Model. The clocks of the data loggers will be synchronized, and each logger will be programmed to display and record data in the “depth to water” mode relative to the top of the casing. To verify the accuracy of the transducers during the monitoring period, the “depth to water” displayed on the logger will be compared with manual readings taken with a water-level sounder. If the manually measured depth to water varies by more than 0.05 ft from the data logger value, the data logger will be reset. Procedures from the user manual from In-situ, Inc., or Geoguard will be followed for logger setup, calibration, and programming.

After completion of data collection, water levels will be downloaded to a laptop computer. Files will be named and stored according to conventions described in the *Data Logger Management Plan* (DOE 1996a).

Manual water-level measurements will be performed according to the Environmental Procedures Catalog (GJO 1997) procedure LQ–2(T), “Standard Practice for the Measurement of Water Levels in Ground Water Monitoring Wells.”

8.6.2 Step-Drawdown Aquifer Test

Field Procedure

The step-drawdown test will be performed by pumping the well at a low constant discharge until drawdown within the well stabilizes. The likely initial extraction rate for a well completed in the alluvial aquifer will be 1 to 2 gpm. The pumping rate will be increased to a higher constant-discharge rate, and the ground water will be pumped until drawdown in the well stabilizes. The process will be repeated until the maximum sustainable yield for the well has been determined.

Flow will be measured by using an instantaneous flow meter such as a Great Plains Industrial flow meter or equivalent. Flow rates will be logged on a data form or in a field logbook. After downloading baseline water-level data, the data loggers will be reprogrammed for a logarithmic sampling schedule. Water-level data will be continuously recorded by a data logger as the test proceeds. Proper operation of the transducer and data logger will be confirmed by taking manual water-level measurements at 1-hour intervals and by comparing the results with data logger output. Recorded data will be transferred to a laptop computer by using hardware interfaces and software and will be converted to working files by using the appropriate software.

Data Analysis

Various methods are available to analyze step-drawdown test results for an unconfined aquifer (alluvial aquifer). The step-drawdown data will be analyzed by the Hantush-Bierschenk method (Kruseman and deRidder 1990), the Rorabaugh straight-line method (Kruseman and deRidder 1990), or Sheanhan’s curve-fitting method (Kruseman and deRidder 1990), or two or all three methods. These methods also apply to analysis of step-drawdown data for a confined or semiconfined aquifer (bedrock aquifer). Step-drawdown data from testing the bedrock aquifer can also be analyzed by the Eden-Hazel method (Kruseman and deRidder 1990).

8.6.3 Aquifer Tests

Baseline Data

Baseline water-level data will be collected from selected monitor wells before aquifer testing. The baseline water-level data will be used to determine if rising or falling water levels exist before the start of the aquifer tests. Baseline water levels will be collected at half-hour intervals for at least 5 days before the start of the test.

Procedure

The aquifer tests will be performed by pumping the well at a constant discharge for at least 48 hours. As reported by Todd (1980), the minimum pumping time required to attain a delayed-yield response in an unconfined aquifer is approximately 30 hours. The pumping rate required to propagate a drawdown cone through the alluvial ground water will be determined from the results of the step-drawdown tests. Whether a delayed-yield response is expected from the Mancos Shale aquitard has not yet been determined. Consequently, the Mancos aquitard pumping test will be run for at least 48 hours as well. Recovery of ground-water levels (residual drawdown) will be measured until 95 percent of the maximum drawdown has dissipated.

Flow will be measured by using an instantaneous flow meter such as a Great Plains Industrial flow meter or equivalent. Flow rates will be logged on a data form or in a logbook. After baseline water-level data are downloaded, data loggers at the wells to be tested will be reprogrammed for a logarithmic sampling schedule. Water levels in the observation wells will be continuously recorded by a data logger as the test proceeds. Proper operation of the transducer and data logger will be confirmed by taking manual water-level measurements at 1-hour intervals and comparing the results with data logger output. Recorded data will be transferred to a laptop computer by using hardware interfaces and software and will be converted to working files by using the appropriate software.

Slug tests will be performed by instantaneously removing a known volume of water from the well and logging the well response using an electronic pressure transducer/data-logger combination.

Data Analysis

For the aquifer tests in the alluvial aquifer, assuming unconfined and unsteady conditions, Neuman’s or Moench’s curve-fitting methods (Kruseman and deRidder 1990; Moench 1995, or both) will be used to reduce data. The same methods will be used to analyze data from the Mancos Shale tests if the Mancos aquitard is found to be unconfined. If the Mancos Shale is best regarded as a confined aquifer, a partial-penetration version of the Theis model will be used (Kruseman and deRidder 1990).

For slug tests, the Bouwer and Rice (1976) and Bouwer (1989) methods of analysis will be used.

Aquifer tests and data analysis will be conducted in general accordance with the following GJO (1997) and ASTM (1996) procedures:

- LQ–22(T), “Standard Test Method for Conducting Slug Tests in Aquifers.”

- LQ–15(P), “Standard Practice for Analyzing Slug Test Data for Estimating the Hydraulic Conductivity of Saturated Porous Media.”

- D4043–91, “Standard Guide for the Selection of Aquifer-Test Method in Determining of Hydraulic Properties by Well Techniques.”

- D4050–91, “Standard Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems.”

- D5472–93, “Standard Test Method for Determining Specific Capacity and Estimating Transmissivity at the Control Well.”

- D5473–93, “Test Method (Analytical Procedure) for Analyzing the Effects of Partial Penetration of Control Well and Determining the Horizontal and Vertical Hydraulic Conductivity in a Nonleaky Confined Aquifer.”

8.7 Land Surveys

At the conclusion of the drilling, physical coordinates and elevations for selected physical features and all monitor wells and soil borings will be determined by a registered land surveyor. The survey team will follow standard contractor survey practices and procedures.

8.8 Vegetation Sampling and Analysis

Species composition and relative abundance in plant communities will be characterized using a modified relevé method (Bonham 1989). This method involves subjectively selecting representative stands of each vegetation type, walking through the stands and compiling a list of all species noted, and assigning species to cover classes. Cover will not be measured precisely. A species will be placed in one of six cover classes (< 1 percent, 1–5 percent, 6–25 percent, 26–50 percent, 51–75 percent, and 76–100 percent).

Samples of species rooting into ground water will be analyzed for ground-water ecological COPCs (Table 5–1). Samples will be collected from areas underlain by contaminated ground water as well as in reference areas. Analytical methods may include those of the Association of Official Analytical Chemists, EPA SW–846 (EPA 1986), EPA Contract Laboratory Program Special Analytical Services, or combinations of these methods. Acceptance criteria for laboratory analysis, including calibration of laboratory equipment and internal laboratory quality control (QC) checks (e.g. reagent blanks, duplicates, matrix spikes) are specified by the analytical method. Laboratory documentation will be maintained for all analytical results. Approximately 20 samples will be analyzed.

8.9 Quality Assurance and Quality Control

The objective of quality-assurance and QC measures is to provide systematic control of all tasks so as to maximize accuracy, precision, comparability, and completeness. Sections 8.9.1 through 8.9.4 describe the measures that will provide quality assurance and QC for sampling and analysis.

8.9.1 Sampling Procedures

Basic sampling procedures are presented in the Environmental Procedures Catalog (GJO 1997). Deviations from these procedures will be noted in a Field Variance Log with an explanation and a description of its possible effect on data quality.

8.9.2 Sample Control

To maintain evidence of authenticity, the samples collected must be properly identified and easily distinguished from other samples. Samples collected at the Shiprock sites will be identified by a label attached to the sample container specifying the sample identification number, location, date collected, time collected, and the sampler’s name or initials.

Soil and ground-water samples for laboratory analyses will be kept under custody from the time of collection to the time of analysis. Chain-of-custody forms will be used to list all sample transfers to show that the sample was in constant custody between collection and analysis.

While the samples are in shipment to the GJO Analytical Laboratory, custody seals will be placed over the sample cooler opening to ensure that the integrity of the samples has not been compromised. The receiving laboratory must examine the seals on arrival and document that the seals are intact. Upon opening the container, the receiving laboratory will note the condition of the sample containers (e.g., broken or leaking bottles).

All sample shipments will be made in compliance with U.S. Department of Transportation (DOT) regulations (49 CFR 171–179) governing shipment of hazardous materials and substances. These regulations govern the packaging, documentation, and shipping of hazardous material, substances, and waste. Special care will be taken to ensure the integrity of the sample through proper packaging and shipping.

To determine the proper identification of a hazardous sample, field personnel will review field measurement data and field notes for relevant information concerning the sample material in a container. This information will include organic vapors detected, pH, explosive potential, and any other information that might be useful in classifying the sample for shipment. If a sample is known or suspected to contain a specific hazardous material, the sampler will note its presence on the sample label. This information is important to the receiving laboratory to determine the proper handling of the sample before analysis.

8.9.3 Laboratory Quality Control

Laboratory QC will follow the relevent specifications in EPA SW–846 (EPA 1986) or the *Handbook of Analytical and Sample-Preparation Procedures*, Volumes I, II, and III (*WASTREN–GJ* undated). Quality control will include analysis of blanks, duplicates, spikes, and check samples.

8.9.4 Field Quality Control

Approximately 10 percent of the samples collected and analyzed will be field QC samples. QC samples will include equipment blanks, trip blanks, check samples, and duplicates. These samples will be analyzed for the same analytes as other samples.

9.0 Environmental Compliance Requirements/Actions

The actions described below are based on a review of the requirements under federal, state, tribal, and local laws and regulations. In some cases, Navajo Nation laws and regulations may supersede federal and state authority.

9.1 Environmental Assessment

All actions proposed in this work plan will be assessed under DOE's National Environmental Policy Act (NEPA) regulations. It appears that the proposed work will meet the requirements for categorical exclusion in accordance with DOE's NEPA regulations, 10 CFR Part 1021. Therefore, an environmental checklist will be prepared and a recommendation for categorical exclusion transmitted to DOE-Albuquerque (DOE–AL) for approval. Permits and authorizations are required to be submitted and approved before categorical exclusion approval by the DOE–AL NEPA compliance officer.

9.2 Well Installation/Water Use

The Navajo Nation regulations are not intended to regulate wells installed for characterization activities under the UMTRA Ground Water Project. However, in consultation with Navajo Nation officials, well permits and water-use permits will be completed and filed as agreed with Navajo Nation policies and procedures. Permit and access agreement processes will begin as soon as the well locations are chosen.

9.3 Cultural Resources Issues

Cultural resources will be protected in accordance with federal, state, and tribal laws and regulations. During a visit to the Shiprock site by MACTEC Environmental Restoration Services (MACTEC–ERS) in March 1997, Mr. Ray Charlie (Navajo Nation representative) provided two maps prepared by International Engineering Company. The maps are entitled Archeological Clearance and Threatened Species (Map No. DE–AC04–83AL18796) and are attached to a letter to the Navajo Nation dated November 1, 1984. They include survey notes and boundaries for archeological and threatened-species investigations that have been completed. Two archeological sites were identified. The area of the two archaeological (historical) sites and the areas that were surveyed for cultural resources are shown in Figure 9S1. The MACTEC–ERS field supervisor will consult with the Navajo Nation representative to confirm the boundaries of the investigations in the field and ensure that no activities are conducted outside the boundaries. Required protection of the two identified archeological sites will be provided in consultation with the Navajo Nation representative. Both sites are in the northeast quarter of Section 1, Township 29 North, Range 18 West and are approximately 1,000 ft south of the southernmost corner of the disposal cell. No off-road or off-site activities will take place without authorization from the designated Navajo Nation representative. Field investigations may be necessary in areas where the surface has not been disturbed.

9.4 Wetlands/Floodplain

Because of concerns regarding wetlands and floodplain protection along the San Juan River, no activities will occur in this area that may adversely affect these resources, without consulting the Corps of Engineers and other appropriate federal, state, or tribal agencies. All vehicles entering the area will stay on established roads and trails. Notifications will be forwarded to the Corps of Engineers, as necessary, for any activity that meets criteria for a 404 Nationwide Permit.

9.5 Threatened and Endangered Species

A biological assessment was conducted on approximately 580 acres of land in 1983. The Mesa Verde cactus is the only threatened and endangered plant species confirmed to be within the boundary of the biological assessment. This species is concentrated around the Many Devils Wash area in the northwest quarter of Section 6, Township 29 North, Range 17 West and the northeast quarter of Section 1, Township 29 North, Range 18 West. The Mesa Verde cactus area and the area surveyed for threatened and endangered species are shown in Figure 9–2. No surface disturbance in these areas can be performed without clearance from the U.S. Fish and Wildlife Service. Any planned surface disturbance in this area (e.g., new wells, excavation) will also be cleared through the Navajo Nation field representative. All other activities, including routine vehicle traffic, will be confined to established dirt roads. All activities outside of disturbed areas will be reviewed by the MACTEC–ERS Environmental Compliance Point of Contact (telephone 970–248–6503).

9.6 Off-Road Activities

Established dirt roads and trails (including previous routes used as access to wells) will be used whenever possible. Any off-road activities, routes, and access will be cleared through the Navajo Nation field representative to minimize adverse effects on soils, vegetation, and other natural resources. At all times, particularly during periods of inclement weather, the MACTEC–ERS field supervisor is responsible, in consultation with the Navajo Nation representative, for determining the conditions under which off-road travel will be permitted. Any adverse effects of off-road travel, including rutting and erosion potential, will be mitigated. Mitigation will be coordinated through the designated Navajo Nation representative and may include recontouring and reseeding.

9.7 Waste Management

The strategy for the management of investigation-derived waste (IDW) generated from drilling, well development, and monitoring is tiered to the *Management Plan for Field-Generated Investigation Derived Waste* (DOE 1997b) (the IDW Plan). Proper implementation of this strategy will ensure that IDW is managed in a manner that is protective of human health and the environment and is in accordance with regulatory requirements.

The IDW to be generated during this site investigation and subsequent monitoring activities will consist of both liquid and solid media. Examples of liquid IDW include well development water, decontamination water for equipment and personal protective equipment (PPE), well purge

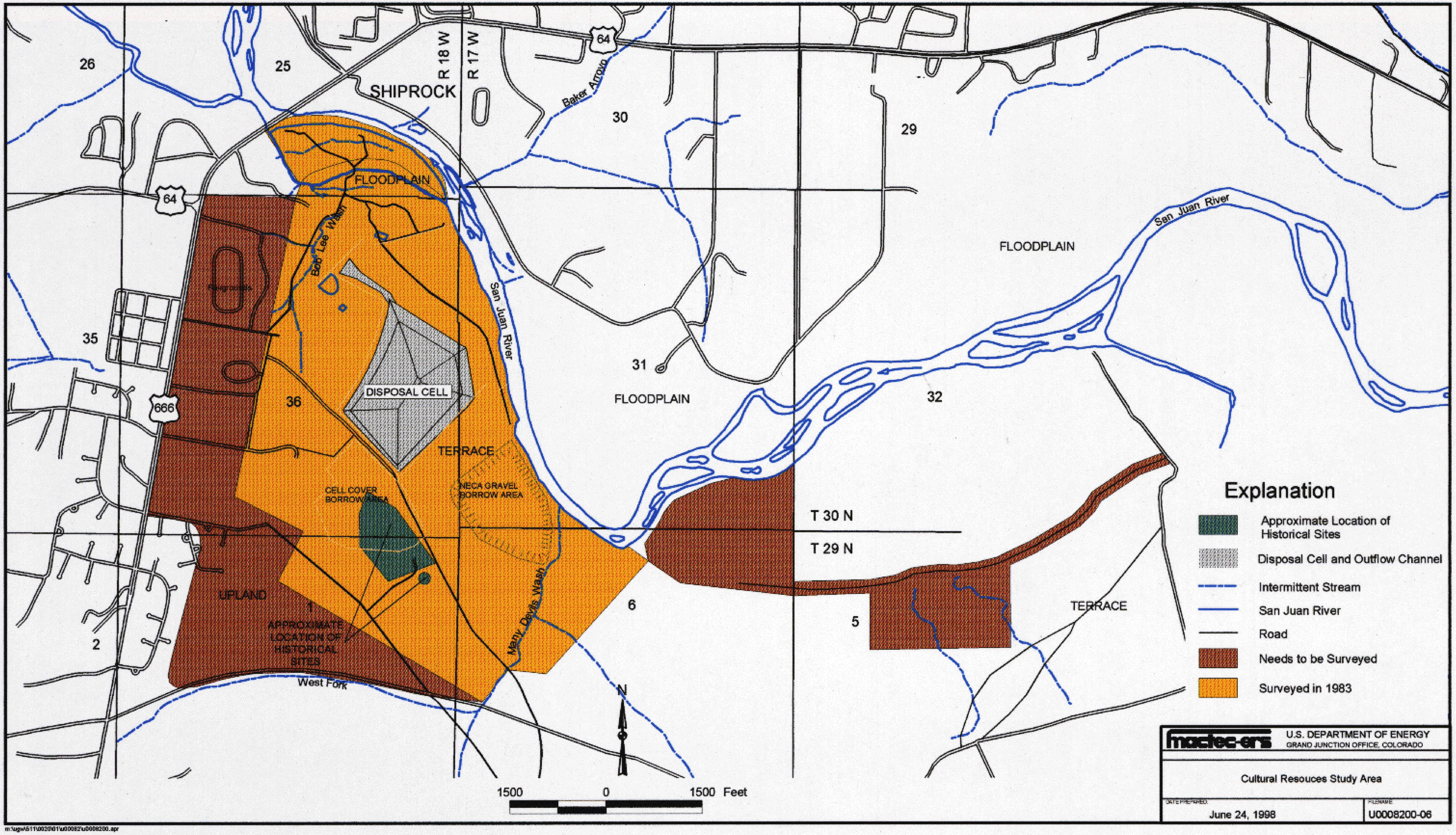

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Figure 9–1. Cultural Resources Study Areas, Shiprock Site

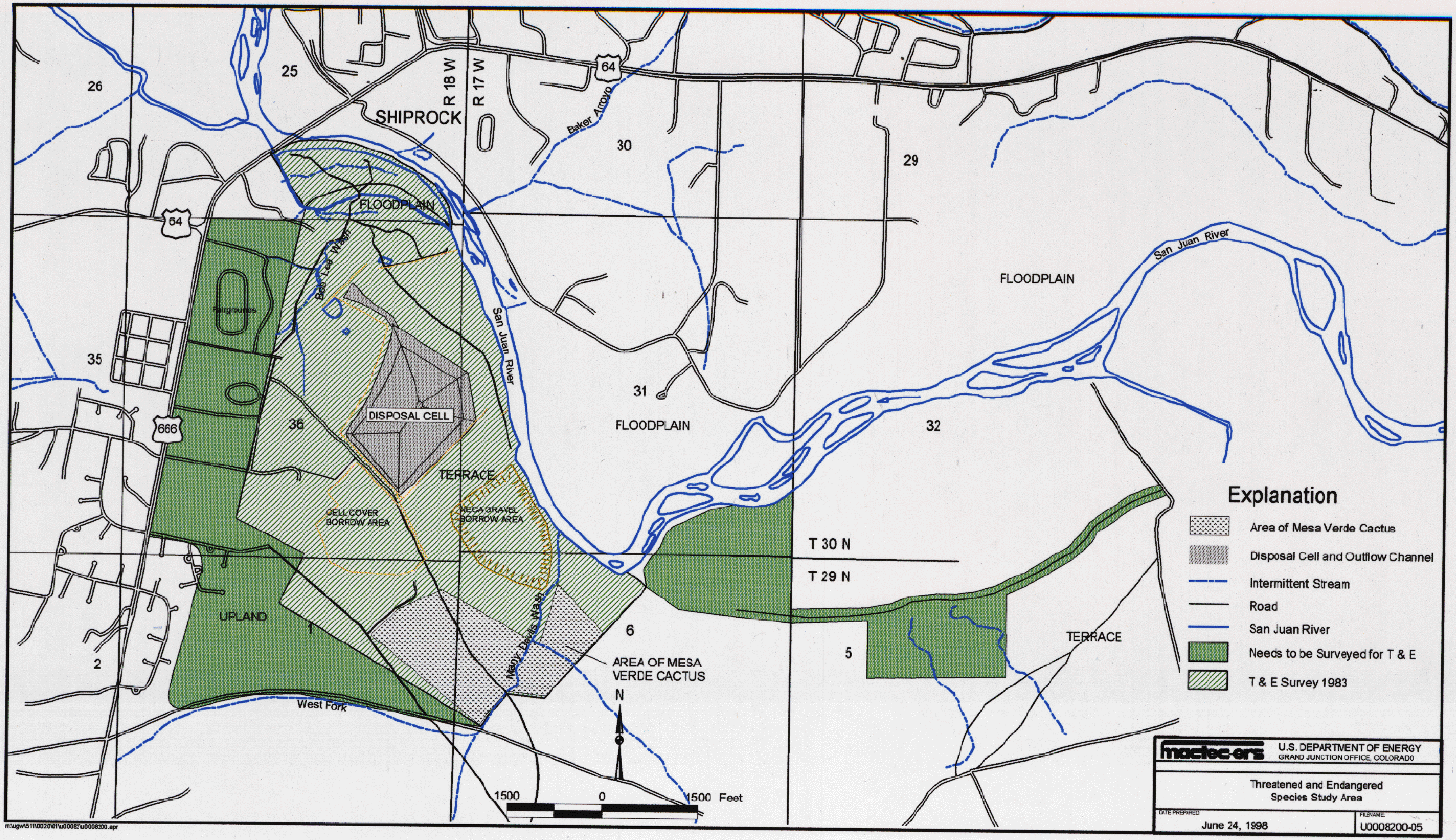

Figure 9–2. Threatened and Endangered Species Study Areas, Shiprock Site

water, excess sample material, and field generated analytical process waste. Examples of solid IDW include drill cuttings, borehole soil, PPE, excess sample material, and field test kits and calibration standards.

It is DOE’s intention to dispose of investigation derived wastes that cannot be disposed of on-site (e.g., PPE classified as residual radioactive material [RRM], disposable sampling equipment, and miscellaneous debris) at the Cheney repository in Mesa County, Colorado. Approvals from DOE–AL Office, the State of Colorado, and the Nuclear Regulatory Commission will be obtained before initiating off-site shipments to the repository.

9.7.1 Regulatory Requirements

IDW generated during this site investigation will be managed in accordance with all applicable Federal, State, and Navajo Nation requirements. A summary of the key regulations applicable to the management and disposal of these wastes is delineated in the IDW Plan. Brief descriptions of regulations pertaining to the Shiprock site are provided in the following paragraphs.

The UMTRA remediation standard for ground water represents the value below which there are no regulatory requirements for management of the radioactive content in liquid IDW, including sample residuals and analytical process wastes associated with the UMTRA Ground Water Project. Liquid IDW in the form of sample residuals and analytical process wastes, which meet the UMTRA remediation standard of less than 30 pCi/L U-234 and U-238 (0.044 mg/L, assuming secular equilibrium), and are not otherwise regulated (or meet the criteria of Resource Conservation and Recovery Act [RCRA]-exempt waste) may be solidified, managed as solid waste, and disposed of at a RCRA Subtitle D landfill. The UMTRA surface remediation standard (5 picocuries per gram Ra-226 and Ra-228) is applicable to surface-contaminated material. Those solids contaminated in bulk will be tested for radioactivity in accordance with the IDW Plan.

The UMTRA Ground Water Project is not a generator of RCRA regulated wastes if, during the site investigation, small quantities (less than 100 kilograms per month) of waste materials are produced and do not meet the definition of RRM or by-product material. These waste materials will be managed in compliance with 40 CFR 261.5, “Special Requirements for Hazardous Waste Generated by Conditionally Exempt Small Quantity Generators,” and in accordance with applicable Navajo Nation and state regulations. Under RCRA, these small quantity wastes are not subject to regulation under parts 262 through 266, 268, and parts 270 and 124 of 40 CFR, and the notification requirements of section 3010 of RCRA.

The Navajo Nation requires that no entity shall be entitled to take any action affecting the use of water within the Navajo Nation, unless such action is authorized by a permit. The Director of the Division of Water Resources shall provide forms for Applications for Permit (water use permit), as authorized under Subchapter 6 of the Navajo Nation Water Code (Navajo Nation 1984). Although there are no specific regulations regarding the discharge of well water to the ground, the water use Application for Permit can also function as a discharge permit. This option is integrated throughout the management of liquid and solid IDW.

9.7.2 Disposition of IDW

As approved by the Navajo Resources Committee through the water use permit, and to the extent allowable under the specific screening procedures identified in the sections below, the following RRM IDW materials will be disposed on-site, either around or in the well itself or beneath the surface of the ground: well development water, well purge water, pumping test water, equipment decontamination water, borehole drill cuttings and soil, and excess field samples. As stated in the IDW Plan, water, soil and excess samples from drilling, developing, and routine monitoring of background wells will be dispersed on the ground in the area around the well.

9.7.2.1 On-Site Disposal of Liquid IDW

The surface-dispersion of purge water IDW from routine well monitoring at this site was evaluated on the basis of the potential for purge water to present a risk to human health or the environment. The results of this evaluation are documented in the IDW Plan. The study indicated that no effect on agricultural crops or humans would result from applying contaminated ground water generated as a result of well development, purging, and monitoring activities in the area around the well. Organic contaminants were not evaluated in this study. Consequently, well water generated during installation and monitoring activities will be dispersed in the area around the well in a manner that will not disturb the surface soil.

If a well is suspected of being contaminated with organic compounds, a photoionization detector will be used to detect organic vapors in the headspace. If no organic vapors are detected, the water will be dispersed on the ground. If the instrument detects organic vapors, the water will be evaporated in stock tanks or placed in trenches at least 6 in. below ground surface in the area around the well.

Excess water samples collected for field analysis will be managed in same manner as well development and purge waters. Sample bottles will be rinsed with water and scanned for radioactivity. Decontaminated bottles will be disposed of as solid waste at a local landfill. In the unlikely event that the bottles cannot be decontaminated, they will be managed as RRM and disposed of at the Cheney repository.

9.7.2.2 On-Site Disposal of Solid IDW

Drill cuttings and core will be placed on plastic sheets as they are brought to the surface. Because the site has undergone remediation to remove source material, there is little potential for these activities to produce contaminated soils. Consequently, boreholes that are not completed as monitor wells will be refilled with the cuttings.

As a precautionary measure, for boreholes and wells that are in areas where residual radioactivity may remain, the drill cuttings and soils will be scanned with a hand-held scintillometer to measure the gamma activity. If the gamma activity is less than twice background, the soils and cuttings will be spread around the area of the well from which they were taken. If gamma activity is twice background or greater, the drill cuttings will be buried at least 6 in. beneath the ground surface in the area of the well.

If the cuttings and core are suspected of being contaminated with organic compounds, the material will be scanned with a portable photoionization detector. If no organic vapors are detected, the soil and core will be dispersed on the ground around the well. If organic vapors are present, the cuttings will be used to backfill the annular space of the borehole or buried at least 6 in. below the ground surface in the area of the well.

Aquifer pumping tests will be conducted on wells that are relatively clean based on a sitewide comparison (e.g., water quality typical of well 612). Water resulting from the pumping tests will be discharged to the river at the water uptake area in the north part of the site. This discharge to the river must be approved by the Navajo Nation through the Application for Permit (water use permit), which can also function as a discharge permit.

9.7.2.3 Off-Site Disposal of IDW

The following IDW materials will be disposed of off site: excess sample material associated with the off-site analyses, field test kit waste, field calibration standards, and PPE. Excess liquid sample material and any analytical laboratory process waste generated as a result of off-site sample analyses will be managed and disposed of by the off-site laboratory. Soil samples analyzed by the GJO Analytical Laboratory will be stored at the GJO until the established retention period expires. At that time, the samples will be disposed of at the municipal landfill or the Cheney repository, as appropriate.

The UMTRA Ground Water Project is not a generator of hazardous waste. Therefore, small quantities of wastes that may contain regulated constituents will be managed in accordance with the allowances under 40 CFR 261.5, as a conditionally exempt small quantity generator. Subsequently, unless field-generated wastes (e.g., field calibration standards, used portions of field test kits, and sample residues) are determined to be radiologically contaminated, they will be disposed of at a RCRA Subtitle D facility (municipal landfill) as general refuse at the conclusion of the site investigation. All field-generated wastes determined to be radioactively contaminated will be managed as RRM and disposed of at the Cheney repository.

Disposable PPE will be decontaminated in the field and disposed of at the local county landfill. In the event that PPE cannot be decontaminated, it will be managed as RRM and disposed of at the Cheney repository.

IDW that is expected to be generated during site investigation, the estimated volumes, and the approach for IDW management and disposal are summarized in the IDW Plan.

9.7.3 Management of Spills

Because the only significant equipment used for characterization is trucks and drill rigs, should a spill occur it will most likely be a petroleum product, such as fuel. Actions that prevent spills and overfills should be used when refueling drill rig generators or trucks in the field.

For example, the volume available in the fuel tank should be greater than the volume of fuel in the transfer container, and close attention should be given to all refueling operations, watching constantly to prevent spills and overfills.

In the event of a spill, the following actions should be taken:

- Take immediate action to stop and contain the spill.

- Report petroleum spills over 25 gallons to the regulatory authority (e.g., state, Navajo Nation representative, EPA regional administrator) within 24 hours.

- Remove all potential fire hazards and ensure that the spill poses no immediate hazards.

- Avoid vapor inhalation and skin contact with the spilled material.

Spill clean-up of petroleum products should entail

- Removing all stained soil and overexcavating a few inches.

- Placing the excavated material on a plastic tarpaulin.

- Periodic mixing of the soil with a shovel or by lifting the corners of the tarp and alternating ends to roll the material.

When the soil no longer contains a flammable concentration of organic material, the soil can be disposed of at a municipal landfill or at the Cheney repository if it qualifies as RRM.

For spills of other regulated materials the general rules are similar. Workers should stop and contain the spill, ensure that the spill poses no immediate hazards by removing all potential fire hazards, and avoid vapor inhalation and skin contact with the spilled material. For all spills, field personnel must contact the UMTRA Project Environmental Compliance Point-of-Contact for the regulatory requirements pertinent to specific types of spill cleanup and notifications, as soon as possible.

9.7.4 Waste Transportation and Disposal

Regulated wastes will be transported in accordance with DOT regulations and disposed of in compliance with federal regulations and the permit and licensing requirements of the receiving facility. See Section 7 of the IDW Plan (DOE 1997b) for more detailed information. Any questions regarding the off-site shipment of regulated wastes should be directed to the MACTEC–ERS Waste Management Group.

10.0 Health and Safety

A site-specific project safety plan (DOE 1998a) has been prepared for the Shiprock UMTRA Project site in accordance with applicable parts of 29 CFR 1910 (General Industry Standards), 29 CFR 1926 (Construction Safety Standards), the contractor’s health and safety policies, the UMTRA Project Environmental Health and Safety Plan, UMTRA–DOE/AL–150224.006, and the DOE Headquarters Environmental Safety and Health/Office of Environmental Management interim document *Handbook for Occupational Health and Safety During Hazardous Waste Activities*, DOE/EH–0478. The health and safety policies, procedures, and hazard analysis referenced in this plan incorporate and take precedence over previous health and safety documentation.

All fieldwork will be performed according to the site-specific health and safety requirements developed for each task.

11.0 Logistics and Schedule

11.1 Work Readiness Review

A work readiness review will be conducted by MACTEC–ERS at the GJO before the field team mobilizes for drilling. The purpose of the work readiness review is to ensure that all personnel, facilities, systems, and processes are ready before the start of the fieldwork and to minimize the possibility of delays and problems due to incomplete planning and preparations.

Examples of topics that will be discussed include health and safety monitoring and training, logistics, schedule, DQOs, personnel, waste management issues, training requirements and certification, and site access and security.

The scope of the work readiness review will be defined by the following checklist, which will be more fully developed and will include at least the following major categories:

- Site Access Requirements and Specific Cultural Considerations
- Review and Approval of Project Documents
- Project Team Members and Responsibilities
- Schedule and Vehicle Requirements
- Communication Requirements
- Training
- Site Health and Safety
- Field Activities
- Field Base Maps
- Field Notebooks
- Attendees
- Approval Authority
- Compliance Issues
- IDW Disposal

11.2 Schedule

Table 11–1. Schedule of Fieldwork at the Shiprock Site

Activity	Start	Finish
Install stilling well along the San Juan River	03/31/98	04/01/98
DOE approval of Drilling Statement of Work and Project Safety Plan	06/19/98	06/19/98
DOE and Stakeholder review of Work Plan	06/22/98	07/06/98
DOE and Stakeholder approval of Work Plan	06/09/98	07/09/98
Preparation for fieldwork	07/06/98	08/05/98
Conduct slug tests and yield tests on terrace	07/27/98	07/30/98
Readiness Review Meeting	08/06/98	08/06/98
Mobilize to Shiprock for drilling/fieldwork	08/13/98	08/14/98
Unload/setup/inspection/pre-entry briefing	08/15/98	08/16/98
Install 14 monitor wells on floodplain	08/17/98	09/10/98
Conduct direct-push sampling on terrace	08/21/98	09/10/98
Install 24 monitor wells on terrace	08/22/98	09/29/98
Develop wells	09/10/98	10/09/98
Install data loggers in new wells	09/25/98	10/09/98
Restore site	09/28/98	10/09/98
Demobilize drill rigs/crews from Shiprock	09/30/98	10/10/98
Construct intake and pipeline for gradient manipulation	08/17/98	08/21/98
Collect ecological field samples	09/01/98	09/10/98
Collect sediment and surface-water samples	08/17/98	08/25/98
Laboratory analysis of sediment and water samples	08/31/98	10/15/98
Conduct land surveys	10/01/98	10/15/98
Conduct aquifer tests on floodplain	10/12/98	10/20/98
Collect ground-water samples	10/12/98	10/19/98
Laboratory analysis of ground-water samples	10/21/98	12/20/98

12.0 Deliverables

The major deliverables for this project are (1) data reports and (2) revision 1 of the SOWP.

Data reports will be provided for several aspects of the fieldwork. Each data report will present the data collected during the fieldwork, data reduction methods, and interpretation of results. Separate data reports will be provided for lithologic logs, well completion diagrams, well yield tests, soil and water sample analyses, and other hydrologic tests and analyses.

The SOWP (Revision 0) will be revised to include results of the field investigation and an evaluation of alternative remedial technologies. The data reports will provide the basis for the revision of the SOWP during 1999 and the recommended approach to remediation.

13.0 References

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