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UMTRA PROJECT WATER SAMPLING AND ANALYSIS PLAN TUBA CITY, ARIZONA

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WATER SAMPLING AND ANALYSIS PLAN
TUBA CITY, ARIZONA

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Prepared for
U.S. Department of Energy
Grand Junction, Colorado

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LIST OF ACRONYMS

Acronym	Definition
BGS	below ground surface
DCO	data collection objectives
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
GJPO	Grand Junction Projects Office
LTSP	long-term surveillance plan
MCL	maximum contaminant levels
NRC	U.S. Nuclear Regulatory Commission
SOP	standard operating procedures
SOWP	site observational work plan
TDS	total dissolved solids
UMTRA	Uranium Mill Tailings Remedial Action
WSAP	water sampling and analysis plan

1.0 INTRODUCTION

1.1 PURPOSE

Planned, routine ground water sampling activities at the U. S. Department of Energy (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project site in Tuba City, Arizona, are described in the following sections of this water sampling and analysis plan (WSAP). This plan identifies and justifies the sampling locations, analytical parameters, detection limits, and sampling frequency for the stations routinely monitored at the site. The ground water data are used for site characterization and risk assessment.

The regulatory basis for routine ground water monitoring at UMTRA Project sites is derived from the U. S. Environmental Protection Agency (EPA) regulations in 40 CFR Part 192 (1994) and the final EPA standards of 1995 (60 FR 2854). Sampling procedures are guided by the UMTRA Project standard operating procedures (SOP) (JEG, n.d.), and the most effective technical approach for the site.

1.2 SITE LOCATION

The Tuba City disposal site is on the Navajo Reservation, 6 miles (mi) (10 kilometers [km]) east of Tuba City in Conconino County, Arizona, and 85 mi (140 km) northeast of Flagstaff, Arizona (Figures 1.1 and 1.2).

1.3 SITE HISTORY

The uranium mill at the Tuba City site was operated by Rare Metals Corporation of America from start-up in 1956 until 1962. In 1962, Rare Metals merged with El Paso Natural Gas Company, which ran the mill until it closed in 1966. The mill processed approximately 800,000 tons (725,000 metric tons) of ore during the 10-year period, with tailings placed as slurry (a mixture of water and solids) in three contiguous piles at the site. Between 1956 and 1962, an average of 300 tons (270 metric tons) of ore per day were processed using sulfuric acid in an acid leach process. The plant was reconfigured in 1962 to use sodium carbonate in an alkaline process. Between 1963 and 1966, an average of 200 tons (180 metric tons) per day of ore was processed. All three tailings piles covered about 25 acres (ac) (10 hectares [ha]) at the site.

The acid leach process used 3 to 5 tons (2.7 to 4.5 metric tons) of water per ton of ore processed (Merritt, 1971). The alkaline leach process water use was lower, probably 2 to 3 tons (1.8 to 2.7 metric tons) of water per ton of ore processed (Merritt, 1971). This water was discharged with the milled tailings to tailings ponds and evaporation ponds. An average of 4 tons (3.6 metric tons) of water per ton of ore for acid leach process gives and annual water use rate of 309 acre-feet (ac-ft) per year (191 gallons [gal] per minute). An average of 2.5 tons (2.3 metric tons) of water per ton of ore for the alkaline leach process

Figure 1.1
Tuba City Site Location Map
Tuba City, Arizona

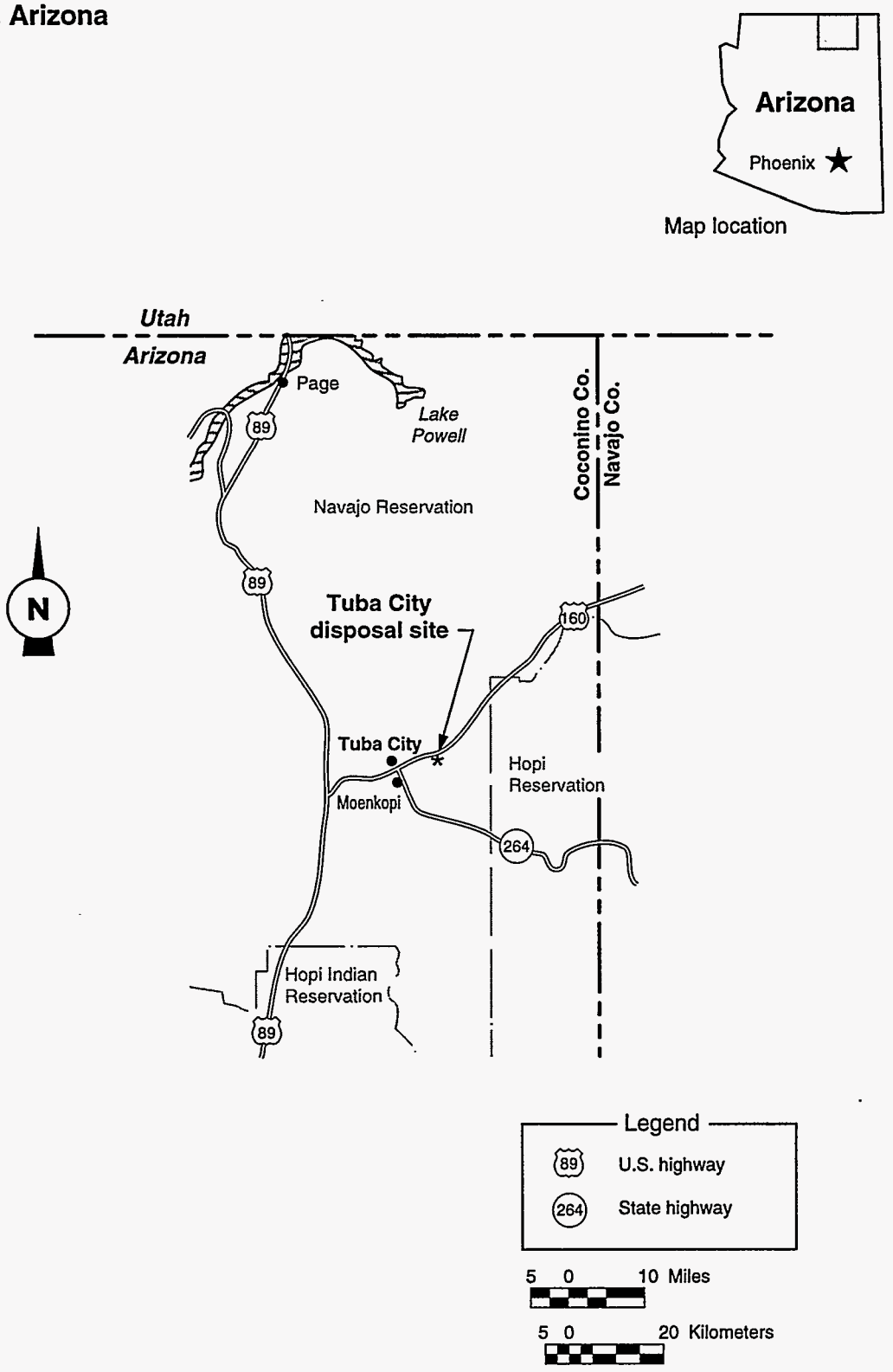

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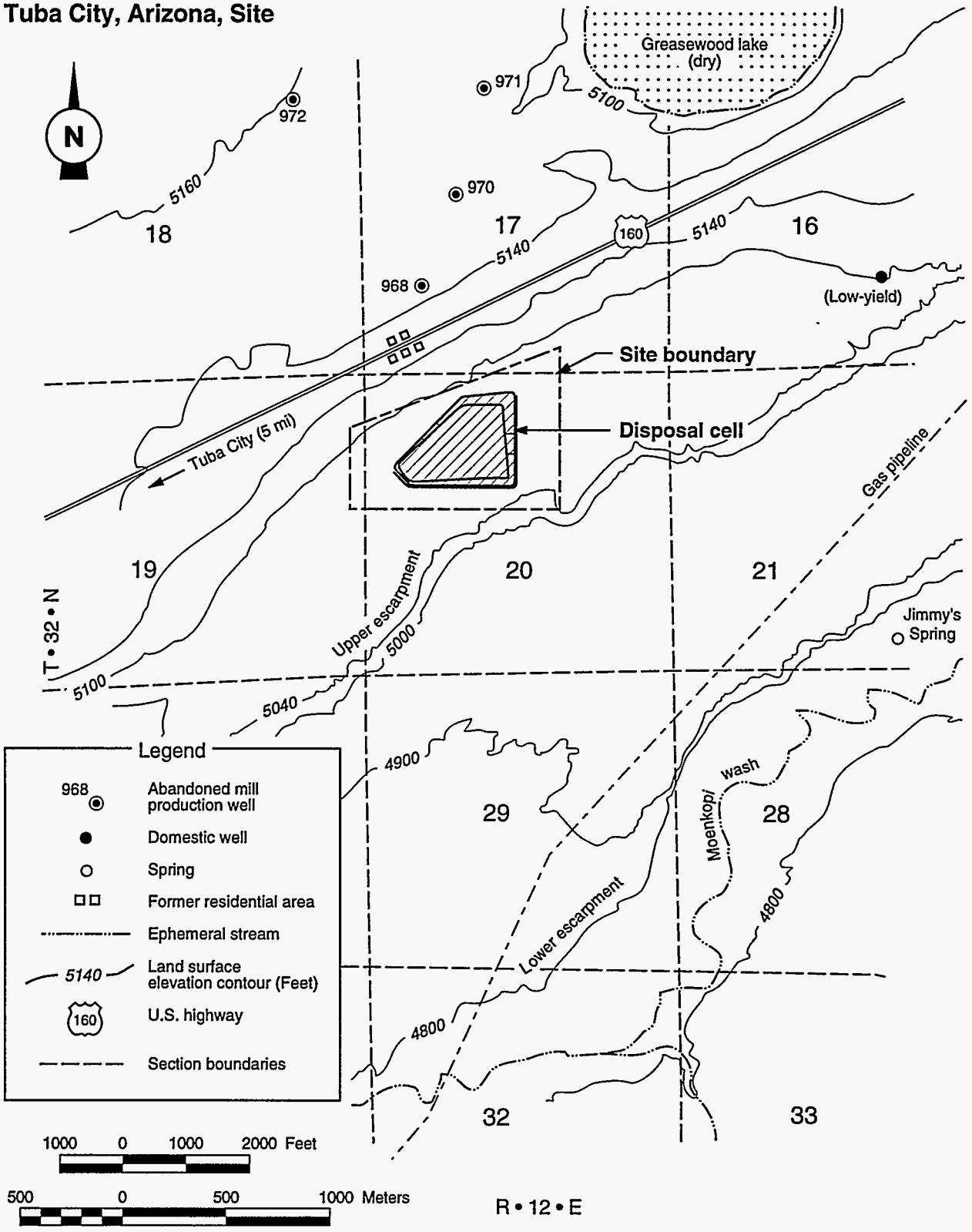
Figure 1.2
Physiographic Setting
Tuba City, Arizona, Site



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gives a use of 135 ac-ft per year (84 gal per minute). The mill used four deep water supply wells, completed in the Navajo Sandstone aquifer on the north side of U. S. Highway 160, to supply the mill with water. The raffinate ponds covered an additional 25 ac (10 ha). Thus, a total of 50 ac (20 ha) was available for evaporation. The ponds were unlined and allowed unevaporated water to percolate through to the ground water below.

The yearly average net evaporation rate (evaporation less rainfall) for the Tuba City site is approximately 80 inches (204 centimeter [cm]) per year (DOC, 1968). However, the effects of the seasonal variation in temperature on infiltration are similar to those for rainfall. Very little deep percolation may have occurred during the summer because of high evaporation, but a larger portion of the water disposed of in the winter would be available for infiltration to the Navajo Sandstone aquifer.

Based on the above water usages, pond areas, and yearly average net evaporation, the rate at which the pond water reached the ground water is estimated as follows:

- 1956 to 1962 - 133 ac-ft per year (82 gal per minute) (40 percent of the water pumped to the ponds).

- 1963 to 1966 - 0 ac-ft per year.

The 0 ac-ft per year value of the 1963 to 1966 water balance estimate is low because the tailings piles were unlined and already leaking downward before 1963. If it is assumed that the minimum amount of water reaching the aquifer was half the previous rate, or 20 percent of the water pumped to the ponds, approximately 27 ac-ft per year (17 gal per minute) of water percolated through the pond bottom from 1963 to 1966. The total estimated volume of pond water reaching the aquifers is about 38 million cubic feet (ft^3) (290 million gal). The estimated amounts of sulfate, nitrate, and chloride (the three major components of the plume) that were used in the milling process are 7000, 7000, and 600 tons (6349, 6349, and 544 metric tons), respectively. Not all of this mass would have been dissolved in the pond water.

Surface remedial action was initiated at the Tuba City site in 1988 by the DOE. The uranium mill tailings and other associated materials were stabilized in place in an engineered disposal cell, which means that the tailings were essentially left undisturbed instead of being moved to a new site.

Surrounding lagoon and windblown contaminated soils were also placed in the disposal cell. The tailings pile was shaped to allow the placement of progressively less contaminated materials into the final pile configuration in the upslope portion. After placing all the contaminated materials into a pile, a clayey sand layer was placed and compacted over the entire pile to reduce radon emissions and the infiltration of water and to help protect ground water

from further contamination. Graded layers of durable rock were then placed over the pile to protect it against erosion. No liner was placed on the bottom of the cell to retard leakage.

The remedial action was completed in April 1990. A total of 1,400,000 cubic yards (yd^3) (1,100,000 cubic meters [m^3]) of contaminated materials were stabilized in a disposal cell covering 50 ac (20 ha) within the 145-ac (59-ha) disposal site.

As engineering compaction efforts consolidated the wet tailings, contaminated pore water was forced out through the bottom of the cell, a phenomenon known as transient drainage. The flow rate from transient drainage decays exponentially, with the bulk of the flow occurring relatively quickly. The total time over which transient drainage is expected to occur is about 120 years; however, the flow rate for the final 80 years is very low (DOE, 1989). Recent ground water level and quality data suggest that transient drainage is now occurring at the Tuba City site. The estimated volume of water released over time by transient drainage is 10 million gal (38 million liters [L]). Assuming the water was released across the 50 ac (20 ha) of the cell, the 3-ft (0.9-meter [m]) rise observed at well 906 appears explainable using a specific yield of 0.2 (Hood and Danielson, 1979).

Contamination related to the uranium processing activities at the Tuba City site is present in ground water in the uppermost aquifer. During milling operations, the sources for contaminants were the tailings piles and processing activities. The water that drained from the tailings piles was the principal migration pathway of contaminants into the aquifer. Slow drainage of contaminated water from the wet tailings also probably occurred between 1966 and 1990 (when the surface remediation activities were completed) and may have contributed to ground water contamination. In addition, transient drainage has contributed to ground water contamination. The contaminants from the tailings include molybdenum, nitrate, selenium, strontium, sulfate, and uranium. Site-related contamination in ground water has been detected at least 1500 ft (450 m) downgradient from the processing site and up to a depth of 75 ft (20 m) below the water table. This contamination in the ground water currently poses no risk to human health and the environment, but it may pose a potential risk if the ground water is used in the future.

1.4 SITE STATUS

The Tuba City site is currently in a post-stabilization, prelicensing phase. The site is expected to remain in this status until licensed by the Nuclear Regulatory Commission (NRC) under the provisions of 10 CFR Part 40 (1994) for long-term surveillance and maintenance. Licensing will be a two-step process for the Tuba City site. The first step requires NRC concurrence on the completion of the surface remedial action and approval of the long-term surveillance plan (LTSP). At that time, the general license will take effect, and responsibility for conducting the long-term surveillance program for the disposal cell will be

transferred from the DOE-Albuquerque UMTRA Project to the DOE's long-term surveillance and maintenance program at the DOE Grand Junction Projects Office (GJPO). The second step deals with contaminated ground water at the processing site. After the DOE verifies and the NRC concurs that ground water compliance has been met in accordance with 40 CFR Part 192, the LTSP will be appropriately amended. This will signify that the second step of the licensing process has been completed.

1.5 SAMPLING PLAN SUMMARY

Ground water samples have been collected and analyzed from a network of existing DOE monitor wells from 1988 through 1994. In late 1995, 22 new wells were installed at the site. These included 17 monitor wells, 4 extraction wells, and 1 water supply well.

The current sampling plan for the Tuba City site, including previously existing and newly installed wells to be sampled and sampling frequency, is summarized in Table 1.1. Well status, available data rounds, and well completion information are also presented in Table 1.1. Figure 1.3 presents locations of all site wells.

Filtered ground water samples will be analyzed for major elements and field parameters as indicators of general water quality and for constituents identified as site-related contaminants in ground water based on information presented in the *Baseline Risk Assessment of Ground Water Contamination at the Uranium Mill Tailings Site near Tuba City, Arizona* (DOE, 1994a). Unfiltered samples will be analyzed for those metals that may be adsorbed on suspended particulates.

Analytical parameters for ground water and surface water at the processing site are listed in Section 5.2 of this document. Additionally, the static water level and total depth of the well will be measured during sample collection to provide information on water table elevation and potential siltation of the well sump.

The last sampling event at the site was completed in April 1995. The next scheduled water quality sampling round will occur in December 1995 and will include all locations listed in Table 1.1. It is recommended that the proposed sampling schedule summarized in Table 1.1 be implemented for the next two years. Data needs should then be reassessed and sampling frequency should be reevaluated. The end of routine monitoring will occur when compliance with 40 CFR 192 is demonstrated.

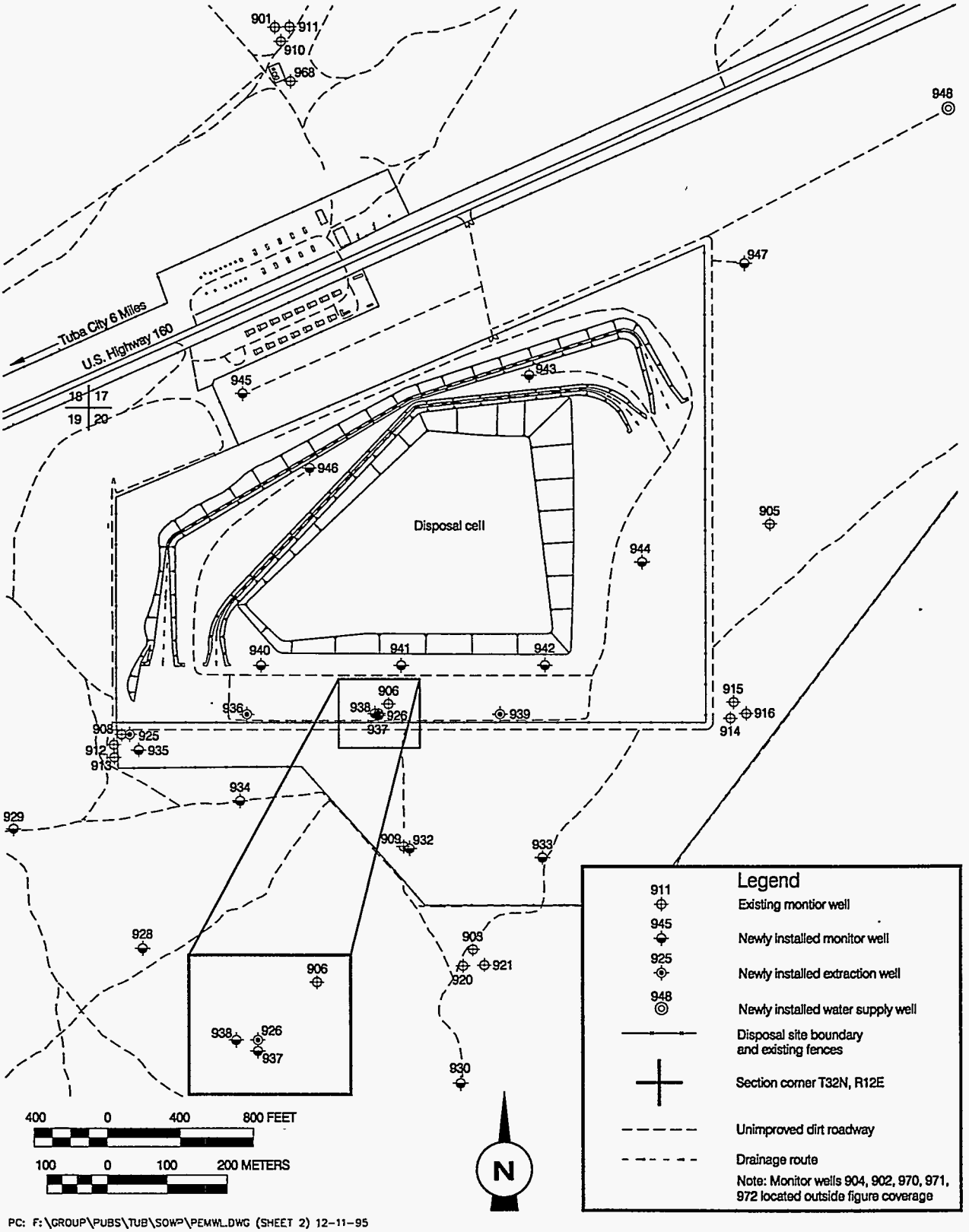
Table 1.1 Wells to be sampled at the Tuba City UMTRA site

Monitor well	Well status	Data rounds available	Casing depth (ft BGS)	Screen Interval (ft BGS)	Sampling frequency
Background					
TUB-01-0901	Previously existing	19	80	58-78	Quarterly
Upgradient					
TUB-01-0945	Newly installed	None	135	110-130	Semiannually
TUB-01-0947	Newly installed	None	129	106-126	Semiannually
TUB-01-0948	Newly installed	None	410	225-405	Semiannually
Adjacent to the site					
TUB-01-0926	Newly installed	None	95	42-92	Quarterly
TUB-01-0940	Newly installed	None	68	45-65	Quarterly
TUB-01-0941	Newly installed	None	77	54-74	Quarterly
TUB-01-0942	Newly installed	None	77	54-74	Quarterly
TUB-01-0943	Newly installed	None	124	101-121	Quarterly
TUB-01-0944	Newly installed	None	108	85-105	Quarterly
TUB-01-0906	Previously existing	19	70	44-64	Quarterly
Downgradient and crossgradient					
TUB-01-0936	Newly installed	None	88	45-85	Quarterly
TUB-01-0937	Newly installed	None	98	40-95	Semiannually
TUB-01-0938	Newly installed	None	98	40-95	Semiannually
TUB-01-0939	Newly installed	None	98	40-95	Quarterly
TUB-01-0908	Previously existing	20	80	52-67	Annually
TUB-01-0912	Previously existing	18	165	123-163	Annually
TUB-01-0913	Previously existing	12	380	329-369	Annually
TUB-01-0925	Newly installed	None	94	55-95	Quarterly
TUB-01-0935	Newly installed	None	93	50-90	Quarterly
TUB-01-0929	Newly installed	None	88	45-85	Annually
TUB-01-0930	Newly installed	None	53	20-50	Annually
TUB-01-0934	Newly installed	None	93	45-90	Annually
TUB-01-0928	Newly installed	None	58	25-55	Annually
TUB-01-0909	Previously existing	18	85	65-80	Annually
TUB-01-0932	Newly installed	None	133	110-130	Alternate years
TUB-01-0933	Newly installed	None	50	25-50	Alternate years
TUB-01-0903	Previously existing	19	50	28-48	Alternate years
TUB-01-0920	Previously existing	16	170	116-152	Alternate years
TUB-01-0921	Previously existing	17	360	315-355	Alternate years
TUB-01-0914	Previously existing	18	156	144-154	Annually
TUB-01-0915	Previously existing	12	182	170-180	Alternate years
TUB-01-0916	Previously existing	9	358	346-356	Alternate years
TUB-01-0917	Previously existing	12	150	128-148	Alternate years
TUB-01-0904	Previously existing	18	44	28-38	Alternate years

Note: Casing depth and screen interval specifications for newly installed wells are preliminary.

BGS – below ground surface.

Figure 1.3
Ground Water Monitor Well, Extraction Well, and Water Supply Well Locations Tuba City, Arizona, Site



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2.0 SITE CONDITIONS

2.1 SITE BACKGROUND INFORMATION

2.1.1 Surrounding land uses

The ownership of the Tuba City site remains in dispute between the Navajo Nation and the Hopi Tribe. The Tuba City disposal site is located within the 1934 Hopi-Navajo dispute area, where development and remedial action require joint approval by the Navajo Nation and the Hopi Tribe. The Hopi Tribe is currently appealing a 1992 court decision that defined the Hopi Reservation as shown on Figure 2.1, plus Moenkopi and approximately 3 mi (5 km) upstream of the village along Moenkopi Wash. The remainder of the land, including the land around the disposal site, is Navajo according to these most recent findings.

Land use in the immediate vicinity of the Tuba City site is limited to grazing. Adjacent lands are also used for dry land and irrigated farming, for home sites, and for gathering firewood, yucca, stone, and clay. Within 2 mi (3 km) of the site are five traditional Navajo hogans and several Navajo camps. Other farms and residences are scattered along both sides of U. S. Highway 160 between the tailings site and Tuba City.

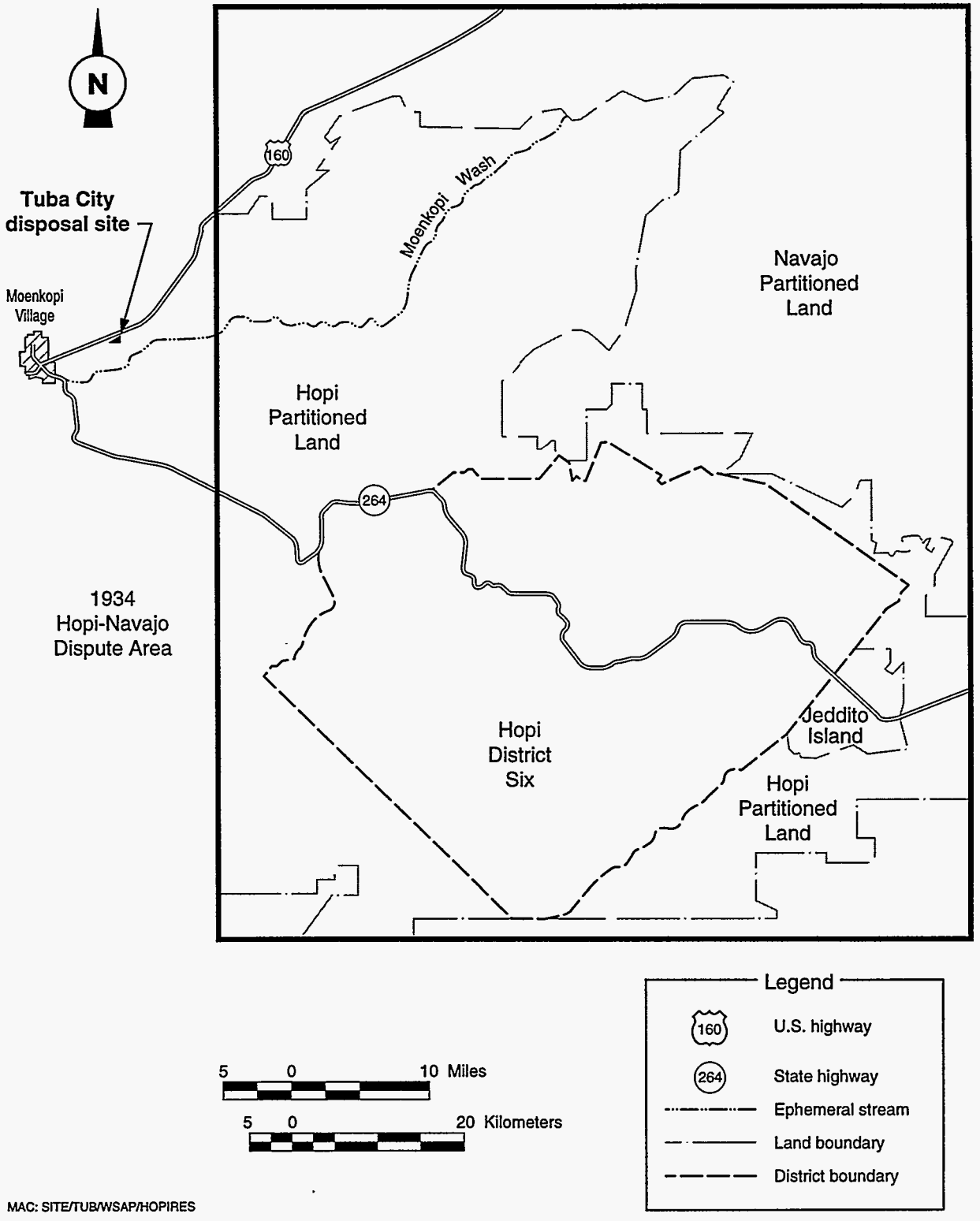
Approximately 6 mi (10 km) west of the site are the Navajo community of Tuba City and the Hopi villages of Upper and Lower Moenkopi. Tuba City and Moenkopi have been developing eastward toward the tailings site but are still several miles west of the site. The population of Moenkopi is approximately 1000 persons, nearly 10 percent of the Hopi Tribe.

Individual members from both tribes do not own land; rather, land use rights are maintained by several systems of land tenure. For Hopis, each village is considered to have its own territory. For Lower Moenkopi, these lands are assigned to clans of the village by a village chief (Kikmongwi). Use rights are granted by clan leaders to individuals and families. Clan lands are held by and passed on through the female heads of households, customarily from mother to daughter. Upper Moenkopi is less traditional and has a governor that assigns village lands, which can include assignment to male "owners."

The Navajo system for land assignment consists of grazing permits. The grazing permit system was developed in the 1940s to assign land based on sheep units. A Navajo cannot establish a residence without a grazing permit, which is generally passed down or subdivided for family members. The Bureau of Indian Affairs, Land Operations, oversees permit registration.

Although there is a considerable amount of open space around the disposal site, it is not available for new development because most of the land is subject to some type of village, clan, family, or other claim.

Figure 2.1
Hopi Reservation
Near Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/HOPIRES

2.1.2 Surrounding water use

Stock watering and agricultural diversions are the water uses established for the Hopi Tribe and Navajo Nation for Moenkopi Wash in the vicinity of the former processing site. Moenkopi Wash has been identified as a vital source of water for irrigation for the Hopis. Traditional Hopi agriculture is important for sustenance as well as for cultural and religious reasons. Crops such as corn and beans are used in a variety of foods and play an extensive role in religious ceremonies.

Because of the limited and highly variable supply of surface water, ground water is an important resource. The N-aquifer is the primary source of ground water due to the good quality and generally good yield to wells; the alluvial aquifer is used where the alluvium is extensive. There are currently no withdrawals of ground water between the tailings pile and Moenkopi Wash. This includes the area that is currently contaminated and the area that may become contaminated as the contaminant plume moves toward the wash.

Two points of ground water withdrawal are currently known to exist within a 2-mi (3-km) radius of the site. A low-yield domestic well, about 1.5 mi (2.4 km) east-northeast of the site, is used by two or three families. Jimmy's Spring, about 1.2 mi (1.9 km) east-southeast of the site near Moenkopi Wash, is used to water livestock. Because of their locations, these sources of ground water will probably not be affected by contaminants that may emanate from the site.

The nearest residents to the site, less than a mile southeast, haul water from the Tuba City chapter house. This is a common practice on both reservations, since more than half of the homes do not have plumbing or water supplies. The entire village of Lower Moenkopi does not have a community water or sewage system; however, Tuba City and parts of Upper Moenkopi do.

Installation of wells and water systems is funded and arranged by the Indian Health Service; however, traditional Hopis are often reluctant to accept this federal assistance. After these systems are built on the Navajo reservation, they are managed by the Navajo Tribal Utility Authority. The Navajo Tribal Utility Authority is a tribal enterprise that charges a fee to transmit the water to users' homes ($3.25 per 1000 gal), however, they cannot charge for the water itself. For both reservations, no one owns the water and there are no permanent water rights.

2.1.3 Contaminant sources

Ground water in the contaminated region underlying the Tuba City disposal site contains chemicals and their derivatives used in the milling process and elements associated with uranium ore. The raffinate ponds, discussed in Section 1.3, were a key source of contaminants to the ground water system. For example, sulfate and carbonate are present as a result of the sulfuric acid and carbonate leach processes, and selenium and uranium were leached from

the uranium ore. Ground water in the center of the plume, represented by monitor wells 906 and 908, is characterized by high nitrate, uranium, sulfate, and total dissolved solids (TDS) as well as other inorganic constituents (DOE, 1994b) and a lower pH and reduction/oxidation potential, compared to background ground water.

2.2 GEOLOGY AND HYDROLOGY

2.2.1 Physical setting

The Tuba City uranium mill tailings site is located on the Kaibito Plateau on a gently sloping terrace just south of U. S. Highway 160. To the north, land surface elevation increases steadily to more than 5500 ft (1676 m) above sea level and continues to rise to the highlands about 25 mi (40 km) to the north. To the east and southeast, land surface elevation changes abruptly towards the 400-ft (122-m) deep Moenkopi Wash, an intermittent stream draining west-southwest into the Little Colorado River.

The Tuba City site lies approximately 5100 ft (1600 m) above sea level on alluvial and eolian deposits in the Southern Kaibito Plateau. The site is on a gently sloping terrace approximately 6000 ft (1800 m) northwest of Moenkopi Wash. Surface drainage is southeast toward Moenkopi Wash. Active and partially stabilized windblown sand deposits and occasional Navajo Sandstone outcrops control the topography. To the east and south, the terrain is more dissected because of erosion along the flank of Moenkopi Wash. South of the site, two broad terraces cut into the Navajo Sandstone. These terraces are modified by arroyos and capped by active and arrested windblown sand (dune) deposits. Although mostly covered by dune deposits, the Navajo Sandstone appears close to the surface throughout the area (DOE, 1987).

2.2.2 Geology

At the Tuba City site, near-surface geologic formations are part of the Glen Canyon group, which is composed of (in descending order from land surface) the Navajo Sandstone, the Kayenta Formation, and the Moenave Formation. The Navajo Sandstone is a fine- to medium-grained sandstone unit locally cemented with carbonate and displaying large-scale crossbeds. The Navajo Sandstone is approximately 430 ft (130 m) thick in the site vicinity. It intertongues with the underlying Kayenta Formation in a zone as much as 300 ft (90 m) thick. The Kayenta Formation consists of interbedded fine-grained sandstone and mudstone. The bedding is lenticular and cross-bedding is common in the sandy units. The Moenave Formation consists of very fine to fine-grained sandstone and thin siltstone strata (DOE, 1987).

Up to 20 ft (6 m) of dune sand, alluvium, and pediment gravels cover much of the Navajo Sandstone near the site. Figure 2.2 provides a generalized geologic cross section of the site stratigraphy. Figure 2.3 illustrates the generalized

Figure 2.2
Generalized Geologic Cross Section
Tuba City, Arizona, Site

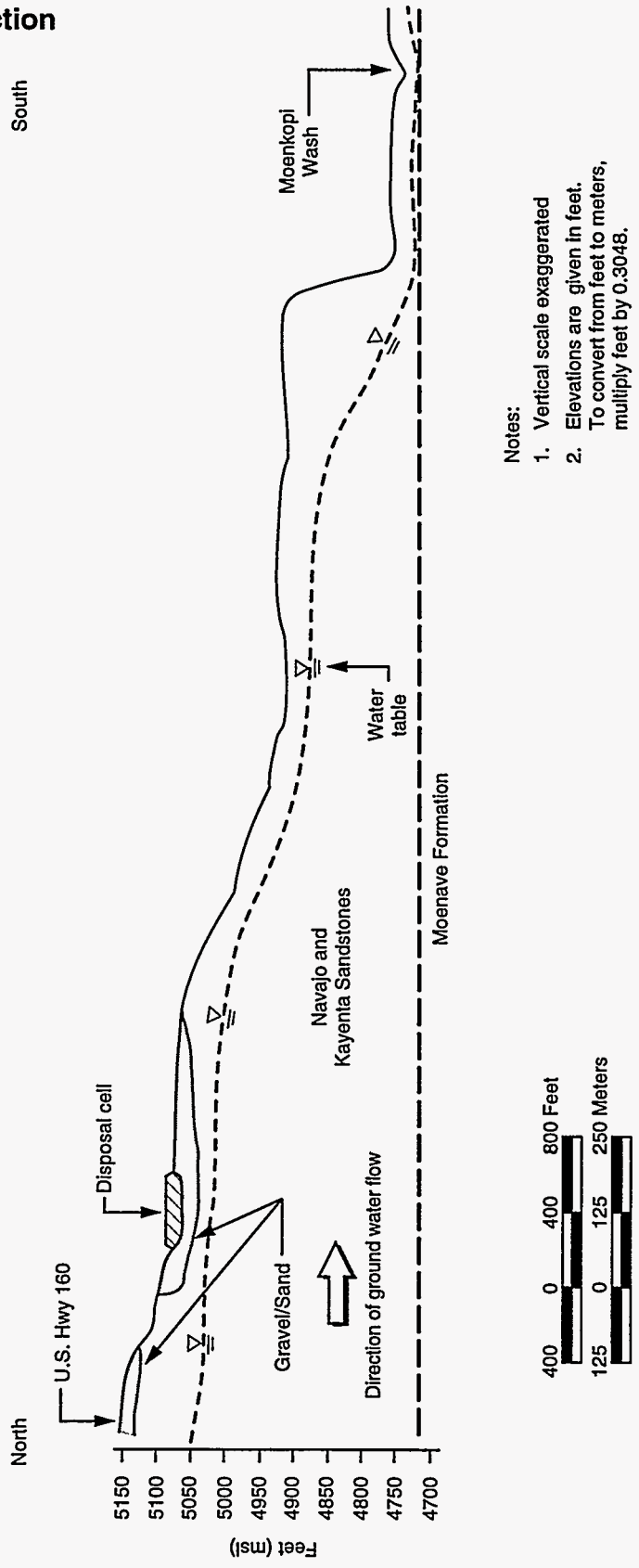


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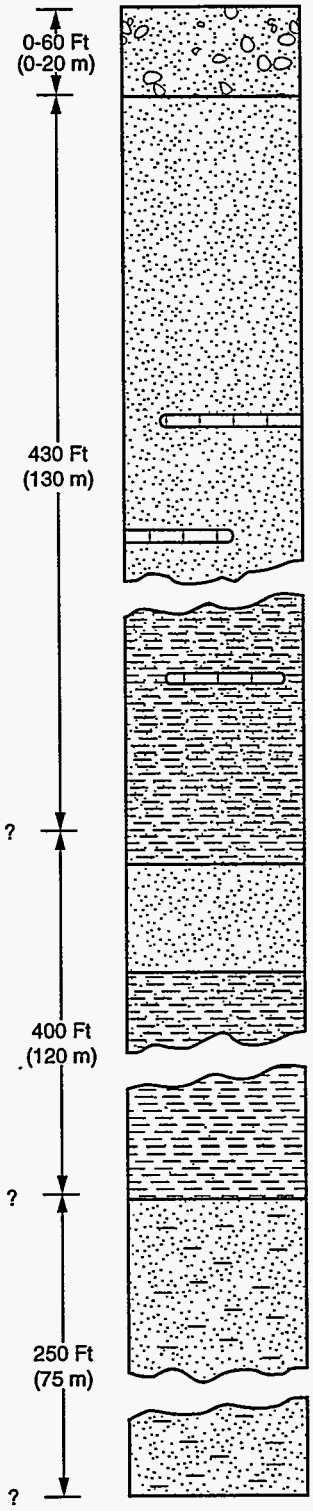
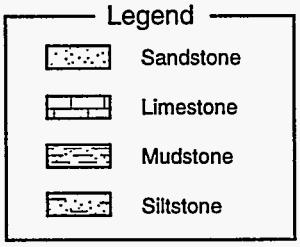
Figure 2.3
Generalized Stratigraphic Section
Tuba City, Arizona, Site



Unconsolidated dune sand and pediment gravels; alluvium along Moenkopi wash.

Navajo Sandstone - Weakly cemented medium- to fine-grained sandstone. Contains lenticular beds of cherty limestone. Major aquifer for area; depth to water ranges from 30 to 60 ft (10 to 20 m) below land surface.



Kayenta Formation - Siltstone, mudstone, and sandstone. The lower portions of the Kayenta Formation probably act as the lower confining unit for the Navajo Sandstone.

Moenave Formation - Sandstone and Silt. The presence of an abundance of calcareous cement reduces the water-bearing capacity of this unit. It also acts as a confining unit beneath the Navajo Sandstone.

MAC: SITE/TUB/WSAP/STRATISECT

stratigraphic section at the Tuba City site. The bedrock dips northeast 1 to 2 degrees toward the Tuba City Syncline (DOE, 1987).

2.2.3 Ground water hydrology

The Navajo Sandstone is the major aquifer in the Tuba City site vicinity and, along with the underlying Kayenta Formation, makes up what is referred to as the "N-aquifer" of the region (Cooley et al., 1969). There is no continuous hydraulic barrier to ground water flow between the Navajo Sandstone and Kayenta Formation (DOE, 1987). The lower bound of the N-aquifer occurs at the contact between the Kayenta and Moenave formations. Although overlain by the Carmel Formation and a silty member of the Entrada Sandstone, which created confined aquifer conditions in many areas (Harshbarger et al., 1957), the N-aquifer is unconfined in the Tuba City area. The major recharge area for the N-aquifer is in the vicinity of Shonto, about 40 miles north of Tuba City (Eychaner, 1983). Ground water flow diverges from the recharge area, flowing northeast toward Laguna Creek and south toward Tuba City and Moenkopi Wash. Local infiltration, including Greasewood Lake (dry), undoubtedly provides some recharge in the site area.

The depth to the water table in the Navajo Sandstone ranges from about 20 to 150 ft (6 to 45 m) below land surface in the site vicinity. The water table slopes toward Moenkopi Wash, and consequently, ground water flows southeast toward the wash (Figure 2.4). Springs occurring on both sides of Moenkopi Wash indicate that the N-aquifer discharges to the wash (USGS, 1969).

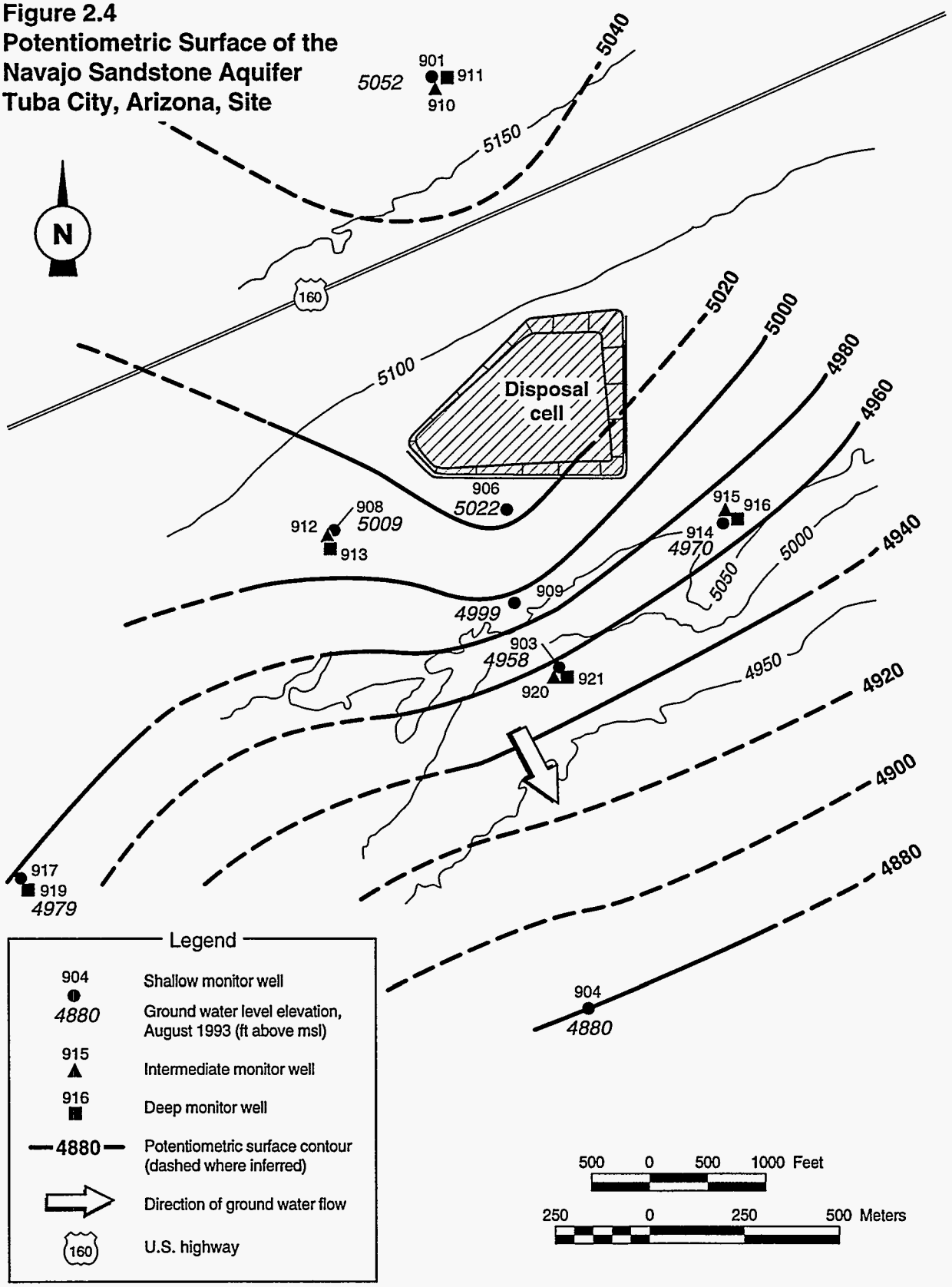
Slug tests have been performed on eight monitor wells. These data were analyzed using the Bouwer-Rice (Bouwer, 1989) and Hvorslev (Hvorslev, 1951) methods, yielding hydraulic conductivities ranging from 50 to 900 ft per year (15 to 270 m per year), with a geometric mean of 160 ft per year (50 m per year). Assuming a hydraulic gradient of 0.04 (based on the potentiometric surface contours) and an effective porosity of 0.2 (based on literature values [Freeze and Cherry, 1979]), the average linear ground water velocity would range from 10 to 200 ft per year (3 to 60 m per year) with a geometric mean of 30 ft per year (10 m per year) (DOE, 1987).

2.2.4 Surface water hydrology

The Tuba City disposal site is approximately 10,000 ft (3000 m) northwest of Moenkopi Wash, an intermittent stream draining west-southwest into the Little Colorado River. No other watercourses, intermittent or ephemeral, exist in the tailings site vicinity. The disposal site is approximately 300 to 400 ft (90 to 120 m) in elevation above Moenkopi Wash.

Moenkopi Wash has a drainage area approximately 2500 square miles (mi^2) (6500 square kilometers [km^2]) near the Tuba City disposal site. Surface drainage for the disposal site is southeast toward Moenkopi Wash. The

Figure 2.4
Potentiometric Surface of the Navajo Sandstone Aquifer Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/POTENTIO ELEV

drainage area above the disposal site is bounded by U. S. Highway 160, which runs along a low ridge. All drainage on the north side of the highway flows toward Greasewood Lake, a large depression centered approximately 1.5 mi (2.4 km) northeast of the disposal site.

A former stream gauging station at the bridge near U. S. Highway 89 (11 mi [18 km] southwest of Tuba City) recorded average annual flows in Moenkopi Wash of 10,650 ac-ft (13,000,000 m^3) from 1926 to 1941. The magnitude of this flow varied substantially, ranging from several days of no flow to a measured peak flow of 14,500 cubic feet (ft^3) per second (410,000 L per second) (Beal, 1985).

2.3 WATER QUALITY

Ground water quality at the Tuba City site has been determined by collecting and analyzing ground water samples from a network of DOE monitor wells. Figure 2.5 shows the locations of these wells, and Table 2.1 outlines their sampling history. Table 2.2 presents a statistical summary of analytical results from filtered ground water samples collected by the DOE from both background and baseline monitor wells at the Tuba City site during the period from 1988 through 1994.

2.3.1 Background water quality

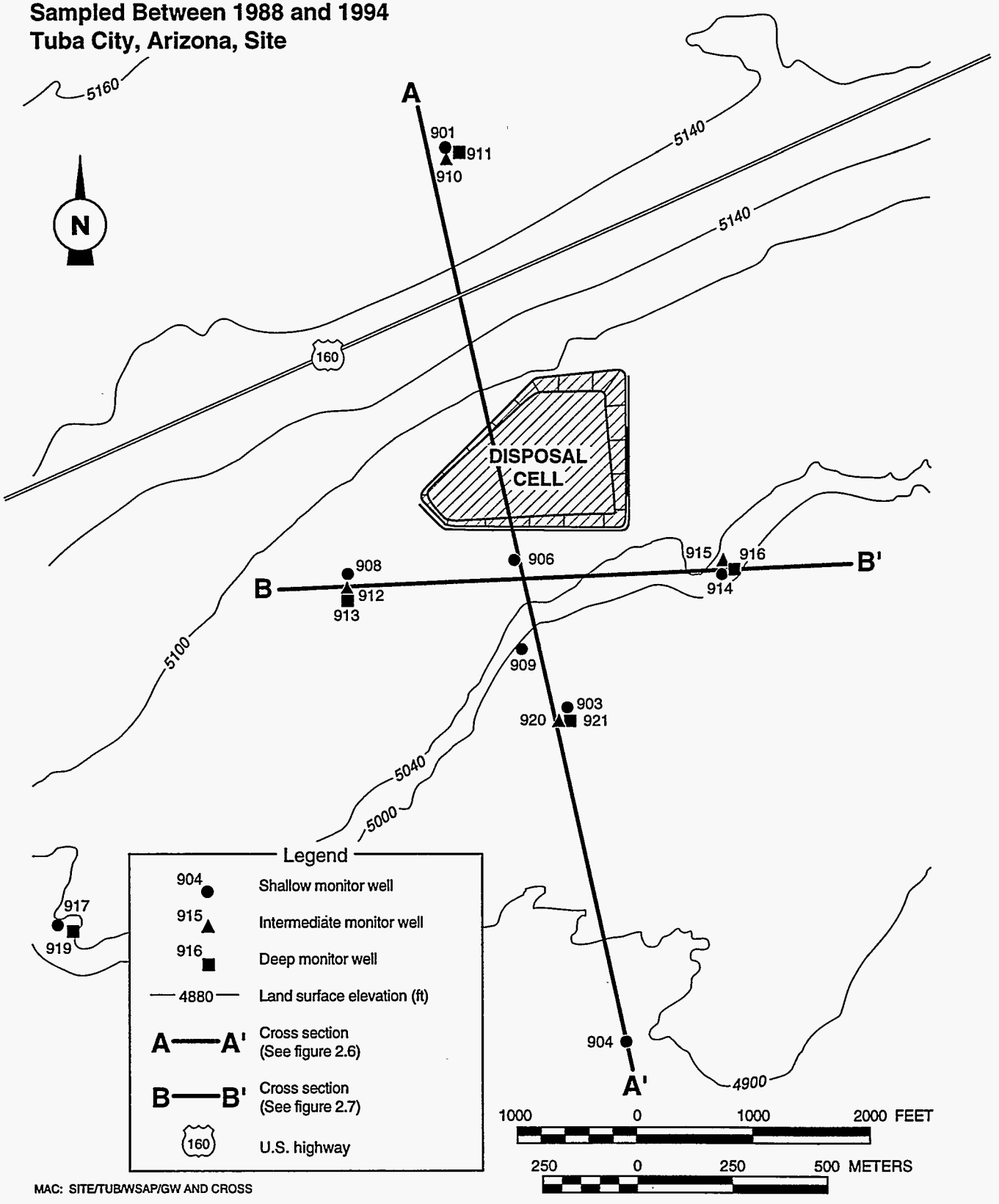
Background ground water quality is defined as the quality of ground water that would exist had uranium processing activities not occurred. Background ground water quality in the N-aquifer (represented by monitor well 901 [Figure 2.5]) is characterized by concentrations of nitrate at 13 milligrams per liter (mg/L), sulfate at 18 mg/L, and TDS at 184 mg/L (Table 2.3).

Baseline ground water quality

Because tailings at the Tuba City site were stabilized in place, the ground water quality under and downgradient of the disposal cell was degraded by contaminants leached from materials on the site prior to cell construction. To gauge the performance of the cell and evaluate the efficacy of any ground water clean-up program initiated at the site, a baseline must be developed to reflect ground water quality at the site prior to cell construction.

Wells in areas downgradient from the contaminant plume at the site are called "transition" wells in the LTSP. The present location of the contaminant plume beneath the site suggests that monitor wells 913, 914, 915, 920, and 921 (Figure 2.5) are not yet in the plume and should not exhibit contaminant concentrations above background. However, the plume is migrating in their direction, and the contaminant concentrations in these wells could increase to levels above background. Therefore, these wells were not included in the discussion of background. As with the background wells, data collected from 1988 to 1991 established a baseline for these wells. Fewer data points were

Figure 2.5
Locations of Ground Water Monitor Wells Sampled Between 1988 and 1994 Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/GW AND CROSS

Table 2.1 Water quality sampling history, Tuba City, Arizona, site

LOCATION		SAMPLING PERIOD																		
ID	TYPE	04/88	05/88	09/88	12/88	06/89	02/90	06/90	07/90	11/90	03/91	06/91	09/91	04/92	09/92	12/92	04/93	08/93	05/94		
0759	SL	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0759	.	.		
0778	SL	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0778	.	.		
0780	SL	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0780	.	.		
0901	WL	.	0901	0901	0901	.	0901	0901	.	0901	0901	0901	0901	0901	0901	0901	.	0901	0901		
0902	WL	.	.	.	.	.	.	.	0902	0902	0902	0902	0902	.	.	.	.	.	.		
0903	WL	.	0903	0903	0903	0903	0903	.	0903	0903	0903	0903	0903	0903	0903	0903	.	0903	0903		
0904	WL	.	0904	0904	0904	0904	0904	.	0904	0904	0904	0904	0904	0904	0904	0904	.	0904	.		
0906	WL	.	0906	0906	0906	0906	0906	0906	.	0906	0906	0906	0906	0906	0906	0906	.	0906	0906		
0908	WL	.	0908	0908	0908	0908	0908	0908	.	0908	0908	0908	0908	0908	0908	0908	.	0908	0908		
0909	WL	.	0909	0909	0909	0909	0909	.	0909	0909	0909	0909	0909	0909	0909	0909	.	.	0909		
0910	WL	.	0910	0910	0910	0910	0910	0910	.	0910	0910	0910	0910	0910	0910	0910	.	0910	.		
0911	WL	.	.	.	.	.	.	0911	.	0911	0911	0911	0911	0911	0911	.	.	.	.		
0912	WL	0912	.	0912	0912	0912	0912	0912	.	0912	0912	0912	0912	0912	0912	0912	.	0912	0912		
0913	WL	.	.	.	.	.	.	0913	.	0913	0913	0913	0913	0913	0913	0913	.	0913	.		
0914	WL	.	0914	0914	0914	0914	0914	0914	.	0914	0914	0914	0914	0914	0914	0914	.	0914	.		
0915	WL	.	.	.	.	.	.	.	.	0915	0915	0915	0915	0915	0915	0915	.	0915	.		
0916	WL	.	.	.	.	.	.	0916	.	0916	0916	0916	0916	0916	0916	.	.	.	.		
0917	WL	.	.	.	.	.	.	.	0917	0917	0917	0917	0917	0917	0917	0917	.	0917	0917		
0919	WL	.	.	.	.	.	.	.	0919	0919	0919	0919	0919	0919	0919	.	.	.	.		
0920	WL	.	0920	0920	0920	.	0920	.	0920	0920	0920	0920	0920	0920	0920	0920	.	0920	.		
0921	WL	.	0921	0921	0921	0921	0921	.	0921	0921	0921	0921	0921	0921	0921	0921	.	0921	.		

DATA FILE NAME: \DART\TUB01\LOT10001.DAT

LOG DATES: 06/09/82 TO 05/17/94
REPORT DATE: 09/13/94

Table 2.2 Statistical summary of filtered ground water quality for samples taken between 1988 and 1994, Tuba City, Arizona, site

Constituent[a]	Frequency of detection[b]	Observed		
		Minimum	Median[c]	Maximum
		(mg/L)		
Ammonium				
Background	4/29	<0.01	<0.10	1.6
Plume	10/43	<0.01	<0.10	269
Cadmium				
Background	0/23	<0.001	<0.001	<0.001
Plume	7/39	<0.001	<0.001	0.004
Calcium				
Background	34/34	29	34	43[d]
Plume	51/51	320	612	1071
Chloride				
Background	34/34	8.0	11	14
Plume	51/51	9.0	104	420[d]
Chromium				
Background	1/32	<0.003	<0.01	<0.01
Plume	9/52	<0.003	<0.01	0.18
Iron				
Background	7/32	<0.005	<0.03	0.085
Plume	25/47	<0.005	0.03	0.21
Magnesium				
Background	34/34	5.2	6.1	7.6
Plume	51/51	63	190	753
Manganese				
Background	1/32	<0.0008	<0.01	0.25[d]
Plume	28/47	<0.0008	0.03	0.50[d]
Molybdenum				
Background	1/35	<0.0048	<0.01	0.01
Plume	19/55	<0.0048	<0.01	0.80
Nitrate				
Background	31/31	11	15	22
Plume	41/47	189	841	1310
Potassium				
Background	34/34	0.83	1.4	2.2
Plume	51/51	3.2	5.6	36

Table 2.2 Statistical summary of filtered ground water quality for samples taken between 1988 and 1994, Tuba City, Arizona, site (Concluded)

Constituent[a]	Frequency of detection[b]	Observed		
		Minimum	Median[c]	Maximum
		(mg/L)		
Selenium				
Background	1/35	<0.0016	<0.005	0.014[d]
Plume	37/55	0.002	0.009	0.18[d]
Sodium				
Background	34/34	6.9	14	21[d]
Plume	51/51	50	180	775
Strontium				
Background	23/23	0.19	0.30	0.38[d]
Plume	32/32	3.3	5.2	9.1
Sulfate				
Background	35/35	7.4	16	46
Plume	55/55	549	1680	3820
Tin				
Background	0/24	<0.005	<0.005	<0.005
Plume	7/36	<0.005	<0.006	0.057
Uranium				
Background	26/32	0.0006	0.001	0.012
Plume	51/51	0.022	0.085	1.75
Zinc				
Background	20/32	<0.005	0.008	0.056
Plume	31/52	<0.0026	0.012	0.62

[a]Constituents listed were identified from Tuba City baseline risk assessment as having, on average, higher levels in plume wells than in background wells. Plume wells are 906, 908, 909 and 912. Background wells are 901 and 917.
[b]Frequency of detection = number of samples reported equal or above laboratory detection limit/total number of samples.
[c]The median represents the 50th percentile of the pooled data for all wells in the group.
[d]Reported minimum or maximum occurred in May 1994 sampling round. At the time of this report this sampling round has not completed the quality assurance validation process.

Table 2.3 Summary of ground water quality[a] in the Navajo Sandstone in the vicinity of the Tuba City, Arizona, site

Constituent	MCL (mg/L)	Background monitor well 901 (mg/L)	Contaminated area monitor well 906 (mg/L)	Downgradient monitor well 903 (mg/L)
Ammonium[d]		<0.1	2.3	<0.1
Cadmium	0.005	<0.001	<0.001	<0.001
Calcium[d]		34	705	49
Chloride[d]	250[c]	11	353	18
Chromium	0.01	<0.01[b]	<0.01[b]	<0.01[b]
Iron[d]	0.3[c]	<0.03	<0.15	<0.03
Lead	0.05	<0.003	0.003	<0.003
Magnesium[d]		6	428	10
Molybdenum	0.1	<0.01	0.8	<0.01
Nitrate	44	13.1	1310	43
pH	6.5-8.5	7.89	6.59	7.76
Potassium[d]		1	10	2
Selenium	0.05	<0.005	0.011	<0.005
Sodium[d]		17	775	12
Strontium		0.296[b]	8.45[b]	0.834[b]
Sulfate[d]	250[c]	18	3640	37
TDS[d]	500[c]	184	7100	268
Tin		<0.005[b]	<0.05[b]	<0.005[b]
Uranium	0.044	0.001	1.750	0.001
Zinc	5[c]	0.0066[b]	0.131[b]	0.009[b]

[a]Water quality data based on samples collected August 1993.
[b]Water quality data based on samples collected September 1992.
[c]Secondary drinking water standard.
[d]Within acceptance nutritional or dietary range, or has very low toxicity.

MCL - maximum concentration limit

available for wells 913 and 915 because they were not routinely sampled until 1990.

In terms of major ions, baseline ground waters are similar to background waters. TDS range from approximately 35 to 260 mg/L, and pH ranges from 7.3 to 9.3. Sulfate concentrations are similar to those of background waters (excluding well 904); the range in chloride to sulfate proportions (1:1 to 1:2) is also similar. As in background water, many of the contaminant species concentrations in these "transition" wells were at or below detection. Barium, nitrate, uranium, and combined radium-226 and radium-228 concentrations were above detection limits more than 50 percent of the time, but still below maximum contaminant levels (MCL).

The nitrate concentration in well 903 reveals one statistically significant difference between background and "transition" wells. Transition well 903, closest to the plume, had higher nitrate concentrations than other transition and background wells, although the observed concentration is still below the MCL. The higher concentrations may indicate that the leading edge of the contaminant plume has reached monitor well 903. Sulfate appears to show similar behavior.

2.3.2 Point of compliance

At this time, there are no point-of-compliance wells at the Tuba City, Arizona, UMTRA site.

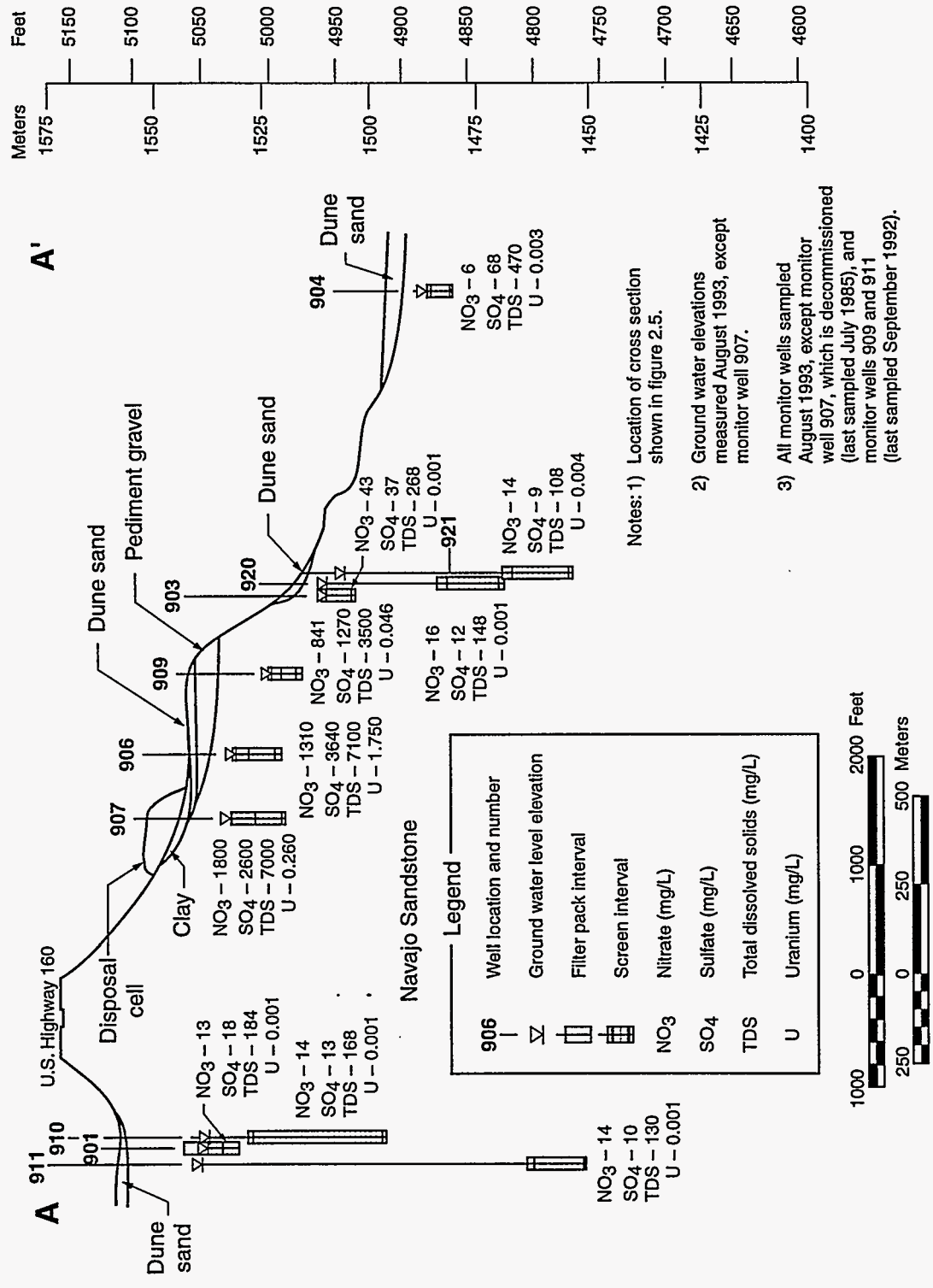
2.3.3 Contaminant delineation

Contaminated ground water in the uppermost aquifer near the source area (represented by monitor well 906) is characterized by concentrations of nitrate at 1310 mg/L, sulfate at 3640 mg/L, and TDS at 7100 mg/L (Table 2.3).

Ground water quality at the fringe of the contaminated area (represented by monitor well 903) is characterized by concentrations of nitrate at 43 mg/L, sulfate at 37 mg/L, and TDS at 268 mg/L) (Table 2.3).

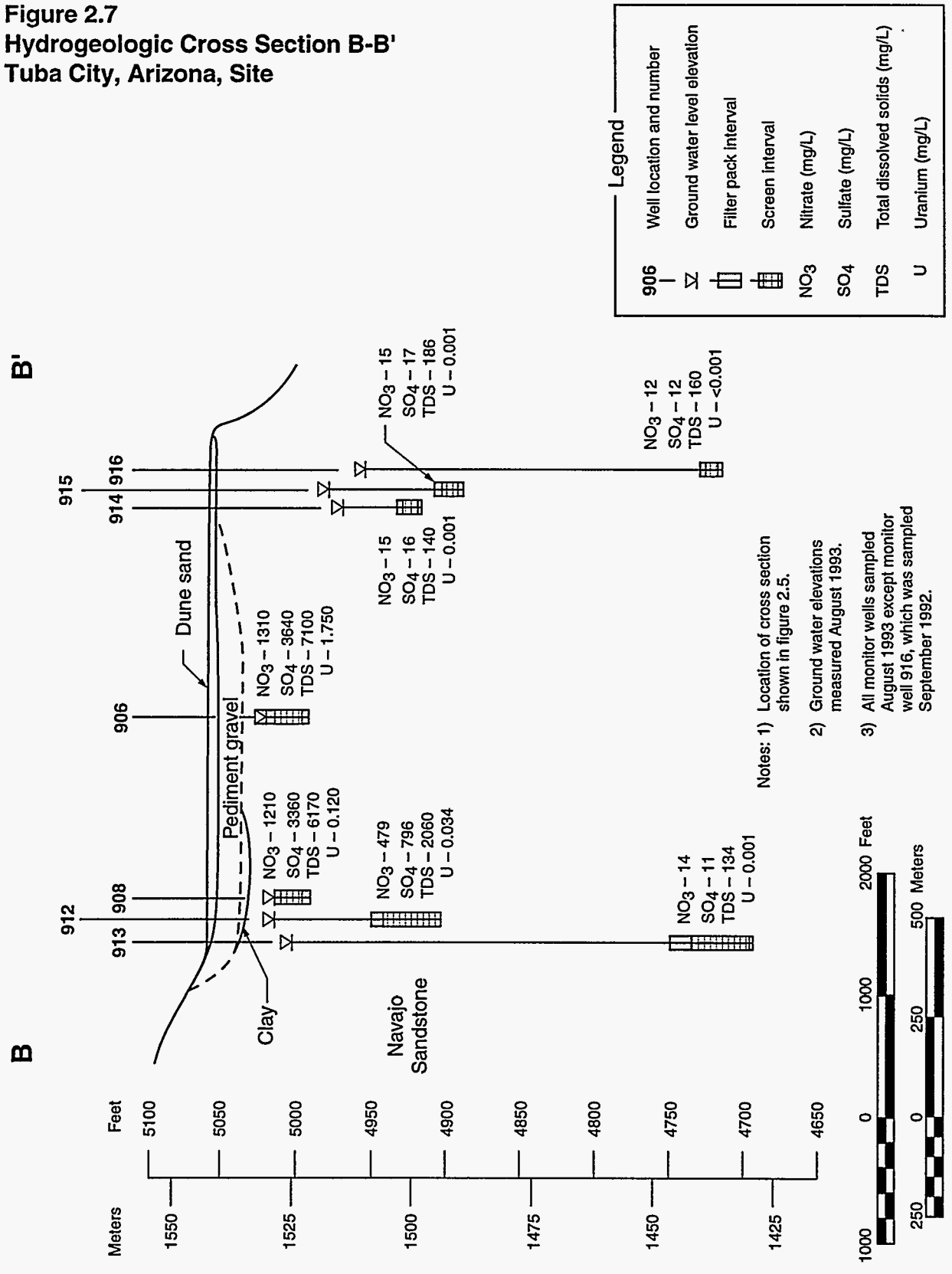
The vertical distribution of nitrate, sulfate, TDS, and uranium is shown with well screens in the cross section in Figures 2.6 and 2.7. Note that in the upgradient monitor wells (901, 910, and 911), the uniform ground water quality is being brought under the site by the regional flow system. The plume, however, tends to be stratified vertically, with the constituents concentrated in the upper 50 ft (15 m) of the aquifer. The monitor well cluster 908, 912, and 913 provides the most striking illustration of stratification, with nitrate concentrations ranging from 1200 mg/L in the shallowest well (908) to virtually background in the deepest well (913). The stratification of contaminants and ground water is expected because the source was located on the surface, the Navajo Sandstone is naturally stratified, and there is no local natural recharge to drive constituents deep into the aquifer. In addition, the difference in water levels in well clusters

Figure 2.6
Hydrogeologic Cross Section A-A'
Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/HYDROX-SEC(A-A')

Figure 2.7
Hydrogeologic Cross Section B-B'
Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/HYDROX-SSEC(B-B')

suggests that the vertical migration of ground water is impeded by subsurface barriers.

The plan view distribution of nitrate is shown in Figure 2.8. The complete extent of ground water contamination cannot be determined from the current monitoring network. Peak concentrations have been consistently observed in monitor well 906, immediately downgradient from the disposal cell. High concentrations also exist in monitor well 908 to the southwest and may be the result of a subsurface barrier diverting the infiltrated tailings water.

The nitrate concentrations over time in ground water samples from several wells are shown in Figure 2.9. Note that the upgradient monitor well (901) and the downgradient monitor well (903) have similar levels of nitrates, both being very low. However, a slight upward trend can be seen in nitrate concentrations at monitor well 903 from roughly July 1993 onward. That trend may represent movement of the contaminated ground water. All the monitor wells (906, 908, 909, and 903) in the contaminated area (Figure 2.8) show more or less constant nitrate levels over most of the sampling history. Transient drainage from the disposal cell is anticipated as consolidation of the tailings squeezes out the contaminated pore water, which will result in increased water levels and concentrations.

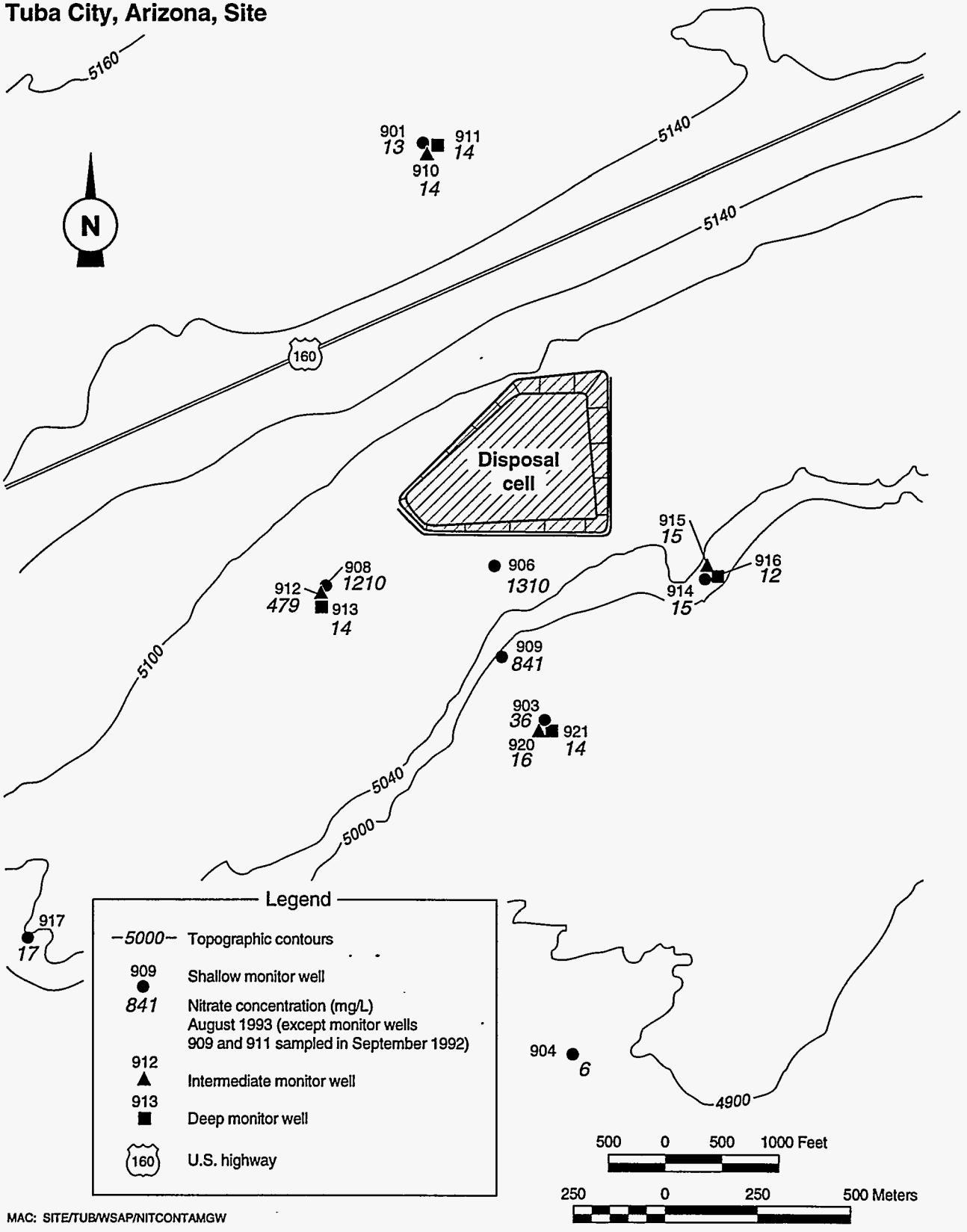
The effects of uranium milling activities are primarily evident in increased concentrations of nitrate, sulfate, and TDS. However, available water quality data indicate that 18 constituents are higher in the contaminated area, represented by monitor wells 903, 906, 908, 909, and 912, than in the background wells. These constituents are ammonium, cadmium, calcium, chloride, chromium, iron, magnesium, manganese, molybdenum, nitrate, potassium, selenium, sodium, strontium, sulfate, tin, uranium, and zinc. Evidence for elevated concentrations of lead is not conclusive because the elevated values were all obtained in a single sample.

2.3.4 Surface water sampling locations

Based on the current location of the plume and flow rate calculations using ground water velocities, it is unlikely that the water in the Moenkopi Wash originated as ground water from under the disposal cell.

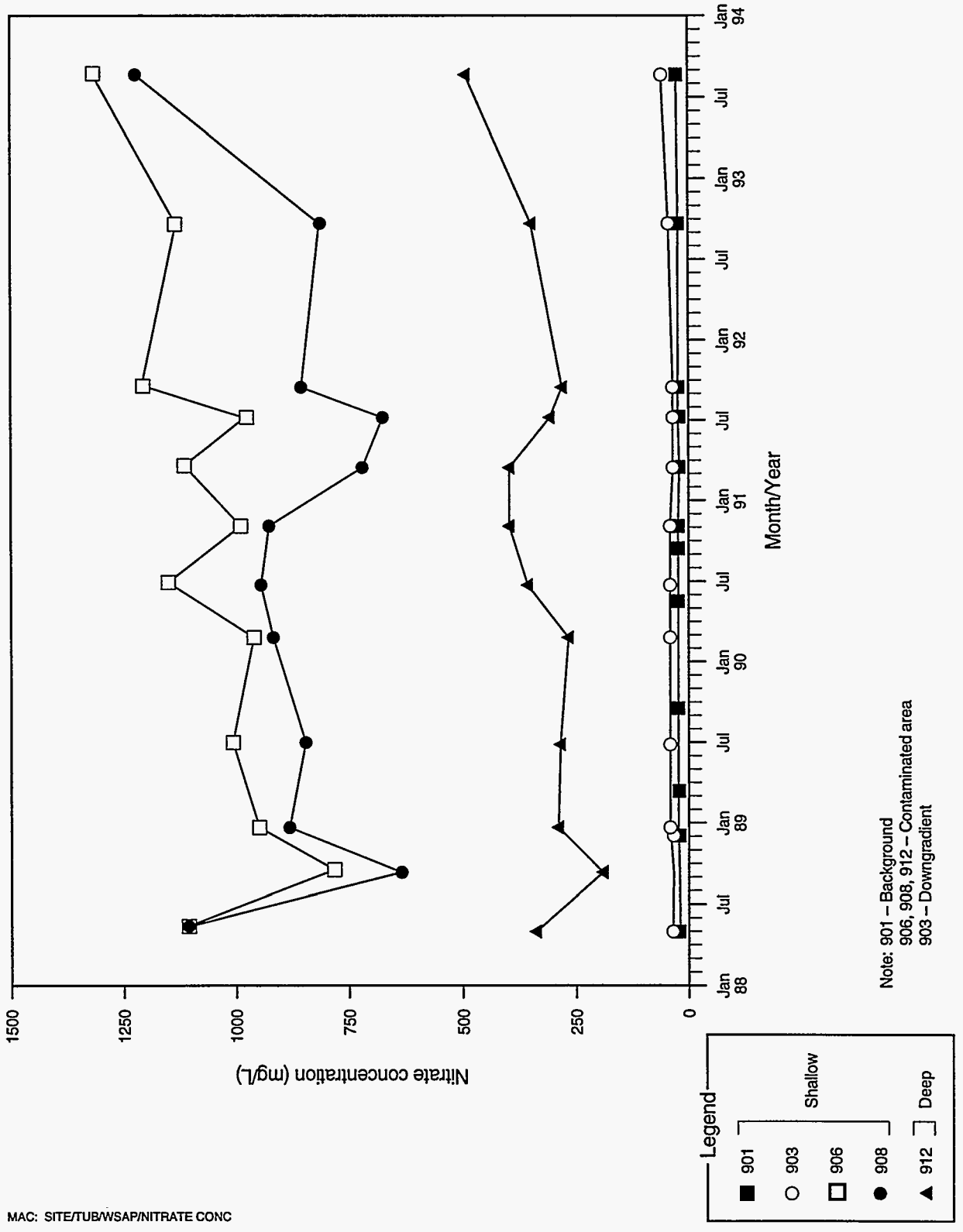
The locations of surface water sampling points in Moenkopi Wash are shown in Figure 2.10. Surface water quality monitoring stations in the Moenkopi Wash show elevated levels of TDS, iron, sulfates, and gross alpha. Although several of the constituents were detected at downstream locations in higher concentrations than at upstream locations, the opposite was true for several other constituents, including three of the contaminants of concern. The concentrations detected at upstream locations for molybdenum, nitrate, and selenium were higher than those detected at the downstream locations. The upstream concentrations for cadmium, strontium, sulfate, and uranium were lower than those detected at downstream locations.

Figure 2.8
Nitrate Distribution in Ground Water
Tuba City, Arizona, Site



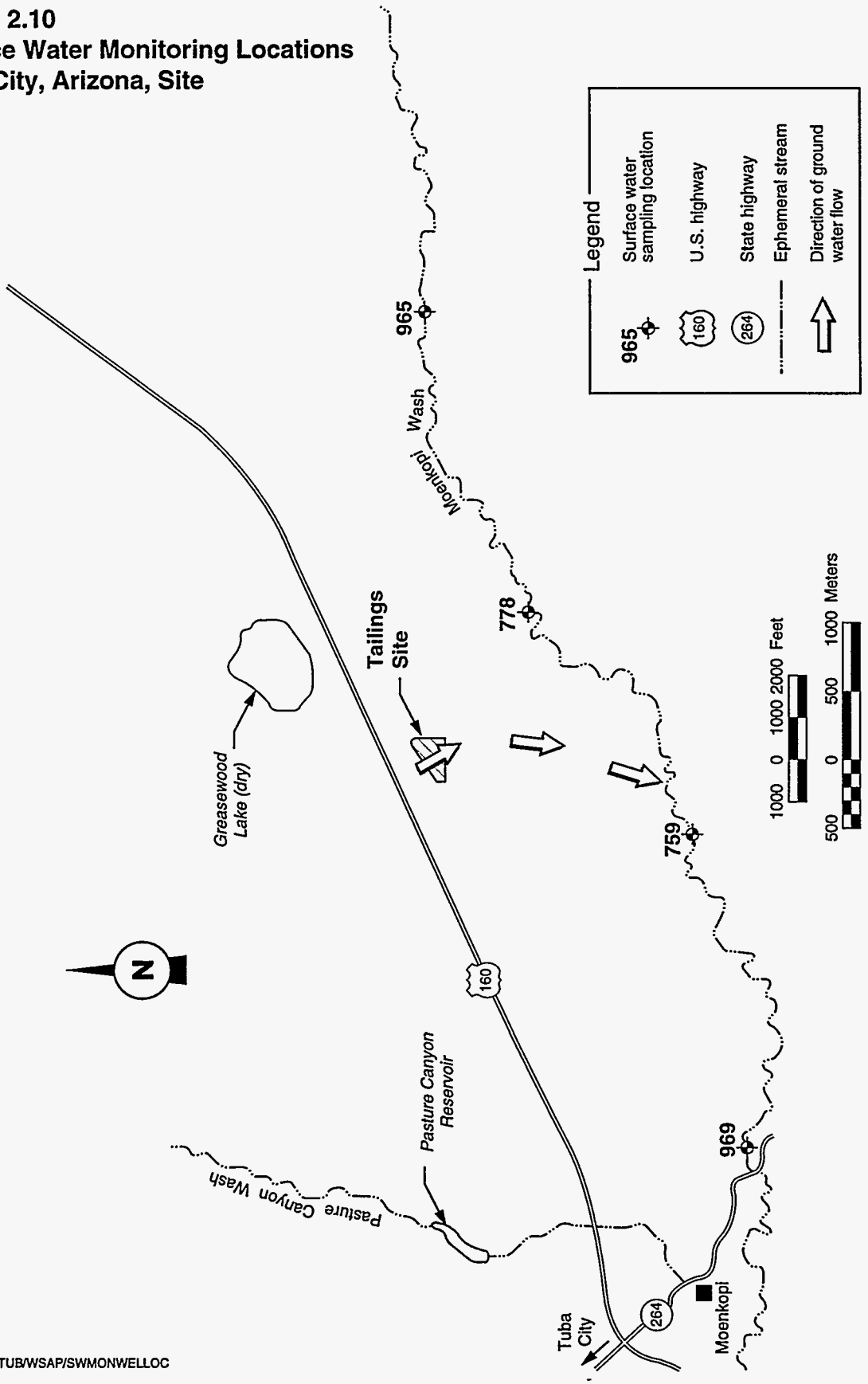
MAC: SITE/TUB/WSAP/NITCONTAMGW

Figure 2.9
Nitrate Concentration Over Time in Ground Water
Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/NITRATE CONC

Figure 2.10
Surface Water Monitoring Locations
Tuba City, Arizona, Site



MAC: SITE/TUB/WSAP/SWMONWELLOC

Precipitation and snowmelt may have carried both dissolved and suspended contaminants along surface drainages to Moenkopi Wash. Metal contaminants transported as dissolved species would have become diluted when mixed with the water in Moenkopi Wash. Alternatively, dissolved species could have precipitated, becoming adsorbed to sediments or absorbed into biota with varying biochemical and geochemical conditions. Contaminants transported from the disposal site that were sorbed onto soil particles would have been deposited as stream sediments. Variations in geochemical conditions or biological action could release constituents adsorbed onto sediments into surface waters. Thus, deposited sediments could act as a source of site-derived surface water contamination.

In summary, the potential exists that surface drainages could have acted as a contaminant transport mechanism from the site to Moenkopi Wash. However, there was no trend of progressively higher concentrations at downstream locations that would suggest an influx of site-related contamination.

2.4 SITE CONCEPTUAL MODEL

The conceptual model of the site summarizes how the uranium milling activities affected the environment in the area, the effect of surface remediation on the ground water, the properties of the N-aquifer, general geology, ground water sources and sinks, extent of ground water contamination, and transport processes that take place in the aquifer near the Tuba City site. The purposes of a conceptual model of the site are to simplify the field problem, to allow identification of the most important information, and to organize the data so that the problem can be more readily analyzed.

The conceptual site model for the Tuba City site is based on reviewing and evaluating existing characterization information, including data from monitor wells installed in the vicinity of the site (Figure 2.5 and Table 2.4) and regional studies. The conceptual site model is shown in Figure 2.11. This is a preliminary model because the data are incomplete, limiting the amount of detailed interpretation as described below. As additional information is collected, the conceptual model will be updated.

Milling of ore to extract uranium caused both surface and ground water contamination. Surface contamination resulted from the wind blowing the radioactive materials off-site. Ground water contamination was caused by infiltration of about 290 million gal (1,100 million L; 890 ac-ft) of process water that contained uranium and the various chemicals used in the milling process.

The tailings piles and surrounding soil contamination remediation was completed under the UMTRA surface remediation program in April 1990. The contaminated material was stabilized more or less in the location where it was left at the end of milling operations and covered with barrier material to reduce radon emanation and water infiltration. Durable rock was then placed over the

Table 2.4 Monitor well information at the Tuba City, Arizona, site

LOCATION ID	NORTH COORDINATE (FT)	EAST COORDINATE (FT)	GROUND ELEVATION (FT MSL)	BOREHOLE DEPTH (FT)	BOREHOLE DIAMETER (INCHES)	CASING ELEVATION (FT MSL)	CASING LENGTH (FT)	CASING DIAMETER (INCHES)	SCREEN BEGINNING DEPTH (FT)	SCREEN LENGTH (FT)	FLOW CODE	FORMATION OF COMPLETION
0661	9053.0	11960.1	5076.41	20.00	6.000	-	-	-	-	-	N	TA
0664	9053.0	11960.1	5076.41	10.00	6.000	-	-	-	-	-	N	TA
0666	9053.0	11960.1	5076.41	5.00	6.000	-	-	-	-	-	N	TA
0673	9350.9	12452.0	5085.85	35.00	6.000	-	-	-	-	-	N	TA
0676	9350.9	12452.0	5085.85	25.00	6.000	-	-	-	-	-	N	TA
0677	9350.9	12452.0	5085.85	20.00	6.000	-	-	-	-	-	N	TA
0679	9350.9	12452.0	5085.85	15.00	6.000	-	-	-	-	-	N	TA
0680	9350.9	12452.0	5085.85	10.00	6.000	-	-	-	-	-	N	TA
0682	9350.9	12452.0	5085.85	5.00	6.000	-	-	-	-	-	N	TA
0901	12095.8	11034.6	5105.08	80.0	6.625	5106.81	82.0	2.0	58.0	20.0	U	NA
0902	-1533.8	10903.5	4732.94	75.0	6.500	4734.94	77.0	2.0	63.0	10.0	N	NA
0903	6994.3	12116.7	4980.44	50.0	6.500	4982.44	50.0	2.0	28.0	10.0	D	NA
0904	4196.4	12585.8	4899.35	44.0	6.625	4901.35	42.0	2.0	28.0	10.0	N	NA
0905	9351.9	13758.5	5070.12	82.0	6.625	5072.12	79.0	2.0	60.0	15.0	D	NA
0906	8352.0	11652.6	5060.39	70.5	6.625	5061.39	67.0	2.0	44.0	20.0	O	NA
0907	9088.1	12074.2	5077.17	90.5	6.000	5079.17	92.5	2.0	68.5	20.0	O	NA
0908	8183.7	10178.9	5055.88	80.0	6.625	5056.88	69.0	2.0	52.0	15.0	D	NA
0909	7562.4	11734.9	5054.16	85.0	6.625	5055.46	79.0	2.0	65.0	15.0	D	NA
0910	12018.4	11067.7	5105.94	200.0	8.500	5107.81	199.0	4.0	95.0	100.0	N	NA
0911	12097.8	11115.1	5106.15	351.4	8.500	5108.15	353.4	4.0	309.4	40.0	N	NA
0912	8127.1	10136.1	5057.85	165.0	8.500	5059.87	167.0	4.0	123.0	40.0	D	NA
0913	8056.4	10138.2	5057.88	380.0	8.500	5060.11	372.7	4.0	328.7	40.0	D	NA
0914	8272.0	13537.0	5068.37	156.2	8.500	5070.16	158.2	4.0	144.0	10.0	D	NA
0915	8361.9	13554.7	5068.58	182.0	8.500	5070.58	184.0	4.0	170.0	10.0	D	NA
0916	8298.0	13625.1	5068.10	357.7	8.500	5069.93	359.7	4.0	346.0	10.0	D	NA
0917	4847.0	8034.9	5046.05	150.0	8.500	5048.06	152.0	4.0	128.0	20.0	D	NA
0918	4927.9	8075.4	5047.39	70.0	8.500	5049.36	70.0	4.0	61.0	5.0	D	NA
0919	4857.8	8133.3	5046.17	355.0	8.500	5048.23	351.7	4.0	337.7	10.0	D	NA
0920	6903.8	12062.5	4980.64	170.0	8.500	4982.61	158.4	4.0	116.0	40.0	D	NA
0921	6907.3	12179.8	4976.84	360.0	8.500	4978.81	358.8	4.0	315.2	40.0	D	NA
0925	-	-	-	-	-	-	-	-	-	-	N	AL
0926	-	-	-	-	-	-	-	-	-	-	N	AL
0927	-	-	-	-	-	-	-	-	-	-	N	AL
0928	-	-	-	-	-	-	-	-	-	-	N	AL
0929	-	-	-	-	-	-	-	-	-	-	N	AL
0930	-	-	-	-	-	-	-	-	-	-	N	AL
0968	11800.0	11120.0	5120.00	-	-	-	-	-	-	-	U	NA
0970	12741.2	11508.9	5106.03	-	-	5106.78	-	-	-	-	U	NA
0971	14471.6	12462.2	5104.91	-	-	5105.69	-	-	-	-	U	NA
0972	14184.7	8899.5	5137.27	-	-	5138.02	-	-	-	-	U	NA

FORMATION OF COMPLETION CODE:
TA - URANIUM MILL TAILINGS
NA - NAVAJO SANDSTONE
AL - ALLUVIUM

FLOW RELATIONSHIP CODE:
N - UNKNOWN
U - UPGRADIENT
D - DOWN GRADIENT
O - ON-SITE

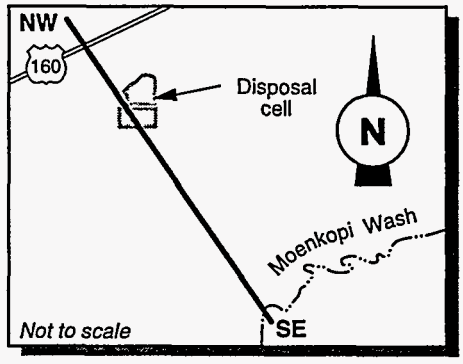
DATA FILE: \DART\TUB01\MWI10003.DAT

FIELDS DISPLAYED WITH A DASH INDICATE THE DATA IS UNAVAILABLE

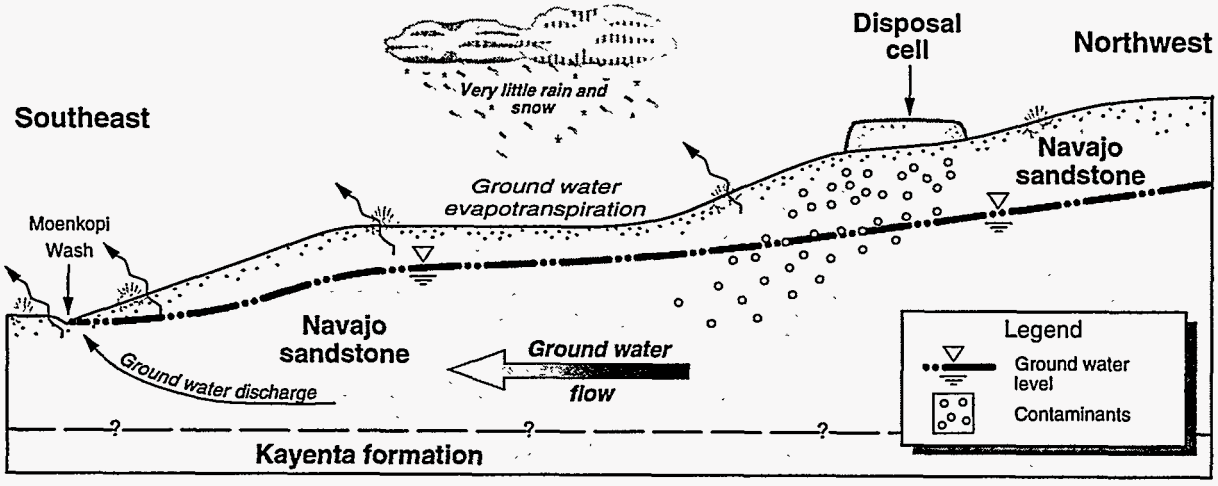
Figure 2.11
Diagram of the Conceptual Site Model
Tuba City, Arizona, Site

On the surface:

- Approximately 1.4 million yd^3 (1.1 million m^3) of contaminated materials were stabilized in place. Surface remedial action was completed in 1990.
- There is very little use of ground water in the area where the Navajo Sandstone is contaminated.



Location map



Not to scale

Tuba City Site Cross Section

Below the surface:

- Ground water occurs in the Navajo Sandstone under the site.
- Shallow portions of the Navajo Sandstone are contaminated.
- Ground water discharges into the Moenkopi Wash and along bluffs.
- The deep Navajo Sandstone aquifer is not contaminated
- ~890 acre-ft of process water infiltrated into the subsurface

MAC: SITE/TUB/WSAP/X-SEC

barrier to protect the cell from erosion. Thus, the source of possible further contamination was removed.

As previously discussed, process water from uranium milling operations from 1956 to 1966 infiltrated the aquifer and contaminated ground water where the wet tailings were piled after milling. The infiltrated process water constitutes the most significant source of contaminants to the aquifer. However, detailed records of the milling operations water usage are not available and only general estimates (derived from knowledge of the milling processes used) of the amount of water used in milling and subsequently disposed of on-site can be made, which limits the quantification of the source of ground water contamination. Slow drainage of water from the tailings from 1966 to 1988 (when surface remediation started) also contributed to ground water contamination to an unknown extent. Finally, transient drainage from consolidation of the tailings also represents a source of ground water contamination. The constituents present in ground water at elevated levels as a result of milling operations include nitrate and sulfate (used in the milling process), TDS, and uranium. Concentrations in ground water are highest near the former ponds where the disposal cell currently exists.

The uppermost aquifer at the Tuba City site is the N-Aquifer, which includes the Navajo Sandstone, a good water-bearing formation used for water supply by the mill and by Tuba City. The Navajo Sandstone is comprised of ancient windblown dune sand deposits, which are relatively uniform because of the sorting action of the wind during deposition. The most striking feature of the Navajo Sandstone is its large cross bedding, which arises from the laying down of sand along the inclined faces of the dunes. This cross bedding may influence ground water flow since the material along a bed will tend to be better connected than material between beds. Faults are uncommon in the site area, although there is some jointing that may have locally increased the hydraulic conductivity of the rock. It is unlikely that the faulting and joints exert widespread control on the ground water flow field. Ground water in the Navajo Sandstone originates as precipitation on the highlands to the northwest. The Tuba City site is at the end of the regional flow system, with a major ground water discharge area located along Moenkopi Wash.

3.0 DATA COLLECTION OBJECTIVES

Water quality and hydrologic data obtained by implementing this sampling plan will address data collection objectives (DCO) relating to 1) regulatory requirements compliance, 2) initial performance demonstration of the disposal cell, 3) site characterization, 4) risk assessment considerations, and 5) other site-specific considerations.

3.1 REGULATORY REQUIREMENTS

The regulatory requirements for sampling at the site are specified in 40 CFR Part 192 (1994) and are described in the WSAP guidance document (DOE, 1995).

3.2 COMPLIANCE MONITORING

The DCOs for cell performance assessment at the Tuba City site are discussed in the LTSP for Tuba City, Arizona (DOE, 1992). The DCOs focus on early detection of contaminant leakage from the disposal cell through a screening monitoring program. This program consists of regular sampling of background wells and wells downgradient of the disposal cell for contaminants of concern. The DCOs may also involve evaluative monitoring and/or indirect monitoring if cell performance is in question.

Section 5.0 discusses selecting monitor well locations, analytes, and monitoring frequency for cell performance assessment. Monitor well locations were chosen in order to meet one or more of the following four basic DCOs:

- Obtain information regarding disposal cell performance as a best management practice as described in the LTSP (DOE, 1992).
- Develop baseline data for 21 of the 22 new wells (17 monitor wells and 4 extraction wells installed in October and November 1995) for the purpose of further defining the extent of ground water contamination prior to the implementation of remedial action alternatives for ground water.
- Characterize and monitor the distribution of site-related contaminants in ground water.
- Provide information to evaluate the effectiveness of potential containment actions.

The criteria for selecting analytes and determining monitoring frequency are discussed in detail in Sections 5.2 and 5.3, respectively.

3.3 SITE CHARACTERIZATION

Characterization of contaminant migration will be an ongoing site activity. Because nitrate is a major contaminant of concern and is not retarded by precipitation or adsorption reactions, its concentration is used to define the plume distribution and migration rate. Although the nitrate concentration may decrease due to denitrification reactions, the natural rate of this reaction is slow enough to be a secondary effect. Additionally, sulfate concentrations provide a backup to nitrate concentrations in terms of plume distribution and migration rate. Sampling well 903 is particularly important in defining the plume migration rate because it is on the plume's outermost edge. Additional wells would be required to sufficiently characterize the lateral and vertical extent of ground water contamination at the site.

No evidence exists that the Tuba City disposal cell contributes to water quality in Moenkopi Wash. Those contaminants found in the plume are at or near background ground water concentrations for water sampled from Moenkopi Wash. To the extent practicable, surface stabilization of the tailings has eliminated the source of any surface water contamination from the site.

3.4 OTHER CONSIDERATIONS

The contaminants of concern, identified in the baseline risk assessment (DOE, 1994a), are cadmium, lead, molybdenum, nitrate, selenium, sulfate, and uranium. Molybdenum exceeded its MCL only once in two separate wells. Data are inconclusive whether lead is present above background levels. Additional sampling for lead is needed to evaluate its presence because even low levels can be significant. Selenium was detected above its MCL in background and in on-site wells close to the former tailings pile or the evaporation ponds. Uranium and nitrate exceeded their respective MCLs in on-site wells and, therefore, are the main contaminants of concern.

Currently, there are no other water sampling concerns that have not already been addressed in Sections 3.1 through 3.3.

4.0 DATA QUALITY REQUIREMENTS

Data quality requirements define the manner in which samples are collected, handled, and analyzed. The objectives include 1) defining analytical support levels, 2) following standard procedures for water sampling, preservation, transport, and various other field activities, 3) performing activities in accordance with quality assurance and quality control protocols, and 4) providing analytical data validation. Data quality objectives to be followed during data collection and evaluation activities are stated in the WSAP Guidance Document (DOE, 1995) and applicable SOPs (JEG, n.d.)

5.0 SAMPLING PLAN

This section presents the sampling locations, analytes (including field analyses), and sampling frequencies for the upcoming 2 years. It also includes the projected sampling needs for an additional 5 years (i.e., the 5 years after the detailed 2-year sampling description). Also presented in this section are the data evaluation methods and requirements for response to anomalous data. This plan covers sampling at the Tuba City uranium processing site (TUB-01), which includes the former mill site, former tailings piles, and the existing disposal cell. Sampling at the disposal cell is in accordance with the LTSP (DOE, 1992).

5.1 SAMPLING LOCATIONS

A list of all monitor wells to be sampled is provided in Table 5.1. These locations have been chosen in order to meet one or more of the four basic DCOs discussed in Section 3.2. The Tuba City site is a "stabilization in place" site and the DCOs stated in Section 3.2 address ground water monitoring and characterization issues that involve both the UMTRA Surface and Ground Water Projects. Consequently, Table 5.1 also indicates whether sampling is to be conducted in support of the UMTRA Surface or Ground Water Projects at each location.

Point-of-compliance wells have not been proposed for the site at this time. However, DOE will continue to monitor ground water quality and water levels at selected locations (Table 5.1) adjacent to the disposal cell to demonstrate that surface remedial action is as close as reasonable to meeting ground water protection standards (DOE, 1992).

In general, ground water monitor wells will be sampled in order of increasing contamination (or in order of increasing potential for contamination) to minimize possible effects of equipment contamination. Background well 901 will be sampled first followed by far downgradient wells, newly installed upgradient wells, and downgradient wells that are closer to the site in the order provided in Table 5.1.

5.2 ANALYTE SELECTION

Table 5.2 summarizes proposed monitored constituents at the processing site. Analytes to be measured in ground water at the processing site include field parameters as indicators of general water quality and selected constituents identified as site-related contaminants in ground water (DOE, 1994a). Measured field parameters are static water levels, total depth of well, alkalinity, dissolved oxygen, oxidation-reduction potential, pH, specific conductivity, temperature, and turbidity. Selected site-related contaminants to be analyzed in the laboratory are cadmium, calcium, chloride, iron, lead, magnesium, manganese, molybdenum, nitrate, potassium, selenium, sodium, strontium, sulfate, TDS, and uranium. These were selected because they are demonstrated to be site-related

Table 5.1 Order for sampling and summary of ground water monitoring wells for routine sampling at the Tuba City, processing and disposal site

Well Number	Well Status	Monitor concentrations in background	Develop baseline data/monitor concentrations in background	Monitor contaminant concentrations
TUB-01-0901	Existing (G)	X		
TUB-01-0917	Existing (G)			X
TUB-01-0904	Existing (G)			X
TUB-01-0948	Newly installed (S)		X	
TUB-01-0947	Newly installed (S)		X	
TUB-01-0945	Newly installed (G)		X	
TUB-01-0930	Newly installed (G)		X	
TUB-01-0928	Newly installed (G)		X	
TUB-01-0929	Newly installed (G)		X	
TUB-01-0903	Existing (G)			X
TUB-01-0914	Existing (G)			X
TUB-01-0915	Existing (G)			X
TUB-01-0916	Existing (G)			X
TUB-01-0920	Existing (G)			X
TUB-01-0921	Existing (G)			X
TUB-01-0912	Existing (G)			X
TUB-01-0913	Existing (G)			X
TUB-01-0932	Newly installed (G)		X	
TUB-01-0909	Existing (G)			X
TUB-01-0934	Newly installed (G)		X	
TUB-01-0933	Newly installed (G)		X	
TUB-01-0925	Newly installed (S)		X	
TUB-01-0935	Newly installed (G)		X	
TUB-01-0908	Existing (G)			X
TUB-01-0944	Newly installed (G)		X	

Table 5.1 Order for sampling and summary of ground water monitoring wells for routine sampling at the Tuba City, processing and disposal site (Concluded)

Well Number	Well Status	Monitor concentrations in background	Develop baseline data/monitor concentrations in background	Monitor contaminant concentrations
TUB-01-0943	Newly installed (S)		X	
TUB-01-0939	Newly installed (S)		X	
TUB-01-0938	Newly installed (G)		X	
TUB-01-0937	Newly installed (G)		X	
TUB-01-0936	Newly installed (S)		X	
TUB-01-0926	Newly installed (S)		X	
TUB-01-0906	Existing (G)			X
TUB-01-0942	Newly installed (S)		X	
TUB-01-0941	Newly installed (S)		X	
TUB-01-0940	Newly installed (S)		X	
TUB-01-0946	Newly installed (S)		X	

S – Wells to be sampled under UMTRA Surface program budget.

G – Wells to be sampled under UMTRA Ground Water program budget.

Table 5.2 Summary of field parameters and laboratory analytes to be measured in ground water, Tuba City, Arizona, site

Field measurements	Laboratory measurements
Static water level	**Filtered samples**
Total depth of well	Cadmium
Alkalinity	Calcium
Dissolved oxygen	Chloride
Oxidation-reduction potential	Iron
pH	Lead
Specific conductivity	Magnesium
Turbidity	Manganese
Temperature	Molybdenum
	Nitrate
	Potassium
	Selenium
	Sodium
	Strontium
	Sulfate
	Total dissolved solids
	Uranium
	Unfiltered samples
	Cadmium
	Iron
	Lead

contaminants, demonstrated to have maximum levels that clearly exceed background and that could pose a risk to human health and the environment (DOE, 1994a), or required for ion balance (quality assurance/quality control) checks. Iron and manganese were included as indicators of redox conditions in ground water at the site in order to evaluate the potential for biological remediation identified in the site observational work plan (SOWP) for the Tuba City site (DOE, 1994b). TDS were included as an indicator of site-related contamination. Finally, more information is needed to determine if lead is (or is not) a site-related contaminant in ground water. Therefore, this element will also be analyzed. The list includes the constituents (nitrate, molybdenum, selenium, and uranium) identified in the LTSP for the Tuba City site (DOE, 1992) as hazardous constituents that are required to be monitored. A statistical summary of observed levels of all constituents is presented in Table 2.2.

The analytes at the Tuba City site have been selected to efficiently monitor the level of contamination at the site, to meet regulatory requirements, and to provide information for future revisions of the SOWP (DOE, 1994b). The analyte selection does not include constituents that have been determined not to exceed background concentrations (DOE, 1994b). Also not selected are some constituents (ammonium, chromium, tin, and zinc) that were identified as possible ground water contaminants in the Tuba City baseline risk assessment (DOE, 1994a). The decision not to analyze these constituents is based upon the information that the maximum observed levels are well below those that would pose a significant risk to human health or the environment (DOE, 1994a) and that no evidence of increasing trends with time has been observed.

5.3 SAMPLING FREQUENCY

Sampling frequency for monitor wells at the Tuba City site is summarized in Table 1.1. In view of the potential for change in aquifer dynamics and contaminant distribution due to transient drainage, it is recommended that newly installed and existing monitor wells that are located adjacent to the disposal cell be sampled on a quarterly basis. This group includes newly installed monitor wells 940, 941, 942, 943, 944, and 946 (Figure 1.3). Existing monitor well 906 (currently the most contaminated well) is included in this group to provide a link between newly installed monitor well information and existing data. Monitor well 901 is included in the quarterly sampling schedule to monitor changes in background and provide a comparison to site conditions. This sampling frequency will also serve to build a database to describe existing conditions before containment activities begin. This is necessary information to evaluate the effectiveness of the containment process.

Newly installed monitor wells that are located upgradient (945 and 947) and downgradient (932, 933, 935, 937, and 938) (Figure 1.3) of the disposal cell are recommended for semiannual sampling. This is to monitor the containment action, monitor seasonal variability that may affect contaminant concentrations, and to build a statistically defensible database for these new locations. Existing monitor wells in these areas are recommended for annual sampling. These

locations (908, 909, 912, 913, and 914; Figure 1.3) are necessary to monitor contaminant migration downgradient of the site. A reduced sampling frequency is appropriate because there is large existing water quality database for each well (Table 1.1). Newly installed monitor wells 928, 929, and 934 are also recommended for annual sampling because, while these wells are believed to be on the fringe of current contamination, changes in contaminant distribution are likely to be slow in these peripheral areas.

Finally, a group of far downgradient, newly installed and existing monitor wells, which are designed to monitor for the migration of contamination into new areas, is proposed for sampling on alternate years. This sampling frequency is justified by the relatively slow movement of ground water at the site (2 to 100 ft [0.6 to 30 m] per year [DOE, 1995]). The monitor wells included in this group are 903, 904, 915, 916, 917, 920, 921, and 930 (Figure 1.3).

Sampling is recommended to continue with frequencies described above for the next two years at which point quarterly sampling should be scaled back to semiannual sampling. It is recommended that the proposed sampling plan be implemented through 1999. However, after two years, DCOs should be reevaluated and the sampling plan for the following period modified to reflect remaining data needs at the Project site. No changes should be made to the disposal site sampling plan as set forth in the LTSP without the concurrence of the NRC. Routine monitoring at the disposal cell will end when the NRC accepts the ground water compliance strategy for subpart B of 40 CFR 192.

5.4 DATA EVALUATION METHODS

Data results will be compared to previous data and to background data to determine changes or trends in site-related contaminants. Decreases or increases in constituent concentrations will be evaluated to determine if there is

- Evidence for increased or decreased levels of contamination in ground water or surface water at the processing site, which would affect the conclusions of the baseline risk assessment (DOE, 1994a).

- Evidence that MCLs were exceeded for the first time at a sampled location at the site.

- Evidence of movement of contaminated ground water into areas not previously identified as being contaminated.

- Evidence of changes in the ground water flow regime.

5.5 RESPONSE TO ANOMALOUS DATA

Data will be compared to the range of expected values (if known) for each ground water and surface water sampling location. This list includes physical

parameters, such as ground water levels, and chemical parameters, such as pH and uranium. Future data that lie outside of these ranges will be assessed to determine if the value is reasonably expected given the standard deviation of previous sampling rounds or the existence of trends. If the value is not reasonably expected, then field and laboratory records will be checked for the possibility of a sampling or transcription error. If that is not the case, remaining sample (if any) will be re-analyzed to determine if the value is an analytical error. If the anomalous data cannot be shown to be due to sampling or analytical errors, then the well will be resampled for the anomalous parameter during the next sampling event.

6.0 LIST OF CONTRIBUTORS

The following individuals contributed to the preparation of this report.

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A. Holm	Senior technical review
C. Yancey, E. Larsen	Document coordinator, authorship
J. Carman, L. Pivonka	Authorship
D. Erskine	Geochemistry, authorship
J. Carman, D. Erskine, C. Yancey	Peer review
B. Toth	Toxicology
L. Sanchez	Text processing
J. Jones	Editing
K. DeGruyter, S. Suniga	Graphic design

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