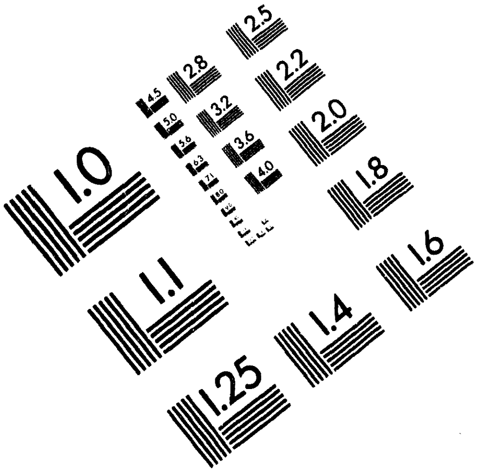
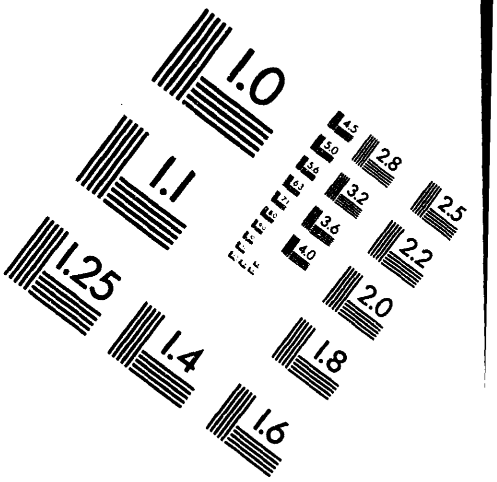


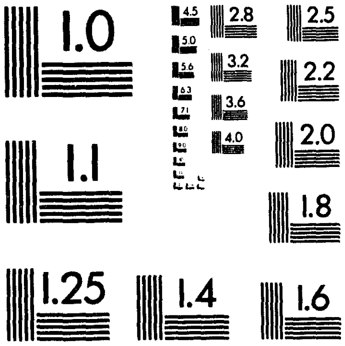
AIIM

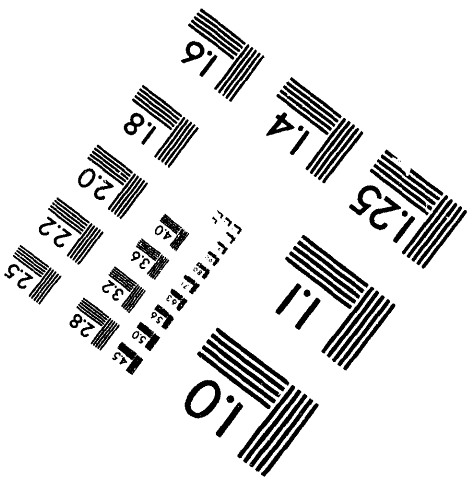
Association for Information and Image Management

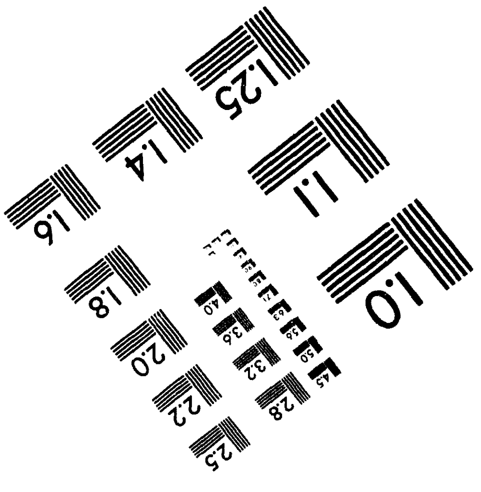
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202









MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DOE/AL/62350-24F-Attach.3-4
REV. 0

REMEDIAL ACTION PLAN AND SITE DESIGN FOR STABILIZATION OF THE INACTIVE URANIUM MILL TAILINGS SITE MAYBELL, COLORADO

Attachment 3, Ground Water Hydrology Report
Attachment 4, Water Resources Protection Strategy

Final

June 1994

Appendix B of the
Cooperative Agreement
No. DE-FC04-81AL16257

Number of pages in this report: 100

DOE/AL/62350-24F
REV. 0

ATTACHMENT 3

GROUND WATER HYDROLOGY REPORT

Final

June 1994

Prepared for
U.S. Department of Energy
UMTRA Project Office
Albuquerque, New Mexico

Prepared by
Jacobs Engineering Group Inc.
Albuquerque, New Mexico

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
ac	acre
CDH	Colorado Department of Health
cm/s	centimeters per second
cm^2/s	square centimeters per second
CSU	Colorado State University
DOE	U.S. Department of Energy
Eh	oxidation/reduction potential
EPA	U.S. Environmental Protection Agency
ft	foot
ft/day	feet per day
ha	hectare
km	kilometer
LBL	Lawrence Berkeley Laboratory
m	meter
mBq/g	millibecquerels per gram
MCL	maximum concentration limit
meq/100 g	milliequivalents per 100 grams
mg/L	milligrams per liter
mi	mile
Pb-210	lead-210
pCi/g	picocuries per gram
pCi/L	picocuries per liter
ppm	parts per million
PVC	polyvinyl chloride
Ra	radium
RRM	residual radioactive materials
TAC	Technical Assistance Contractor
TAD	Technical Approach Document
TDS	total dissolved solids
TEC	Trace Elements Corporation
Th-230	thorium-230
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has established health and environmental regulations to correct and prevent ground water contamination resulting from former uranium processing activities at inactive uranium processing sites (40 CFR Part 192 (1993)) (52 FR 36000 (1978)). According to the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (42 USC §7901 *et seq.*), the U.S. Department of Energy (DOE) is responsible for assessing the inactive uranium processing sites. The DOE has decided that each assessment will include information on hydrogeologic site characterization. The water resources protection strategy that describes the proposed action compliance with the EPA ground water protection standards is presented in Attachment 4, *Water Resources Protection Strategy*. Site characterization activities discussed in this section include the following:

- Definition of the hydrogeologic characteristics of the environment, including hydrostratigraphy, aquifer parameters, areas of aquifer recharge and discharge, potentiometric surfaces, and ground water velocities.
- Definition of background ground water quality and comparison with proposed EPA ground water protection standards.
- Evaluation of the physical and chemical characteristics of the contaminant source and/or residual radioactive materials.
- Definition of existing ground water contamination by comparison with the EPA ground water protection standards.
- Description of the geochemical processes that affect the migration of the source contaminants at the processing site.
- Description of water resource use, including availability, current and future use and value, and alternate water supplies.

On January 5, 1983 (40 CFR Part 192 (1993)), the EPA promulgated final standards for the disposal and cleanup of the inactive uranium processing sites under the UMTRCA. The standards became effective March 7, 1983; however, on September 3, 1985, the ground water provisions of the regulations were remanded to the EPA by the U.S. Court of Appeals for the Tenth Circuit. On September 24, 1987, the EPA issued a proposed revision to the standards (52 FR 36000 (1987)).

Under the UMTRCA, the DOE must comply with the proposed standards until the standards are promulgated in final form. The DOE has characterized the Maybell site and determined that the proposed remedial action would comply with the requirements of Subpart A of the proposed EPA ground water protection standards (52 FR 36000 (1987)). When the final standards are promulgated, the DOE will evaluate ground water protection requirements and undertake action necessary to ensure that the final standards are met. At the Maybell site, the need for and extent of ground water restoration will be evaluated in accordance with the National Environmental Policy Act (42 USC §4321 *et seq.*). Studies are under way to develop plans, guidance materials, and procedures for ground water remediation activities. Additional investigations will be conducted to identify and evaluate remediation strategies for the Browns Park Formation aquifer at the Maybell site. The final decision on how to meet EPA ground water cleanup standards will be part of the Uranium Mill Tailings Remedial Action (UMTRA) Ground Water Project.

Water quality at the Maybell site was characterized by comparison with background ground water quality upgradient and downgradient of the tailings pile and with the hazardous constituents listed or referenced in the proposed EPA ground water standards for inactive (Title I) uranium processing sites. Table 1.1 lists the EPA ground water protection standards (52 FR 36000 (1987) and 40 CFR Part 264 (1993)).

Table 1.1 Maximum concentration limits for hazardous constituents

Constituent	Maximum concentration[a]
Arsenic	0.05[b]
Barium	1.0[b]
Cadmium	0.01[b]
Chromium	0.05[b]
Lead	0.05[b]
Mercury	0.002[b]
Selenium	0.01[b]
Silver	0.05[b]
Endrin (1,2,3,4,10,10-hexachloro-1,7-epoxy-1,4, 4a,5,6,7,8,9a-octahydro-1,4-endo, endo-5, 8-dimethano naphthalene)	0.0002[b]
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.004[b]
Methoxychlor (1,1,1-Trichloro-2,2-bis (p-methoxyphenylethane))	0.1[b]
Toxaphene ($C_{10}H_{10}Cl_6$, Technical chlorinated camphene, 67 to 69 percent chlorine)	0.005[b]
2,4-D (2,4-Dichlorophenoxyacetic acid)	0.1[b]
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	0.01
Nitrate (as N)	10[c]
Molybdenum	0.1[c]
Combined radium-226 and radium-228	5 pCi/L[c]
Combined uranium-234 and uranium-238	30 pCi/L[c] (0.044 mg/L)[d]
Gross-alpha particle activity (excluding radon and uranium)	15 pCi/L[c]

---

[a] Milligrams per liter unless stated otherwise; pCi/L = picocuries per liter.
[b] 40 CFR §264.94, Table 1 (40 CFR Part 264 (1993)).
[c] 40 CFR §192.02(a)(3)(ii), Table A (52 FR 36000 (1987)).
[d] The uranium concentration of 30 pCi/L is equivalent to 0.044 mg/L.

2.0 HYDROGEOLOGICAL SITE CHARACTERIZATION SUMMARY

The DOE has characterized the hydrogeology, water quality, and water resources at the Maybell site, 5 miles (mi) (8 kilometers [km]) northeast of the town of Maybell, in Moffat County, Colorado (Figure 2.1). Major points are summarized below.

- The existing tailings pile is underlain by the Tertiary Browns Park Formation of Miocene age, which unconformably overlies truncated rocks of the Cretaceous Mancos Shale. In this area, the formation consists of poorly cemented fluviolacustrine and eolian sandstones. Within these sandstones are small lenses of siltstone, claystone, and some well-cemented intervals of calcite. The underlying Cretaceous Mancos Shale consists of relatively impermeable dark gray marine shale, with lenticular sandstone beds near the top and base.

- The principal aquifer (uppermost aquifer) is the upper sandstone unit of the Browns Park Formation. The top of the unconfined ground water table occurs within this formation at depths ranging from 35 to in excess of 300 feet (ft) (11 to greater than 90 meters [m]) beneath the ground surface. The average hydraulic conductivity of this aquifer is 1.7 ft per day (ft/day) (6×10^{-4} centimeters per second [cm/s]), and the average linear ground water velocity is 0.17 ft/day (5.2 cm/day) (62 ft/yr [19 m/yr]).

- The Maybell site is located in a recharge area with a limited upslope catchment basin. Recharge to the Browns Park Formation aquifer is principally from the infiltration of precipitation in the form of rain or snow. Discharge of ground water from the Browns Park Formation is to the Yampa River alluvial aquifer system. The potentiometric surface indicates that the ground water is flowing away from the tailings site in a southwestward direction.

- Upgradient background ground water quality in the Browns Park Formation has maximum observed concentrations of arsenic, cadmium, lead, molybdenum, selenium, uranium, and the combined activities of radium (Ra)-226 and Ra-228 that exceed the proposed EPA maximum concentration limits (MCL) (52 FR 36000 (1987)). Downgradient background ground water quality in the Browns Park Formation has maximum observed concentrations of arsenic, cadmium, lead, molybdenum, nitrate, selenium, and uranium that exceed the proposed EPA MCLs (52 FR 36000 (1987)). The integration of data from both upgradient and uncontaminated downgradient monitor wells yields a more complete picture of the variable (and often poor) water quality that is present in the Browns Park Formation. Browns Park Formation domestic well 650 in particular shows elevated levels of hazardous constituents (e.g., nitrate), yet it is located near Maybell several miles downgradient of the tailings pile. This well is far beyond the possible influence of contamination from the tailings pile.

- Chemical analysis of tailings pore water samples obtained from suction lysimeters installed in the existing tailings pile provided the determination of hazardous constituents that exceed proposed EPA MCLs (52 FR 36000 (1987) and 40 CFR Part 264 (1993)) (see Table 3.1). Mean concentrations of arsenic, cadmium,

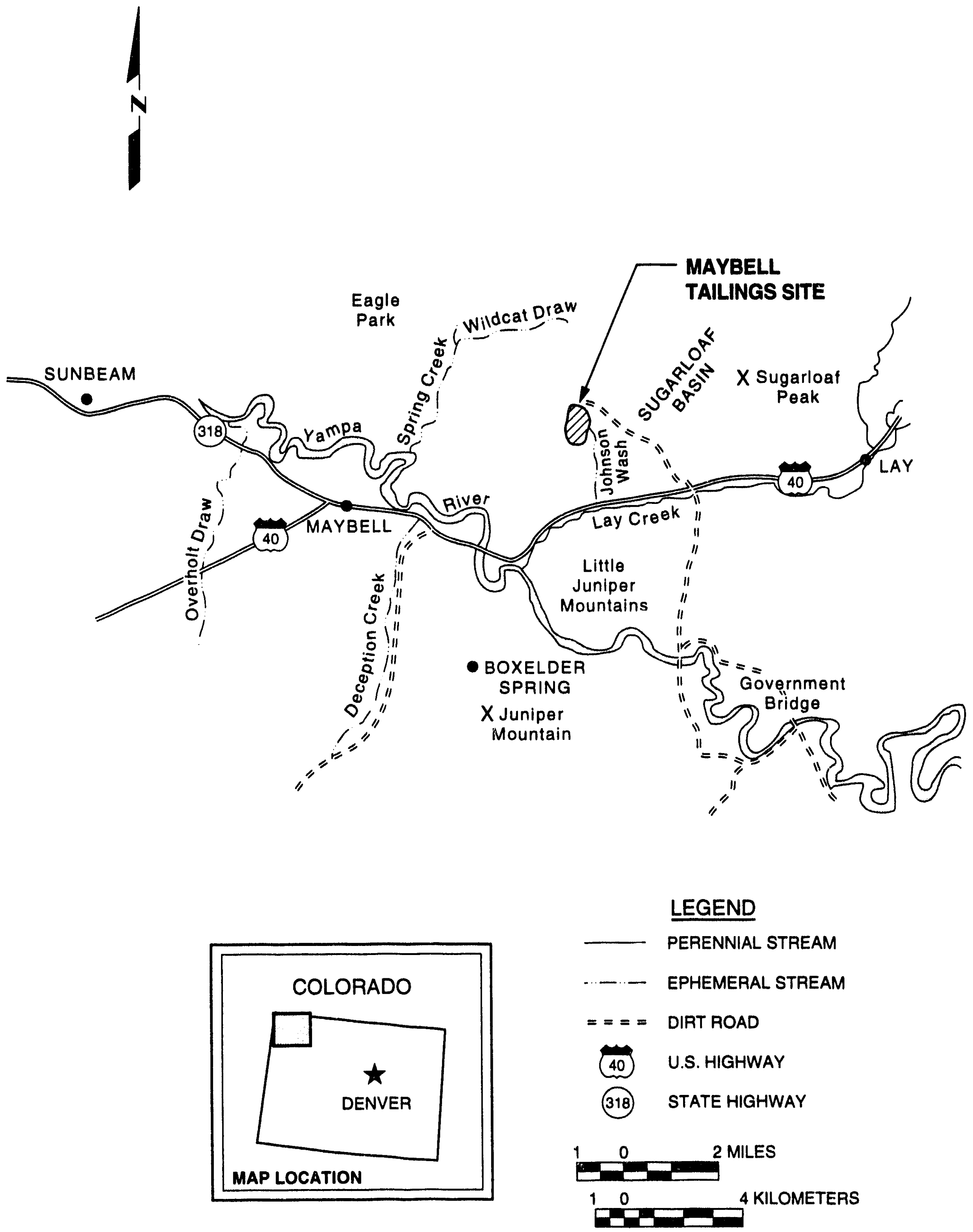


FIGURE 2.1
LOCATION MAP OF THE MAYBELL TAILINGS SITE
NEAR MAYBELL, COLORADO

molybdenum, nitrate, selenium, uranium, and the combined activities of Ra-226 and Ra-228 in the tailings pore water exceeded the proposed EPA MCLs.

- The geochemical properties of the tailings material and the Browns Park Formation sediments affect the solubility of minerals and solid compounds that contain hazardous constituents at the Maybell site. Mineralogical and chemical analyses of background soil samples and sediment samples from beneath the tailings, along with a review of the literature on contaminant mobility and the ground water quality data at the Maybell site, suggest that arsenic, molybdenum, selenium, uranium, Ra-226, and Ra-228 are largely removed from solution through precipitation and adsorption processes. In addition, nitrate is removed by biologically mediated denitrification processes as suggested by microbiological studies.

- The nearest downgradient domestic well is 3 mi (5 km) south of the Maybell tailings site and is completed in the Yampa River Valley alluvium, which is recharged by the Browns Park Formation.

Ground water from the Browns Park Formation has been used for limited livestock watering, as two windmill-operated wells formerly existed for this purpose. One windmill-operated well was located along Johnson Wash approximately 1 mi (1.6 km) south of the tailings pile but was removed between 1990 and 1992 (TAC, 1990; 1992). The second windmill-operated well was located 2.3 mi (3.7 km) northeast of the tailings pile. Discussions with the well owner indicated that the owner had not used this windmill since about 1982 (McIntyre, 1987).

3.0 GROUND WATER INVESTIGATIONS

3.1 PREVIOUS INVESTIGATIONS

Several investigations of the hydrogeologic environment have been undertaken in the vicinity of the Maybell tailings site. These investigations include stratigraphic and hydrogeologic reconnaissance surveys, surface and subsurface radioactivity surveys, and sampling and water quality analyses.

Previous hydrogeologic investigations of the Maybell tailings site were conducted by Trace Elements Corporation (TEC) (Travelli, l959). These studies determined that the depth to ground water within the Browns Park Formation was approximately 145 ft (44 m) and the aquifer was unconfined.

Dames & Moore (1975) studied hydrological conditions within the Browns Park Formation at the Union Carbide Corporation's uranium heap leaching facility 1.3 mi (2.1 km) west of the Maybell tailings site. Results of the study indicated that ground water flow was to the west and that hydraulic conductivity of the Browns Park Formation ranged from 0.5 to 13.4 ft (0.2 to 4.1 m) per day (180 to 4890 ft [73 to 1500 m] per year).

A water quality sampling program for inorganic parameters was conducted by Umetco Minerals Corporation from 1976 to 1986 (Umetco, 1986). Several surface water samples were obtained from Rob Pit and ground water samples were obtained from monitor wells completed in the Browns Park Formation (Dames & Moore, 1975). Results of these chemical analyses vary widely and may be influenced by analytical error where charge-balance errors range from 0.4 to 38 percent. Sulfate concentrations in ground water in the Browns Park Formation ranged from 317 to 1486 milligrams per liter (mg/L). Sulfate concentrations decrease with depth in the Browns Park Formation aquifer.

Oak Ridge National Laboratories conducted studies that measured lead-210 (Pb-210), Ra-226, and thorium-230 (Th-230) activities in surface water samples from Johnson Wash and Lay Creek and in ground water samples from the Browns Park Formation (Haywood et al., 1980). Activities of these isotopes were elevated above background in five surface water samples and one ground water sample from the Browns Park Formation.

Ford, Bacon & Davis Utah, Inc. (1981) performed engineering assessments at the Maybell tailings site. These studies described geological conditions, and an initial investigation on ground water quality within the Browns Park Formation beneath the tailings pile was performed. Results of these studies indicate that the Browns Park Formation underlies the tailings pile and is primarily a homogeneous sandstone with some discontinuous shale beds. The investigators commented that activities of Ra-226 and -228 in ground water were related to the presence of an ore body rather than a result of tailings leachate.

Lawrence Berkeley Laboratories conducted a hydrochemical investigation at the Maybell tailings site (Narasimhan et al., 1982). Water quality data were collected from three suction lysimeters and three monitor wells in the tailings pile. Results of the investigation show that the tailings pore water was acidic and contained a high total dissolved solids (TDS) content. The study also indicated that acidic tailings leachate has migrated to the water table.

Geochemical and Environmental Chemistry Research, Inc. (GECR, 1983) conducted a ground water, surface water, tailings, and soil sampling program in the area of the Maybell tailings site. A total of 25 samples were collected and analyzed for major and trace element concentrations. Analyses were reported for several surface water samples from Johnson Wash, Lay Creek, Spring Creek, Small Creek, and the Yampa River, both upstream and downstream of the Maybell tailings site. Additional surface water samples were collected from several springs, including Juniper Hot Springs. Other surface water samples were taken from the pond on the tailings pile. Water and acid extracts were performed on solid samples collected within and adjacent to the tailings pile. Three wells near the towns of Maybell and Lay were also sampled during the investigation. Results of this study were in agreement with previous investigations (Narasimhan et al., 1982), confirming the presence of acidic tailings pore fluids within the tailings pile. These fluids are characterized by elevated concentrations of uranium, sulfate, and other elements.

Leaching extracts of tailings samples and soils below the tailings pile/Browns Park Formation contact were analyzed in a survey conducted by Colorado State University (CSU, 1983). Results of the study indicate that no significant movement of radionuclides or other contaminants (including anions such as sulfate) beyond a neutralization zone was evident from the analysis of foundation materials.

Radiological sampling of stream sediments along Johnson Wash and Lay Creek and of tailings material were conducted (BFEC, 1985). Anomalously high activities of Ra-226 (up to 552 picocuries per gram [pCi/g]) (20,400 millibecquerels per gram [mBq/g]) and Th-230 (up to 806 pCi/g) (29,800 mBq/g) were reported in soil samples obtained from Johnson Wash and Lay Creek. These high activities of Ra-226 and Th-230 were the result of multiple surface discharges of tailings effluent to Johnson Wash that eventually migrated to Lay Creek.

3.2 CURRENT INVESTIGATIONS

Hydrogeologic field data have been collected by the DOE from 1986 to 1992 to further characterize the lithology, hydraulic properties, and ground water quality in the vicinity of the Maybell tailings site. The DOE completed 39 monitor wells in the Browns Park Formation. Monitor wells were located hydraulically upgradient and downgradient from the tailings site to characterize background ground water quality in the Browns Park Formation. The locations of the upgradient and downgradient background monitor wells with respect to area uranium mines are presented in Figure 3.1. In addition to the upgradient and downgradient background monitor wells, several monitor wells were completed through the tailings pile and adjacent to the tailings pile. Monitor well and lysimeter locations are shown in Figure 3.2. The DOE monitor wells were constructed either with 2- or 4-inch (5- or 10-cm)-diameter polyvinyl chloride (PVC) casing. All of the DOE monitor wells were completed in the Browns Park Formation and range in depth from 90 to 400 ft (27 to 120 m). Also, six domestic wells (650 through 655) near the town of Maybell have been monitored as part of site characterization. Five of the six domestic wells (651 through 655) were completed in the Yampa River Valley alluvium and one monitor well (650) was completed in the Browns Park Formation (Figure 3.3). Four additional boreholes were drilled to depths of 100 to 300 ft (30 to 90 m) below the land surface to obtain lithological samples. The boreholes were cemented from bottom to ground surface after sampling was completed. Information concerning well completion and well log records is available at the UMTRA Project Office in Albuquerque, New Mexico.

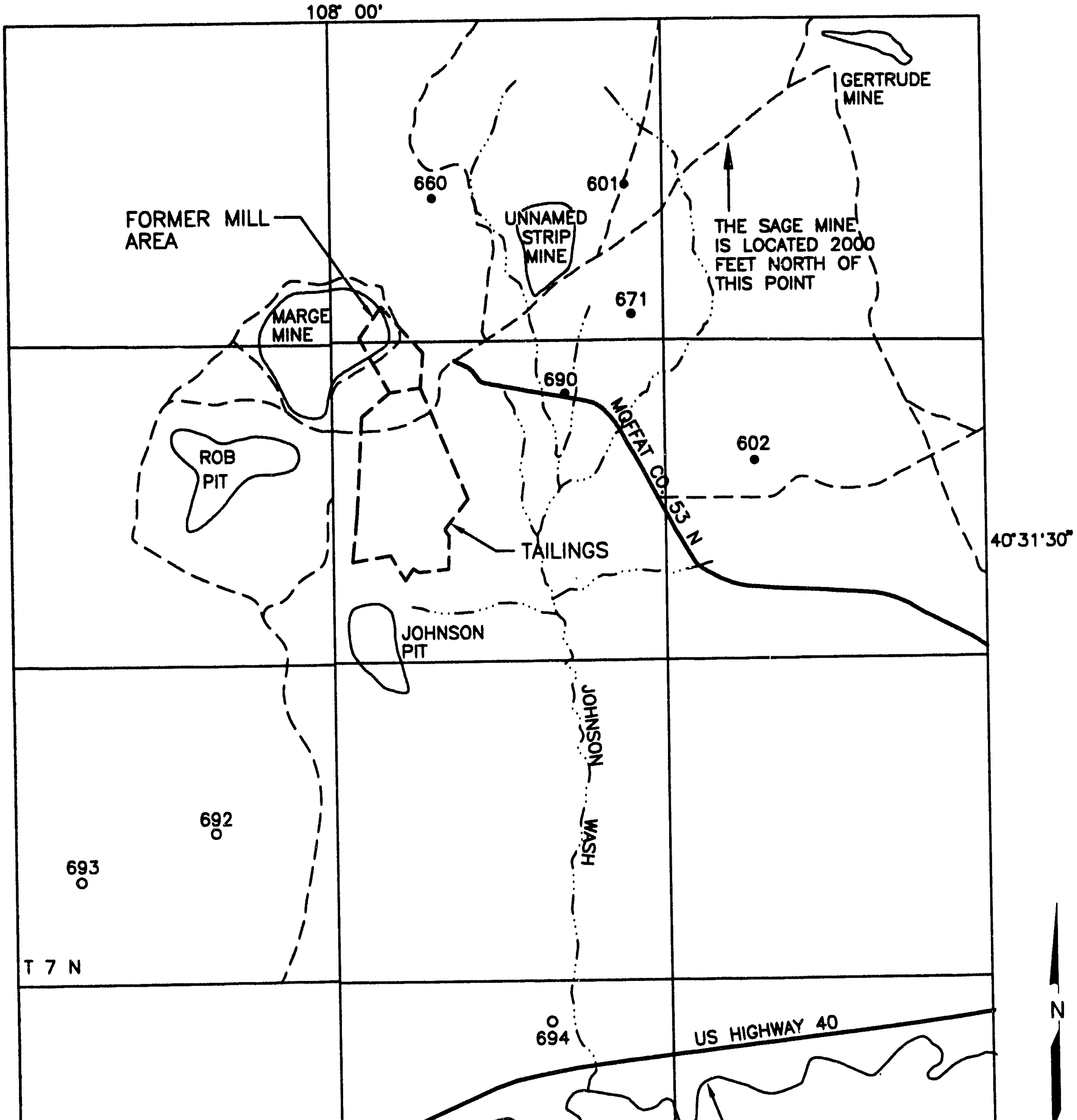
Following installation and development of the monitor wells, slug withdrawal tests and pumping tests were performed to measure the hydraulic parameters of the Browns Park Formation. The monitor wells were surveyed and ground water elevations were measured to determine the hydraulic gradient and ground water flow direction.

The monitor wells were sampled for water quality analysis in accordance with sampling procedures developed by the DOE. All contracted laboratories use modified EPA or DOE analytical methods. The samples were analyzed for water quality parameters listed in Table 8.1 of the Technical Approach Document (TAD) (DOE, 1989), Table 1 of 40 CFR §264.94 (40 CFR Part 264 (1993)), Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000 (1987)), and the field parameters alkalinity, oxidation-reduction potential (Eh), pH, specific conductivity, and temperature. The analytical results submitted by each laboratory were subjected to a rigorous quality assurance program. Ground water quality data by location are presented in Appendix B to Attachment 3, *Ground Water Hydrology Report*.

3.3 HYDROSTRATIGRAPHY

The Maybell tailings site is underlain by the Tertiary Browns Park Formation of Miocene age, which unconformably overlies truncated rocks of the Cretaceous Mancos Shale. The beds of the Browns Park Formation generally dip less than 10 degrees to the north toward the east-west trending axis of the Lay Syncline, located north of the site (Figure 3.4). In this area, the Browns Park Formation is comprised of fluviolacustrine and eolian sandstones overlying a fluvial basal conglomerate (Chenoweth, 1986). The lower conglomerate unit (from 0 to 150 ft [0 to 45 m] thick) consists of pebble- to cobble-sized clasts of igneous and volcanic rocks in a finer-grained matrix of arkosic sand and clay, intercalated with a few thin, fine- to coarse-grained sandstone beds. The upper sandstone unit (approximately 1000 ft [300 m] thick) consists of tan to gray, fine- to

MAYBE-31.CDR MAYBELL RAP ACAD MASTER FILE MAYA01.DWG (NEW FILE MAYBE-31.DWG XREF MAYBBASE.DWG) H:\USERS\UNIGA\MAYBELL



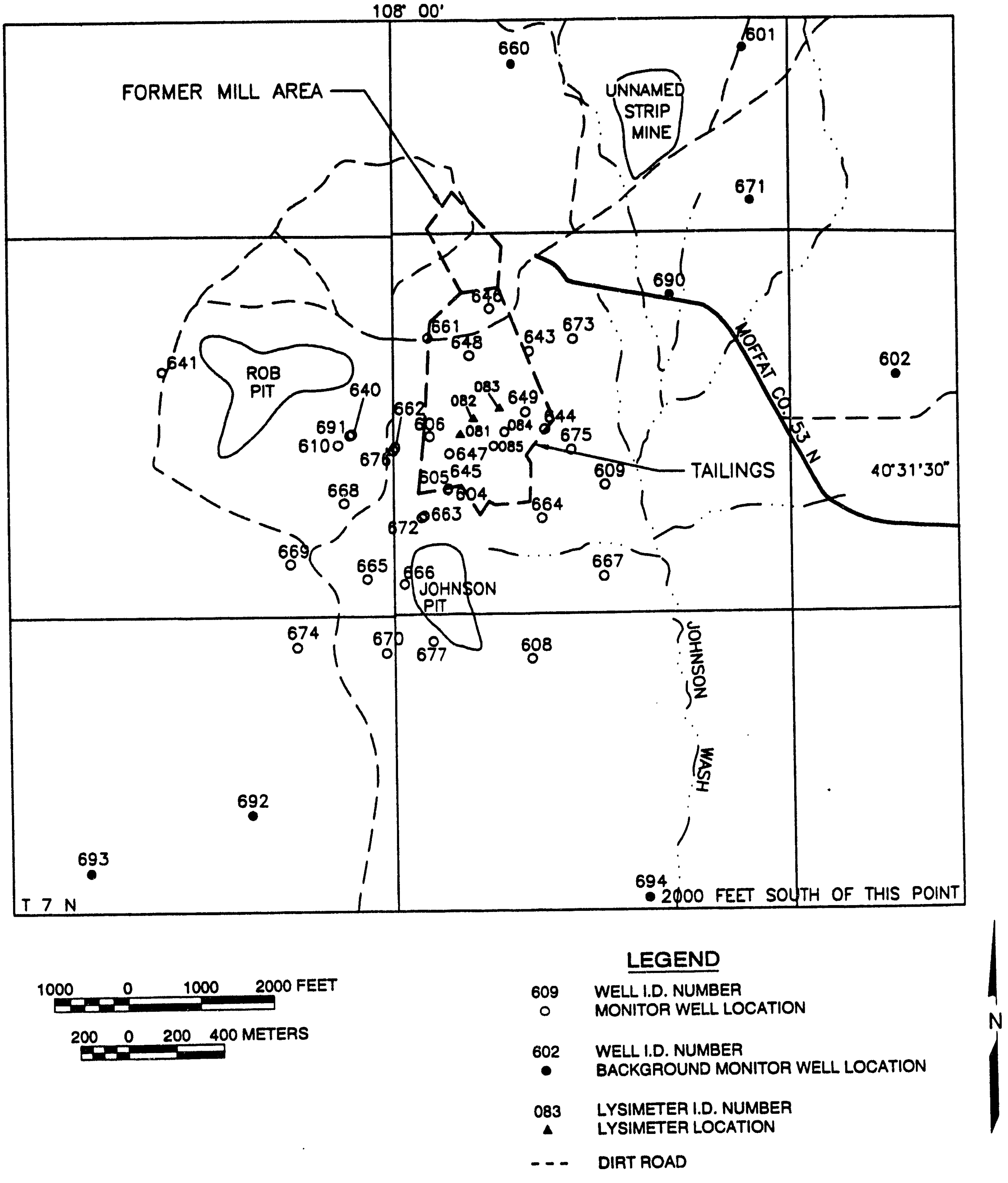
1000 0 1000 2000 FEET

200 0 200 400 METERS

LEGEND

602 ●	WELL I.D. NUMBER UPGRADIENT BACKGROUND MONITOR WELL LOCATION
692 ○	WELL I.D. NUMBER DOWNGRADIENT BACKGROUND MONITOR WELL LOCATION
- - -	DIRT ROAD
~	PERENNIAL STREAM
—··—	EPHEMERAL STREAM

FIGURE 3.1
LOCATIONS OF UPGRADIENT AND DOWNGRADIENT BACKGROUND MONITOR WELLS AND AREA URANIUM MINES AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO



H:\USERS\SUNG\MAYBELL 6-2-94

ACAD MASTER FILE MAYA01.DWG (NEW FILE MAYBE-32.DWG XREF MAYBBASE.DWG)

MAYBELL RAP

MAYBE-32.CDR

FIGURE 3.2
LOCATIONS OF MONITOR WELLS AND LYSYMETERS AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

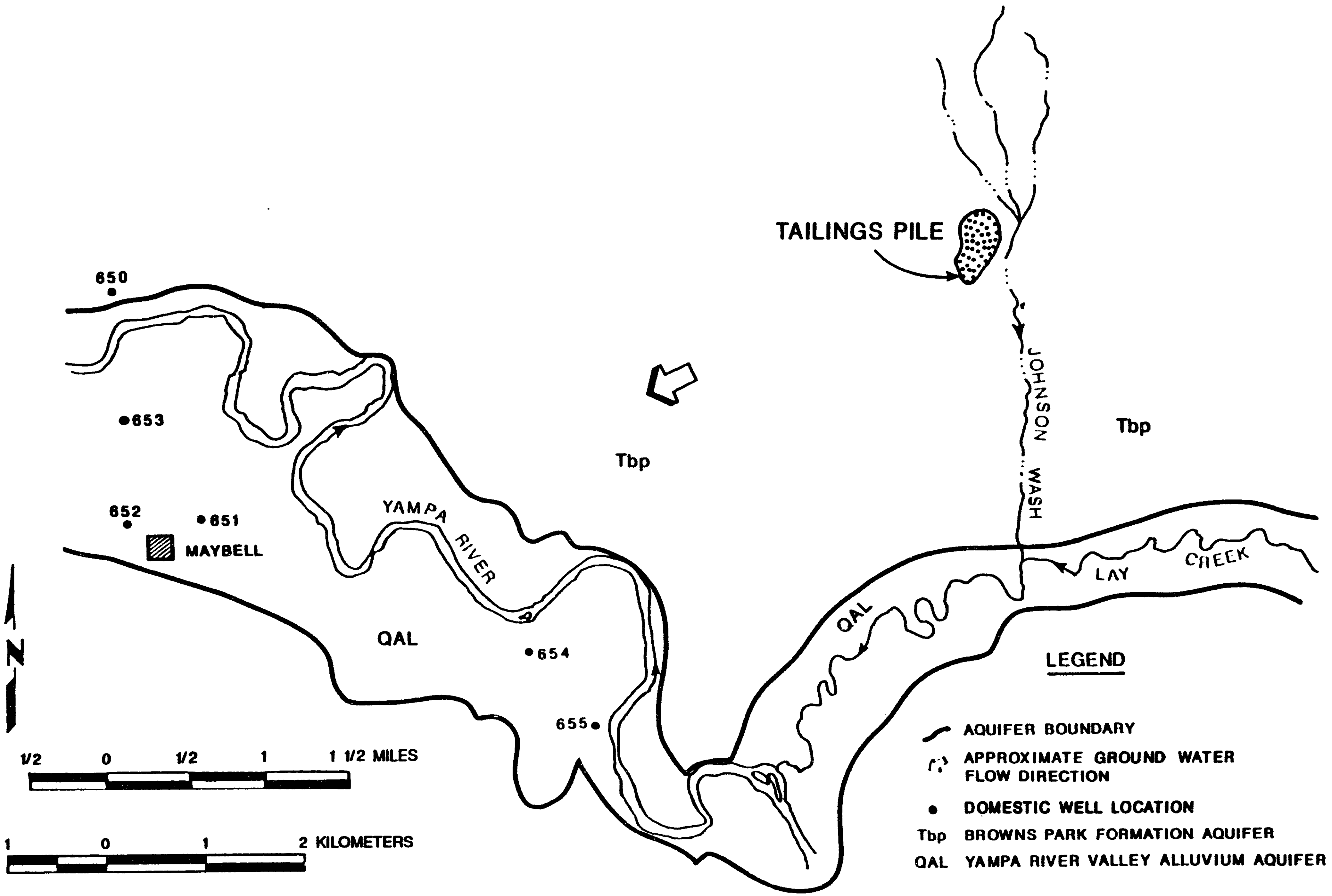
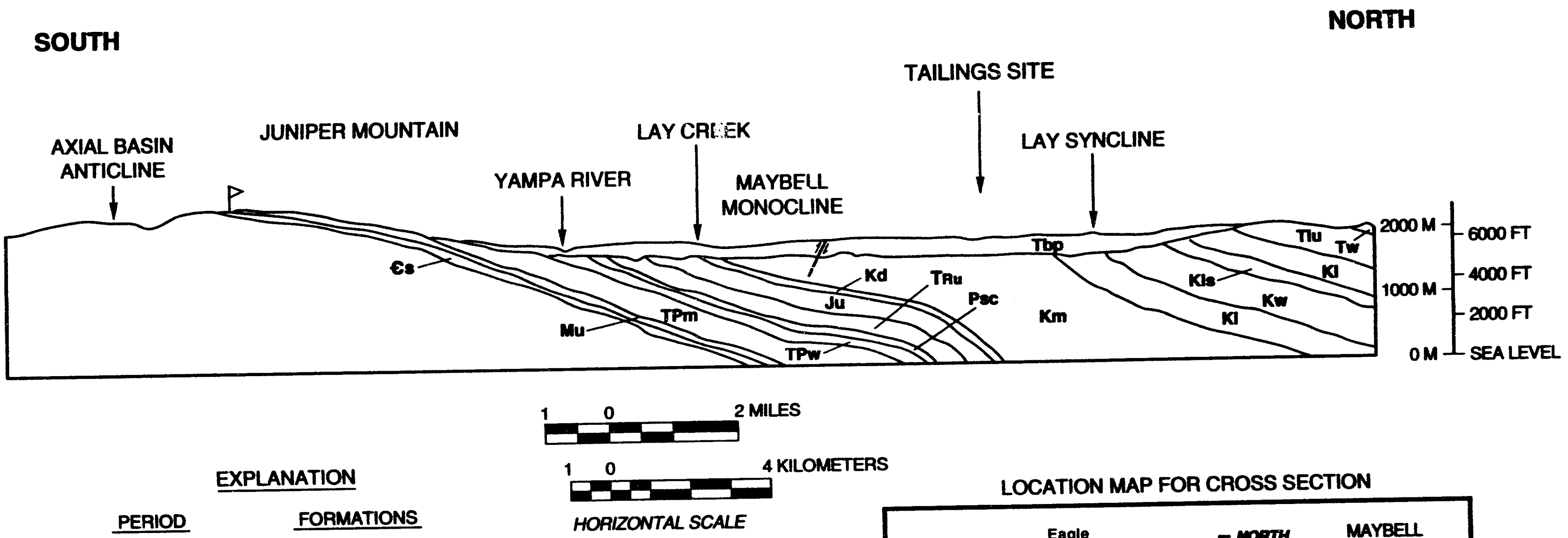


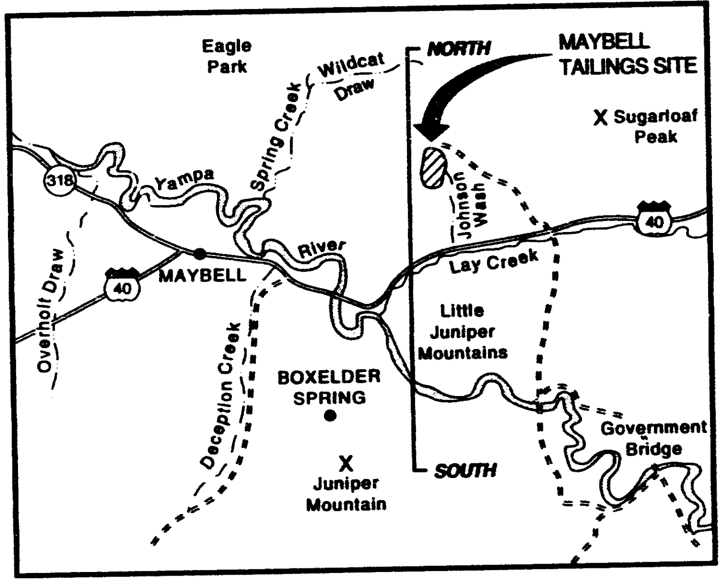
FIGURE 3.3
LOCATIONS OF DOMESTIC WELLS
MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO



EXPLANATION

PERIOD		FORMATIONS
TERTIARY	Tbp	BROWNS PARK
	Tw	WASATCH
	Tlu	FORT UNION
CRETACEOUS	Kl	LANCE
	Kls	LEWIS SHALE
	Kw	WILLIAMS FORK
	Kl	ILES
	Km	MANCOS SHALE
	Kd	DATOTA
JURASSIC	Ju	UNDIVIDED ROCKS
TRIASSIC	TRu	UNDIVIDED ROCKS
PERMIAN	Psc	SOUTH CANYON MEM., MAROON FM.
PENNSYLVANIAN	TPw	WEBER SANDSTONE
	TPm	MORGAN
MISSISSIPPIAN	Mu	UNDIVIDED ROCKS
CAMBRIAN	€s	SAWATCH
PRECAMBRIAN	p€	UINTA MTN. GROUP

LOCATION MAP FOR CROSS SECTION



REF: BERGIN, 1959

FIGURE 3.4
STRUCTURAL CROSS SECTION THROUGH THE MAYBELL SITE AREA NEAR MAYBELL, COLORADO

MAC: SITE/MAY/RAP/STRUCT CROSS SECT

medium-grained sandstone and minor interbeds and lenses of conglomerate, chert, siltstone, marlstone, and volcanic ash and pumice (which is commonly altered to clay). The tan sandstones, typical of the oxidized zone, are commonly stained with limonite/hematite and jarosite. The unoxidized (or reduced) gray sandstones contain finely divided pyrite. Depth to the top of the reduced zone ranges from 40 to 240 ft (12 to 73 m), which corresponds approximately to the first occurrence of ground water. The sandstone is commonly weakly cemented above the water table but is generally friable and uncemented below the water table. Occasional thin lenses are moderately hard with carbonate cementation. The minor cementing materials in the subsurface are calcite and clay. The underlying Cretaceous Mancos Shale consists of relatively impermeable dark gray marine shale, with lenticular sandstone beds near the top and base.

Uranium deposits were discovered in the Maybell Uranium District in 1953. This district was one of the principal areas of uranium production in Colorado. Uranium mineralization generally occurs in the upper sandstone unit of the Browns Park Formation at the Maybell site as amoeba-shaped deposits. The source of the uranium is believed to be tuffaceous beds in the Browns Park Formation. Hydrocarbons escaping from underlying Cretaceous formations are postulated to have been important in creating reducing conditions necessary for precipitation of uranium (Chenoweth, 1986).

3.4 HYDRAULIC CHARACTERISTICS

Ground water occurs in the upper sandstone unit of the Browns Park Formation (uppermost aquifer) under unconfined conditions beneath the Maybell tailings site. Water levels measured in monitor wells in the vicinity of the site range from 35 to over 300 ft (11 to 90 m) beneath the surface. Fluctuations of ground water elevations were generally less than 2 ft (0.6 m) (from lowest to highest ground water elevation) during a period of measurement of over 3 years. These minor fluctuations are in response to temporal and spatial variation in precipitation and subsequent recharge of the aquifer.

Ground water also occurs in the alluvium associated with the Yampa River and Lay Creek. Ground water in the Yampa River Valley alluvium is unconfined and ranges in depth from 10 to 20 ft (3 to 6 m) below land surface. Based upon ground water elevations projected from the potentiometric surface of the Browns Park Formation, it appears that the Yampa River alluvium is recharged by ground water from the Browns Park Formation.

Ground water beneath the Maybell site is recharged from a limited upslope catchment basin. Recharge is principally from infiltration of precipitation in the form of rain or snow. The average annual precipitation in the area is 13.3 inches (34 cm) per year (NOAA, 1977) and the average annual pan evaporation rate is 48 inches (122 cm) per year (NOAA, 1968).

Ground water elevations measured in monitor wells were used to construct a potentiometric surface map (water table map) to determine the direction of ground water flow and hydraulic gradient in the Browns Park Formation aquifer (Figure 3.5). The potentiometric surface indicates that the ground water flow direction is generally toward the southwest beneath the site, with a hydraulic gradient of approximately 0.02 ft/ft (0.6 cm/cm) (Calculation MAY-11-93-14-07-00) (see Attachment 3, Appendix A, *Hydrological Services Calculations*). The area beneath and upgradient from the tailings pile appears to have a steeper hydraulic gradient, which reflects the ground water recharge of the upper reaches of Johnson Wash and seepage from the tailings pile. A ground water mound appears to exist beneath and upgradient from the tailings pile and is very likely the result of tailings seepage recharging the water table. It is inconclusive whether the mound is real or whether it is an artifact of improper installation of wells placed through the tailings pile. Some of the monitor wells (the 640-series wells), which define the mound, were installed before the Technical Assistance Contractor (TAC) became involved with the UMTRA Project. Completion records are incomplete for these wells, and it is difficult to determine whether their construction was adequate to prevent hydraulic communication between tailings seepage and the water table. Because these wells were installed through tailings, the potential exists for a well to become a conduit for contamination if improperly constructed. Thus, water level data and ground water quality data obtained from these wells may be suspect. However, there is evidence that suggests that this mound may be real. First, water levels from monitor wells located immediately beyond the tailings pile footprint are higher in elevation than that of the regional water table elevation (Figure 3.5). Second, the elevated nitrate concentrations in monitor well 673 located hydraulically upgradient of the tailings pile could occur from local radial ground water flow which is superimposed on the regional ground water table.

Pumping tests were conducted in four monitor wells (662, 663, 665, and 672) to measure hydraulic parameters of the upper portion of the Browns Park Formation at the Maybell tailings pile. Ground water was pumped from the aquifer at a specified constant rate of discharge for a designated time interval, and drawdown versus time was measured in the pumped wells and in adjacent observation wells. After the pumping tests were completed, recovery of the water levels in the wells was also measured versus time. Both pumping and recovery data from the pumping tests were analyzed using the Theis non-equilibrium equation (type-curve method) (Freeze and Cherry, 1979; Lohman, 1972). Results indicated unconfined conditions with delayed yield during the latter stages of the tests. Calculations based on pumping test data from the four monitor wells indicated an arithmetic mean for transmissivity of 92 ft^2/day (0.99 square centimeters per second [cm^2/s]). Hydraulic conductivity was determined by dividing the calculated transmissivity by the average saturated thickness of the aquifer. The average hydraulic conductivity of the upper sandstone unit was estimated to be 1.7 ft/day (6.0×10^{-4} cm/s). An estimate of specific yield (storativity) was obtained from late time drawdown data (delayed yield curves). The storativity arithmetic mean was 4.0×10^{-3}. Data and calculations from the pumping tests are on file at the UMTRA Project

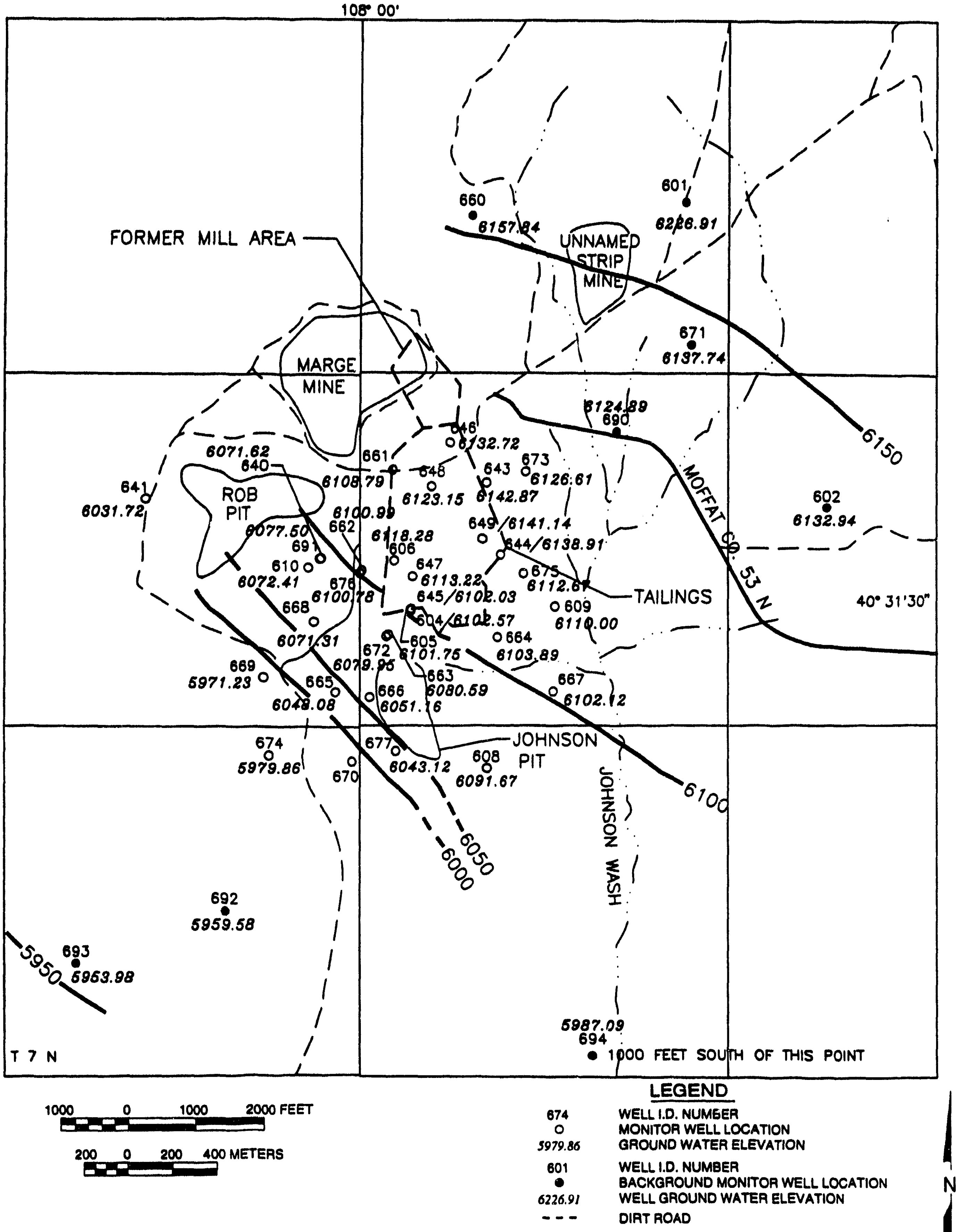


FIGURE 3.5
POTENTIOMETRIC SURFACE MAP FOR THE BROWNS PARK FORMATION AQUIFER, MAY 1992, NEAR MAYBELL, COLORADO

Office in Albuquerque, New Mexico (Calculation MAY-03-90-14-03-00) (see Attachment 3, Appendix A).

Falling head slug tests were conducted in monitor wells to estimate the hydraulic conductivity of the upper sandstone unit of the Browns Park Formation beneath the Maybell site. Hydraulic conductivities derived from slug tests are less reliable than those derived from pumping tests due to limitations inherent in the technique. The slug tests provide a relative indication of the range of variability in hydraulic conductivity across the site. The Bouwer and Rice Method (Bouwer, 1989) was used to analyze the slug test data. The results of the slug tests confirm the spatial variability of hydraulic conductivity in the aquifer, and the results were within an order of magnitude of the hydraulic conductivities obtained from the pumping tests. Data and calculations for the slug tests are on file at the UMTRA Project Office in Albuquerque, New Mexico (Calculation MAY-09-90-14-02-00) (see Attachment 3, Appendix A).

The average linear ground water velocity was estimated from reasonable values for hydraulic parameters, including hydraulic conductivity, hydraulic gradient, and effective porosity. These parameters are quantified based on the most representative values (generally averaged) available from hydrogeologic characterization data for the site. Darcy's Law was used to calculate the average linear ground water velocity in the upper sandstone unit of the Browns Park Formation. The average linear ground water velocity was 0.17 ft/day, based on an average hydraulic conductivity of 1.7 ft/day (derived from pumping test data) (6×10^{-4} cm/s), an average hydraulic gradient of 0.02 ft/ft (0.6 cm/cm) (from potentiometric surface map), and an effective porosity of 0.20 (Freeze and Cherry, 1979) (Calculation MAY-11-93-14-07-00) (Attachment 3, Appendix A).

3.5 BACKGROUND GROUND WATER QUALITY

Background ground water quality is defined as the quality of ground water that would exist at the site if contamination had not occurred from the designated uranium processing facility. Background ground water quality has been determined by chemical analyses of ground water samples collected from upgradient monitor wells 601, 602, 660, 671, and 690 and downgradient monitor wells 692, 693, 694, and domestic well 650 completed in the Browns Park Formation. These monitor wells are located sufficiently upgradient or downgradient from the tailings pile to not be affected by tailings leachate. They are, however, in areas that may have been affected by ambient uranium mineralization, mining activities, or other anthropogenic sources of contamination. The integration of data from both upgradient and uncontaminated downgradient monitor wells yields a more complete picture of the variable (and often poor) water quality present in the Browns Park Formation. Browns Park Formation domestic well 650 in particular shows elevated levels of hazardous constituents (e.g., nitrate), yet it is located near Maybell several miles downgradient of the tailings pile. This well is far beyond the possible influence of contamination from the tailings pile.

For characterization purposes, background ground water quality has been evaluated by determining a mean concentration and a maximum observed concentration. Average background concentrations of hazardous constituents are presented statistically by a mean or median determined by parametric methods if the data fit a normal or lognormal distribution. If the data do not follow these distributions or there are too little data or a high number of non-detects, nonparametric methods are used to estimate the median. A summary of the concentrations of hazardous constituents in background ground water in the Browns Park Formation that exceed the laboratory method reporting limits, the mean or median values, and the maximum observed values are presented in Table 3.1.

Contaminants in ground water may be derived from both natural (mineralized zones) and man-made sources (exploration drilling and open pit mining) that are not related to the uranium milling activities at the Maybell site. Portions of the Browns Park Formation have become oxidized through mining activities, which has resulted in elevated concentrations (with respect to the MCLs) of arsenic, cadmium, molybdenum, lead, selenium, uranium, and the combined activities of Ra-226 and Ra-228 in the background ground water. Table 3.1 compares background ground water quality upgradient and downgradient from the tailings pile. Table 3.1 also presents maximum observed concentrations for hazardous constituents in the upgradient and downgradient background ground water monitor wells.

Table 3.2 compares the ground water quality of upgradient and downgradient background wells on a well-by-well basis with the state of Colorado's agricultural standards (CDH, 1990) for those constituents that exceed the standard. In downgradient background wells, maximum observed concentrations for arsenic, boron, cadmium, chromium, lead, manganese, molybdenum, combined nitrate and nitrite, and selenium have exceeded the agricultural standards in one or more monitor wells. In upgradient background wells, maximum observed concentrations for boron, cadmium, chromium, lead, manganese, molybdenum, and selenium have exceeded the agricultural standards in one or more monitor wells. Upgradient background monitor well 601 has an acidic pH (4.94) that falls below the agricultural standard range; this may be a result of localized sulfide mineral oxidation within the ore zones at the site. Elevated concentrations of manganese and selenium appear to be widespread, since these constituents each exceed the agricultural standards in six of the nine background wells.

Background ground water quality in the Browns Park Formation near the site is influenced by the presence of naturally occurring uranium mineralization. Numerous open pit mines are located hydraulically upgradient of the mill site and the tailings pile. The Rob, Marge, Gertrude, Sage, and Johnson open pit mines are the five largest in the Maybell mining district (Figure 3.1). The Gertrude, Sage, and an unnamed strip mine located just northeast of the Maybell tailings pile are open pit mines that are potential sources of contamination for ground water. A characteristic feature of the deposits at Maybell is the large amount of

Table 3.1 Hazardous constituents detected in ground water and tailings pore water at the Maybell tailings site, Moffat County, Colorado

		Background				Source concentration
		Upgradient[c]		Downgradient[d]		Tailings pore fluid
Hazardous[a] constituent	MCL[b]	Maximum observed concentration	Mean or median	Maximum observed concentration	Mean or median	Lysimeter[e] mean
Arsenic	0.05	0.06	0.011[f]	0.26	0.0125[f]	0.06
Cadmium	0.01	0.031	0.0005[f]	0.021	0.0005[f]	0.011
Lead	0.05	0.17	0.005[f]	0.15	0.005[f]	0.045
Molybdenum	0.10	0.11	0.022[f]	0.28	0.02[f]	2.049
Nitrate (NO_3)	44.0[g]	24.5	2.8[f]	190	1.0[f]	1949
Combined Ra-226 and -228 (pCi/L)[h]	5.0	5.5	1.3[f]	3.1	0.50[f]	17.92
Selenium	0.01	1.3	0.005[f]	0.028	0.005[f]	0.54
Uranium	0.044[i]	0.112	0.016[j]	0.095	0.0019[f]	1.221
Inorganic constituent without MCL						
Antimony	NA	0.14	0.003[f]	0.02	0.003[f]	0.014
Beryllium[k]	NA	<0.025[l]	0.005[m]	<0.01[l]	0.005[m]	0.025
Manganese	NA	6.06	0.30[n]	1.13	0.41[o]	--
Nickel	NA	0.10	0.04[f]	0.08	0.04[f]	0.50

[a] Hazardous constituents from Table 1 of 40 CFR §264.94 and Table A of 40 CFR §192.02(a)(3)(ii) (proposed standards) (52 FR 36000). All concentrations in milligrams per liter unless noted otherwise.

[b] MCL—maximum concentration limit. Table 1 of 40 CFR §264.94 and Table A of 40 CFR §192.02(a)(3)(ii) (proposed standards) (52 FR 36000).

[c] Upgradient background ground water—from monitor wells 601, 602, 660, 671, and 690.

[d] Downgradient background ground water—from monitor wells 650, 692, 693, and 694.

[e] Lysimeter arithmetic mean—lysimeter data are weighted from lysimeters 081, 083, and 085 located on the tailings pile.

[f] Median determined nonparametrically.

[g] The MCL for nitrate as (N) is 10 mg/L.

[h] pCi/L—picocuries per liter.

[i] The uranium concentration of 0.044 mg/L is equivalent to 30 pCi/L, which is the MCL.

[j] Median lognormal distribution.

[k] All values recorded are less than the method detection limit.

[l] Maximum method detection limit.

[m] Mean or median not calculated, as all values are less than the method detection limit.

[n] Mean lognormal distribution.

[o] Mean normal distribution.

Table 3.2 Maximum observed concentrations for those constituents that have exceeded the state of Colorado's agricultural standards in background monitor well[a]

		Downgradient background monitor wells			
Constituent	Agricultural standard (mg/L)	650	692	693	694
Arsenic	0.1	0.012	0.26[b]	0.02	0.022
Boron	0.75	0.17	0.08	0.12	0.77[b]
Cadmium	0.01	0.021[b]	<0.001	0.001	<0.005
Chromium	0.1	0.14[b]	0.06	0.10	0.02
Lead	0.1	0.15[b]	<0.01	0.01	0.01
Manganese	0.2	1.13[b]	0.10	0.85[b]	0.29[b]
Molybdenum	0.10	0.08	0.15[b]	0.28[b]	0.02
Nitrate and Nitrite	100	190[b]	4.9	7.1	2.1
Selenium	0.02	0.023[b]	<0.03	0.028[b]	0.013
pH	6.5-8.5	7.10	6.67	6.57	7.05

		Upgradient background monitor wells				
Constituent	Agricultural standard (mg/L)	601	602	660	671	690
Arsenic	0.1	0.017	0.06	0.024	0.015	0.013
Boron	0.75	0.07	0.07	<0.05	1.1[b]	0.14
Cadmium	0.01	0.031[b]	0.007	<0.005	<0.001	0.001
Chromium	0.1	0.14[b]	0.05	<0.01	<0.01	0.12[b]
Lead	0.1	0.17[b]	0.05	<0.03	<0.01	0.01
Manganese	0.2	6.06[b]	0.124	0.68[b]	0.06	0.645[b]
Molybdenum	0.10	0.06	0.11[b]	0.02	0.02	0.08
Nitrate and Nitrite	100	24.5	4.0	10	18.7	3.7
Selenium	0.02	1.3[b]	0.009	0.022[b]	0.024[b]	0.025[b]
pH	6.5-8.5	4.94[b]	6.75	6.17	7.08	6.86

[a] All concentrations in milligrams per liter, except pH values.
[b] Concentration that exceeds the agricultural standard.
Reference: Colorado Department of Health (CDH), 1990.

low-grade to sub-economic mineralized material that is still present in the Browns Park Formation. A study conducted by the DOE as part of the National Uranium Resource Program speculated that the Maybell area could contain at least 200 million pounds (91 million kilograms) of uranium oxide in intermediate-grade resources (Chenoweth, 1986). These unmined intermediate-grade deposits have affected, and will continue to affect, the ground water quality within the region.

3.6 TAILINGS CHARACTERIZATION

Radioactive materials were processed at the Maybell site from 1957 to 1964 (Chenoweth, 1986). The milling process at the site consisted of sulfuric acid extraction of uranium from the feed ore by a complex chemical leaching and precipitation process (Merritt, 1971). An upgrader circuit was used to treat low-grade ores before leaching in combination with a continuous, countercurrent resin-in-pulp process. An ammonium nitrate solution was used to elute uranium from the loaded resin and the uranium was precipitated with anhydrous ammonia.

The Maybell tailings consist of interbedded sand and slimes that are located in one pile with a total surface area of 79 acres (ac) (32 hectares [ha]). A 6-inch (15-cm)-thick temporary cover of sandy silt was used to stabilize the tailings. Approximately 20 percent of the temporary cover has been eroded by surface water flow (FBDU, 1981). Generally, the slimes are 100 percent saturated with tailings pore water, whereas the sands are approximately 56 percent saturated (CSU, 1983). The depths to saturation beneath the tailings pile surface range from 5 to 37 ft (1.5 to 11 m). The total saturated thickness within the tailings pile ranges from 0 to 22 ft (0 to 7 m).

Existing concentrations of hazardous constituents in the Maybell tailings pile were estimated by chemical analyses of tailings pore water samples from suction lysimeters. Hazardous constituents were those listed in Table 1 of 40 CFR §264.94 (40 CFR Part 264 (1993)) and Table A of 40 CFR §192.02(a) (3)(ii) (52 FR 36000) (1978)). Mean concentrations of hazardous constituents were compared with proposed EPA MCLs (52 FR 36000 (1987) and 40 CFR Part 264 (1993)) or maximum observed background concentrations.

Three shallow suction lysimeters (081, 082, and 083) and two monitor wells (084 and 085) were installed in the tailings pile, to depths ranging from 9 to 60 ft (3 to 18 m) to sample tailings pore water and ground water (Figure 3.2). The tailings pore water has a pH that ranges from approximately 2.8 to 3.1 and (along with contaminated ground water from beneath the tailings) is classified as a calcium sulfate-type water. Mean concentrations of hazardous constituents from the lysimeter samples that exceeded the proposed EPA MCLs are arsenic, cadmium, molybdenum, nitrate, selenium, uranium, and the combined activities of Ra-226 and Ra-228 (Table 3.1).

Analyses of the lysimeter samples indicate that mean concentrations of arsenic, cadmium, lead, molybdenum, nitrate, selenium, uranium, and the combined activities of Ra-226 and Ra-228 are higher in the tailings pore water relative to mean or median concentrations and activities in background ground water beneath the tailings pile. The mobilities of the hazardous constituents in the tailings pile, after they are released by sulfuric acid dissolution of residual ore and gangue materials, are controlled by precipitation-dissolution reaction, coprecipitation reactions, solid solution substitutions, and adsorption-desorption reactions. These reactions will have an effect on the relative amounts of contaminants in the disposal cell available for potential generation of leachate in the future.

3.7 TAILINGS SUBSOIL CHARACTERIZATION

Chemical and physical properties of the tailings subsoil and uncontaminated Browns Park Formation were characterized to determine their effect on contaminant migration and attenuation. The locations of the tailings subsoil characterizations performed by Colorado State University (CSU) (1983) are presented in Figure 3.6. The results of characterization of the uncontaminated Browns Park Formation are shown in Figure 3.7. Tables 3.3 and 3.4 summarize the chemical and physical properties, respectively, of these characterizations.

Soil pH values derived from water extract analyses of soil samples from beneath the tailings pile indicate that an acid front extends no farther than 10 ft (3 m) beneath the tailings pile/Browns Park Formation contact (CSU, 1983). This zone is characterized by low calcium carbonate content in the soil, and concentrations of arsenic, selenium, uranium, and activities of Ra-226 are elevated above background levels. Soil pH and calcium carbonate contents increase and metal concentrations and radionuclide activities decrease with depth in the Browns Park Formation (Table 3.3). The presence of abundant calcite in the core samples (Table 3.4) confirms that the Browns Park Formation has sufficient carbonate buffering capacity to continue neutralizing the acidic tailings leachate beneath the acid front. Three monitor wells (647, 648, and 649) were installed through the tailings in 1981 by Lawrence Berkeley Laboratory (LBL) (1982). The three monitor wells encountered ground water at depths ranging from 80 to 100 ft (24 to 30 m) below the tailings pile surface. The significant thickness (ranging from 50 to 95 ft [15 to 29 m]) of the unsaturated section below the tailings/sediment interface penetrated by these wells is in itself a substantial barrier to the migration of contamination to the water table.

Physical and chemical properties of the tailings subsoil and uncontaminated Browns Park Formation are listed in Table 3.4. The effects of acidic leachate on the tailings subsoil are apparent. The tailings subsoil has an average pH value of 3.75, whereas the uncontaminated unsaturated Browns Park Formation has an average pH value of 7.41. The measured Eh is more oxidizing in the tailings subsoil relative to background soils in the Browns Park Formation. The acid-neutralizing capacity has been partly exhausted in the tailings subsoil.

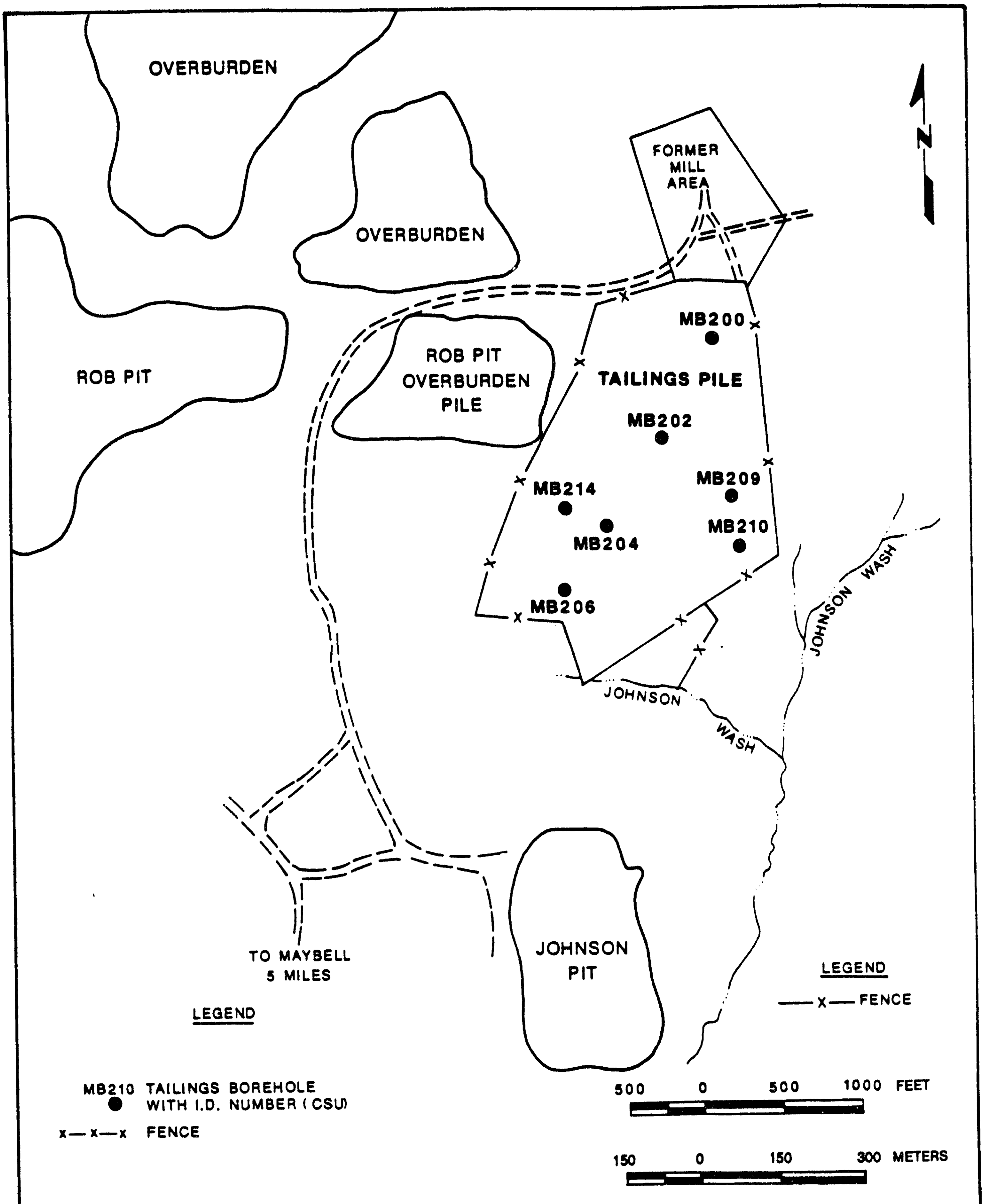
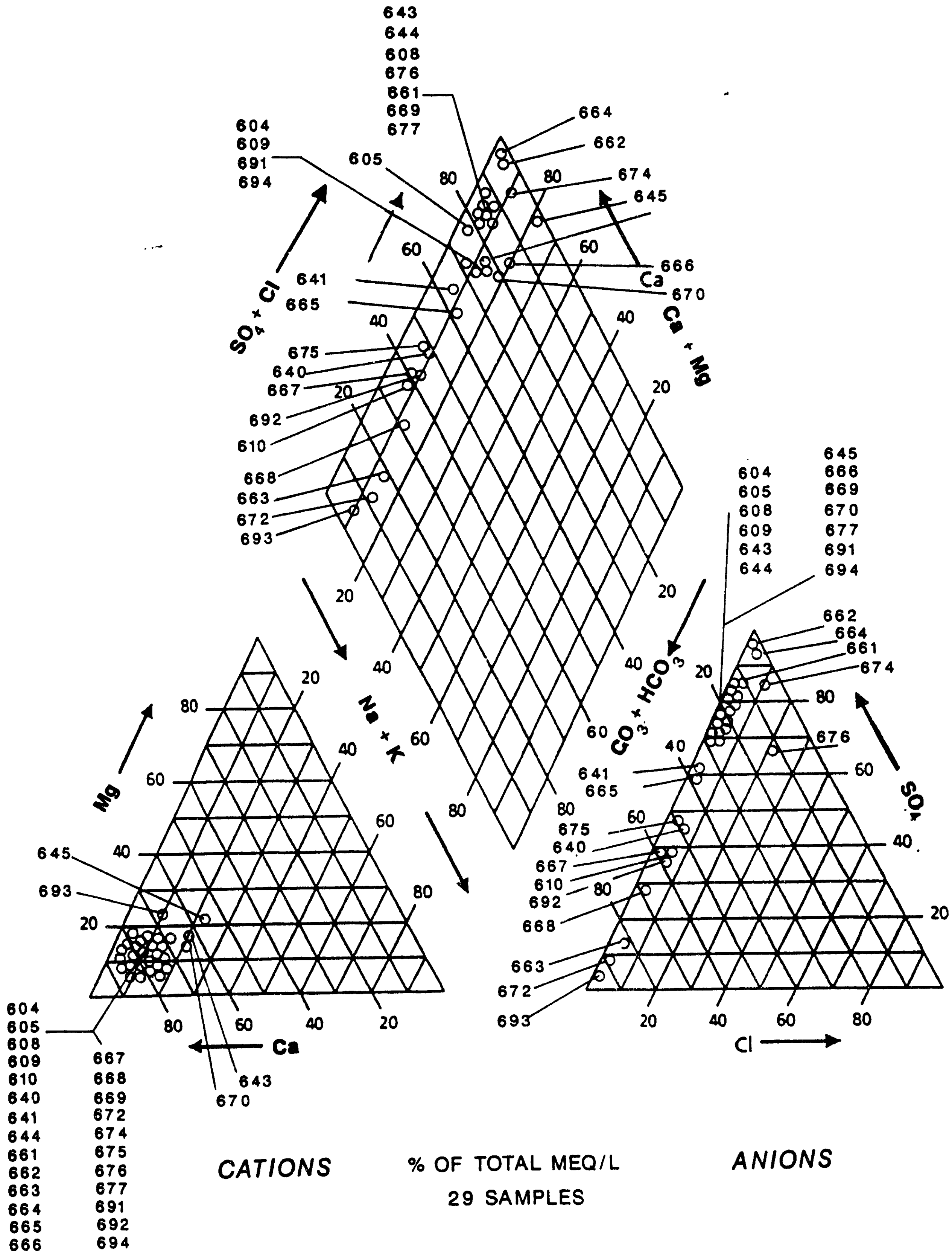


FIGURE 3.6
LOCATIONS OF COLORADO STATE UNIVERSITY (CSU) URANIUM TAILINGS BOREHOLES AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO



NOTE: SAMPLES COLLECTED IN OCTOBER 1989.

FIGURE 3.7
TRILINEAR DIAGRAM OF GROUND WATER SAMPLES FROM DOWNGRADIENT AND CROSSGRADIENT MONITOR WELLS AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

Table 3.3 Summary of Colorado State University soil analyses, Maybell tailings site, Colorado

Boring No.	Depth below tailings pile/Browns Park Formation interface (ft)	pH (units)	Pore H_2O content (%)	Parameter							
				SO_4-S[a]	Fe	Ca	Mg	Na	Cl	Al	Mn
				----(all values reported in micrograms per gram)----							
MB-200	0	6.8	16.9	660	63	455	38	28	<20	138	40
MB-200	7.5	6.3	15.8	840	274	106	24	36	20	176	43
MB-200	12.5	6.3	10.6	610	226	104	28	32	<20	170	48
MB-200	22.5	7.0	15.8	440	381	98	61	46	<20	262	232
MB-202	5	6.8	7.6	680	263	85	28	35	20	163	206
MB-202	15	7.1	8.4	430	175	223	126	52	<20	131	53
MB-202	25	7.2	10.8	170	174	49	18	121	20	174	7
MB-204	9	3.4	6.3	6060	709	4410	123	45	<20	343	232
MB-204	6	5.4	15.2	2500	380	1930	109	143	<20	472	104
MB-204	11	7.1	14.2	430	282	674	47	135	<20	379	43
MB-204	21	7.2	9.0	290	132	249	33	171	30	227	27
MB-206[b]	4	6.8	--	280	343	117	24	80	30	328	22
MB-206[b]	6	6.8	--	348	410	213	28	100	20	306	15
MB-206[b]	10	7.0	--	126	231	55	13	74	30	287	4
MB-206[b]	14	7.0	--	158	269	71	19	84	50	177	3
MB-209	0	6.6	11.4	2640	404	2380	80	33	<20	210	192
MB-209	5	7.2	11.8	1900	230	1980	86	35	<20	384	184
MB-209	15	7.1	14.2	430	282	674	47	135	<20	379	42
MB-210	0	3.9	7.5	1000	314	378	91	35	<20	687	377
MB-210	10	7.3	14.8	380	178	104	25	44	30	153	8
MB-210	15	6.8	21.5	210	54	149	40	40	<20	94	8
MB-210	20	7.5	19.1	160	188	103	25	33	<20	99	5
MB-214	0	3.1	--	1520	540	885	67	34	<20	367	111
MB-214	4.5	7.1	33.1	1950	577	1900	114	62	30	521	461

Table 3.3 Summary of Colorado State University soil analyses, Maybell tailings site, Colorado (Concluded)

				Parameter						
Boring No.	Depth below tailings pile/ Browns Park Formation interface (ft)	pH (units)	Pore H_2O content (%)	As	Se	U[c]	Ra-226[c] (pCi/g)	Th-232[c] (pCi/g)	K[c] (%)	$CaCO_3$[d] equivalent (%)
				----(all values reported in micrograms per gram)----						
MB-200	0	6.8	16.9	0.18	0.08	120	2.22	0.09	1.3	<0.1
MB-200	7.5	6.3	15.8	0.43	0.42	4	1.98	0.33	1.6	<0.1
MB-200	12.5	6.3	10.6	<1	<1	3	1.44	0.84	2.3	0.1
MB-200	22.5	7.0	15.8	2	1	--	--	--	--	0.3
MB-202	5	6.8	7.6	0.66	0.20	34	13.37	1.07	2.0	0.1
MB-202	15	7.1	8.4	1	<1	13	3.53	1.32	1.7	0.2
MB-202	25	7.2	10.8	0.38	0.11	11	1.71	0.92	2.0	<0.1
MB-204	9	3.4	6.3	5.78	16.6	60	43.51	0.36	1.4	<0.1
MB-204	6	5.4	15.2	2	3	97	41.03	1.36	1.9	<0.1
MB-204	11	7.1	14.2	1	1	16	5.28	0.70	1.4	0.2
MB-204	21	7.2	9.0	0.6	0.44	10	3.26	1.16	1.8	1.1
MB-206[b]	4	6.8	--	<1	<1	--	--	--	--	0.16
MB-206[b]	6	6.8	--	<1	<1	--	--	--	--	0.16
MB-206[b]	10	7.0	--	<1	<1	--	--	--	--	0.16
MB-206[b]	14	7.0	--	<1	<1	--	--	--	--	0.16
MB-209	0	6.6	11.4	4	5	220	133.32	1.45	2.6	<0.1
MB-209	5	7.2	11.8	2	3	60	43.5	0.36	1.4	0.5
MB-209	15	7.1	14.2	1	1	9	3.29	1.40	1.8	1.1
MB-210	0	3.9	7.5	1	2	32	17.54	0.59	1.8	<0.1
MB-210	10	7.3	14.8	2	<1	6	4.13	1.32	2.2	<0.1
MB-210	15	6.8	21.5	<1	<1	4	1.38	1.09	1.8	0.1
MB-210	20	7.5	19.1	<1	<1	4	0.94	--	1.7	0.1
MB-214	0	3.1	--	1	2	141	278.21	2.27	2.6	<0.1
MB-214	4.5	7.1	33.1	2	3	29	19.02	1.32	2.1	5.0

[a] Sulfate (SO_4) is reported as SO_4-S; the conversion to concentration of SO_4 can be made by multiplying that of SO_4-S concentration by three.

[b] Core sample - not analyzed for radionuclides.

[c] Analysis by Bendix Field Engineering Corporation Laboratory, Grand Junction, Colorado. All other analysis by CSU, Soil Testing Laboratory, Fort Collins, Colorado; K = potassium.

[d] $CaCO_3$ = calcium carbonate.

Source: CSU, 1983.

Table 3.4 Characterization of tailings subsoil and the Browns Park Formation, Maybell, Colorado[a]

Property[b]	Tailings subsoil	Browns Park Formation
Water content (g/g)(%) (after air drying)	0.35	0.08
Particle density (g/cm^3)	2.63	2.63
Particle size distribution (weight %)		
Sand (50-2000 micron)	13	18
Silt (2-50 micron)	72	66
Clay (<2 micron)	15	16
pH of saturated paste	3.75	7.41
Eh of saturated paste (millivolts)	+520	+276
Organic matter (g/g)(%)	0.05	0.22
Acid-soluble iron (g/g)(%)	1.51	0.16
$CaCO_3$ (g/g)(%)	0.04	25.5
Gypsum (g/g)(%)	1.26	<0.01
Acid neutralizing capacity (tons $CaCo_3$ equivalent/1000 tons)	-0.84	320.0
Cation exchange capacity (CEC)(meq/100 g)	13.4	13.8

[a] Average of six measurements for tailings subsoil and Browns Park Formation.
[b] meq/100 g = milliequivalents per 100 grams; $CaCO_3$ = calcium carbonate.

Precipitation of gypsum has occurred beneath the tailings pile as a result of sulfuric acid reacting with calcium carbonate present in the tailings subsoil. However, this reaction does not remove significant amounts of sulfate from soil pore water, as gypsum is a soluble mineral.

The cation exchange capacity is similar for tailings subsoil samples and background soil samples from the Browns Park Formation. The dominant clay minerals are illite (15 percent) and calcium montmorillonite (85 percent). The anion exchange capacity of the sediments ranges from 0.5 to 5.7 milliequivalents per 100 grams (meq/100 g). The relatively low ion exchange capacities for the Browns Park Formation suggest that both cationic and anionic contaminants will not be completely removed from solution through ion exchange processes with clay minerals.

X-ray diffraction analyses were performed on several core samples collected from the Browns Park Formation at the site. One sample collected near monitor well 665 (Figure 3.2) contained abundant calcite, quartz, feldspar, and clay minerals, including illite and montmorillonite. These minerals were also found in core samples collected directly below the tailings pile, with lesser amounts of calcite present. A zeolite mineral, gismondine $(Ca(Al_2Si_2)\ O_8.4H_2O)$, was tentatively identified at both core locations. Gismondine is a potential ion-exchange mineral that may remove contaminants from tailings leachate.

Acid-soluble iron is approximately 10 times more abundant in the tailings subsoil than in the uncontaminated soils of the Browns Park Formation (Table 3.4). This indicates that soluble iron has precipitated, most likely in the form of iron oxyhydroxides, during neutralization of tailings leachate. Iron oxyhydroxides have a strong affinity for many contaminant species, and the precipitation of these iron-rich phases should enhance the sorption of molybdenum, arsenic, selenium, radium, and uranium present in contaminated pore water. The sorption of these contaminants in the iron-rich subpile sediments would explain (in part) the low concentrations of these elements in the saturated section penetrated by downgradient wells at Maybell. Some of these contaminants (arsenic, molybdenum, selenium, and uranium) are not completely adsorbed onto the surfaces of soil particles under the moderately acidic to alkaline pH conditions found in the subpile setting. These contaminants are likely present as mobile anionic species in the unsaturated zone of the Browns Park Formation and, consequently, a small flux of these constituents is in the saturated section of the Browns Park Formation.

Because of the tendency of radium to coprecipitate with gypsum and barite in sulfate-rich solutions such as tailings pore water (Granger et al., 1961; Borrowman and Brooks, 1975) and its high sorptive affinity for zeolites, clays and iron oxyhydroxides (Ames et al., 1983a; Ames et al., 1983b), Ra-226 and Ra-228 are reduced to background levels within the unsaturated zone immediately beneath the tailings pile.

3.8 EXTENT OF EXISTING GROUND WATER CONTAMINATION

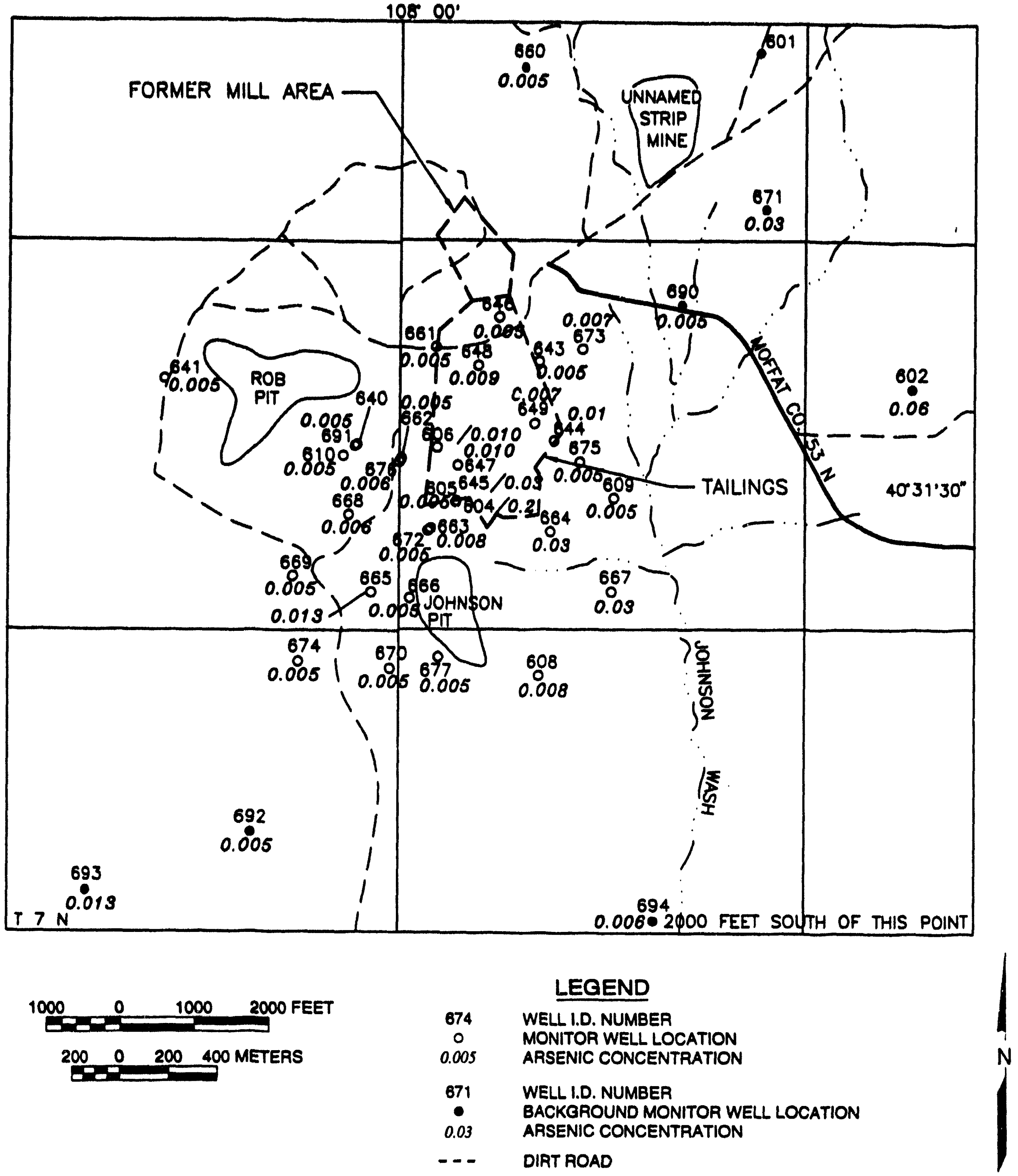
Ground water in the Browns Park Formation has been monitored to determine the effects of uranium processing activities on ground water quality beneath and adjacent to the Maybell tailings site. The existing ground water quality has been determined by evaluating chemical analyses of ground water samples collected from monitor wells completed on the site and adjacent to the Maybell tailings pile (Figure 3.2). Existing ground water quality was characterized by analyzing constituents listed in Table 8.1 of the TAD (DOE, 1989), Table 1 of 40 CFR §264.94 (40 CFR Part 264 (1993)) and Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000 (1987)), and the field parameters alkalinity, Eh, pH, specific conductivity, and temperature.

Analytical data from ground water samples collected from on-site and adjacent monitor wells indicate pH values ranging from 4.94 to 7.77. The ground water is dominantly a calcium, bicarbonate/sulfate type (Figure 3.7). The average TDS content is 2466 mg/L and is generally higher in on-site monitor wells relative to monitor wells adjacent to the site. Based on chemical analyses of ground water samples beneath and immediately downgradient from the tailings pile, maximum observed concentrations of arsenic (Figure 3.8), cadmium, lead, molybdenum (Figure 3.9), nitrate (Figure 3.10), selenium (Figure 3.11), and uranium (Figure 3.12), and activities of Ra-226 and Ra-228 exceeded the proposed EPA MCLs (Table 3.1). The integration of data from both upgradient and uncontaminated downgradient monitor wells yields a more complete picture of the variable (and often poor) water quality present in the Browns Park Formation. Browns Park Formation domestic well 650 in particular shows elevated levels of hazardous constituents (e.g., nitrate), yet it is located near Maybell several miles downgradient of the tailings pile. This well is far beyond the possible influence of contamination from the tailings pile.

The ground water directly beneath the tailings pile is relatively oxidizing and slightly acidic (Table 3.5). Although the subpile sediments at Maybell are efficient scavengers of many contaminants, elevated concentrations of arsenic, molybdenum, selenium, and uranium (Figures 3.8, 3.9, 3.11, and 3.12) are found in the saturated section beneath the tailings pile . Unlike radium, these contaminants can form stable anionic species that are relatively mobile under moderately acidic to alkaline conditions. Although the concentrations of these constituents have been greatly attenuated by sorption processes in the subpile environment, they have not been reduced to concentrations below their respective MCLs.

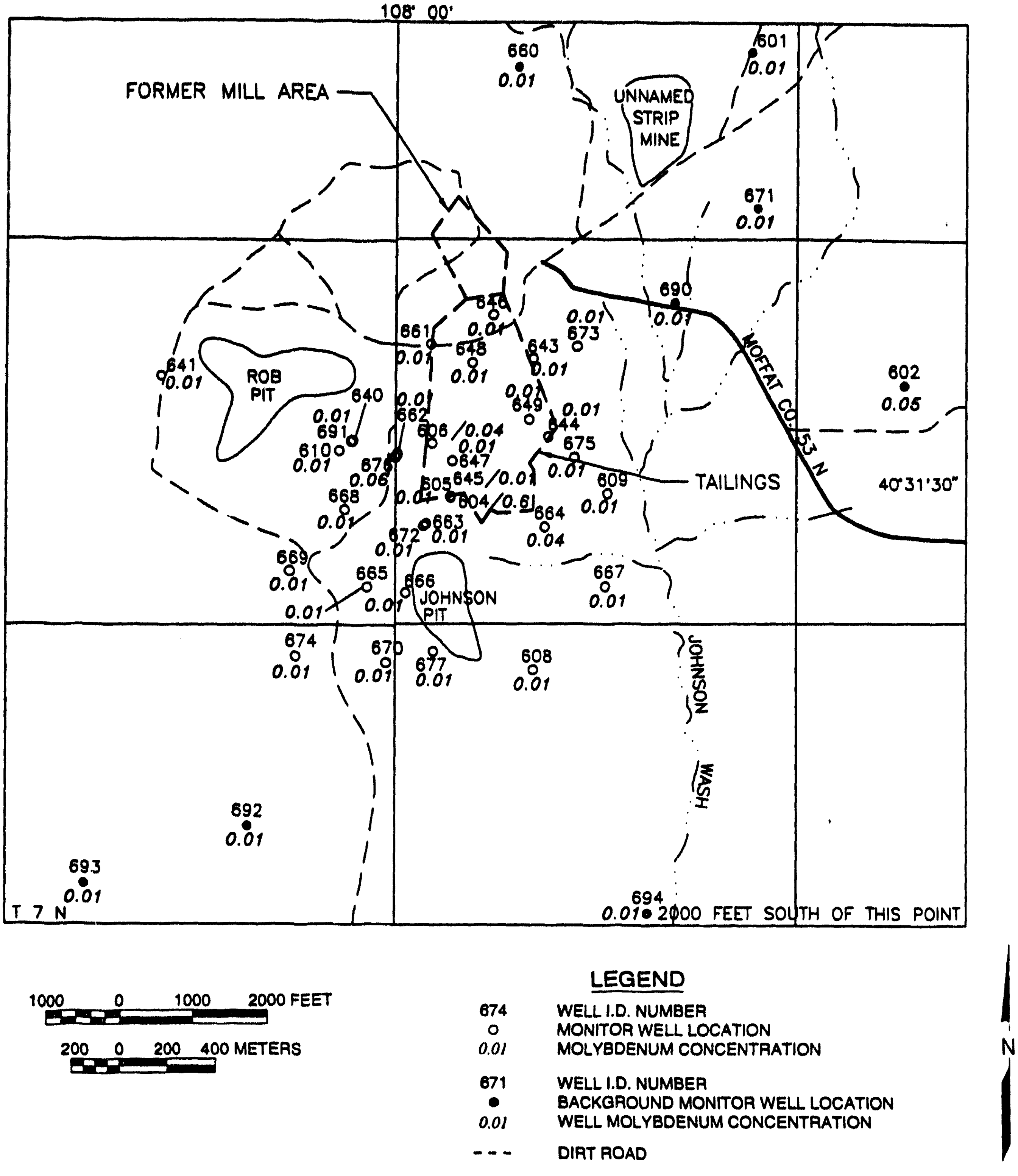
Nitrate is also present in elevated concentrations in the saturated section around the tailings pile (Figure 3.10). Biologically mediated denitrification processes, however, appear to reduce concentrations of nitrate to the proposed MCL immediately downgradient from the tailings pile (Thomson & Associates, 1990).

A scan for the presence of hazardous organic constituents was conducted in October 1989. Ground water samples collected from monitor wells 643, 645,



NOTE: SAMPLES COLLECTED IN MAY 1992

FIGURE 3.8
ARSENIC CONCENTRATION DISTRIBUTION
IN THE BROWNS PARK FORMATION AQUIFER
AT THE MAYBELL SITE NEAR MAYBELL, COLORADO

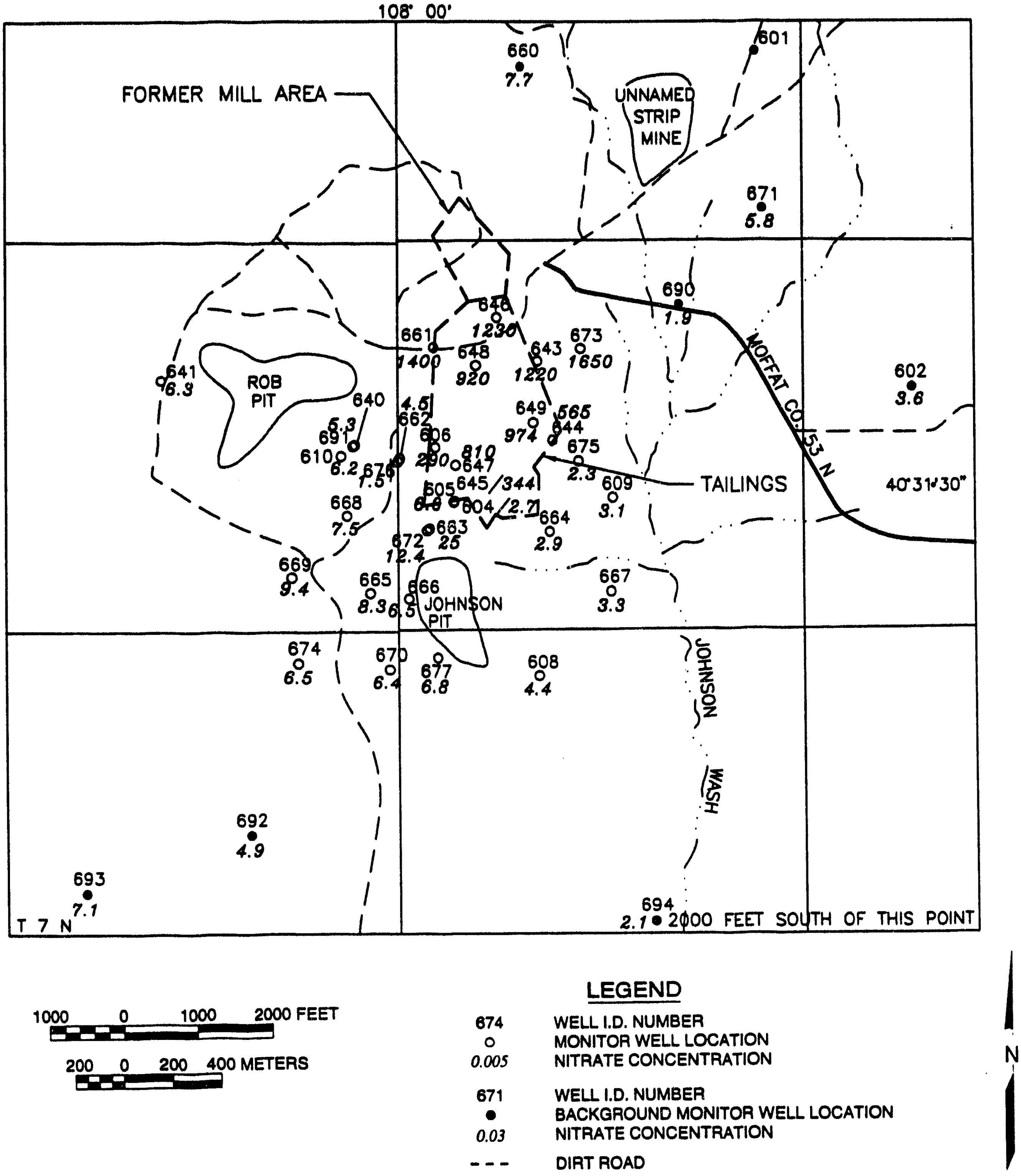


LEGEND

674	WELL I.D. NUMBER
○	MONITOR WELL LOCATION
0.01	MOLYBDENUM CONCENTRATION
671	WELL I.D. NUMBER
●	BACKGROUND MONITOR WELL LOCATION
0.01	WELL MOLYBDENUM CONCENTRATION
- - -	DIRT ROAD

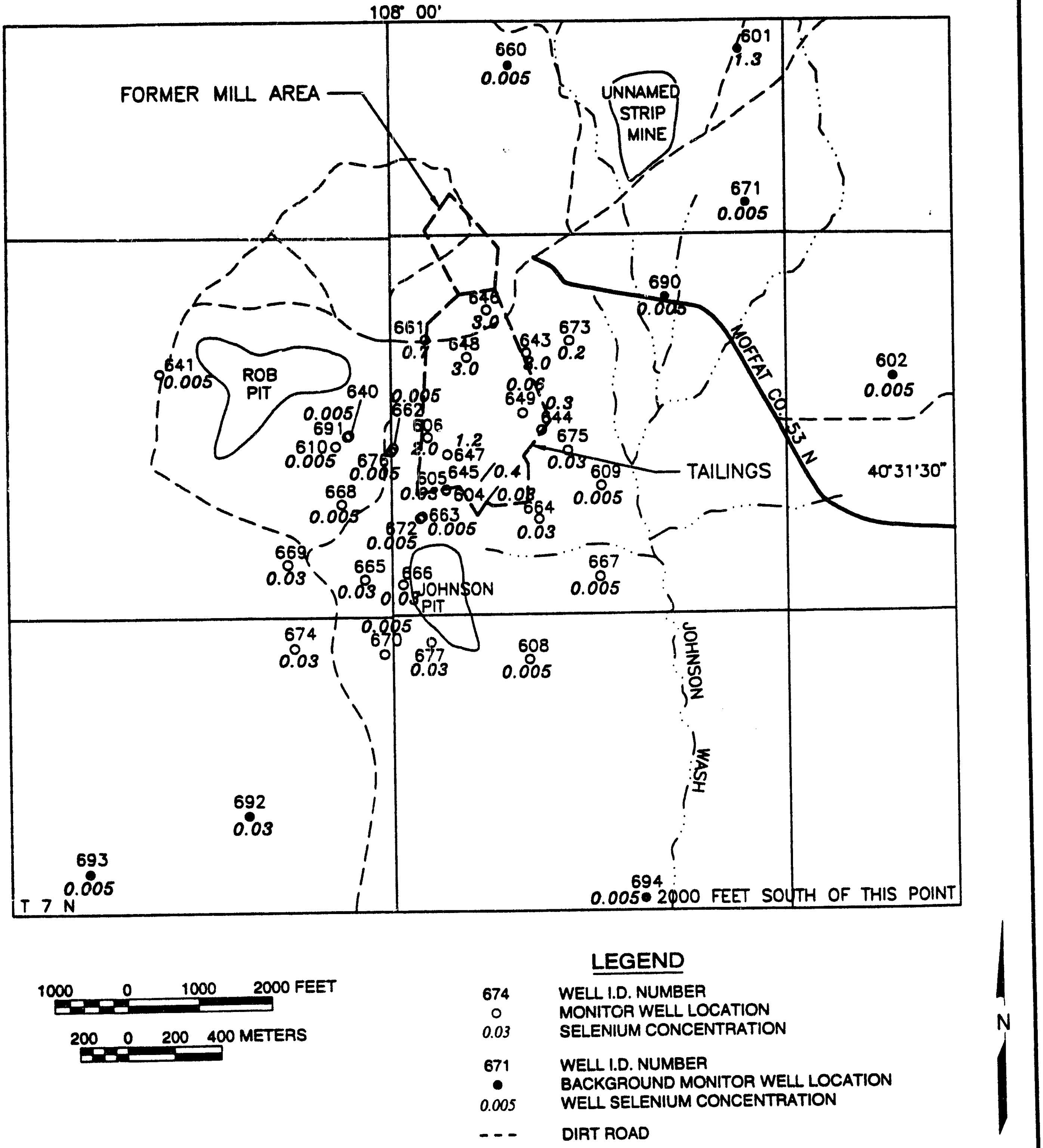
NOTE: SAMPLES COLLECTED IN MAY 1992

FIGURE 3.9
MOLYBDENUM CONCENTRATION DISTRIBUTION
IN THE BROWNS PARK FORMATION AQUIFER
AT THE MAYBELL SITE NEAR MAYBELL, COLORADO



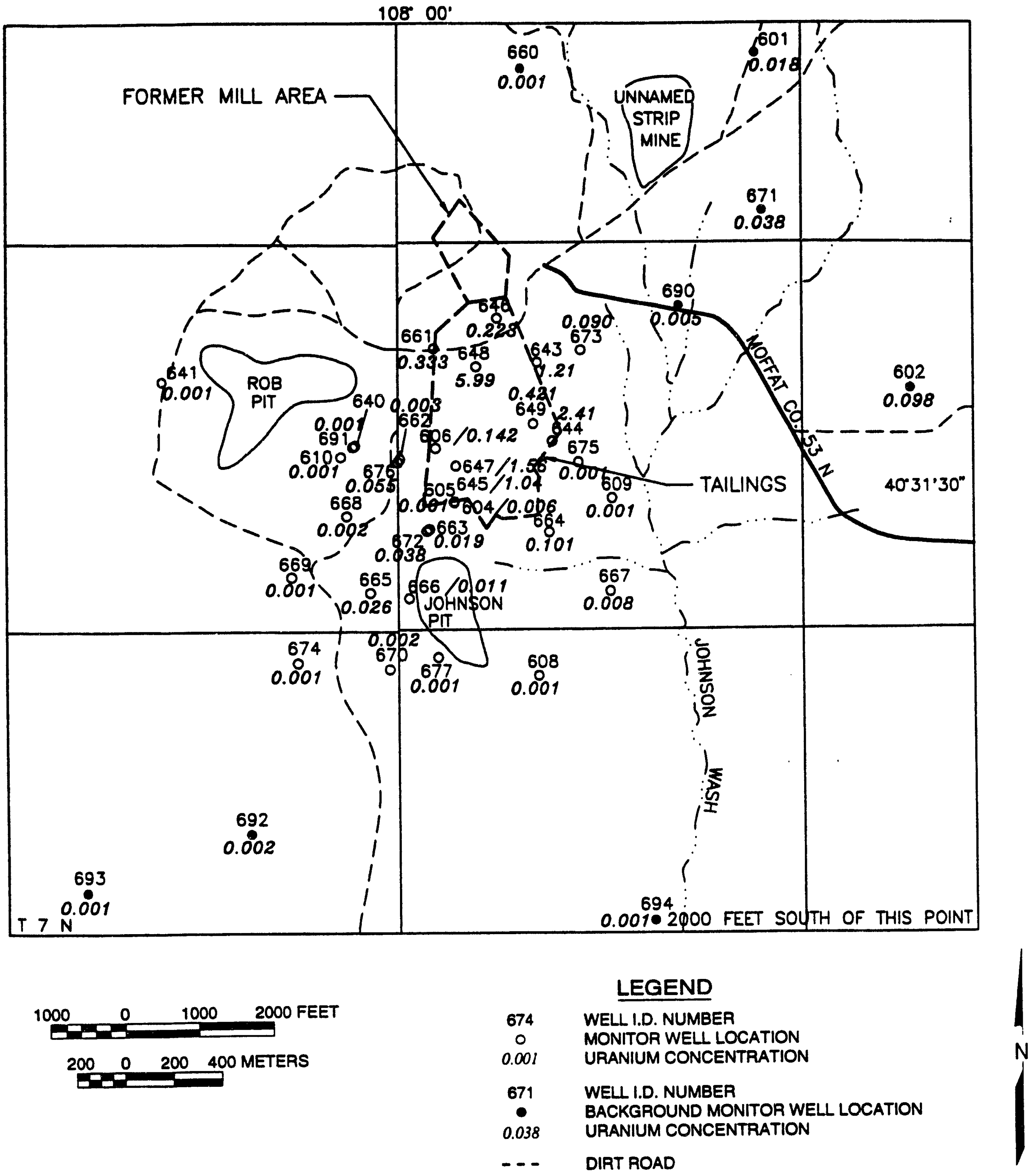
NOTE: SAMPLES COLLECTED IN MAY 1992

FIGURE 3.10
NITRATE CONCENTRATION DISTRIBUTION IN THE BROWNS PARK FORMATION AQUIFER AT THE MAYBELL SITE NEAR MAYBELL, COLORADO



NOTE: SAMPLES COLLECTED IN MAY 1992

FIGURE 3.11
SELENIUM CONCENTRATION DISTRIBUTION
IN THE BROWNS PARK FORMATION AQUIFER
AT THE MAYBELL SITE NEAR MAYBELL, COLORADO



NOTE: SAMPLES COLLECTED IN MAY 1992

FIGURE 3.12
URANIUM CONCENTRATION DISTRIBUTION
IN THE BROWNS PARK FORMATION AQUIFER
AT THE MAYBELL SITE NEAR MAYBELL, COLORADO

Table 3.5 Selected field geochemical data, Maybell site, Colorado[a]

Monitor well no.	pH	Eh	Temp (°F)	Temp (°C)	Alkalinity ($CaCO_3$ mg/L)	Electrical conductance (micromhos/cm)
601	4.94	+447	48.7	9.3	4	2910
602	7.05	+431	52.3	11.3	153	500
604	7.24	+382	50.7	10.4	193	1610
605	7.10	+336	56.8	13.8	184	1360
606	6.02	+484	50.4	10.2	234	3650
608	6.76	+467	55.8	13.2	237	2310
609	7.06	+454	51.1	10.6	220	1240
610	7.22	+445	56.5	13.6	248	752
641	7.31	+209	57.0	13.9	187	900
643	5.83	+442	50.2	10.1	305	3190
644	6.26	+432	51.6	10.9	700	3200
646	5.90	+474	51.1	10.6	403	5340
647	6.13	+452	49.6	9.8	240	3950
649	5.84	+446	47.7	8.7	458	5160
660	6.56	+232	56.5	13.6	364	2170
661	6.15	+354	52.2	11.2	256	4820
662	6.94	+315	55.0	12.8	172	1640
664	7.77	+385	51.4	10.8	54	1800
667	7.47	+397	51.3	10.7	142	490
671	7.19	+417	53.4	11.9	233	310
673	6.62	+484	51.3	10.7	153	5640
674	6.76	+170	59.5	15.3	408	1260
675	6.96	+360	51.3	10.7	260	2790
690	7.15	+444	51.6	10.9	216	2350
693	6.93	+209	54.0	12.2	320	2090
694	7.05	+434	53.1	11.7	391	1870

[a] Data collected in October 1991.
°F = degrees Fahrenheit.
°C = degrees Celsius.
$CaCO_3$ mg/L = calcium carbonate in milligrams per liter.

and 648 were analyzed for hazardous organic constituents listed in Appendix IX of 40 CFR Part 264 (1993). No Appendix IX organic constituents were detected. Monitor wells 643, 645, and 648 are located within the tailings pile footprint, and ground water samples analyzed from these wells would serve as the best indicator for the presence of organic hazardous constituents due to tailings seepage.

3.9 GEOCHEMICAL CONDITIONS

The ground water compliance strategy for the Maybell site is based on the application of a supplemental ground water standard. Nevertheless, a general discussion of the geochemical setting of this site is warranted. The main objective of this section is to identify and discuss the geochemical mechanisms that are preventing significant contamination of the Browns Park Formation by the tailings.

The geochemical properties of the tailings material and the Browns Park Formation sediments control the solubility of minerals and solid compounds that contain hazardous constituents at the Maybell site. Mineralogical and chemical analyses of background soil samples and sediment samples from beneath the tailings were performed to define the geochemical properties of site materials (Table 3.4). The geochemical properties of the soils and sediments, along with a review of the literature on contaminant mobility and the ground water quality data at the Maybell site, suggest that arsenic, molybdenum, selenium, uranium, Ra-226, and Ra-228 are largely removed from solution through precipitation and adsorption processes. In addition, nitrate is removed by biologically mediated denitrification processes as suggested by microbiological studies.

The geochemical controls on the distribution of arsenic, cadmium, lead, molybdenum, nitrate, selenium, uranium, and radium are discussed below.

Arsenic

The present distribution of arsenic in the Browns Park Formation is shown in Figure 3.8. Arsenic has not migrated significantly beyond the downgradient limit of the tailings pile. Although maximum observed concentrations of arsenic have exceeded the proposed EPA MCL (0.05 mg/L) in monitor well 665, the exceedance may be related to the range of variability in background or to seasonality rather than contamination related to uranium processing. For instance, the maximum observed value for arsenic in upgradient background wells is 0.06 mg/L. The maximum observed downgradient background concentration is 0.26 mg/L (Table 3.1).

Arsenic concentrations in ground water in the Browns Park Formation are probably controlled by adsorption processes more than precipitation reactions. Studies of arsenic retention by soil have shown that adsorption is controlled by the amount of iron and aluminum oxyhydroxides (Rai and Zachara, 1984). Iron and aluminum hydroxysulfates are also likely absorbers of arsenic in the soils beneath the tailings. The mineralogic characterization of subsoils (discussed in Section 3.7) strongly suggests that iron oxyhydroxides are present in sufficient amounts to adsorb most of the arsenic migrating from the tailings into the subpile sediments. The dilution of the remaining arsenic in the tailings seepage by ground water underflow also accounts for the low concentrations of arsenic in the Browns Park Formation downgradient of the tailings pile.

Cadmium

Concentrations of cadmium have exceeded the proposed EPA MCL of 0.01 mg/L in background ground water. The maximum observed concentration for cadmium in upgradient background wells is 0.031 mg/L. The maximum observed concentration in downgradient background wells is 0.021 mg/L (Table 3.1).

Cadmium will be rapidly removed by the precipitation of the mineral octavite ($CdCO_3$) and by hydrolysis and adsorption reactions as the low pH tailings leachate is neutralized by alkaline ground water and the calcite in the aquifer matrix. Dilution with background ground water should produce cadmium concentrations in downgradient ground water that are typical of background levels. Levels of cadmium elevated above background should be restricted to the areas underneath or immediately adjacent to the tailings pile.

Lead

Lead is a hazardous constituent that exceeds the proposed EPA MCL of 0.05 mg/L in background ground water. The maximum observed concentration for lead in upgradient background wells is 0.17 mg/L. The maximum observed concentration in downgradient background wells is 0.15 mg/L (Table 3.1).

The fate and transport processes that affect lead concentrations are similar to those that affect cadmium concentrations in general. The dominant aqueous species of lead will be Pb^{2+} in acidic environments and Pb^{2+}-carbonate complexes in alkaline environments. The mineral cerrusite is a major control on lead concentrations in alkaline, carbonate-rich systems such as the alluvial aquifer at Maybell. Iron and manganese hydroxides are strong adsorbents of lead and should also be major controls on lead solubility at Maybell. Given these strong controls on lead solubility and transport in alkaline systems, lead, if introduced into the ground water system, will be rapidly removed from solution at Maybell and stabilized in the aquifer matrix.

Molybdenum

Molybdenum is a hazardous constituent in tailings pore water but is currently not a significant ground water contaminant. The distribution of molybdenum in ground water in the Browns Park Formation is related to the range of variability in background water quality, as shown in Figure 3.9. For example, the maximum observed upgradient background concentration for molybdenum is

0.11 mg/L. The maximum observed background downgradient concentration is 0.28 mg/L (Table 3.1).

The adsorption behavior of molybdenum in soils beneath the tailings is also strongly influenced by the presence of iron and aluminum oxyhydroxides (Rai and Zachara, 1984). In addition, solution pH and ionic strength influence molybdenum adsorption. Less adsorption of the molybdate anion occurs on soil particles as pH increases above 7 due to the increasing negative charge density on ferric oxyhydroxides. Under alkaline pH conditions downgradient of the tailings pile, molybdate is expected to be mobile. The presence of iron and aluminum oxyhydroxides and hydroxysulfates promotes the adsorption of molybdenum in the soils beneath and downgradient of the tailings. Low concentrations of molybdenum currently found downgradient of the tailings are also the result of the dilution of tailings seepage by ground water underflow.

Nitrate

Nitrate is a hazardous constituent in the tailings pore water but is not a significant ground water contaminant downgradient (except in monitor well 673) from the tailings pile. Nitrate concentration distributions in the Browns Park Formation are shown in Figure 3.10. Ammonium nitrate was used during the ore extraction process when the uranium mill was operating at the Maybell site (Merritt, 1971). Dissociation of ammonium nitrate has produced an average concentration of 1949 mg/L nitrate in the tailings pore water and elevated levels in ground water adjacent to the tailings. The maximum observed upgradient background concentration recorded for nitrate is 24.5 mg/L, and the maximum downgradient concentration is 190 mg/L (Table 3.1). Note, however, that this elevated level (190 mg/L) is from domestic well 650. This well is located near Maybell several miles downgradient of the tailings pile, far beyond the possible influence of contamination from the tailing pile. The highest nitrate value from the remaining downgradient background wells is 4.9 mg/L in well 692 (May 1992 data).

At Maybell, nitrate concentrations are significantly lowered as a result of denitrification. Denitrification is the process by which nitrate is reduced to nitrogen gas via the formation of gaseous nitric oxide. The inert nitrogen gas is able to diffuse through the soil as a harmless reaction product. Denitrification is a common reaction catalyzed by the presence of microbacteria. At the Maybell tailings site, the presence of three genera of microbacteria capable of nitrate reduction have been documented (*Acinetobacter, Pseudomonas,* and *Flavobacterium*) (Thomson & Associates, 1990). In addition to the presence of microbacteria capable of nitrate reduction, several other conditions are needed for denitrification to occur. These include the 1) presence of nitrate, 2) presence of trace nutrients including phosphorus, and 3) absence of dissolved oxygen (Thomson & Associates, 1990). All of the above conditions exist at the Maybell tailings site and support the inference that denitrification has lowered nitrate concentrations downgradient from the tailings pile.

Laboratory studies were conducted to test the hypothesis that microbial denitrification is responsible for the disappearance of nitrate at the Maybell tailings site. This investigation used two types of experiments. First, core samples were analyzed to determine the presence of denitrifying organisms using classic microbiological identification procedures. A second set of experiments simulated conditions within the saturated strata beneath the pile in anoxic microcosms. Mixed culture inoculums consisting of soil samples from the pile were added to the microcosms, and the disappearance of nitrate with time was measured. The laboratory investigation determined an average nitrate removal of approximately 40 percent was achieved within 13 days (Thomson & Associates, 1990). In other words, denitrification is very effective in removing nitrate from ground water in the Browns Park Formation.

Selenium

Background and on-site selenium concentrations in ground water in the Browns Park Formation exceed the proposed EPA MCL (0.01 mg/L) (40 CFR Part 264 (1993)) (Figure 3.11). Selenium is not a ground water contaminant downgradient of the tailings pile because there is high natural variability in the concentration of selenium. The maximum observed upgradient background concentration of selenium is 1.3 mg/L, the average tailings pore water concentration is 0.54 mg/L, and the maximum observed background downgradient concentration is 0.028 mg/L (Table 3.1).

Selenium forms soluble oxyanions between pH 4 and 10 under relatively oxidizing conditions characteristic of tailings pore fluid and ground water directly beneath the tailings pile (Rai and Zachara, 1984). Selenium exists in natural aqueous environments in -2, +4 (selenite), and +6 (selenate) valence states. Maximum adsorption of selenite and selenate occurs mainly through specific adsorption onto ferric oxyhydroxides and clay minerals in the acidic pH range (Brown et al., 1988; Balistrieri and Chao, 1990). Experimental studies conducted by Leckie et al. (1980) show that sulfate, present as a competing anion, decreases selenate adsorption onto amorphous ferric hydroxides. Therefore, tailings leachate enriched with sulfate may decrease the amount of selenate adsorbing onto soils beneath the tailings and onto aquifer materials present in the Browns Park Formation beneath the tailings. This results in elevated concentrations of selenate directly beneath the tailings pile. Selenium concentrations immediately downgradient from the tailings pile approach background. Sorption by iron oxyhydroxides, clay, zeolites, and solid organic matter may have removed significant amounts of selenium from ground water. Dilution by ground water underflow would also contribute to decreased selenium concentration downgradient of the tailings pile.

Uranium

The contaminant distribution map of uranium in the Browns Park Formation is shown in Figure 3.12. Concentrations of uranium in ground water upgradient and downgradient from the tailings pile exceed the proposed EPA MCL

(0.044 mg/L) (equivalent to 30 picocuries per liter [pCi/L]) (52 FR 36000 (1987)). The maximum observed upgradient background concentration of uranium is 0.112 mg/L, the average tailings pore water concentration is 1.221 mg/L, and the maximum observed background downgradient concentration is 0.095 mg/L (Table 3.1). Directly beneath the tailings pile, the maximum observed concentration of uranium has been as high as 6.8 mg/L in ground water.

Experimental studies conducted by Hsi and Langmuir (1985) and Tripathy (1983) show that uranyl carbonate complexes are the dominant form of hexavalent uranium in the presence of CO_2 (carbon dioxide) gas. Geochemical modeling confirms this. These conditions probably exist beneath the tailings pile where tailings leachate containing sulfuric acid has reacted with interstitial calcium carbonate, producing CO_2 gas during the neutralization process. In addition, the investigators show that adsorption of uranyl carbonate complexes onto iron oxyhydroxides is greatly reduced in the presence of CO_2 gas. Therefore, based on their experimental investigations, elevated concentrations of uranium may be the result of desorption processes occurring in ground water beneath the tailings pile under relatively oxidizing conditions.

The mechanism of uranium removal at the Maybell site also involves adsorption, ion exchange, and complexation. Several experimental studies conducted by Szalay (1964), Nash et al. (1981), and Shanbhag and Choppin (1981) have suggested that the uranyl ion (UO_2^{+2}) undergoes complexation reactions with carboxylic and other acidic functional groups comprising solid organic matter (humic substances). Organic analyses of a ground water sample from monitor well 643 confirmed the presence of humic acids, although specific hydrophobic and hydrophilic fractions were not identified. Concentrations of humic acid were less than one part per million (ppm) in ground water samples from monitor wells 602 and 644. The range of total organic carbon in ground water samples is from 0.5 to 212 mg/L. These data and studies as summarized by Chenoweth (1986) suggest that uranium sorption is enhanced by solid and dissolved organic carbon, liquid and gaseous hydrocarbons, and hydrogen sulfide present in the Browns Park Formation at the Maybell site.

Radium-226 and -228

Radium exceeds the EPA MCL (5 pCi/L) (52 FR 36000 (1987)) in tailings pore water but is not present as a significant contaminant in background ground water upgradient and sufficiently far downgradient of the tailings pile. For example, the maximum observed upgradient background concentration for the combined activities of Ra-226 and Ra-228 is 5.5 pCi/L, which was recorded from monitor well 601 as a one-time exceedance of the EPA-proposed MCL. The EPA-proposed MCL of 5.0 pCi/L was not exceeded in any of the other upgradient background monitor wells. The maximum observed background downgradient concentration is 3.1 pCi/L.

Radium is stable as the 2^+ cation in uranium tailings pore water and within the unsaturated zone beneath the tailings. Radium is extremely insoluble in sulfate-rich water and coprecipitates with barite and possibly gypsum. Geochemical modeling has shown that tailings pore water is barite- and gypsum-saturated and may precipitate several sulfate minerals. Dissolved radium is also adsorbed by clay minerals and iron and manganese hydroxides. Even though the cation exchange capacity is only moderate in the subsoils beneath the tailings, it may be contributing to the removal of Ra-226 and Ra-228 before the tailings seepage reaches the water table. Geochemical characterization of tailings subsoils, discussed in Section 3.7, indicates that radium has been concentrated in the soils beneath the tailings.

4.0 GROUND WATER USE, VALUE, AND ALTERNATIVE SUPPLIES

A water resource inventory of domestic, municipal, agricultural, and industrial wells surrounding the Maybell tailings site was conducted by inspecting well records on file at the Colorado Division of Water Resources. According to the most recent records available (March 1990), no wells were within a 3-mi (5-km) radius of the Maybell tailings site. Several domestic wells are in and near the town of Maybell, 5 mi (8 km) southwest of the tailings pile. These wells typically are less than 130 ft (40 m) deep and are completed in the Yampa River Valley alluvium. One well (monitor well 650) is completed in the Browns Park Formation aquifer (Figure 3.3).

Water for the milling of uranium ore at the Maybell site was derived from the Browns Park Formation. No industrial water users are currently extracting ground water from the Browns Park Formation within 3 mi (5 km) of the Maybell tailings site. Ground water from the Browns Park Formation has been used for limited livestock watering, as two windmill-operated wells formerly existed for this purpose. One windmill-operated well was located along Johnson Wash, approximately 1 mi (1.6 km) south of the tailings pile. Field surveys observed this windmill in 1990 (TAC, 1990), but the entire aboveground structure was observed to have been removed during a 1992 field survey (TAC, 1992). The second windmill-operated well was located 2.3 mi (3.7 km) northeast of the tailings pile. Field sampling in 1987 found this windmill well to be unsecured and no monitor well cap was present. Discussions with the well owner indicated that the owner had not used this windmill since about 1982 (McIntyre, 1987).

The existing value of ground water for domestic use in the Maybell area was estimated using information from the nearby town of Craig. The existing value of ground water represents an annual figure that is based on water use and the unit cost of water. This value was calculated using the following information. The estimated monthly use per person was 2500 gallons (9500 liters), at a cost of $14.50. An annual cost of water was estimated to be $174 per person (12 x $14.50). Maybell's population, which also includes area ranches, is currently estimated at approximately 100 residents (Johnson, 1986; Moch, 1992). Therefore, the average annual cost of water use in the town of Maybell was determined to be $17,400 (100 x $174).

Future use of ground water as a drinking water source in the affected hydrogeological environment will be minimal because of the remote location of the Maybell tailings site to existing and future potential water users and the generally poor quality of ground water in the mineralized portions of the Browns Park Formation aquifer. The historical lack of use of ground water near the Maybell tailings site supports this conclusion.

The future drinking water value of water resources within the Browns Park Formation is difficult to estimate because the water value is related to population and water demand, and it is difficult to estimate long-term population changes. Several factors can be used to evaluate the future value of the Browns Park Formation aquifer qualitatively near the Maybell tailings site. These factors are as follows: 1) the expected future use is low; 2) water quality in the mineralized Browns Park Formation aquifer is generally poor; 3) the

Maybell tailings site is in a remote location; and 4) alternative supplies, including the Yampa River Valley alluvium near the town of Maybell, are readily available. Based on these factors, the expected future value of the Browns Park Formation aquifer as a drinking water source near the Maybell tailings site is low.

5.0 LIST OF CONTRIBUTORS

The following individuals contributed to the preparation of this remedial action plan.

Name	Contribution
J. Blount, R. Heydenburg, B. Meyers, G. Ruskauff	Document review
M. Hansen	Author, document coordination
J. McBee	Site management, document review
D. Thalley	Technical editing; document production coordination
L. Keith	Text processing
B. Harvey, L. Wagner	Graphic design
E. Storms, G. Ruskauff	Site hydrologists
J. Blount	Site geochemist

6.0 REFERENCES

Ames et al. (L. L. Ames, J. E. McGarrah, and B. A. Walker), 1983a. "Sorption of Trace Constituents from Aqueous Solutions Onto Secondary Minerals II, Radium," in *Clays and Clay Minerals*, Volume 31, No. 5, pp. 335-342. (Ames et al., 1983)

Ames et al. (L. L. Ames, J. E. McGarrah, B. A. Walker, and P. F. Salter), 1983b. "Uranium and Radium Sorption on Amorphous Ferric Oxyhydroxide," in *Chemical Geology*, Vol. 40, pp. 135-148.

Balistrieri, L. S., and T. T. Chao, 1990. "Adsorption of Selenium by Amorphous Iron Oxyhydroxide and Manganese Oxide," *Geochimica et Cosmochimica Acta*, Vol. 54, pp. 739-751.

Bergin, M. J., 1959. Preliminary Geologic Map of the Maybell-Lay Area, Moffat County, Colorado, U.S. Geological Survey Open-File Report.

BFEC (Bendix Field Engineering Corporation), 1985. *Radiologic Characterization of the Maybell, Colorado, Uranium Mill Tailings Remedial Action Site*, GJ-39, prepared by BFEC, Grand Junction, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Borrowman, S. R., and P. T. Brooks, 1975. "Radium Removal from Uranium Ores and Mill Trainings," *Bureau of Mines Report of Investigations 8099*.

Bouwer, H., 1989, "The Bouwer and Rice Slug Test—An Update," in *Ground Water*, Vol. 27, No. 3, May-June 1989.

Brown et al. (G. E. Brown Jr., G. A. Parks, and C. J. Chisholm-Brause), 1988. "In Situ X-Ray Absorption Spectroscopic Studies of Ions at Oxide-Water Interfaces," *Chimica*, Vol. 43, pp. 248-256.

CDH (Colorado Department of Health), 1990. *The Basic Standards for Ground Water*, Water Quality Control Commission, Section 3.11.0 (5 CCR 1002-8), Table 3 Agricultural Standards, as amended, effective October 30, 1990, Denver, Colorado.

Chenoweth, W. L., 1986. "Geology and Production History of the Uranium Deposits in the Maybell, Colorado, Area," in *New Interpretations of Northwest Colorado Geology*, Rocky Mountain Association of Geologists, pp. 289-292.

CSU (Colorado State University), 1983. "Interpretation of Contaminant Migration Conditions at 12 UMTRA Project Inactive Uranium Mill Tailings Sites," prepared for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Dames & Moore, 1975. "Report of Environmental Studies, Proposed Uranium Heap Leaching Project near Maybell, Colorado, for Union Carbide Corporation," Job No. 0822-081-06, copy on file in the U.S. Department of Energy UMTRA Project Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1989. *Technical Approach Document*, UMTRA-DOE/AL-050425.0002, Revision II, December 1989, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

EPA (U.S. Environmental Protection Agency), 1989. *Statistical Analysis of Ground water Monitoring Data at RCRA Facilities—Interim Final Guidance*, EPA/530-SW-89-026, EPA Office of Solid Waste, Waste Management Division, Washington, D.C.

FBDU (Ford, Bacon & Davis Utah Inc.), 1981. *Engineering Assessment of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado*, DOE/UMT-0116, FBDU 360-11, UC 70, September 1981, prepared by FBDU, Salt Lake City, Utah, Contract No. DE-AC04-76GJ01658, for the U.S. Department of Energy, Albuquerque Operations Office, Uranium Mill Tailings Remedial Actions Project Office, Albuquerque, New Mexico.

Freeze, R. A., and J. A. Cherry, 1979. *Ground Water*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

GECR (Geochemistry and Environmental Chemistry Research, Inc.), 1983. *Data for the Geochemical Investigation of UMTRAP Designated Site at Maybell, Colorado*, DOE/UMT/0246, GECR No. R-8311, prepared by GECR for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Granger et al. (H. C. Granger, E. S. Santos, B. G. Dean, and F. B. Moore), 1961. "Sandstone-Type Uranium Deposits at Ambrosia Lake, New Mexico - An Interim Report," *Bulletin of the Society of Economic Geologists*, Vol. 56, No. 7, pp. 1179-1210.

Haywood et al. (F. F. Haywood, P. T. Perdue, and B. S. Ellis), 1980. *Radiological Survey of the Inactive Uranium Mill Tailings at Maybell, Colorado*, ORNL-5456, Dist. Category UC-41, prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy, Albuquerque, New Mexico.

Hsi, C. D., and D. Langmuir, 1985. "Adsorption of Uranyl Onto Ferric Oxyhydroxides: Application of Surface Complexation Site-Binding Model," *Geochimica et Cosmochimica Acta*, Vol. 49, pp. 1931-1941.

Johnson, B., 1986. Resident deputy, Moffat County Sheriff's Department, Maybell, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, September 25, 1986.

LBL (Lawrence Berkeley Laboratories), 1982. *Hydro-Geochemical Studies of Uranium Mill Tailings Pile at Riverton, Wyoming, and Maybell, Colorado*, LBL-14486, UC-70, Berkeley, California.

Leckie et al. (M. M. Benjamin, K. Hayes, G. Kaufman, and S. Altman), 1980. "Adsorption/Co-precipitation of Trace Elements From Water With Iron Oxyhydroxide," CS-1513, prepared by Stanford University for Electric Power Research Institute, Palo Alto, California.

Lohman, S. W., 1972. "Ground Water Hydraulics," U.S. Geological Survey Professional Paper 708, U.S. Geological Survey, U.S. Government Printing Office, Washington, D.C.

Merritt, R. C., 1971. *The Extractive Metallurgy of Uranium*, Colorado School of Mines Research Institute, Golden, Colorado.

McIntyre, S., 1987. Windmill well owner Maybell, Colorado, personal communication to M. Gilfillan and L. Spencer, United Nuclear Corporation (UNC) under subcontract to Jacobs Engineering Group Inc., Albuquerque, New Mexico, December 11, 1987.

Moch, J., 1992. Community Development Secretary, City Hall, Craig, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group, Inc., Albuquerque, New Mexico, September 21, 1992.

Narasimhan et al. (T. N. Narasimhan, R. M. Galbraith, A. White, A. Smith, H. Schmidt, B. Moed, and T. Tokunaga), 1982. *Hydrogeochemical Studies of Uranium Mill Tailings Piles at Riverton, Wyoming and Maybell, Colorado*, LBL-14486, prepared by Lawrence Berkeley Laboratory for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Nash et al. (K. Nash, S. Fried, A. M. Friedman, and J. C. Sullivan), 1981. "Redox Behavior, Complexing, and Adsorption of Hexavalent Actinides by Humic Acid and Selected Clays," *Environmental Science and Technology*, Vol. 15, pp. 834-837.

NOAA (National Oceanic and Atmospheric Administration), 1977. "Climatography of the United States No. 20, Climate of Craig, Colorado," National Climatic Center, Asheville, North Carolina.

NOAA (National Oceanic and Atmospheric Administration), 1968. U.S. Department of Commerce, National Climatic Center, Asheville, North Carolina.

Rai, D., and J. M. Zachara, 1984. "Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration, Vol. 1: A Critical Review," Report No. EA-3356, Research Project 2198-1, prepared by Battelle, Pacific Northwest Laboratories for Electric Power Research Institute, Palo Alto, California.

Shanbhag, P. M., and G. R. Choppin, 1981. "Binding of Uranyl by Humic Acid," *Journal of Inorganic and Nuclear Chemistry*, Vol. 43, pp. 3369-3372.

Szalay, A., 1964. "Cation Exchange Properties of Humic Acids and Their Importance in the Geochemical Enrichment of UO2+2 and Other Cations," *Geochimica et Cosmochimica Acta*, Vol. 28, pp. 1605-1614.

TAC (Technical Assistance Contractor), 1992. "Unpublished Field Notes, Maybell, Colorado, Uranium Mill Tailings Site," unpublished report prepared by the Technical Assistance Contractor (Jacobs-Weston Team), Albuquerque, New Mexico, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

TAC (Technical Assistance Contractor), 1990. "Unpublished Field Notes, Maybell, Colorado, Uranium Mill Tailings Site," unpublished report prepared by the Technical Assistance Contractor (Jacobs-Weston Team), Albuquerque, New Mexico, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Thomson & Associates, 1990. "Investigation of Microbial Denitrification in Soils Beneath a Uranium Mill Tailings Pile," unpublished report prepared for Jacobs Engineering Group, Inc., Albuquerque, New Mexico.

Travelli, J. A., 1959. "Ground Water in the Rob Pit Area," Trace Elements Corporation, unpublished report.

Tripathy, V. S., 1983. "Uranium VI Transport Modeling: Geochemical Data and Submodels," Ph.D. thesis, Department of Applied Earth Sciences, Stanford University.

Umetco, 1986. Unpublished water quality data, Maybell site, available from the UMTRA Project Document Control Center, U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

CODE OF FEDERAL REGULATIONS

40 CFR Part 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*, U.S. Environmental Protection Agency (1993).

40 CFR Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*, U.S. Environmental Protection Agency (1993).

FEDERAL REGISTER

52 FR 36000, "Standards for Remedial Actions at Inactive Uranium Processing Sites; Proposed Rule," September 24, 1987.

UNITED STATES CODE

42 USC §4321 *et seq., National Environmental Policy Act,* January 1, 1970.

42 USC §7901 *et seq., Uranium Mill Tailings Radiation Control Act,* November 8, 1978.

ATTACHMENT 4

WATER RESOURCES PROTECTION STRATEGY

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
BLM	Bureau of Land Management
°C	degrees Celsius
CDH	Colorado Department of Health
cm	centimeter
cm/s	centimeters per second
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
°F	degrees Fahrenheit
ft	foot
ft/day	feet per day
km	kilometer
L	liter
LTSP	long-term surveillance plan
m	meter
MCL	maximum concentration limit
mg/L	milligrams per liter
mi	mile
NRC	U.S. Nuclear Regulatory Commission
pCi/L	picocuries per liter
POC	point of compliance
Ra	radium
RAS	remedial action selection
RRM	residual radioactive materials
UMTRA	Uranium Mill Tailings Remedial Action

1.0 WATER RESOURCES PROTECTION STRATEGY SUMMARY

The U.S. Department of Energy (DOE) must provide a demonstration of compliance with the proposed U.S. Environmental Protection Agency (EPA) ground water protection standards for inactive mill sites pursuant to 40 CFR Part 192 (1993) (52 FR 36000 (1987)). This section outlines the proposed strategy to demonstrate compliance with the ground water standards at the Maybell, Colorado, Uranium Mill Tailings Remedial Action (UMTRA) Project site. This demonstration consists of 1) the ground water protection standard, 2) a performance assessment, 3) a closure performance demonstration, and 4) a performance monitoring and corrective action program.

To achieve compliance with the proposed EPA ground water standards, the DOE proposes a narrative supplemental standard based on Class III ground water (40 CFR §192.21(g)) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)). Ground water in the Browns Park Formation is not a current or historic source of drinking water. It meets the definition of Class III based on widespread ambient contamination that exists due to naturally occurring uranium mineralization and to mining activities not related to uranium milling operations that occurred on the site (40 CFR §192.11(e)(2)) (52 FR 36000 (1987)). The supplemental ground water standard applies to the uppermost aquifer (upper sandstone of the Browns Park Formation) and will not include numerical concentration limits for the hazardous constituents identified in the contaminated materials at the Maybell site. In addition, no point of compliance (POC) has been proposed. A summary of the principal features of the water resources protection strategy for the Maybell site follows.

- The disposal option proposed for the Maybell tailings site involves stabilizing the tailings and associated contaminated materials at the Maybell site. The materials will be stabilized in place in an aboveground disposal cell designed to reduce radon emanation, minimize water infiltration, withstand differential settlement, resist degradation, and meet the proposed EPA ground water protection standards (52 FR 36000 (1987)).

- Background ground water quality upgradient and downgradient from the tailings pile varies in the Maybell site area, having been affected naturally by extensive low-grade uranium mineralization found in the Browns Park Formation. Ground water quality has also been affected by uranium exploration and open pit mining operations.

- Future use of ground water as a drinking water source in the affected hydrogeological environment will be minimal because of the remote location of the Maybell tailings site to existing and future potential water users and the generally poor quality of ground water in the mineralized portions of the Browns Park Formation. The historical lack of use of ground water for drinking water near the Maybell tailings site supports this conclusion.

- The selection of hazardous constituents was based on hydrogeologic characterization of the Maybell site. Based on a chemical analysis of tailings pore water from suction lysimeters, mean concentrations of hazardous constituents that are listed in Table A of 40 CFR Part 192 (1993) (proposed rule) (52 FR 36000) and Table 1 of 40 CFR

§264.94 (40 CFR Part 264 (1993)) that exceed EPA maximum concentration limits (MCL) are arsenic, cadmium, molybdenum, nitrate, selenium, uranium, and the combined activities of radium (Ra)-226 and Ra-228.

- The remedial action will allow for compliance with the proposed EPA ground water protection standards and is protective of human health and the environment (52 FR 36000) because 1) most downgradient monitor wells within the influence of the tailings pile have not provided evidence of ground water contamination resulting from mill operations at the designated site, 2) the disposal cell design will minimize infiltration of water, and 3) temporary increased seepage rates will occur immediately following disposal cell closure but will return to steady-state conditions after 1.5 years (the effects of this temporary increased seepage rate will be no worse than that which occurred during the period of mill operation), and 4) favorable geochemical conditions will rapidly decrease contamination of ground water downgradient within the influence of the disposal cell.

- The DOE has assessed the performance of the proposed disposal cell at the Maybell site in conjunction with the hydrogeologic system and has shown that the disposal cell will minimize and control releases of hazardous constituents to ground water and surface water, and radon emanations to the atmosphere, to the extent necessary to protect human health and the environment. Natural, stable materials have been proposed for use in construction of the Maybell disposal cell so that long-term performance is ensured.

- No POC is proposed in the uppermost aquifer. Ground water monitoring would not serve any purpose because background ground water quality upgradient and downgradient of the tailings pile is highly variable.

- A long-term surveillance plan (LTSP) will be developed to address the various monitoring needs of the disposal site. Development of the LTSP will follow the DOE's final *Guidance for Implementing the UMTRA Project Long-term Surveillance Program* (DOE, 1992). In lieu of POC ground water monitoring, the DOE proposes a conceptual cell performance monitoring plan to be implemented prior to construction. Details of the conceptual cell performance monitoring plan will be presented in the Maybell LTSP.

- Demonstration of cleanup and control of existing site-related ground water contamination will be addressed under a separate DOE program and will be part of a separate process to comply with the National Environmental Policy Act (42 USC §4321 *et seq.*).

2.0 CONCEPTUAL DESIGN FEATURES FOR WATER RESOURCES PROTECTION

2.1 DESIGN CONSIDERATIONS

Disposal cell design considerations for the Maybell site included the effect of climate on the rate of infiltration through the cover of the cell and the relation of surface topography and final grading to surface drainage. The disposal cell is designed to comply with the longevity requirements of 40 CFR §192.02(a)(1) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)).

Several design features were incorporated into the disposal cell as a result of the design considerations. A multicomponent cover will be used to reduce infiltration and meet the longevity requirements. The contaminated materials will be placed no wetter than the optimum moisture content to minimize transient drainage. The amount of construction water for dust control will be carefully monitored. To verify the expected performance of the completed disposal cell, a detailed cell performance monitoring plan will be provided in the Maybell site-specific LTSP. The cell performance monitoring plan will include the installation and sampling of new monitor wells immediately downgradient of the tailings pile. Section 5.3.4, Closure Performance Demonstration, of the remedial action selection (RAS) report presents more detailed information regarding the DOE-proposed cell performance monitoring plan.

2.1.1 Climate

Climate is an important design consideration because of its influence on the quantity of water available to percolate through the disposal cell and its potential effect on the migration of hazardous constituents to ground water.

The climate at Craig, Colorado, 25 miles (mi) (40 kilometers [km]) east of the Maybell site is semiarid, with a mean annual precipitation of 13.29 inches (34 centimeters [cm]) (NOAA, 1977). The annual precipitation data used covered the 23-year period from 1951 through 1973. Precipitation at the site occurs as both rain and snow; snow is the predominant form. The amount of precipitation received monthly is relatively well distributed, with the mean annual minimum occurring in February (0.8 inch [2 cm]) and the mean annual maximum in August (1.5 inches [3.8 cm]). The mean annual temperature for the 23-year period is 42 degrees Fahrenheit (°F) (5.6 degrees Celsius [°C]), with a range from -45 to +99°F (-43 to +37°C). The length of the freezing season is approximately 197 days. From this information, a frost penetration depth of approximately 60 inches (150 cm) was determined. The frost penetration depth is used in the design to determine a depth below which the radon/infiltration barrier will be protected from the damage of frost (see Calculation MAY-398-03-00, Attachment 1, Volume III). Surface wind data indicate that the wind blows most frequently at speeds whose average ranges from 4.6 to 17.2 miles per hour (7.4 to 27.7 kilometers per hour). The most prevalent wind direction is from the west-southwest.

2.1.2 Surface drainage

The tailings are situated on the sediments of Browns Park Formation. Surface flows from upland drainage areas will be permanently directed away from the disposal cell by constructing two drainage swales. The disposal cell will have a topslope of 3 percent and sideslope of 20 percent, which creates a condition where surface runoff is not allowed to pond on the disposal cell. Surface runoff from the disposal cell will be directed away by means of two permanent drainage ditches, thereby reducing the amount of surface water available to infiltrate into the disposal cell.

2.1.3 Infiltration and ground water recharge

Under natural conditions in the vicinity of the Maybell site, a small portion of the precipitation is expected to deep-percolate to recharge the underlying aquifer. The majority of the precipitation that falls over the tailings site is discharged as surface runoff to the ephemeral drainages of the Yampa River or is lost through evapotranspiration. The high annual rate of pan evaporation of 48 inches (122 cm) (NOAA, 1968), minus the 13.3 inches (34 cm) of precipitation, results in a moisture deficit of approximately 35 inches (89 cm). The actual moisture deficit is somewhat less, because evaporation from bare soil or evapotranspiration from plants is generally less than pan evaporation.

In the steady-state condition, the seepage rate from the disposal cell cover should be a function of the infiltration rate through the radon/infiltration barrier. The saturated hydraulic conductivity of the radon/infiltration barrier will be approximately 1×10^{-7} centimeter per second (cm/s) (2.8×10^{-4} feet per day [ft/day]) or less, based on laboratory testing of 10 percent Redmond bentonite-amended cover material.

Most of the precipitation that falls directly on the disposal cell will either be lost to evaporation or shed from the pile as surface runoff. Since the average rate of evaporation is three times greater than the rate of precipitation, the assumption that the radon/infiltration barrier will remain saturated is conservative (see Calculation MAY-03-94-12-04-00, Attachment 3, Appendix A, *Hydrological Services Calculations*).

Transient drainage of tailings pore fluids will peak immediately after the disposal cell is closed. A saturation front may develop below the layer of slimes during dissipation of the pore water, whose flux rate will approximate the saturated hydraulic conductivity of the Browns Park Formation. On average, the unit flux should approach steady-state conditions 1.5 years after closure (see Calculation MAY-03-94-12-05-00, Attachment 3, Appendix A). Because the subsoils of the Browns Park Formation were able to accept tailings seepage under previous conditions, they should readily accept transient drainage after disposal cell closure (Attachment 3, Appendix A, *Hydrological Services Calculations*).

Although the permeability of the faults observed in the walls of the open pit mines appears to be similar to the surrounding bedrock, it is difficult to quantify their potential as flow paths or barriers to fluid migration. Uranium mineralization was generally associated with the most permeable areas of these faults (greater displacement and junctions with cross-treading faults), which provided pathways for migration of hydrocarbon gases (reductant) that allowed for precipitation of the minerals from solution. The mill site and tailings pile were located in an unmineralized area where the potential for fault-related permeability would be less. Therefore, the potential for ground water contamination related to preferential contaminant fluid migration associated with faults should be minimal beneath the proposed disposal site (existing tailings pile).

2.1.4 Geochemical conditions

Several hazardous constituents are present at average concentrations that exceed the EPA MCLs (Table 3.1 of this attachment) in tailings pore water and in some monitor wells completed in the Browns Park Formation. The geochemical analysis of ground water quality data (presented in Section 3.5 of Attachment 3, *Ground Water Hydrology Report*), shows that none of these hazardous constituents (except nitrate in monitor well 673) are currently present at elevated concentrations outside the immediate downgradient edge of the tailings pile (e.g., monitor well 645) relative to the maximum observed background values.

2.2 DESIGN FEATURES

This section describes the principal design features of the proposed disposal cell at the Maybell site that will ensure compliance with the proposed EPA ground water protection standards (52 FR 36000) and will demonstrate that the design features do not rely on active maintenance to ensure adequate long-term performance. Additional details and specifications of the conceptual design are provided in Section 3.2.4 of the RAS report.

2.2.1 Disposal cell components

The proposed disposal cell configuration is shown in Figure 2.1, and a typical cross section of the disposal cell is presented in Figure 2.2. The disposal cell is designed to stabilize the contaminated materials at the Maybell site, minimize radon emanations, and protect ground water resources.

Disposal cell geometry

The disposal cell will be approximately triangular with a maximum length of 2650 feet (ft) (810 meters [m]) and a maximum width of 1750 ft (530 m). It will cover approximately 66 acres (27 hectares). The completed cell will rise an average of 40 ft (12 m) above the surrounding topography. The tailings and other contaminated materials will be consolidated and contoured to sideslopes

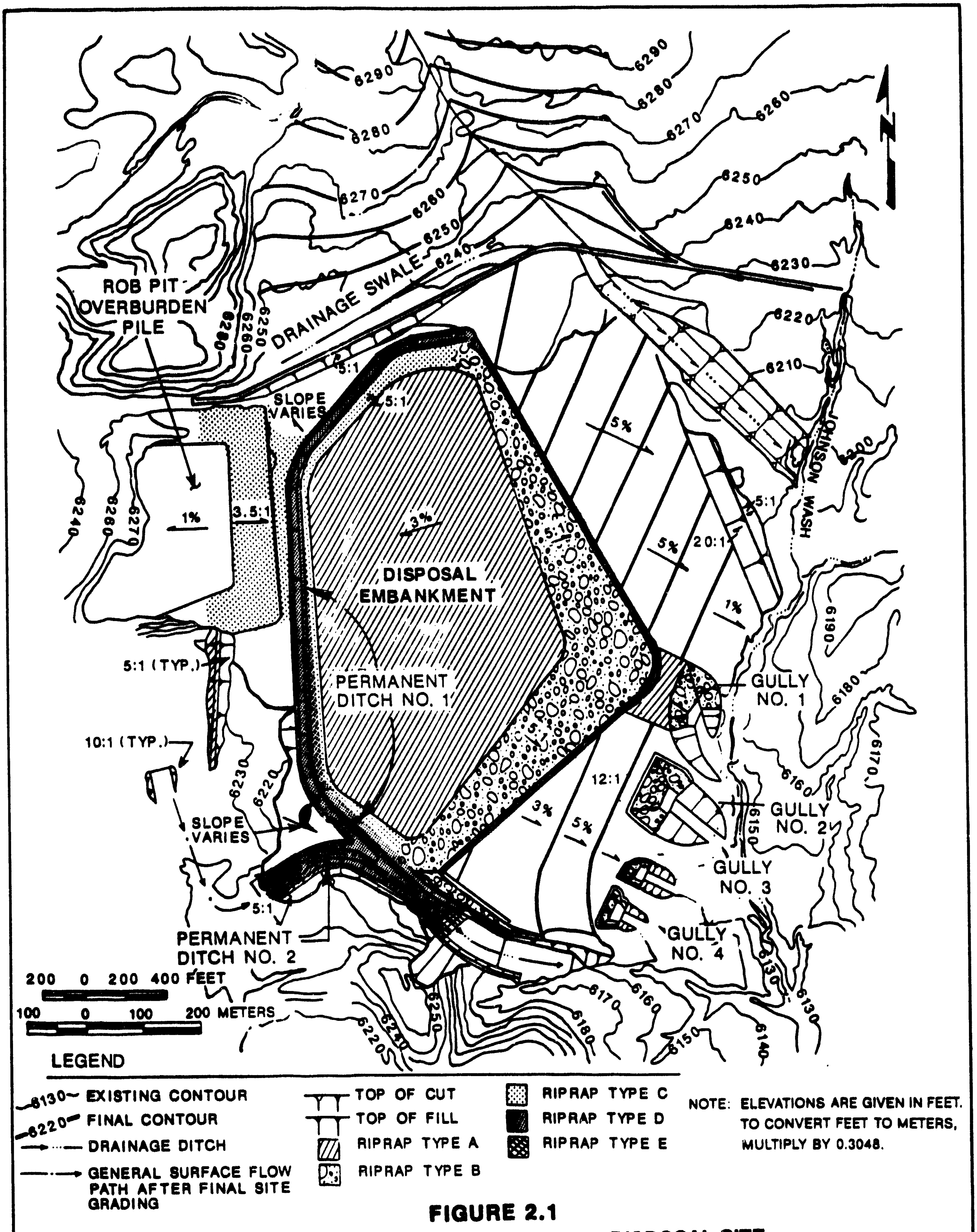
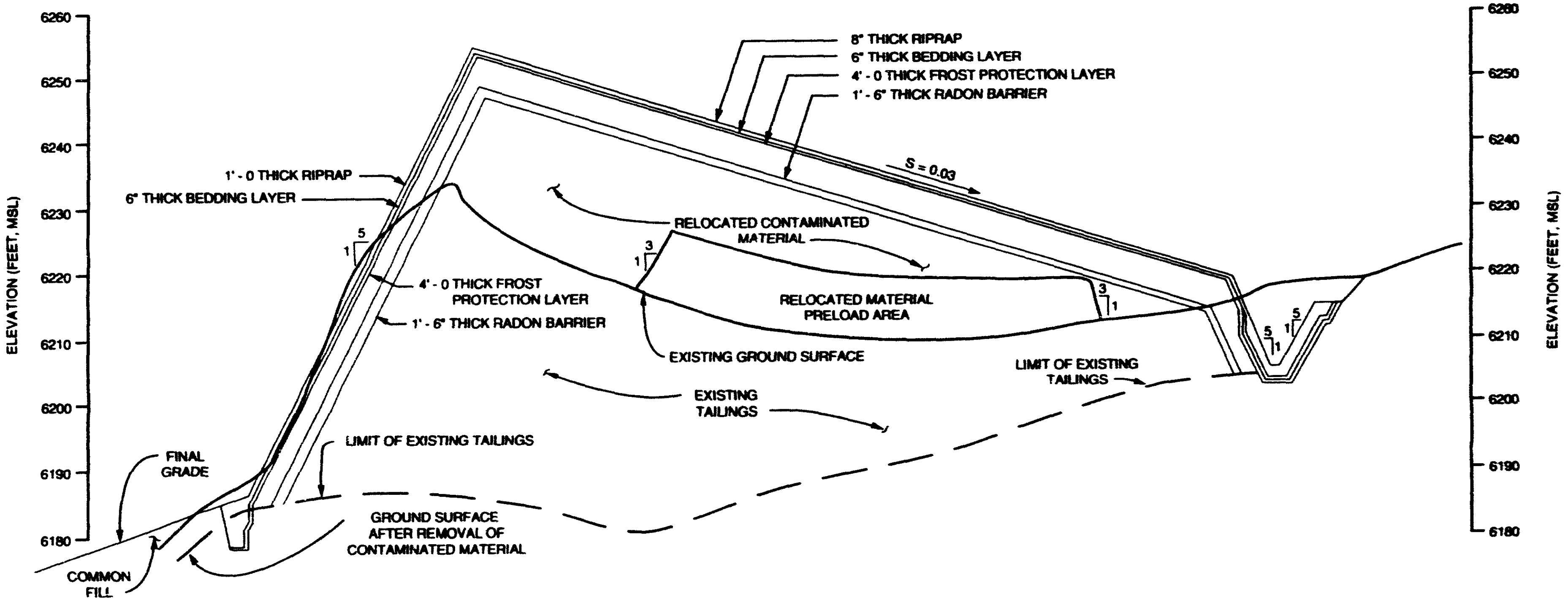


FIGURE 2.1
FINAL CONDITIONS AT THE MAYBELL DISPOSAL SITE NEAR MAYBELL, COLORADO



NOT TO SCALE

NOTE: ELEVATIONS ARE GIVEN IN FEET.
TO CONVERT FROM FEET TO METERS,
MULTIPLY FEET BY 0.3048.

FIGURE 2.2
TYPICAL CROSS SECTION OF
THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

MAC: SITE/RAP/MAY/X-SECT STABIL 2.2

of 20 percent and a topslope of 3 percent. The cover details are shown in Figure 2.2.

The proposed design for the disposal cell cover consists of the following, in ascending order above the contaminated materials.

Topslope

- One and one-half-ft (0.5-m)-thick radon/infiltration barrier consisting of clayey sands amended with 10 percent Redmond bentonite (see Attachment 1, Information for Bidders, Volume III, and Calculation MAY-355-03-01, Attachment 1, Volume III, for a detailed description and list of the geotechnical properties of this material).
- Four-ft (1.2-m)-thick frost protection layer composed of sandy soils. (See Attachment 1, Information for Bidders, Volume III, and Calculation MAY-398-03-00, Attachment 1, Volume III, for a description of the properties of this material).
- One-half-ft (15-cm)-thick bedding layer.
- Eight-inch (20-cm)-thick erosion protection layer. (See Attachment 1, Information for Bidders, Volumes III and IV, and Calculation MAY-336-11-01 in Attachment 1, Volume IV, and Calculations MAY-336-06-00 and MAY-336-07-02 in Attachment 1, Volume I, for a description and list of the properties of the riprap material.)

The topslope will have a 3 percent slope to the west. Runoff will flow to a ditch adjacent to the cell (Figure 2.1). The radon/infiltration barrier materials, clayey sands amended with 10 percent Redmond bentonite, will have a saturated hydraulic conductivity of 1×10^{-7} cm/s (2.8×10^{-4} ft/day) or less, based on laboratory testing (see Calculation MAY-355-03-01, Attachment 1, Volume III). This layer will minimize infiltration into the contaminated materials and thereby minimize the volume of leachate from the bottom of the cell.

Sideslopes

Components of the sideslope are listed in ascending order outward from the contaminated materials:

- One and one-half-ft (0.5-m)-thick radon/infiltration barrier (see above).
- Four-ft (1.2-m)-thick frost protection layer (see above).
- One-half-ft (15-cm)-thick bedding layer.
- One-ft (0.3-m)-thick erosion protection layer. (See Attachment 1, Information for Bidders, Volumes III and IV, and Calculation MAY-336-11-01

in Attachment 1, Volume IV, and Calculations MAY-336-06-00 and MAY-336-07-02 in Attachment 1, Volume I, for a description and list of the properties of the riprap material.)

The sideslopes of the disposal cell will be five horizontal to one vertical (20 percent) and will be protected by a riprap apron on the south and east sides. On the north and west sides of the cell, the sideslopes will be part of the main ditch that will carry surface runoff from the cell and adjacent off-cell areas. All upland runoff will be intercepted and routed around the disposal cell. The relatively high slopes and the high-permeability bedding layer will enhance immediate surface runoff and minimize infiltration of precipitation. The bedding material will be sized to resist erosion of the frost protection materials while maintaining the highest hydraulic conductivity possible.

2.2.2 Disposal cell longevity

Natural, stable materials have been proposed for use in construction of the Maybell disposal cell so that long-term stability is ensured and EPA standards in 40 CFR §192.02(a)(1) will be achieved (40 CFR Part 192 (1993) and 52 FR 36000 (1987)). Materials for the rock erosion layer have been selected, based on durability, suitability, and size, that will perform adequately over the design life of the disposal cell. Bedding materials for the filter layers have been selected using the same durability criteria as for the rock. The filter materials will be sized to drain water rapidly. The radon/infiltration barrier clays (amended with 10 percent Redmond bentonite) will be protected from erosion by the overlying layers. Adherence to design specifications for placement and compaction of the materials at the disposal cell will ensure a uniform hydraulic conductivity of the radon/infiltration barrier. The thickness of materials overlying the barrier will provide frost protection of the radon/infiltration barrier.

3.0 DISPOSAL AND CONTROL OF RADIOACTIVE MATERIALS AND NONRADIOACTIVE CONTAMINANTS

The proposed EPA standards in 40 CFR Part 192 (1993) (52 FR 36000 (1987)) require information and assessments to demonstrate that the disposal of residual radioactive materials (RRM) complies with ground water protection and performance standards. The information and assessments needed can be categorized into four components: 1) the ground water protection standard, 2) a performance assessment, 3) a closure performance assessment, and 4) a performance monitoring and corrective action program. The monitoring for the performance assessment confirms the performance of the disposal cell and provides for corrective actions that may be necessary if the disposal cell does not perform adequately (NRC, 1989). The following sections describe in detail the four components of the ground water protection and performance standards.

3.1 GROUND WATER PROTECTION STANDARD

The proposed EPA ground water protection standards in 40 CFR §192.02(a)(3) (1993) (52 FR 36000 (1987)) require that disposal units be designed to control RRM. The ground water protection standard applies to the uppermost aquifer hydraulically downgradient from the disposal unit (NRC, 1989). Definitions of the uppermost aquifer provided in 10 CFR Part 40 (1993), Appendix A, were used to implement the ground water protection standards of 40 CFR Part 192 (1993) (52 FR 36000 (1987)).

Ground water in the Browns Park Formation is not an historic or current source of drinking water. It meets the Class III supplemental standard criterion of 40 CFR §192.21(g) (1993) (52 FR 36000 (1987)) of the proposed EPA ground water standards based on widespread, ambient contamination that exists due to naturally occurring uranium mineralization and to mining activities not related to uranium milling operations that occurred on-site (40 CFR §192.11(e)(2)) (1993) (52 FR 36000 (1987)).

The ground water protection standard consists of three components: 1) a list of hazardous constituents, 2) a corresponding list of concentration limits for the constituents, and 3) a POC (NRC, 1989). During characterization of the ground water in the site vicinity, the DOE collected samples to identify potential hazardous constituents. The DOE identified hazardous constituents in pore fluids of RRM and in ground water in the Browns Park Formation. For this narrative supplemental standard application, no concentration limits or POC have been established for the identified hazardous constituents because of the highly variable background ground water quality of the Browns Park Formation and because defining concentration limits and a POC would not further protect human health and the environment. As part of the supplemental standard application, land and water use in the site vicinity were reviewed to assess the beneficial use of ground water. This is discussed in Section 3.2.2 of this attachment.

3.1.1 Hazardous constituents

The DOE has characterized the Maybell site by collecting and analyzing samples to identify potential hazardous constituents that are likely to be in, or derived from, RRM at the tailings site. The existence of potential hazardous constituents was identified by characterizing RRM, characterizing ground water quality data, describing the process and reagents used in processing uranium, and assessing what constituents are reasonably expected to be in or derived from RRM at the tailings site. Tailings pore water obtained from lysimeters installed in the tailings was analyzed for hazardous constituents listed in Table A of 40 CFR §192.02(a)(3)(ii) (1993) (proposed rule) (52 FR 36000 (1987)) and Table 1 of 40 CFR §264.94 (40 CFR Part 264 (1993)). Mean concentrations of hazardous constituents that exceed the EPA MCLs in the tailings pore water are arsenic, cadmium, molybdenum, nitrate, selenium, uranium, and the combined activities of Ra-226 and Ra-228 (Table 3.1).

A scan for the presence of hazardous organic constituents was conducted in October 1989. Ground water samples collected from monitor wells 643, 645, and 648 were analyzed for hazardous organic constituents listed in Appendix IX of 40 CFR Part 264 (1993). No Appendix IX hazardous constituents were detected. Monitor wells 643, 645, and 648 are located within the tailings pile footprint, and ground water samples analyzed from these wells would serve as the best indicator for the presence of organic hazardous constituents due to proximity to tailings seepage.

3.1.2 Proposed concentration limits

To achieve compliance with the proposed EPA ground water protection standards (52 FR 36000 (1987)), the DOE proposes a narrative supplemental ground water standard rather than establishing numerical concentration limits at a specified POC. A narrative supplemental ground water standard is appropriate for the Maybell site for the following reasons:

- Background ground water quality in the Browns Park Formation is highly variable.
- The ground water in the uppermost aquifer is not an historic or current drinking water source downgradient of the affected area. Establishing numerical concentration limits for the identified hazardous constituents at a specified POC will not further protect human health and the environment.
- The proposed remedial action at the Maybell site comes as close to meeting the otherwise applicable standards (52 FR 36000 (1987) and 40 CFR Part 264 (1993)) as is reasonable under the circumstances (see Sections 2.1 and 2.2 for a discussion of disposal cell design features).
- The application of a supplemental ground water protection standard ensures protection of human health and the environment (40 CFR Part 192 (1993) and 52 FR 36000 (1987)).

Table 3.1 Hazardous constituents detected in ground water and tailings pore water at the Maybell tailings site, Moffat County, Colorado

		Background				Source concentration
		Upgradient[c]		Downgradient[d]		Tailings pore fluid
Hazardous[a] constituent	MCL[b]	Maximum observed concentration	Mean or median	Maximum observed concentration	Mean or median	Lysimeter[e] mean
Arsenic	0.05	0.06	0.011[f]	0.26	0.0125[f]	0.06
Cadmium	0.01	0.031	0.0005[f]	0.021	0.0005[f]	0.011
Lead	0.05	0.17	0.005[f]	0.15	0.005[f]	0.045
Molybdenum	0.10	0.11	0.022[f]	0.28	0.02[f]	2.049
Nitrate (NO$_3$)	44.0[g]	24.5	2.8[f]	190	1.0[f]	1949
Combined Ra-226 and -228 (pCi/L)[h]	5.0	5.5	1.3[f]	3.1	0.50[f]	17.92
Selenium	0.01	1.3	0.005[f]	0.028	0.005[f]	0.54
Uranium	0.044[i]	0.112	0.016[j]	0.095	0.0019[f]	1.221
Inorganic constituent without MCL						
Antimony	NA	0.14	0.003[f]	0.02	0.003[f]	0.014
Beryllium[k]	NA	<0.025[l]	0.005[m]	<0.01[l]	0.005[m]	0.025
Manganese	NA	6.06	0.30[n]	1.13	0.41[o]	--
Nickel	NA	0.10	0.04[f]	0.08	0.04[f]	0.50

[a] Hazardous constituents from Table 1 of 40 CFR §264.94 and Table A of 40 CFR §192.02(a)(3)(ii) (proposed standards) (52 FR 36000). All concentrations in milligrams per liter unless noted otherwise.

[b] MCL—maximum concentration limit. Table 1 of 40 CFR §264.94 (40 CFR Part 264) and Table A of 40 CFR §192.02(a)(3)(ii) (proposed standards) (52 FR 36000).

[c] Upgradient background ground water—from monitor wells 601, 602, 660, 671, and 690.

[d] Downgradient background ground water—from monitor wells 650, 692, 693, and 694.

[e] Lysimeter arithmetic mean—lysimeter data are weighted from lysimeters 081, 083, and 085 located on the tailings pile.

[f] Median determined nonparametrically.

[g] The MCL for nitrate as (N) is 10 mg/L.

[h] pCi/L—picocuries per liter.

[i] The uranium concentration of 0.044 mg/L is equivalent to 30 pCi/L, which is the MCL.

[j] Median lognormal distribution.

[k] All values recorded are less than the method detection limit.

[l] Maximum method detection limit.

[m] Mean or median not calculated, as all values are less than the method detection limit.

[n] Mean lognormal distribution.

[o] Mean normal distribution.

3.1.3 Point of compliance

A POC has not been established for the Maybell site for the reasons discussed in Section 3.1.2.

3.2 NARRATIVE SUPPLEMENTAL STANDARD

The U.S. Nuclear Regulatory Commission (NRC) requires four items to be considered when applying supplemental standards (NRC, 1989). These include 1) a demonstration of applicability, 2) a description of the supplemental standard, 3) a demonstration that the remedial action complies with the proposed supplemental standard, and 4) a demonstration that the supplemental standard is as low as reasonable under the circumstances.

3.2.1 Applicability criteria

To achieve compliance with the proposed EPA ground water protection standards, the DOE proposes the application of a narrative supplemental standard (Subpart C of 40 CFR Part 192 (1993)) (52 FR 36000 (1987)) at the Maybell site on the basis that ground water in the Browns Park Formation meets the definition of Class III ground water because widespread ambient contamination exists due to naturally occurring uranium mineralization and to mining activities not related to uranium milling operations that occurred on the site (40 CFR §192.11(e)(2) (1993)) (52 FR 36000 (1987)).

Treatability of ground water from the Browns Park Formation

For the following discussion on treatability, the proposed EPA Title I ground water standards (52 FR 36000 (1987) and 40 CFR Part 264 (1993)) and federal secondary drinking water standards were used as the criteria for determining the technical and economic viability of treating ground water from the Browns Park Formation.

Within the context of this section, the terms "background" and "background water quality" refer only to constituent concentrations found in monitor wells designated as background wells by the DOE. To determine water quality levels of contamination, water samples were obtained from monitor wells upgradient and downgradient with respect to the ground water flow direction in the Browns Park Formation.

The treatability argument is presented in the following format: 1) a discussion of drinking water quality and current treatment practices in Colorado; 2) the DOE analysis of ground water conditions in the vicinity of the disposal site; and 3) the implications with respect to treatability after considering any disparities between items 1 and 2.

- Drinking water quality and current treatment practices

  - The Colorado Department of Health (CDH) maintains a data base containing information on 1000 municipal water supply systems located throughout the state. About 200 municipalities obtain their drinking water from surface sources, but ground water is the principal source of drinking water for the remaining 800 cities and towns.

  - Based on a review of documents provided by the CDH and conversations with CDH personnel, 98 percent of the ground water used for public supply in Colorado requires no treatment other than disinfection with chlorine (Bodnar and Rogers, 1992). The remaining 2 percent of the ground water sources supplying municipalities require some treatment—generally to lower the concentration of a single constituent that exceeds a state primary or secondary drinking water standard. For example, water from some of the municipal supply wells in the vicinity of the South Platte River contain elevated levels of nitrate. Ground water from a few municipal supply wells requires softening (i.e., reducing levels of calcium and magnesium ion) prior to distribution. In addition, a few ground water sources contain slightly elevated levels of total dissolved solids. No ground water sources are currently used for municipal supply in Colorado containing elevated levels of metals, wherein treatment is required to meet the current state or federal MCLs; however, water from some supply wells in southern Colorado must be treated to lower elevated concentrations of radium. In most cases, the concentration of radium found in the ground water only slightly exceeds the 5 picocuries per liter (pCi/L) federal standard.

  - Most of the surface water used for municipal supply in Colorado comes from rivers and man-made impoundments. Typically, surface water is treated to 1) reduce turbidity caused by suspended sediment, 2) eliminate pathogenic organisms—chiefly *Giardia*, and 3) alleviate taste and odor problems. The most commonly used processes (treatment train) for treating surface water are aeration, coagulation/flocculation, sedimentation, filtration, and chlorination. None of the surface waters currently used for municipal supply in Colorado are treated to reduce concentrations of any of the constituents regulated under either state or federal primary drinking water standards (Bodnar and Rogers, 1992). Some surface waters have odor problems that violate the federal secondary drinking water standard of 3 threshold odor number. In those cases, the water is treated before being distributed to households and businesses.

  - The consensus among city engineers and water supervisors from Moffat County and adjacent Rio Blanco County is that ground water in northwestern Colorado, even from deep water-bearing strata, is generally of very poor quality and is not suitable for public supply. The occurrence of widespread mineral deposits (including uranium) and extensive hydrocarbon deposits (both liquid and gaseous) is typical of the subsurface geology in this region of Colorado. In addition, much of water-bearing strata in the region, including the Mesaverde Group and Mancos Shale, generally yield mineralized ground water. Thus, naturally occurring, widespread, ambient contamination of ground water resources is common in the plains of northwestern Colorado.

- Analysis of current ground water conditions at the site as presented in Tables 3.1 and 3.2:
    - Maximum observed concentrations of arsenic, cadmium, lead, molybdenum, selenium, uranium, and the combined activities of Ra-226 and Ra-228 in the background ground water from the Browns Park Formation upgradient from the Maybell tailings pile exceed the proposed EPA MCLs (52 FR 36000 (1987) and 40 CFR Part 264 (1993)). In the background ground water downgradient of the Maybell tailings pile, maximum observed concentrations of arsenic, cadmium, lead, molybdenum, nitrate, selenium, and uranium exceed the proposed EPA MCLs (Table 3.1).
    - The concentration of selenium in one upgradient background well exceeds the proposed EPA MCL by nearly one and one-half orders of magnitude. Uranium concentrations in the background ground water upgradient and downgradient from the tailings pile are also consistently above the proposed EPA MCL of 30 pCi/L (equivalent to 0.044 milligrams per liter [mg/L]) (52 FR 36000 (1987)).
    - Maximum observed concentrations of aluminum, iron, manganese, sulfate, and total dissolved solids in the background ground water upgradient and downgradient from the Maybell tailings pile exceed the EPA secondary drinking water standards (40 CFR Part 143 (1993)) (Table 3.2).
    - Ground water from the uppermost aquifer would require treatment to lower concentrations of radionuclides. It is conceivable that there is extensive uranium contamination of the aquifer in the vicinity of the Maybell site due to widespread, low-grade uranium mineralization in the Browns Park Formation. Radium levels are slightly above the primary standard in at least one background well. Net gross alpha maximum observed concentrations are elevated above the Title I primary standard of 15 pCi/L (52 FR 36000 (1987)) in three of the five designated upgradient background wells and one of the four designated downgradient background wells.
    - Although a few municipalities currently treat ground water to lower levels of radium (average inflow concentrations of 5 to 10 pCi/L), no public water systems in Colorado are currently treating ground water to reduce uranium concentrations.

Table 3.2 Secondary drinking water constituents detected in background ground water at the Maybell tailings site, Moffat County, Colorado

Constituent	MCL (mg/L)	Secondary drinking water standard (mg/L)	Upgradient background maximum observed concentration[a] (mg/L)	Downgradient background maximum observed concentration[b] (mg/L)
Arsenic[c]	0.05[d]	NA	0.06	0.26
Cadmium[c]	0.01[d]	NA	0.031	0.021
Lead[c]	0.05[d]	NA	0.17	0.15
Molybdenum[c]	0.10[d]	NA	0.11	0.28
Nitrate (NO_3)[c]	44.0[d,e]	NA	24.5	190
Combined Ra-226 and -228 (pCi/L)[c]	5.0[d]	NA	5.5	3.1
Selenium[c]	0.01[d]	NA	1.3	0.028
Uranium[c]	0.044[d,f]	NA	0.112	0.095
Aluminum[g]	NA	0.05-0.2[h]	0.43	3.0
Iron[g]	NA	0.3[h]	1.64	3.33
Manganese[g]	NA	0.05[h]	6.06	1.13
Sulfate[g]	NA	250[h]	2180	1710
Total dissolved solids[g]	NA	500[h]	3710	4940

[a] Upgradient background ground water is represented by monitor wells 601, 602, 660, 671, and 690.

[b] Downgradient background ground water is represented by monitor wells 650, 692, 693, and 694.

[c] Constituents from Table 1 of 40 CFR §264.94 (40 CFR Part 264) and Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000). All concentrations in milligrams per liter unless noted.

[d] MCL—Maximum concentration limit. Table 1 of 40 CFR §264.94 (40 CFR Part 264) and Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000).

[e] The MCL for nitrate as (N) is 10 mg/L.

[f] The uranium concentration of 0.044 mg/L is equivalent to 30 pCi/L, which is the MCL.

[g] Constituents from 40 CFR §143.3 (40 CFR Part 143). All concentrations in milligrams per liter.

[h] Secondary Drinking Water Standard from 40 CFR §143.3 (40 CFR Part 143).

NA—Not applicable.

  - Although a primary concern is the reduction of contaminant levels exceeding the proposed EPA MCLs, constituents exceeding EPA secondary drinking water standards must also be considered when assessing treatability. Based on data from upgradient and downgradient background ground water monitor wells, water from the Browns Park Formation aquifer generally contains elevated levels of iron, manganese, sulfate, and total dissolved solids.

  - Widespread ground water contamination exists upgradient and downgradient of the site from natural and man-made sources not related to the milling activities that occurred on the site. Any success in treating ground water to achieve drinking water quality standards in the site vicinity (even if it were economically viable) would be short-lived due to the natural mineralization in the Browns Park Formation aquifer.

- Implications with respect to treatability

  - Colorado has nearly 800 ground water sources used to supply potable water for public consumption. Nearly 780 of those ground water sources require no treatment beyond disinfection. Of the remaining ground water sources (approximately 20), all require only a single treatment process, such as ion exchange or reverse osmosis, to reduce concentrations that exceed primary or secondary standards for a single ion. Thus, typical practice in Colorado, especially for smaller water supply systems, is to not treat ground water.

    The cost is minimal for most small Colorado municipalities that choose to treat ground water for a single problem constituent. Because of the number of constituents exceeding the EPA-proposed MCLs in the ground water from the Browns Park Formation aquifer at the Maybell site, multiple treatment technologies would be necessary to reduce contaminant levels to drinking water standards.

  - The process efficiency required to lower the potentially very high levels of selenium to below the proposed EPA Title I MCL (40 CFR Part 264 (1993)) may be as high as 99 percent. Consistently achieving such high removal rates for selenium would be technically difficult, especially for a small treatment facility, and given the high levels of other major ions found in the ground water.

  - The CDH has not identified a single public water source, either surface water or ground water, that requires treatment to lower concentrations of heavy metals. Thus, treating to reduce metal concentrations in public water supplies is not necessary anywhere in Colorado. The upgradient and downgradient background ground water from the Browns Park Formation near the site appears to be contaminated with (in addition to selenium) elevated levels of at least four regulated metals or metalloids:

arsenic, cadmium, lead, and molybdenum. Both chemical and physical processes would be needed to remove metals and arsenic from the ground water.

- Apart from aesthetics, the presence of high levels of ions, such as sulfate, iron, and manganese, can adversely affect treatment processes. For example, high levels of sulfate and calcium (high concentrations of calcium are also found in the water from the Browns Park Formation), can cause scaling (gypsum formation) of the membrane in reverse-osmosis units. Other ions are also potentially detrimental to the efficiency of some treatment processes. Manganese and iron will foul ion-exchange resins if the oxidation states of the two species are not carefully controlled during the treatment process.

- Based on information on water use and treatment practices in the towns closest to the Maybell site, most accessible ground water resources are not considered suitable for public supply in most cases. The largest towns in the region (Craig, Colorado [population 8100] [DOC, 1991] and Vernal, Utah [population 6640] [DOC, 1990]) use surface water to meet all municipal drinking-water demand and most of the local agricultural water needs. Meeker is the only large town in northwestern Colorado that uses ground water for its municipal drinking water supply. In addition, Meeker maintains tanks that allow storage of up to 2.5 million gallons (9.5 million liters [L]) of ground water. Because of a dearth of usable water in the surrounding area, local ranchers rely on the stored ground water to supply most of the water necessary to maintain their livestock.

3.2.2 Demonstration that remedial action complies with supplemental standards

This section describes potential impacts of ground water use to human health and the environment. Potentially exposed populations are described in the land and water use sections. Land and water use are discussed to establish whether there is beneficial use of ground water in the uppermost aquifer.

Land use

The Maybell processing site is 5 mi (8 km) northeast of the town of Maybell, Colorado. The majority of the land around the site is under federal ownership and is administered by the Bureau of Land Management (BLM). However, there is private land south, east, and west of the site. The northern portion of the designated tailings site is on land administered by the BLM; the southern portion of the site is on private land. Umetco Minerals Corporation, a wholly owned subsidiary company of Union Carbide Corporation, has the radioactive materials license for the designated site and continues as the operational controller. Umetco is not a landowner of the designated site. The state of Colorado has been authorized to perform land appraisals of the privately held properties associated with the proposed remedial action. Upon acquisition of the privately held properties, title will then be transferred from the state of Colorado to the DOE.

Virtually all of the land around the site is used for low-density livestock grazing. However, areas northeast, north-northwest, and south of the site have been disturbed by open pit mining and related activities, and four inactive open pit mines are within 1 mi (1.6 km) of the site.

Water use

A water resource inventory of domestic, municipal, agricultural, and industrial wells surrounding the Maybell tailings site was conducted by inspecting well records on file at the Colorado Division of Water Resources. According to the most recent water records available (March 1990), no domestic wells are recorded within a 3-mi (5-km) radius of the Maybell tailings site. Several domestic wells are in and near the town of Maybell, 5 mi (8 km) southwest of the tailings pile. These wells typically are less than 130 ft (40 m) deep and are located in the Yampa River Valley alluvium, with the exception of monitor well 650, which is located in the Browns Park Formation aquifer (Figure 3.1).

The Browns Park Formation provided water for the uranium milling operations at the Maybell site. No industrial water users are currently extracting ground water from the Browns Park Formation within 3 mi (5 km) of the Maybell tailings pile. Ground water from the Browns Park Formation has been used for limited livestock watering, as two windmill-operated wells formerly existed for this purpose. One windmill-operated well (DOE-designated monitor well 632) was located along Johnson Wash, approximately 1 mi (1.6 km) south of the tailings pile, but was removed between 1990 and 1992 (TAC, 1990; 1992). The second windmill-operated well (DOE-designated monitor well 631) was located 2.3 mi (3.7 km) northeast of the tailings pile. Discussions with the well owner indicated that the owner had not used this windmill since about 1982 (McIntyre, 1987). The locations of the two former windmill-operated wells are shown in Figure 3.1.

Construction of the proposed disposal cell at the Maybell tailings site will not preclude any potential future use of the Browns Park Formation aquifer for livestock watering. Disposal cell design features that will be used to ensure compliance with the proposed EPA ground water protection standards (52 FR 36000 (1987)) are described in Section 2.2 of this attachment. Evaluations of the anticipated performance of the disposal cell in regard to protection of the Browns Park Formation aquifer are discussed in Section 3.2.3 of this attachment.

The existing value of ground water for domestic use in the Maybell area was estimated using information from the nearby town of Craig, Colorado. The existing value of ground water represents an annual figure, which is based on water usage and the unit cost of water. The existing value of ground water was calculated using the following information. The estimated monthly use per

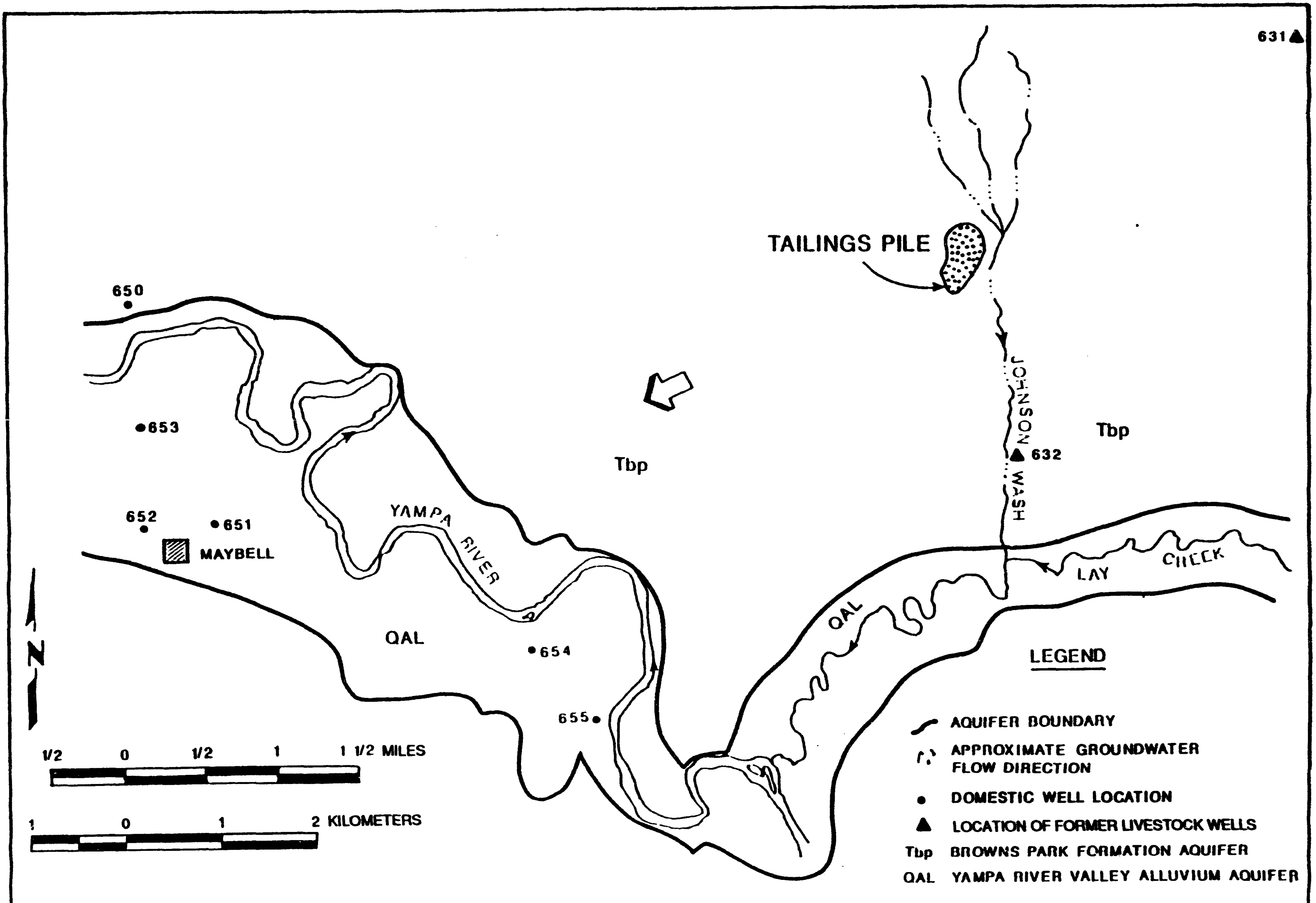


FIGURE 3.1
LOCATIONS OF DOMESTIC AND FORMER LIVESTOCK WELLS
MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

person was 2500 gallons (9500 L), at a cost of $14.50. An annual cost of water was estimated to be $174 per person (12 x $14.50). Maybell's population, which also includes area ranches, is currently estimated at approximately 100 residents (Johnson, 1986; Moch, 1992). Therefore, the average annual cost of water use in the town of Maybell was determined to be $17,400 (100 x $174.00).

Future usage of ground water as a drinking water supply in the affected hydrogeological environment will be minimal because of the remote location of the Maybell tailings site to existing and future potential water users, and the generally poor quality of ground water from the mineralized Browns Park Formation aquifer. The historical lack of ground water use for drinking water near the Maybell tailings site supports this conclusion.

The future value of water resources within the Browns Park Formation is difficult to establish because the water value is strongly related to population and water demand, and estimates of population changes tend to be very short-term. Several factors can be used to qualitatively evaluate the future water value of the Browns Park Formation aquifer near the Maybell tailings site. These factors are as follows: 1) expected population growth is low; 2) quality versus alternative sources: ground water quality in the mineralized Browns Park Formation aquifer is generally poor; 3) the Maybell tailings site is in a remote location; and 4) alternative supplies, including the Yampa River Valley alluvium near the town of Maybell, are readily available.

Based on these factors, the expected future value of the Browns Park Formation aquifer near the Maybell tailings pile is low.

3.2.3 As low as reasonable under the circumstances

The proposed disposal cell design meets the NRC's "as low as reasonable under the circumstances" criterion for application of supplemental ground water protection standards (NRC, 1989). The DOE's consideration of supplemental ground water protection standards has included long-term seepage, transient drainage, and geochemical conditions at the site as they relate to the performance of the disposal cell to ensure that human health and the environment are protected. The Browns Park Formation will be protected by incorporating design features that are as close to meeting the otherwise applicable standard as is reasonable under the circumstances. Alternative designs were considered but rejected because the cost difference did not result in a significant increase in protection of human health or the environment.

Long-term seepage

Long-term seepage from the disposal cell to ground water is conservatively a function of the saturated hydraulic conductivity of the radon barrier, multiplied by a hydraulic gradient of unity. Covering the tailings with a low hydraulic conductivity infiltration barrier will substantially reduce the rate of seepage to the Browns Park Formation.

The following aspects of the cover design will provide for compliance with the proposed EPA ground water standards (52 FR 36000 (1987)). The low hydraulic conductivity of the radon/infiltration barrier will restrict infiltration. In addition, the radon/infiltration barrier will have a 3-percent topslope grade and coarse-grained drainage layer, which will also promote shedding of precipitation off the top of the disposal cell.

Transient drainage

As discussed previously in Section 2.1.3 of this attachment, transient drainage following construction will result in temporary higher rates of seepage from the tailings pile. However, the seepage rate will close to resume steady-state conditions after 1.5 years after the cell is closed. The temporarily higher seepage rates immediately following closure will not create any adverse impacts during the transitory phase.

Geochemical attenuation

Geochemical attenuation, although not necessary to the supplemental standard ground water protection strategy, enhances the disposal cell performance. The ground water quality results demonstrate that the geochemical properties of the Browns Park Formation reduce the concentrations of uranium, arsenic, molybdenum, selenium, lead, radium, and cadmium. The two controlling mechanisms are adsorption and precipitation due to changes in the pH and redox conditions of the contaminated ground water as a result of reactions with the natural sediment.

Alternative designs

In an effort to meet the "as low as reasonable under the circumstances" criterion, several other design options were considered at the Maybell site. Relocation of the tailings to Johnson Pit or to the Umetco Minerals Corporation site were considered as disposal alternatives. A technical evaluation of these disposal alternatives concluded that stabilization in place was the preferred alternative because it was less costly and would involve fewer environmental impacts since the tailings would not have to be relocated (DOE, 1988).

3.3 POINT OF EXPOSURE

Because of poor background ground water quality, the Browns Park Formation is not a current or historic source of drinking water for human consumption. No wells currently exist within the affected environment adjacent to the mill site that withdraw water from the Browns Park Formation aquifer for human consumption.

3.4 PERFORMANCE ASSESSMENT

The DOE is required to demonstrate that the performance of the disposal cell at the Maybell site will comply with the EPA-proposed ground water protection standard 40 CFR §192.02(a)(3)(ii) (1993)) (52 FR 36000 (1987)) and 40 CFR §264.94 (40 CFR Part 264 (1993)). To achieve compliance with the EPA ground water protection standards, the DOE proposes the application of a supplemental ground water standard at the Maybell site. Ground water in the uppermost aquifer meets the definition of a limited use resource (Class III), based on widespread ambient contamination that exists due to naturally occurring uranium mineralization and to mining activities not related to uranium milling operations that occurred on the site (40 CFR §192.21(g) (1993)) (52 FR 36000 (1987)).

To demonstrate compliance of the proposed disposal cell design with the proposed EPA ground water protection standards, design parameters were evaluated in conjunction with the hydrogeologic and geochemical characteristics of the Maybell site to determine 1) the distribution of hazardous constituents in ground water under steady-state conditions, and 2) the potential for contaminant migration after stabilization. The following hydrogeologic characteristics and design features are significant in demonstrating compliance with the proposed EPA standards:

- Existing ground water conditions. Maximum observed concentrations of several hazardous constituents exceed the proposed EPA MCLs in both upgradient and downgradient background monitor wells (Table 3.1).
- Geochemical conditions. Although not necessary to the ground water protection strategy, naturally occurring alkaline and reducing geochemical conditions within the Browns Park Formation in the vicinity of the Maybell tailings site tend to rapidly decrease contamination of ground water downgradient of the existing tailings pile. These same conditions provide additional conservatism for compliance with the proposed EPA ground water protection standards (52 FR 36000 (1987)) with the proposed disposal cell design. Because the disposal cell design will restrict infiltration through the disposal cell, steady-state seepage from the disposal cell will be less than is currently occurring. Therefore, over the long term, contamination of ground water downgradient of the affected area should be less than is now present.

  Although slightly oxidizing conditions exist in ground water directly beneath the tailings pile, relatively reducing conditions are generally present away from the pile. Uranium, selenium, arsenic, and molybdenum will precipitate or be absorbed under relatively alkaline and reducing conditions, thereby resulting in lower concentrations in ground water. Nitrite also is removed by denitrification under these conditions. Ra-226 and Ra-228 are removed from tailings seepage by precipitation and adsorption. Water quality data, mineralogical characterization, and microbiological studies support the hypotheses that contaminants present in the tailings leachate are being removed from solution through precipitation, adsorption, and microbiological processes. Geochemical and biological characteristics of the soils and sediments underlying the tailings pile provide conservatism in the demonstration of compliance with the proposed EPA ground water protection standards. Further discussion of the performance assessment with respect to geochemical attenuation is provided in Section 3.9, Geochemical Conditions, of Attachment 3, *Ground Water Hydrology Report.*

- Infiltration. The proposed disposal cell includes design features that will reduce the infiltration and thereby limit the leachate migrating from the tailings. These features include the following:

    - The top of the cell will have a 3-percent slope and the sides will have a slope of 20 percent to allow rapid drainage of any surface water away from the disposal cell and to prevent runoff from ponding on the disposal cell.

    - The 1.5-ft (0.3-m)-thick radon/infiltration barrier, consisting of clayey sands amended with 10 percent Redmond bentonite, will have a design saturated hydraulic conductivity of 1×10^{-7} cm/s (2.8×10^{-4} ft/day), based on laboratory testing, which will minimize the volume of precipitation that infiltrates through the disposal cell.

- Transient drainage. Following construction of the disposal cell, pore water within the fully saturated *in situ* slime layers will create additional flux during the period of consolidation due to the increased loading of the relocated contaminated materials and the cover system. In addition, drainage from the cell following construction will increase due to drainage of construction water used for compaction and dust control of relocated contaminated materials and the cover components.

  The maximum time to consolidate the slimes will occur in the thickest slime layers. The time of consolidation was estimated assuming instantaneous loading of the full height of the relocated and cover materials. The maximum time to consolidation is indicated at piezecone 504B, where the slime bed is 14 ft (4.3 m) thick. Consolidation will be approximately 95 percent complete after 3 years. The average time to 95 percent consolidation over the entire site is estimated at just under 1.5 years and will produce an average initial rate of drainage close to 1×10^{-5} cm/s (2.8×10^{-2} ft/day) within the first few months following closure (see Hydrological Services Calculation MAY-03-94-12-05, Attachment 3, Appendix A). Drainage from the construction water will occur over a longer period than the period of consolidation of the slimes. However, since the slimes contain the highest concentration of contaminant source term, drainage of the slime pore water will have the most potential to affect ground water quality downgradient of the completed disposal cell.

- Mixing calculations. Volumetric mixing calculations (see Hydrological Services Calculation MAY-03-94-14-03-00, Attachment 3, Appendix A) were performed as a preliminary estimate of resultant concentrations of hazardous constituents that would be present in ground water in the Browns Park Formation beneath the Maybell site at the toe of the pile. Resultant concentrations for designated hazardous constituents in ground water at the toe of the pile were calculated assuming a volume seepage flux from the disposal cell equal to the design saturated hydraulic conductivity of the radon/infiltration barrier of 1×10^{-7} cm/s (2.8×10^{-4} ft/day) times a gradient of unity. These calculations assume that the effects of transient drainage have ceased after a period of 1.5 years following closure of the cell. The volume flux of seepage from the disposal cell was instantaneously mixed with ground water underflow at relative concentrations to calculate a resultant concentration in ground water at the toe of the pile. Estimated (resultant) concentrations for designated hazardous constituents in ground water beneath the disposal cell are below CDH agricultural standards except for aluminum, fluoride, iron, molybdenum, nitrate and nitrite, and selenium. In addition, uranium concentrations exceed the proposed EPA MCL of 30 pCi/L (equivalent to 0.044 mg/L) (52 FR 36000 (1987)). However, there is considerable conservatism in the mixing calculation because no effects of geochemical attenuation are assumed and elevated concentrations (above the proposed EPA MCL or CDH agricultural standards) of these constituents have not been extensively observed downgradient of the tailings pile with an open cell condition being present.

Although not applied to the mixing calculation, the HELP model was used to estimate cover flux based on historical rainfall data at the Maybell site. The model indicates that for the record of precipitation used (1959 through 1972), the cover flux is 60 percent of the assumed saturated cover flux of 1×10^{-7} cm/s (2.8×10^{-4} ft/day) used in the mixing calculation (see Hydrological Services Calculation MAY-03-94-12-04, Attachment 3, Appendix A). With historical rainfall and meteorological conditions predominating, drainage from the cell will more than likely be less than that assumed in the mixing calculation with a saturated cover.

The previous discussion (mixing calculations) regarding constituent concentrations resulting from long-term, steady-state seepage does not take into account the transient effects of increased drainage from the cell immediately following site remediation. The transient drainage condition predicted to occur is discussed in detail in the previous section (mixing calculations). Arguments have been presented to the effect that geochemical attenuation is occurring within the Browns Park Formation. It is anticipated that the same conditions will attenuate the mass loading during the transitory period following construction. In addition, the additional transient drainage from the cell will probably be less than what occurred during the period uranium processing activities were in operation.

Nevertheless, the period of time that any mass loading from this transient drainage may affect the ground water conditions was estimated. The controlling factors are primarily the areal extent of the mass loading from the cell and the horizontal ground water velocity. Hydrodynamic dispersion has a secondary effect on the time of influence. It is estimated that a mass loading pulse to the ground water would take 30 years to pass at the toe of the cell and 40 years some 500 ft (150 m) downgradient of the cell (see Hydrological Services Calculation MAY-030-94-12-06, Attachment 3, Appendix A).

3.5 CLOSURE PERFORMANCE ASSESSMENT

The DOE has assessed the performance of the designed disposal unit at the Maybell site in conjunction with the hydrogeologic system. It has shown that the disposal cell will minimize and control releases of hazardous constituents to ground water and surface water, and radon emanations to the atmosphere, to the extent necessary to protect human health and the environment (40 CFR §192.02(a)(4) (1993) (52 FR 36000 (1987)). Natural, stable materials will be used in construction of the Maybell disposal cell so that the long-term performance is ensured.

3.6 GROUND WATER MONITORING PROGRAM

Following construction of the disposal cell, the DOE will institute an LTSP for the post-disposal period, pursuant to 40 CFR §192.02(a)(4)(b) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)). Development of the post-disposal period LTSP will follow the DOE final *Guidance for Implementing the UMTRA Project Long-term Surveillance Program* (DOE, 1992). Section 5.3.4 of the RAS presents a detailed discussion of the closure performance demonstration for the Maybell site.

3.7 CORRECTIVE ACTION PLAN

Pursuant to 40 CFR §192.02(a)(4)(c) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)), the DOE will define alternative corrective actions that could be implemented to bring the site into compliance if the cell performance monitoring indicates the disposal cell is not functioning properly. Although it is not possible to propose specific detailed corrective action plans, potential failure scenarios for the Maybell disposal site and potential corrective actions are summarized in Table 3.3.

Table 3.3 Corrective action plan summary for the Maybell, Colorado, site

Failure scenario	Corrective action
Contaminated seepage emerges in artificially induced springs below the pile.	Modify cover to eliminate excess infiltration.
Radon barrier cracks due to desiccation.	Replace filter layer with lower permeability layer.
Siltation of erosion protection layer.	No action needed unless it increases infiltration or induces vegetation.
Vegetation threatens integrity of cover.	Add biointrusion layer.
Biointrusion by animals.	Modify rock cover.
Erosion of cover.	Not a realistic failure scenario (pile is designed for PMP and PMF events).

PMP - probable maximum precipitation
PMF - probable maximum flood

The EPA-proposed standards (40 CFR §192.02(a)(4)(c)) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)) require that a corrective action program to restore the disposal cell to the design requirements be implemented within 18 months if initial performance of the disposal cell is not in compliance with the proposed EPA ground water protection standards. The NRC-proposed regulations in Appendix A of 10 CFR Part 40 (1993) specify that the DOE will notify the NRC before implementing any significant action(s) that may be required. When evaluative monitoring determines that corrective action is necessary, the NRC will be notified within 1 month. The DOE will prepare and submit a corrective action plan to the NRC for review and approval. A copy of this plan also will be transmitted to the state of Colorado. The corrective action plan will include a monitoring program that may involve indirect monitoring to demonstrate the effectiveness of the corrective action. The DOE will implement corrective action when NRC approval has been granted.

In preparing a corrective action plan, a risk assessment may be performed to evaluate the potential impact to nearby populations or the environment. If the risk assessment demonstrates no potential harm to human health and the environment, the recommended corrective action may consist of "no action" except continued evaluative monitoring.

4.0 CLEANUP AND CONTROL OF EXISTING CONTAMINATION

Cleanup of contaminated ground water must be addressed under the conditions of Subpart B of the EPA's (52 FR 36000 (1987)) proposed standards for the UMTRA Project. The need for and extent of ground water cleanup at the Maybell site is based on the extent of existing contamination, the potential for current or future use of the aquifer, and the technical practicability of restoring the aquifer from an engineering perspective. Studies are under way to develop plans, guidance materials, and procedures for ground water remediation activities.

From the present site characterization, the DOE has determined that the ground water in the Browns Park Formation aquifer is not a current or historic drinking water source. Furthermore, naturally occurring mineralization in the Browns Park Formation causes exceedances of EPA MCLs for some hazardous constituents in ground water. Additional investigations will be conducted to identify and evaluate remediation strategies for the Browns Park Formation. The final decision of how to meet the EPA ground water cleanup standards will be part of the UMTRA Ground Water Project.

Remedial action will not preclude any future evaluation of ground water at the Maybell site. The DOE is not leaving a threat to human health or the environment in the Browns Park Formation, because no drinking water wells currently exist within the affected environment adjacent to the mill site that withdraw water from the Browns Park Formation aquifer.

5.0 LIST OF CONTRIBUTORS

The following individuals contributed to the preparation of this remedial action plan.

Name	Contribution
J. Blount, J. Crain, R. Meyers, G. Ruskauff, E. Storms	Technical authors
M. Hansen	Author, document coordination
J. Blount, J. Crain, R. Meyers	Document review
J. McBee	Site management, document review
D. Thalley	Technical editing; document production coordination
L. Keith	Word processing
B. Harvey, L. Wagner	Graphic design

6.0 REFERENCES

Bodnar, G., and D. Rogers, 1992. Colorado Department of Health, Engineering Department, Denver, Colorado, personal communication to Jim Crain, Engineering Services, Jacobs Engineering Group, Inc., Albuquerque, New Mexico, October 1992.

DOC (U.S. Department of Commerce), 1991. *Population and Housing, Summary of Population and Housing Characteristics, Colorado*, July 1991, Bureau of the Census, U.S. Government Printing Office, Washington, D.C.

DOC (U.S. Department of Commerce), 1990. *1990 Census of Population, General Population for Utah*, CP-1-46, U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, Washington, D.C.

DOE (U.S. Department of Energy), 1992. *Guidance for Implementing the UMTRA Project Long-term Surveillance Program*, UMTRA-DOE/AL-350125.0000, Revision 1, final, September 1992, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1988. *Comparative Analysis of Disposal Site Alternatives Report for the UMTRA Project Maybell Site, Moffat County, Colorado*, final, January 1988, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

Johnson, B., 1986. Resident deputy, Moffat County Sheriff's Department, Maybell, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated September 25, 1986.

McIntyre, S., 1987. Windmill well owner Maybell, Colorado, personal communication to M. Gilfillan and L. Spencer, United Nuclear Corporation (UNC) under subcontract to Jacobs Engineering Group Inc., Albuquerque, New Mexico, December 11, 1987.

Moch, J., 1992. Community Development Secretary, City Hall, Craig, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated September 21, 1992.

NOAA (National Oceanic and Atmospheric Administration), 1977. "Climatography of the United States No. 20, Climate of Craig, Colorado," National Climatic Center, Asheville, North Carolina.

NOAA (National Oceanic and Atmospheric Administration), 1968. U.S. Department of Commerce, National Climatic Center, Asheville, North Carolina.

NRC (U.S. Nuclear Regulatory Commission), 1989. *Standard Format and Content for Documentation of Remedial Action Selection at Title I Uranium Mill Tailings Sites*, February 24, 1989, Staff Technical Position, Division of Low-Level Waste Management and Decommissioning, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

TAC (Technical Assistance Contractor), 1992. "Unpublished Field Notes, Maybell, Colorado, Uranium Mill Tailings Site," unpublished report prepared by the Technical Assistance Contractor (Jacobs-Weston Team), Albuquerque, New Mexico, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

TAC (Technical Assistance Contractor), 1990. "Unpublished Field Notes, Maybell, Colorado, Uranium Mill Tailings Site," unpublished report prepared by the Technical Assistance Contractor (Jacobs-Weston Team), Albuquerque, New Mexico, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

CODE OF FEDERAL REGULATIONS

10 CFR Part 40, *Domestic Licensing of Source Material*, U.S. Nuclear Regulatory Commission (1993).

40 CFR Part 143, *National Secondary Drinking Water Regulations*, U.S. Environmental Protection Agency (1993).

40 CFR Part 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*, U.S. Environmental Protection Agency (1993).

40 CFR Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*, U.S. Environmental Protection Agency (1993).

FEDERAL REGISTER

52 FR 36000, "Standards for Remedial Actions at Inactive Uranium Processing Sites; Proposed Rule," September 24, 1987.

UNITED STATES CODE

42 USC §4321 *et seq. National Environmental Policy Act*, January 1, 1970.

DATE FILMED

10/5/94

END