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ATTACHMENT 3

GROUND WATER HYDROLOGY REPORT

Final

December 1996

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

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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

CHANGE HISTORY

Document version	Date	Pages/comments
Ver. 1	4/10/93	Initial version. Incorporated NRC and TAC design changes.
Ver. 2	6/4/93	Extensively revised. Incorporated TAC review changes.
Ver. 3	6/17/93	Changed pages iv, 3-1, and 3-7. Blue Folder changes.
Final Rev. 0, Ver. 1	5/26/94	Extensively revised.
Final Rev. 0, Ver. 2	6/20/94	Minor revisions after review. Edited.
Final Rev. 0, Ver. 3	6/25/94	Moderately revised.
Rev. 1, Ver. 1	8/5/96	Page changes in response to NRC comments. "Redmond" deleted from document. Attachment 2 not updated because electronic file is not available.
Rev. 1, Ver. 1	12/05/96	Change all reference to the final EPA ground water protection standards (40 CFR Part 195 [1995]. Incorporate Subpart B compliance into RAP. Minor format editorial changes.

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). 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 final 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), 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)). The final EPA standards were issued on January 11, 1995 (60 FR 2854 (1995)), and appear in the July 1, 1995 edition of the Code of Federal Regulations (40 CFR Part 192 (1995)).

The DOE has characterized the Maybell site and determined that the proposed remedial action would comply with the requirements of Subpart A of the final EPA ground water protection standards (40 CFR Part 192). 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.*). 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 final EPA ground water standards for inactive (Title I) uranium processing sites.
Table 1.1 lists the EPA ground water protection standards (40 CFR Part 192).

Table 1.1 Maximum concentration limits for hazardous constituents[a]

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

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[a] Table 1 to Subpart A (40 CFR Part 192 [1995]).
[b] Milligrams per liter unless stated otherwise; pCi/L = picocuries per liter.
[c] 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 final EPA maximum concentration limits (MCL) (40 CFR Part 192). 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 final EPA MCLs (40 CFR Part 192). 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 final EPA MCLs (40 CFR Part 192) (see Table 3.1). Mean concentrations of arsenic, cadmium, molybdenum, nitrate, selenium, uranium, and

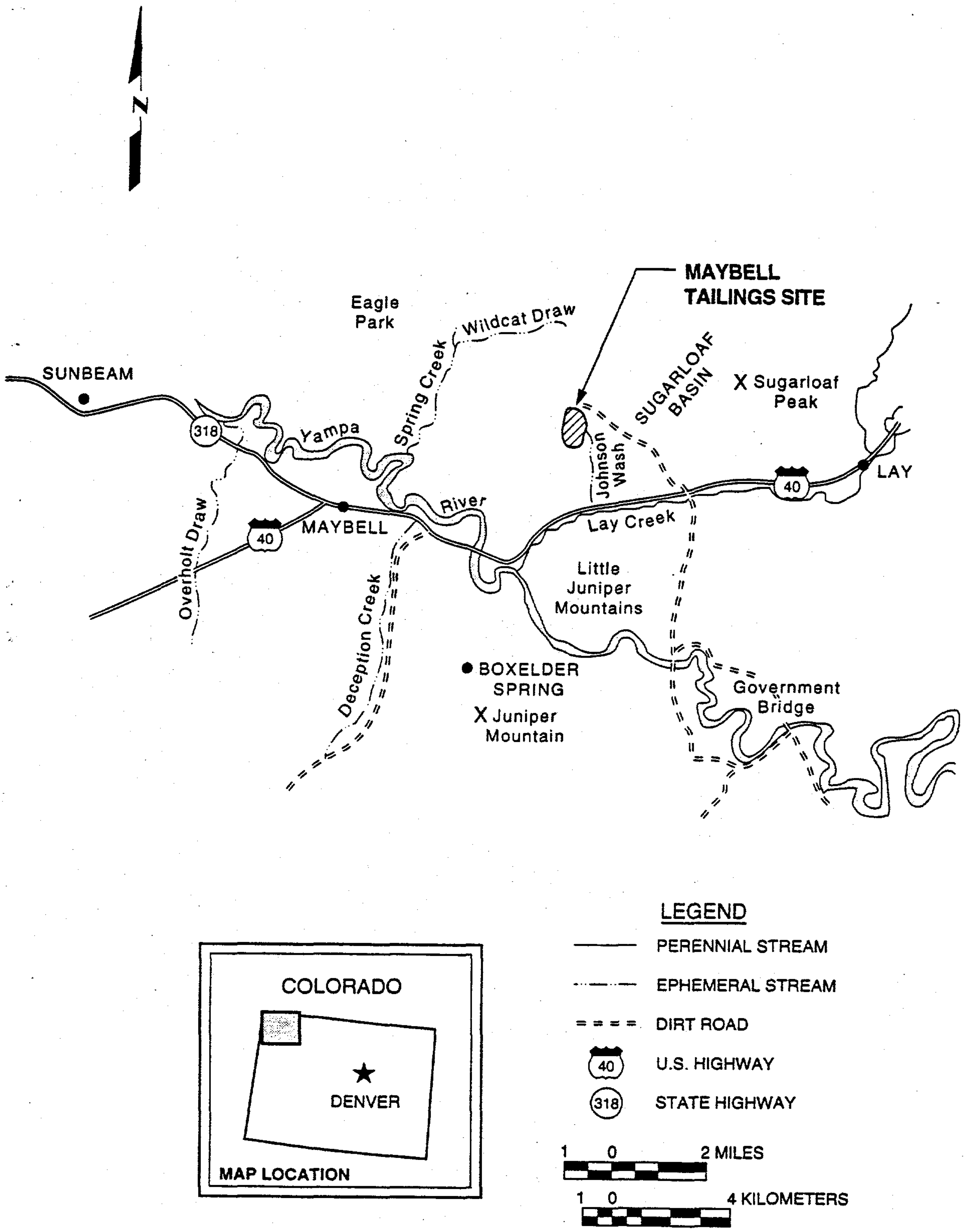

FIGURE 2.1
LOCATION MAP OF THE MAYBELL TAILINGS SITE
NEAR MAYBELL, COLORADO

the combined activities of Ra-226 and Ra-228 in the tailings pore water exceeded the final 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 to Subpart A, and Appendix I to Part 192, 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 medium-grained sandstone and minor interbeds and lenses of conglomerate,

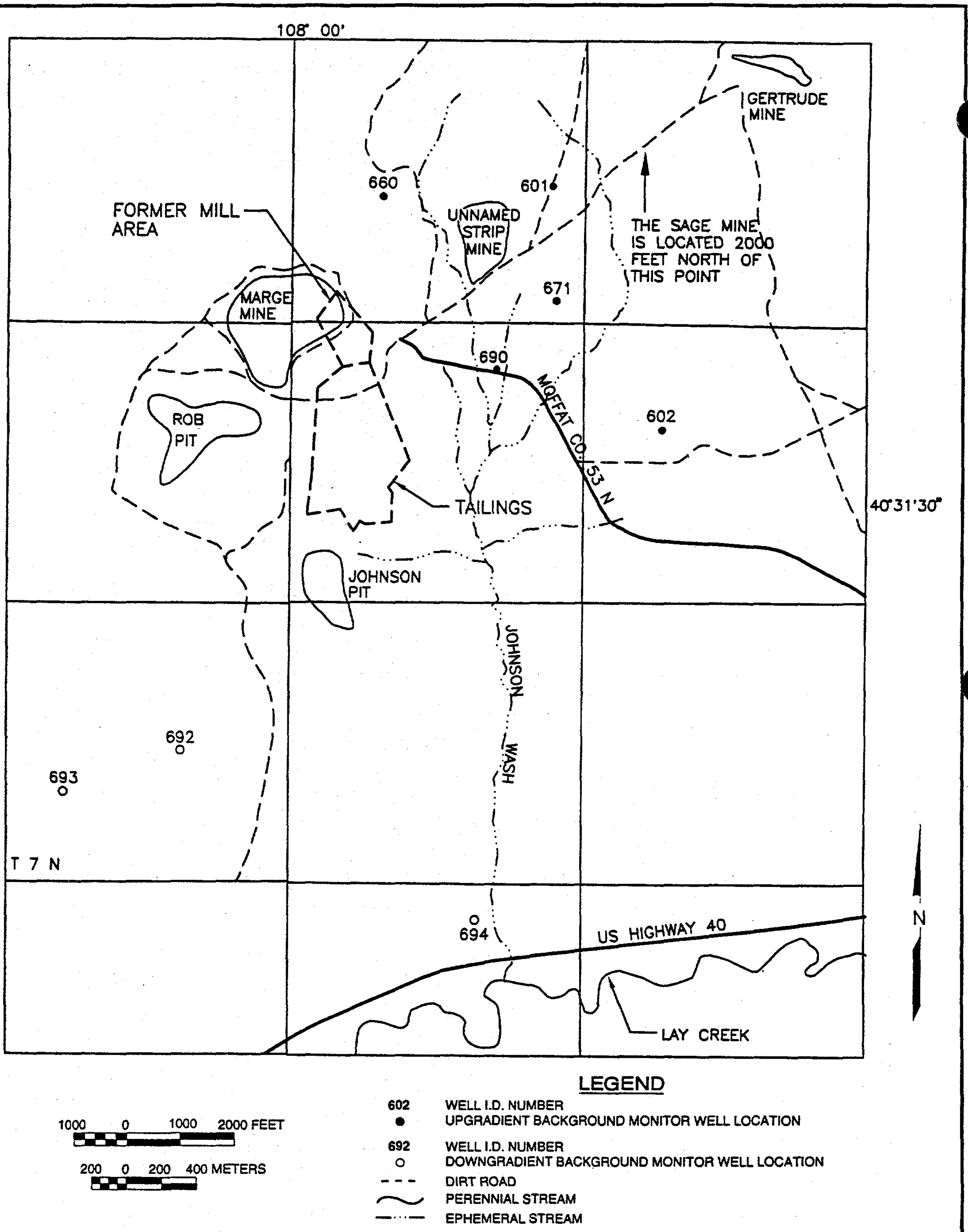

FIGURE 3.1
LOCATIONS OF UPGRADIENT AND DOWNGRADIENT BACKGROUND MONITOR WELLS AND AREA URANIUM MINES AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

MAYBE-31.CDR

MAYBELL.RAP

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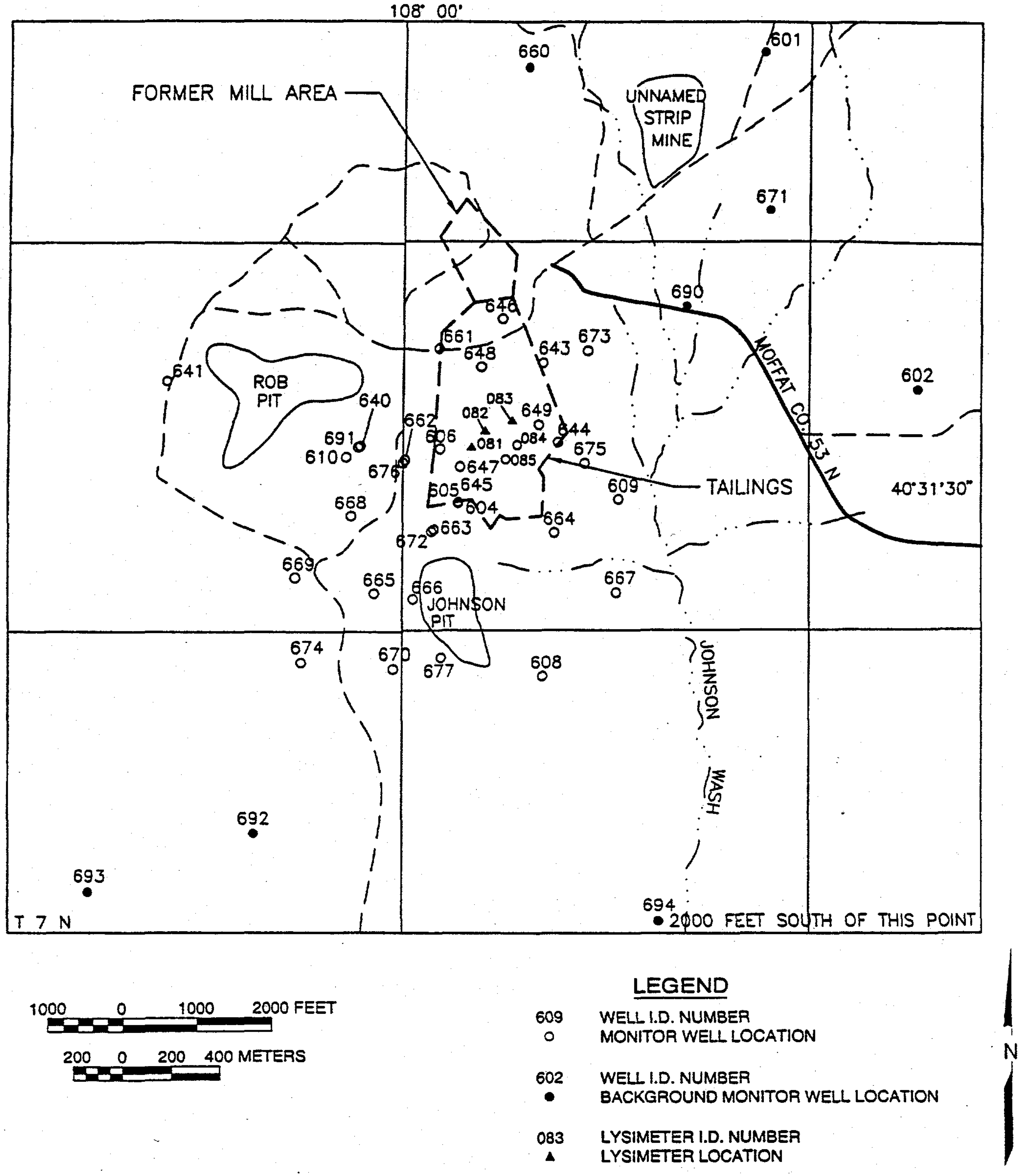

LEGEND

609 ○	WELL I.D. NUMBER MONITOR WELL LOCATION
602 ●	WELL I.D. NUMBER BACKGROUND MONITOR WELL LOCATION
083 ▲	LYSIMETER I.D. NUMBER LYSIMETER LOCATION
- - -	DIRT ROAD

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

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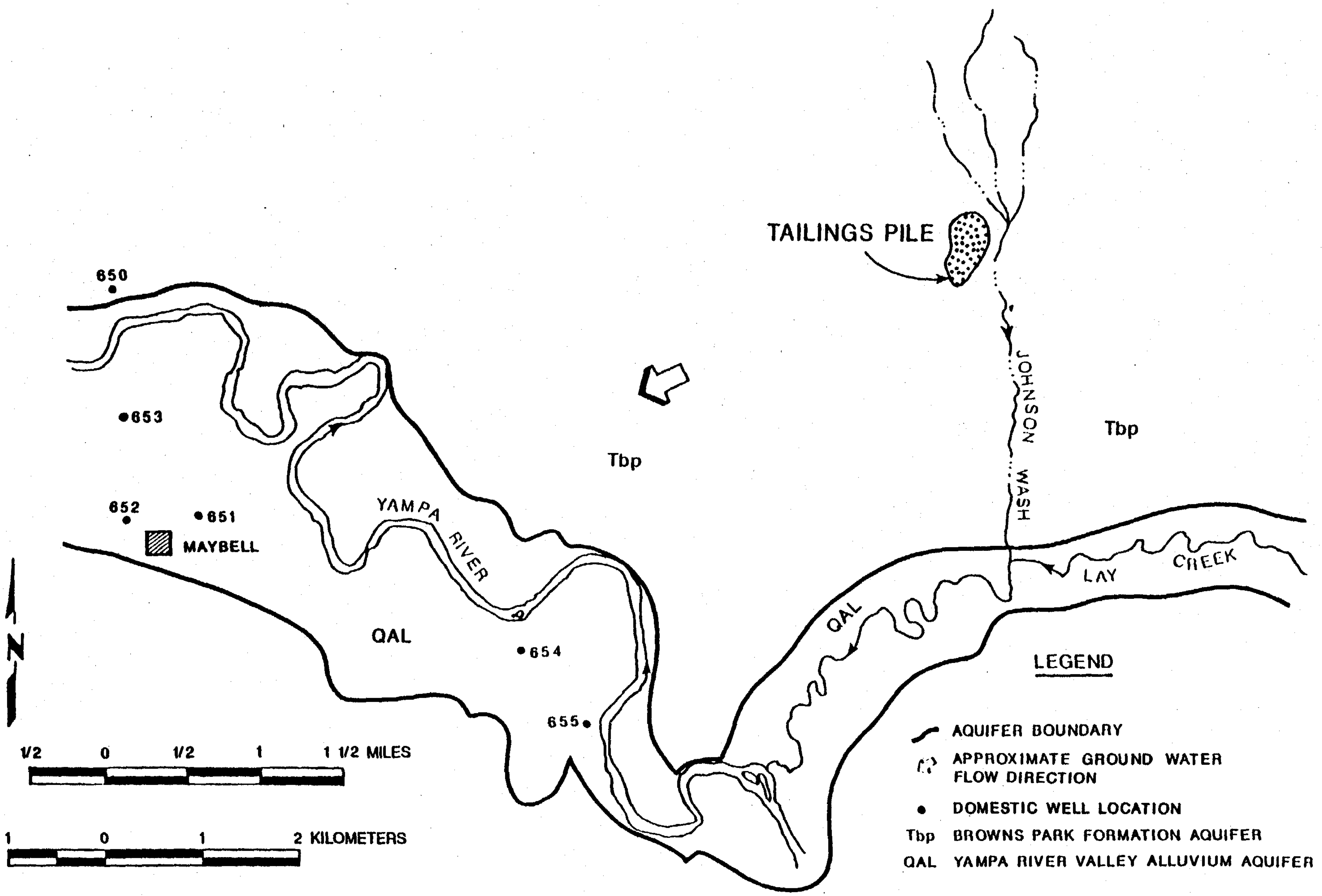
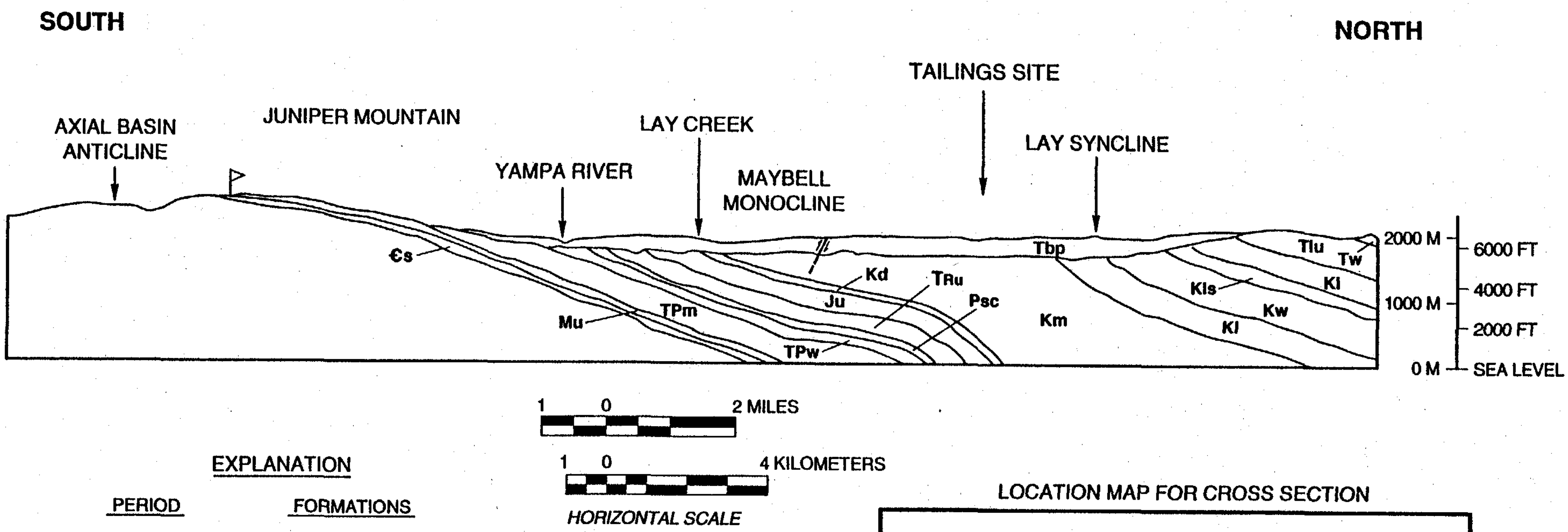


FIGURE 3.3
LOCATIONS OF DOMESTIC WELLS
MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO



EXPLANATION

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

REF: BERGIN, 1959

LOCATION MAP FOR CROSS SECTION

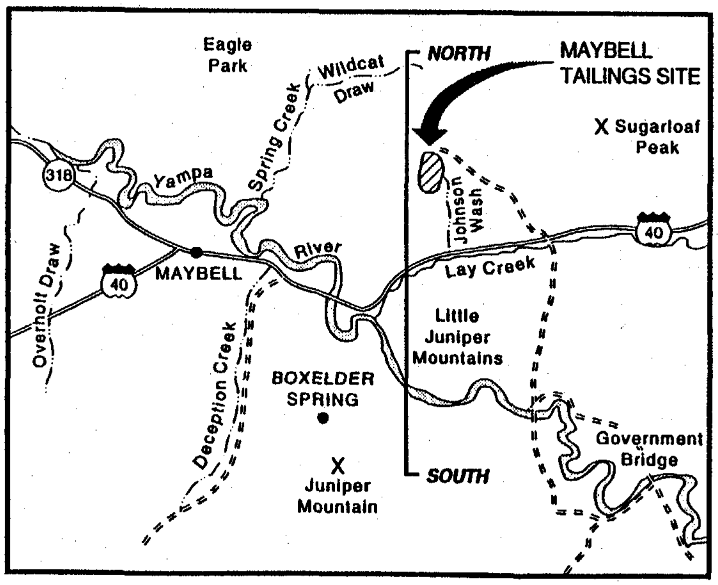


FIGURE 3.4
STRUCTURAL CROSS SECTION THROUGH THE MAYBELL SITE AREA NEAR MAYBELL, COLORADO

MAC: SITE/MAY/RAP/STRUCT CROSS SECT

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

MAYBE-35.CDR

MAYBELL RAP

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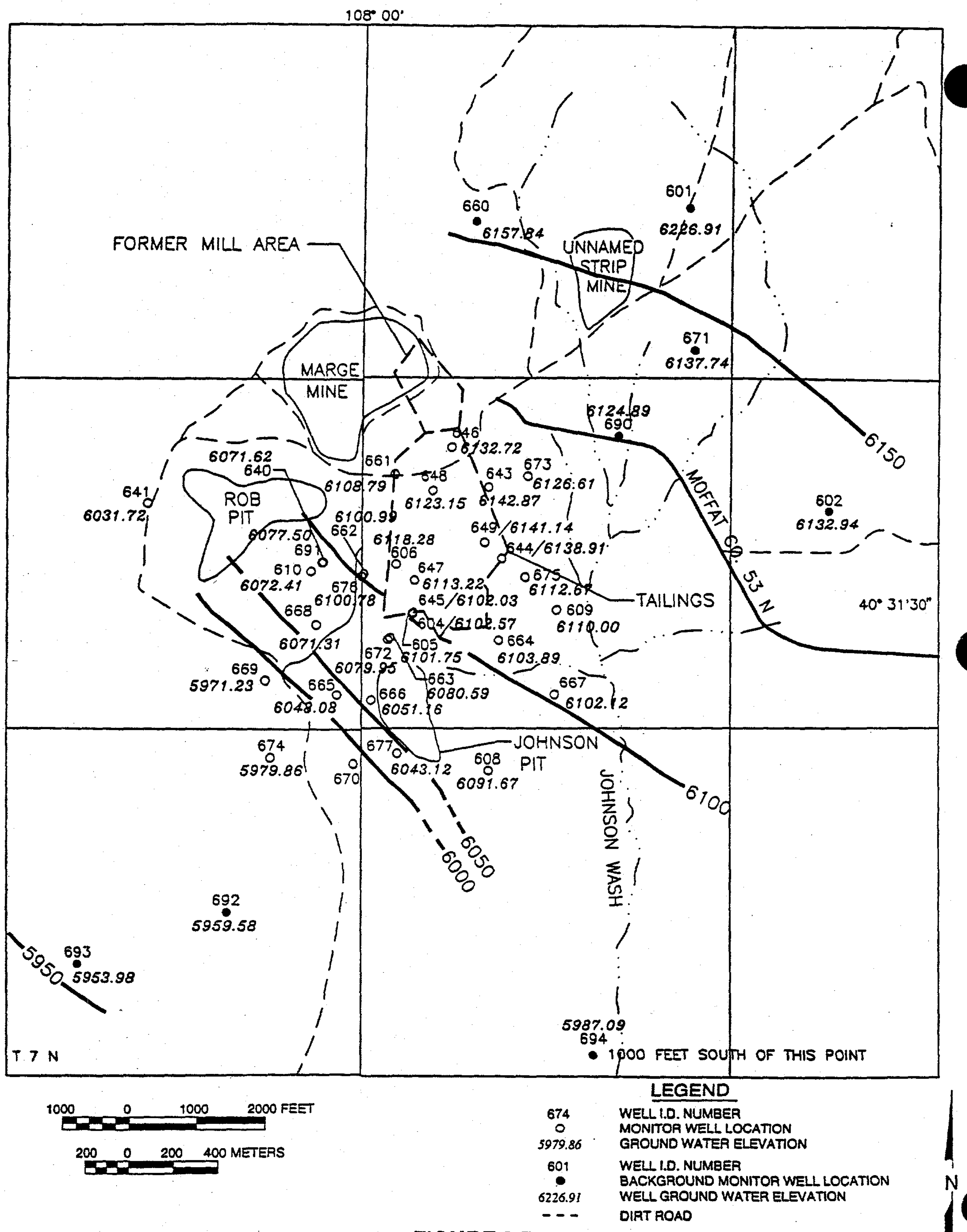


LEGEND

674	WELL I.D. NUMBER
○	MONITOR WELL LOCATION
5979.86	GROUND WATER ELEVATION
601	WELL I.D. NUMBER
●	BACKGROUND MONITOR WELL LOCATION
6226.91	WELL GROUND WATER ELEVATION
- - -	DIRT ROAD

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

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 to Subpart A and Appendix I to Part 192. All concentrations in milligrams per liter unless noted otherwise.
[b] MCL—maximum concentration limit. Table 1 to Subpart A and Appendix I to Part 192.
[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 to Subpart A and Appendix I to Part 192. Mean concentrations of hazardous constituents were compared with final EPA MCLs (40 CFR Part 192) 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 final 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. Precipitation of gypsum has occurred beneath the tailings pile as a result of sulfuric acid reacting with calcium carbonate present in the tailings subsoil.

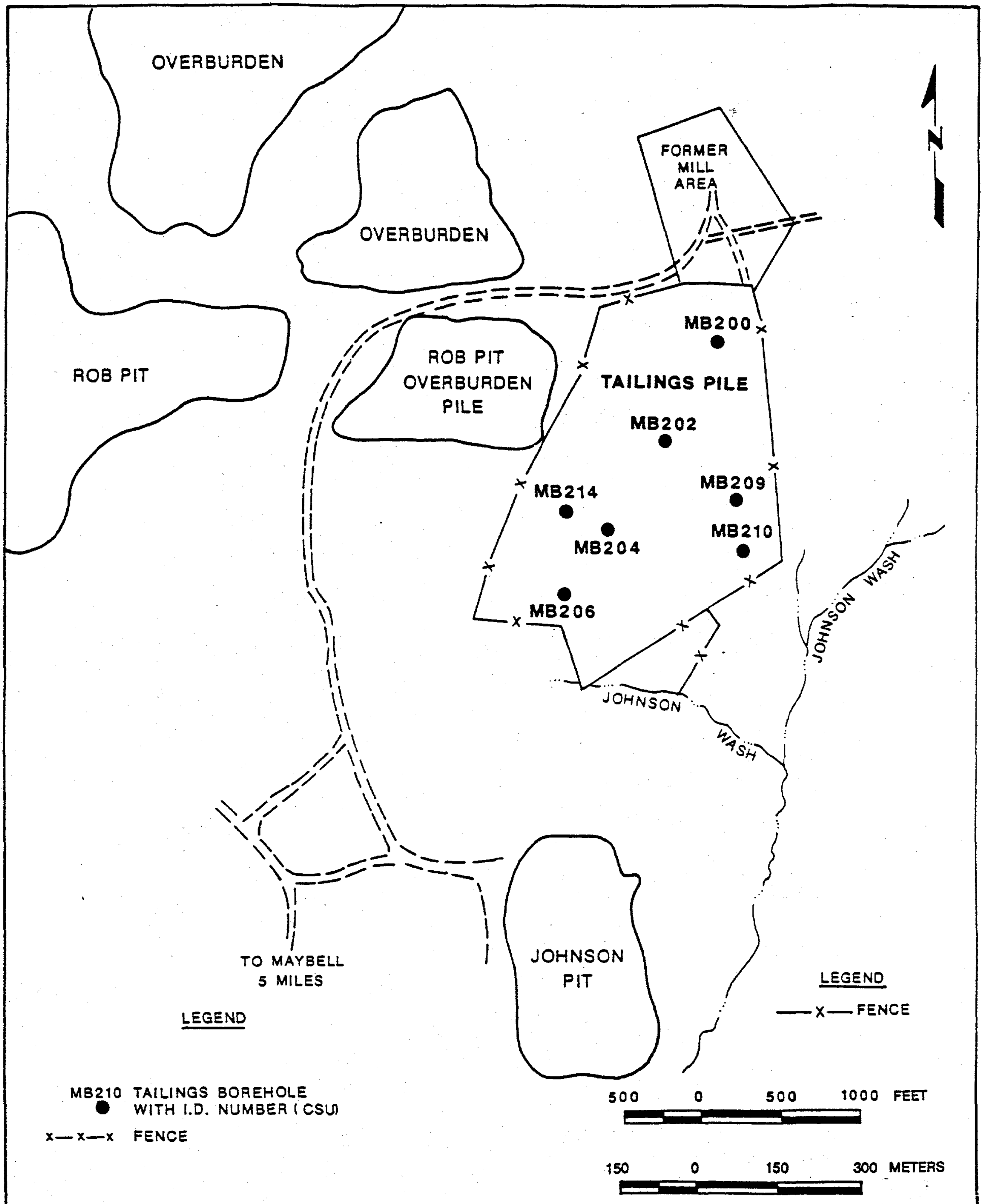
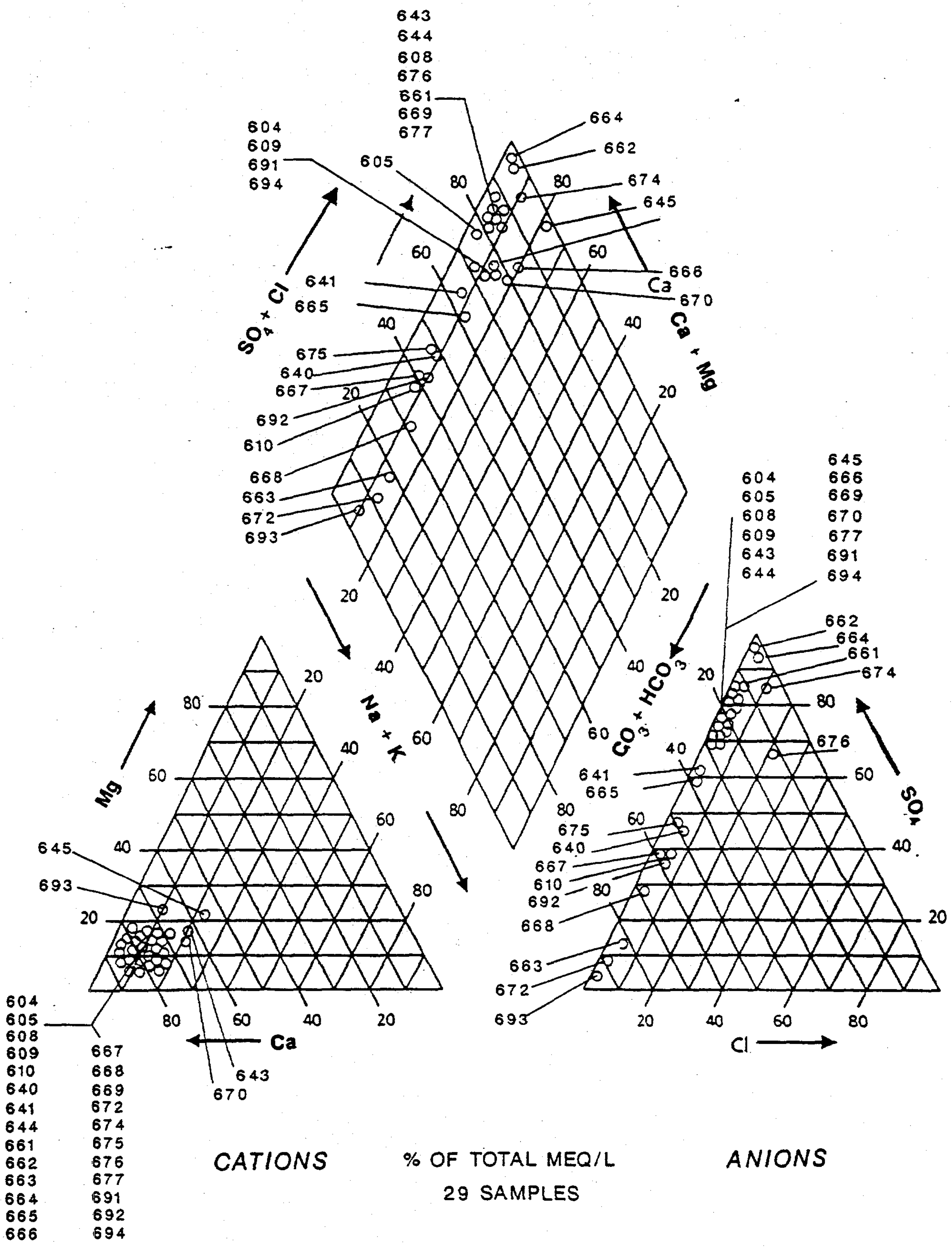


FIGURE 3.6
LOCATIONS OF COLORADO STATE UNIVERSITY (CSU) URANIUM TAILINGS BOREHOLES AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO



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)

Boring No.	Depth below tailings pile/ Browns Park Formation interface (ft)	pH (units)	Pore H_2O content (%)	Parameter						
				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.

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 to Subpart A and Appendix I to Part 192, and the field parameters alkalinity, Eh, pH, specific conductivity, and temperature.

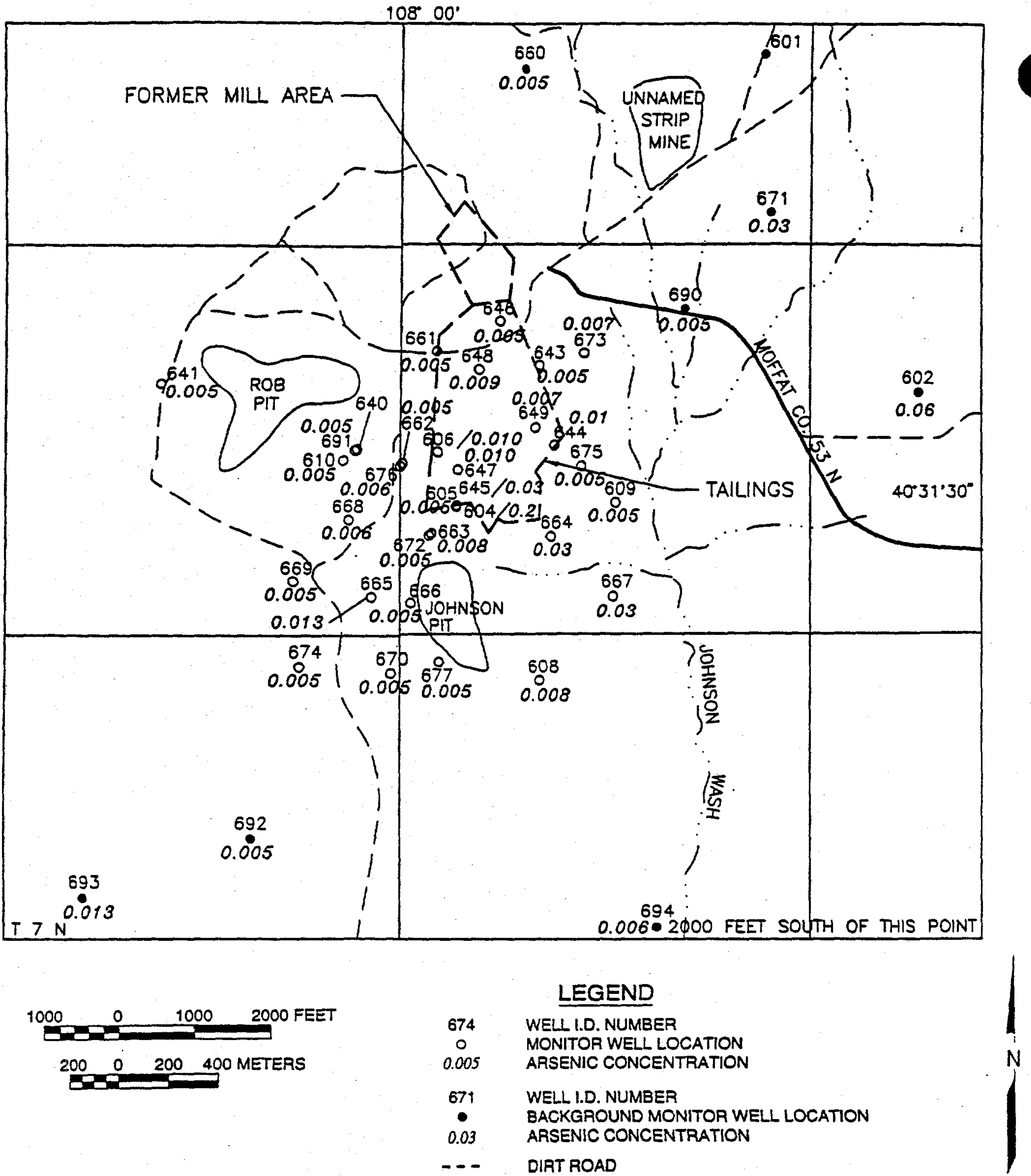
Analytical data from ground water samples collected from on-site and adjacent monitor wells indicate pH values ranging from 4.94 to 7.77. The ground water is dominantly a calcium, bicarbonate/sulfate type (Figure 3.7). The average TDS content is 2466 mg/L and is generally higher in on-site monitor wells 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 final 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, and 648 were analyzed for hazardous organic constituents listed in Appendix I

MAYBE-38.CDR MAYBELL RAP ACAD MASTER FILE MAYA01.DWG (NEW FILE MAYBE-38.DWG XREF MAYBBASE.DWG) H:\USERS\SUNGA\MAYBELL 6-3-94



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

MAYBE-39.CDR

MAYBELL RAP

ACAD MASTER FILE ..... A01.DWG (NEW FILE MAYBE-39.DWG XREF MAYBBASE.DWG)

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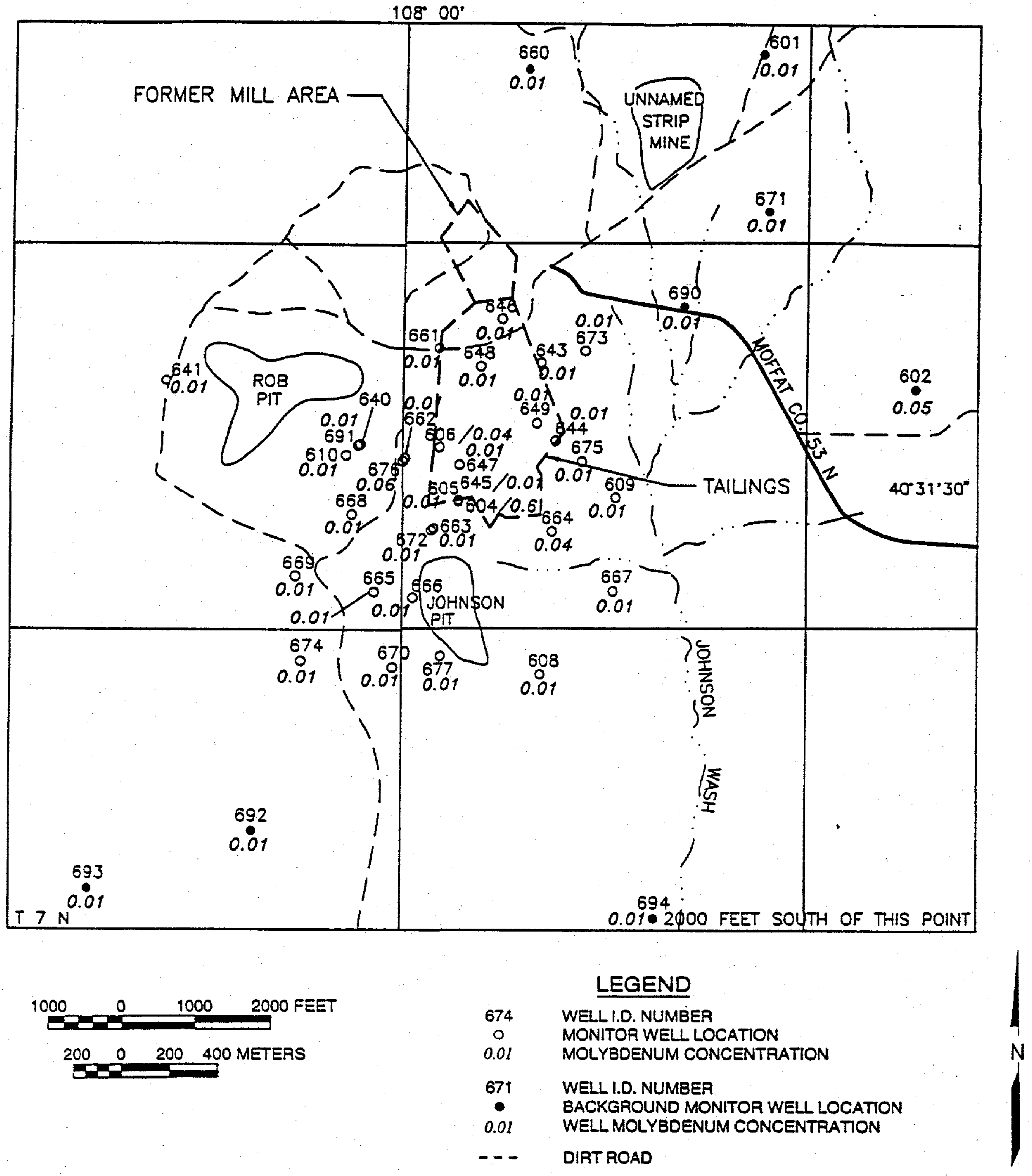

NOTE: SAMPLES COLLECTED IN MAY 1992

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

MAYBE310.CDR

MAYBELL RAP

ACAD MASTER FILE MAYA01.DWG (NEW FILE MAYBE310.DWG XREF MAYBBASE.DWG)

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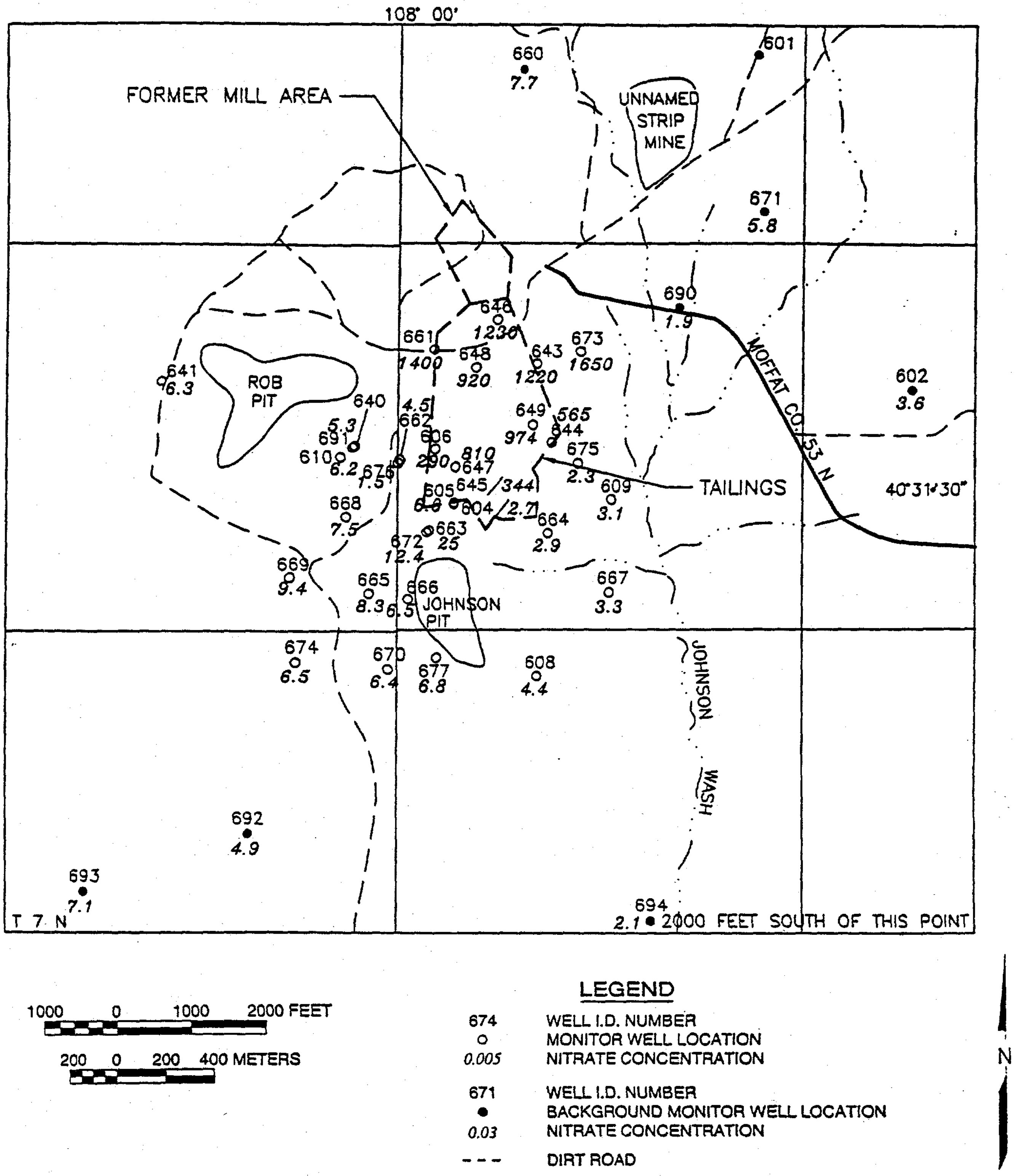
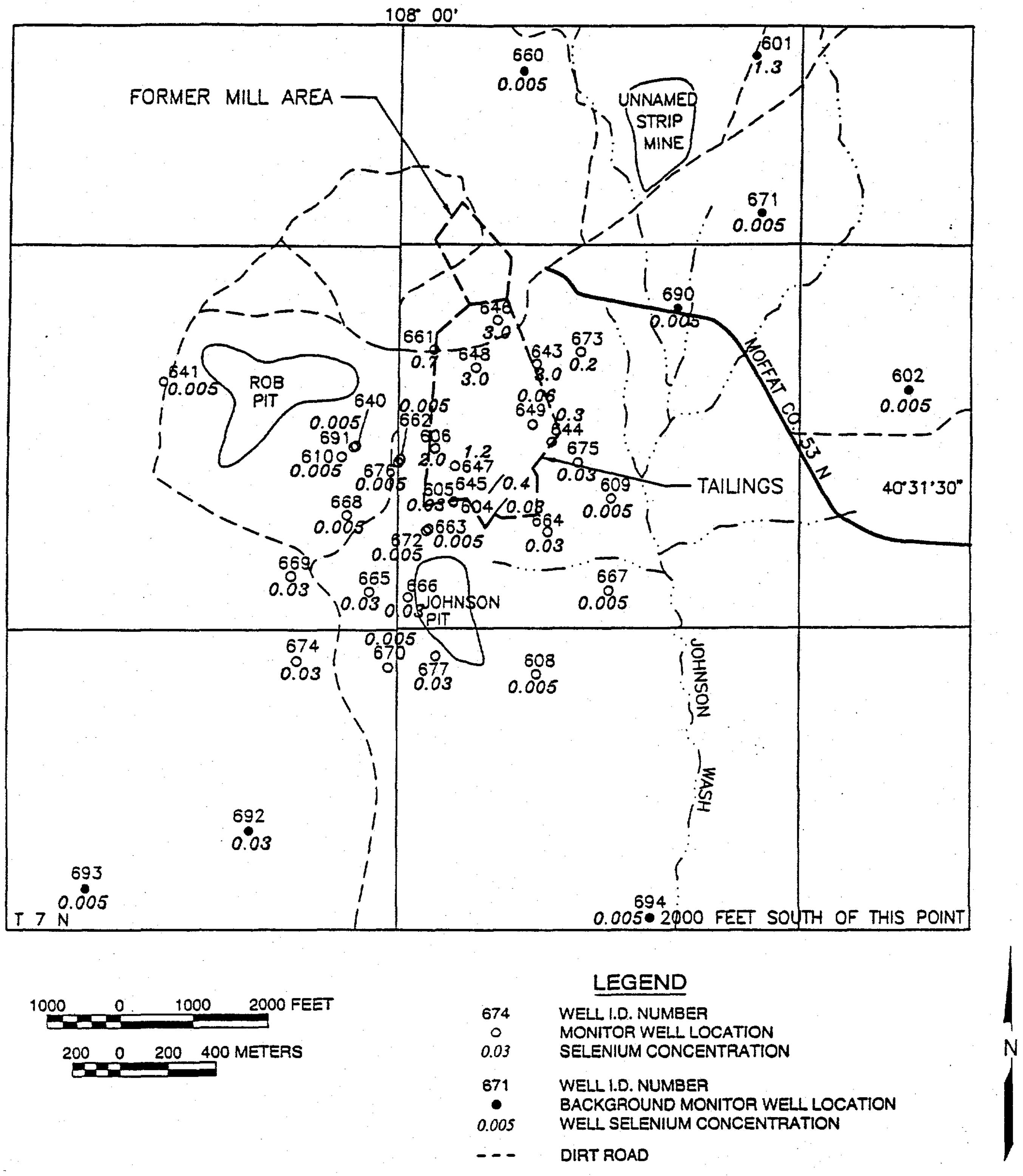


NOTE: SAMPLES COLLECTED IN MAY 1992

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

MAYBE311.CDR
MAYBELL RAP
ACAD MASTER FILE ...01.DWG (NEW FILE MAYBE311.DWG XREF MAYBBASE.DWG)
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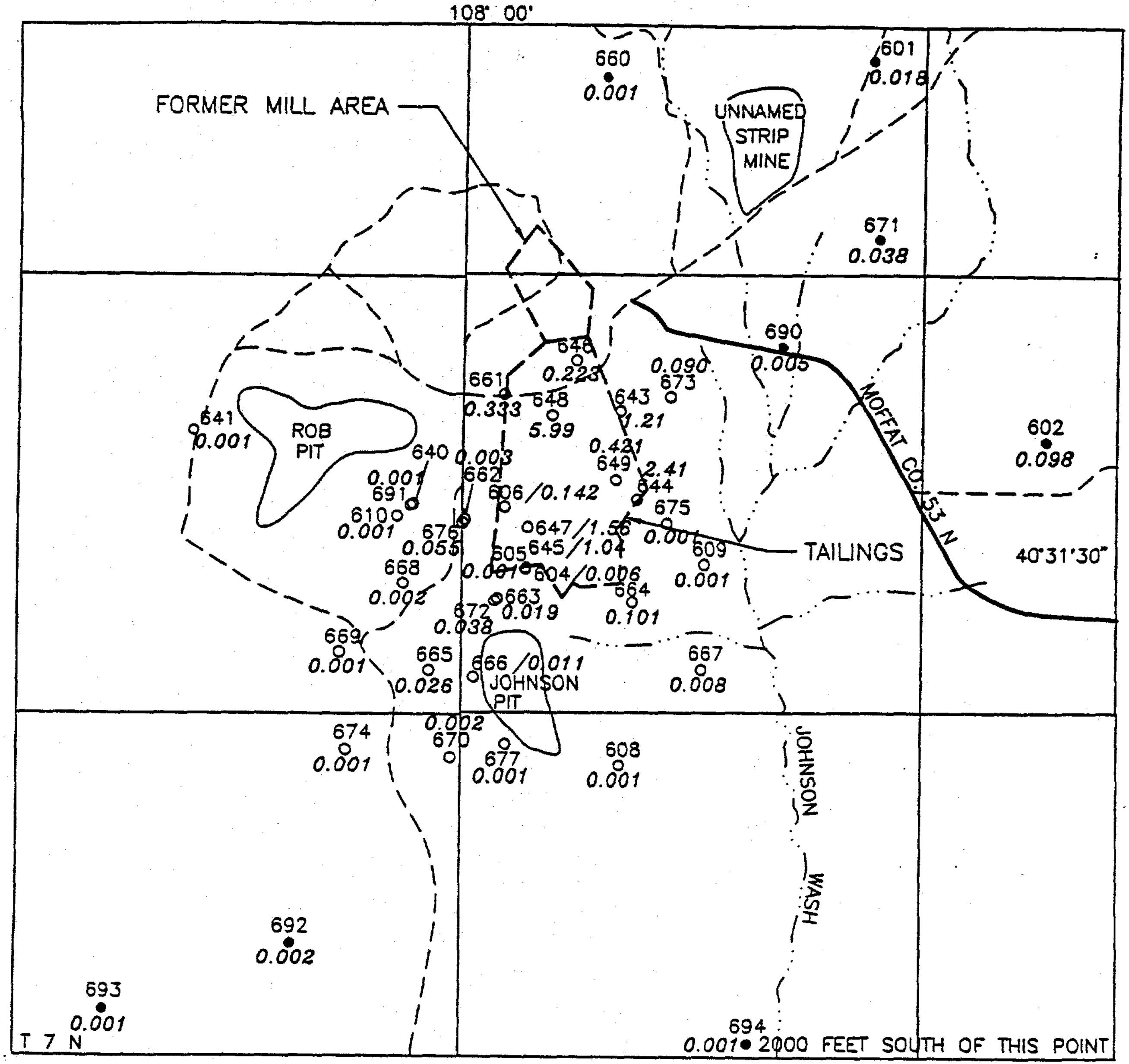
FIGURE 3.11
SELENIUM CONCENTRATION DISTRIBUTION IN THE BROWNS PARK FORMATION AQUIFER AT THE MAYBELL SITE NEAR MAYBELL, COLORADO

MAYBE312.CDR MAYBELL RAP ACAD MASTER FILE MAYA01.DWG (NEW FILE MAYBE312.DWG XREF MAYBBASE.DWG) H:\USERS\SUNGA\MAYBELL



1000 0 1000 2000 FEET

200 0 200 400 METERS

N

LEGEND

674	WELL I.D. NUMBER
○	MONITOR WELL LOCATION
0.001	URANIUM CONCENTRATION
671	WELL I.D. NUMBER
●	BACKGROUND MONITOR WELL LOCATION
0.038	URANIUM CONCENTRATION
- - -	DIRT ROAD

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.

to Part 192. No 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 final 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 final 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 final 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 final EPA MCL (0.01 mg/L) (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 final EPA MCL (0.044 mg/L) (equivalent to 30 picocuries per liter [pCi/L]). 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) 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 final EPA MCL. The final EPA 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.

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