DOE/OR/21548-571 (Final)

Remedial Investigation for the Groundwater Operable Units at the Chemical Plant Area and the Ordnance Works Area, Weldon Spring, Missouri

July 1997

U.S. Department of Energy
Weldon Spring Site Remedial Action Project
Weldon Spring, Missouri

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July 1997

prepared by

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prepared for

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NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this document. Acronyms used only in tables are defined in the respective tables.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
BRA	baseline risk assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPC	contaminants of potential concern
DCE	dichloroethene
DA	U.S. Department of the Army
DNA	dinitroaniline
DNAPL	dense, nonaqueous phase liquid
DNT	dinitrotoluene
DOE	U.S. Department of Energy
ECD	electron capture detector
EPA	U.S. Environmental Protection Agency
EQAPjP	*Environmental Quality Assurance Project Plan*
FS	feasibility study
GC	gas chromatography
GWOU	groundwater operable unit
HPCL	high-performance liquid chromatograph/chromotagraphy
IT	International Technology
K_d	distribution coefficient
K_{oc}	organic fraction partition coeficient
K_{ow}	octanol-water partition coefficient
KPA	Kinetic Phosphorescence Analyzer
LCS	laboratory chemical spike
MCL	maximum contaminant level
MS	matrix spike
NB	nitrobenzene
NPL	National Priorities List
QA	quality assurance
QAPP	quality assurance program plan
QC	quality control
RI	remedial investigation
RBP	Rapid Bioassessment Protocol
RME	reasonable maximally exposed
RPD	relative percent difference
RQD	rock quality designation
SMCL	secondary maximum contaminant level
TCE	trichloroethylene

TNB	trinitrobenzene
TNT	trinitrotoluene
UCL	upper confidence limit
USGS	U.S. Geological Survey
VOC	volatile organic compound

UNITS OF MEASURE

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
cm	centimeter(s)
cm^2	square centimeter(s)
cm^3	cubic centimeter(s)
ft	foot (feet)
ft^3	cubic foot (feet)
g	gram(s)
gal	gallon(s)
h	hour(s)
ha	hectare(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
L	liter(s)
m	meter(s)
m^3	cubic meter(s)
mg	milligram(s)
mi	mile(s)
mi^2	square mile(s)
mL	milliliter(s)
min	minute(s)
pCi	picocurie(s)
ppm	part(s) per million
s	second(s)
t	metric ton(s)
ton	short ton(s)
µg	microgram(s)
µL	microliter(s)
µm	micrometer(s)
µS	microsiemen(s)
yd^3	cubic yard(s)

ENGLISH/METRIC AND METRIC/ENGLISH EQUIVALENTS

In this document, units of measure are presented with the metric equivalent first, followed by the measured English unit in parentheses. In cases where the measurement was originally made in metric units, the values were not converted back to English units; in tables, the data are generally in English or metric units only. The following table lists the appropriate equivalents for English and metric units.

Multiply	By	To Obtain
English/Metric Equivalents		
acres	0.4047	hectares (ha)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
degrees Fahrenheit (°F) - 32	0.5555	degrees Celsius (°C)
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons (gal)	0.003785	cubic meters (m^3)
inches (in.)	2.540	centimeters (cm)
miles (mi)	1.609	kilometers (km)
pounds (lb)	0.4536	kilograms (kg)
short tons (tons)	907.2	kilograms (kg)
short tons (tons)	0.9072	metric tons (t)
square feet (ft^2)	0.09290	square meters (m^2)
square yards (yd^2)	0.8361	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
yards (yd)	0.9144	meters (m)
Metric/English Equivalents		
centimeters (cm)	0.3937	inches (in.)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	1.308	cubic yards (yd^3)
cubic meters (m^3)	264.2	gallons (gal)
degrees Celsius (°C) + 17.78	1.8	degrees Fahrenheit (°F)
hectares (ha)	2.471	acres
kilograms (kg)	2.205	pounds (lb)
kilograms (kg)	0.001102	short tons (tons)
kilometers (km)	0.6214	miles (mi)
liters (L)	0.2642	gallons (gal)
meters (m)	3.281	feet (ft)
meters (m)	1.094	yards (yd)
metric tons (t)	1.102	short tons (tons)
square kilometers (km^2)	0.3861	square miles (mi^2)
square meters (m^2)	10.76	square feet (ft^2)
square meters (m^2)	1.196	square yards (yd^2)

1 INTRODUCTION

The U.S. Department of Energy (DOE) and the U.S. Department of the Army (DA) are conducting cleanup activities at two properties — the DOE chemical plant area and the DA ordnance works area (the latter includes the training area) — located in the Weldon Spring area in St. Charles County, Missouri (Figure 1.1). These areas are on the National Priorities List (NPL), and cleanup activities at both areas are conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended. DOE and DA are conducting a joint remedial investigation (RI) and baseline risk assessment (BRA) as part of the remedial investigation/feasibility study (RI/FS) for the groundwater operable units for the two areas. This joint effort will optimize further data collection and interpretation efforts and facilitate overall remedial decision making since the aquifer of concern is common to both areas. A Work Plan issued jointly in 1995 by DOE and the DA (DOE 1995b) discusses the results of investigations completed at the time of preparation of the report. The investigations were necessary to provide an understanding of the groundwater system beneath the chemical plant area and the ordnance works area. The Work Plan also identifies additional data requirements for verification of the evaluation presented.

1.1 PURPOSE AND SCOPE

The principal groundwater systems identified in the Weldon Spring region are an alluvial aquifer and three bedrock aquifers: shallow, middle, and deep (Kleeschulte and Imes 1994). The focus of this RI for the groundwater operable units is primarily the shallow bedrock aquifer, which is composed of the Burlington-Keokuk Limestone, the Fern Glen Formation, and associated saturated overburden materials. This focus is consistent with the understanding of the groundwater system, which is based on hydrogeologic investigations and groundwater sampling results discussed in the Work Plan (DOE 1995b)

This RI describes the nature and extent of contamination in the shallow aquifer system at the chemical plant area and the ordnance works area. Uranium, nitroaromatic compounds, metals, and anions have been identified as contaminants of potential concern (COPC) (DOE 1995b). Specifically, this RI presents the results of numerous investigations conducted to identify site-related contaminants, characterize the hydrogeology of the area, and identify environmental pathways for contaminant migration from known or suspected contaminant sources. In addition, this RI characterizes the ecological resources that may be affected by the discharge of contaminated groundwater to the surface waters of springs and streams in the area. A BRA was conducted as part of the RI to evaluate potential human health and ecological impacts due to contamination associated with the groundwater operable units (GWOUs) of the two areas. The shallow aquifer is a carbonate system characterized by the presence of a number of losing stream segments and sinkholes, conduits

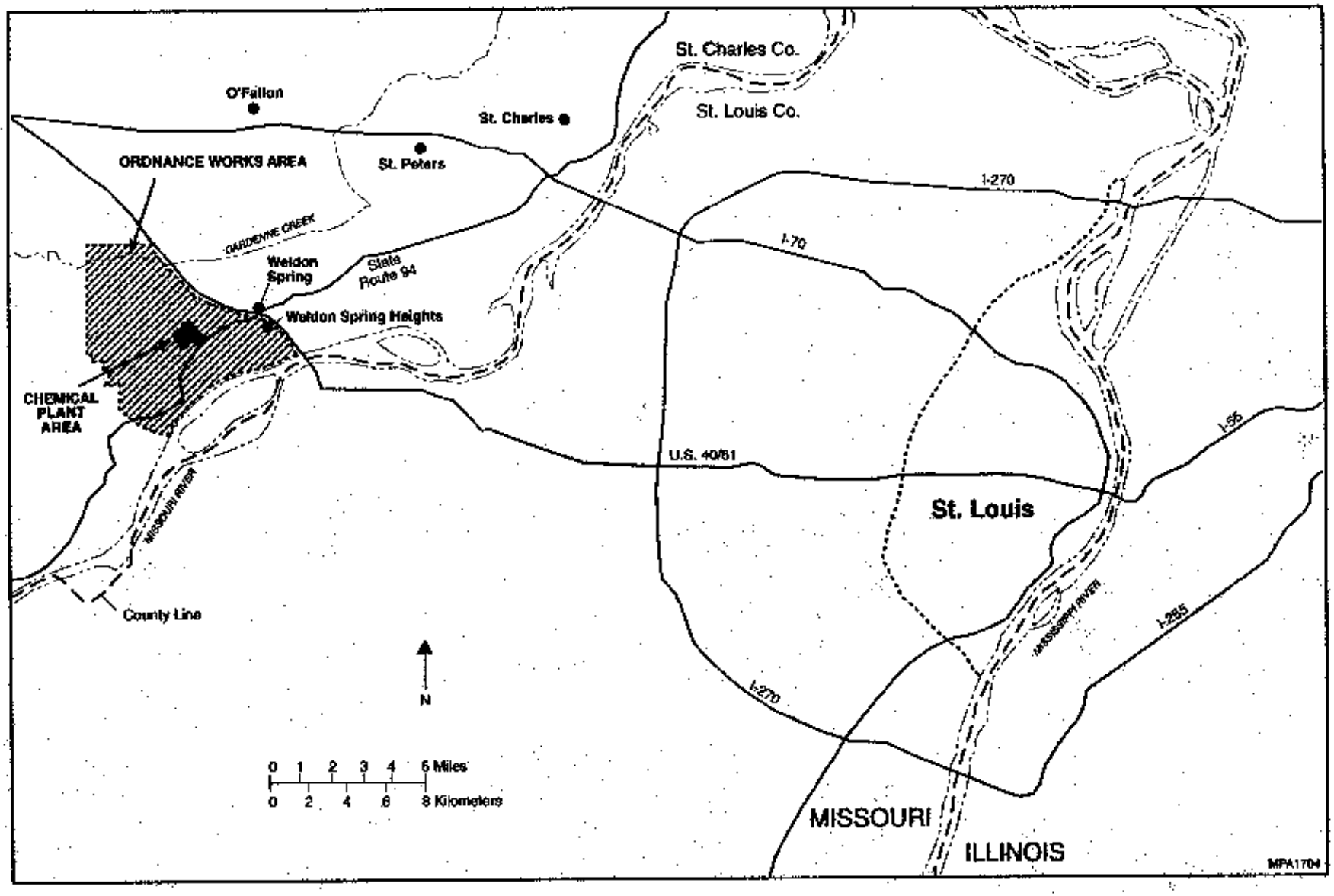


FIGURE 1.1 Locations of the Chemical Plant Area and the Ordnance Works Area

that discharge to springs, solution-broadened joints and fractures, and extensively weathered bedrock. Springs are included in this RI because they represent the hydrologic connection between the shallow groundwater and surface water. The alluvial aquifer located in the very southern portion of the ordnance works area is not being addressed in this RI. Because of its distant location, it does not have a strong connection with the hydrology of the chemical plant area and the ordnance works area to the north. The alluvial aquifer is included in DOE's Weldon Spring Quarry Residuals Operable Unit as discussed in the Work Plan (DOE 1995b).

1.2 REPORT ORGANIZATION

This RI is organized as follows. Chapter 1, this introduction, discusses the purpose and scope and includes a brief summary of the site history and environmental setting relevant to the GWOUs. Chapter 2 discusses the hydrogeological investigations and groundwater sampling and analysis activities conducted as part of this RI; a brief summary of the ecological investigations is also provided. Chapter 3 describes the hydrogeologic conceptual model developed from the investigations discussed in Chapter 2. Chapter 4 discusses the groundwater and spring data collected to support this RI; the nature and extent of site-related contamination are also discussed. Chapter 5 presents the contaminant migration process and contaminant persistence for each of the COPC. Chapter 6 summarizes the risk assessment performed for the GWOUs. Chapter 7 summarizes the quality control and quality assurance measures implemented to support the data collection activities, and Chapter 8 provides the summary and conclusions for this RI. All references cited in this RI are listed in Chapter 9. Appendixes A and B provide information on ecological and hydrological investigations, respectively, that were used to support this RI. Appendix C presents the results of the joint sampling of groundwater and springs, and Appendix D presents chemical and physical property data used in determinations of contaminant fate and transport.

1.3 SITE HISTORY AND DESCRIPTION

1.3.1 Site History

During the early 1940s, the DA acquired 6,974 ha (17,232 acres) of private land in St. Charles County for construction of the Weldon Spring Ordnance Works trinitrotoluene (TNT) dinitrotoluene (DNT) production facility. The Weldon Spring Ordnance Works facility consisted of 18 nearly identical and independent TNT manufacturing lines and 2 DNT lines that were operated by the Atlas Powder Company from 1941 through 1945. In April 1946, the facility was declared surplus property, and by 1949, the bulk of the property was distributed to state and local jurisdictions. The remaining 840 ha (2,063 acres) of the ordnance works, which contained all the TNT/DNT lines and most of the other facilities, was reinstated to the DA in 1954 as a National

Industrial Plant Reserve Property (Daubel 1992). In May 1955, 83 ha (205 acres) of the U.S. Army - National Industrial Plant Reserve was transferred to the U.S. Atomic Energy Commission (AEC) for construction of the Weldon Spring Uranium Feed Materials Plant. About 6 ha (15 acres) of additional land was later transferred from the DA to the AEC for expansion of waste storage capacity.

From 1958 until 1966, the feed materials plant processed uranium ore concentrates and some scrap metals to uranium trioxide, intermediate compounds, and uranium metal for shipment to other AEC facilities. A small amount of thorium was also processed. Operations at the plant ceased in 1966. Responsibility for the land and facilities of the feed materials plant was temporarily transferred back to the DA in 1966; plans by the DA included refitting the plant for chemical herbicide production. Contamination from previous uranium processing activities was found to be too extensive to proceed with the plant renovation. In 1971, a 21-ha (52-acre) tract containing four waste lagoons (raffinate pits) was transferred back to the AEC, while the remaining chemical plant area was retained by the DA. From 1971 to 1981, no activities took place, and the site was placed in caretaker status from 1981 through 1985. Custody of most of the chemical plant building area (67 ha [165 acres]) was transferred from the DA to DOE in October 1985.

DOE established the Weldon Spring Site Remedial Action Project in July 1986. The DA began remedial investigation activities at the former Weldon Spring Ordnance Works area in 1987. The chemical plant and raffinate pit area were added to the NPL in March 1989. The former ordnance works area, including the Weldon Spring Training Area, was added to the NPL in February 1990.

1.3.2 Site Descriptions

The former Weldon Spring ordnance works once encompassed a total area of 6,974 ha (17,232 acres), which has since been divided into several contiguous areas under different ownership. The current disposition of the property is depicted in Figure 1.2 and discussed in Section 1.3.3. The DA currently retains ownership of the 670-ha (1,655-acre) Weldon Spring Training Area, which contained the majority of the production facilities. Public access to the training area is restricted. The 88-ha (217-acre) chemical plant area lies within the boundaries of the former ordnance works area.

The Weldon Spring ordnance works (Figure 1.3) originally included 1,038 structures and buildings. As part of the historical decontamination efforts at the former ordnance works area, abandoned production buildings were disassembled, salvaged, razed, or burned in place (IT Corporation 1993a). Approximately 30 structures remain at the training area (IT Corporation 1993a).

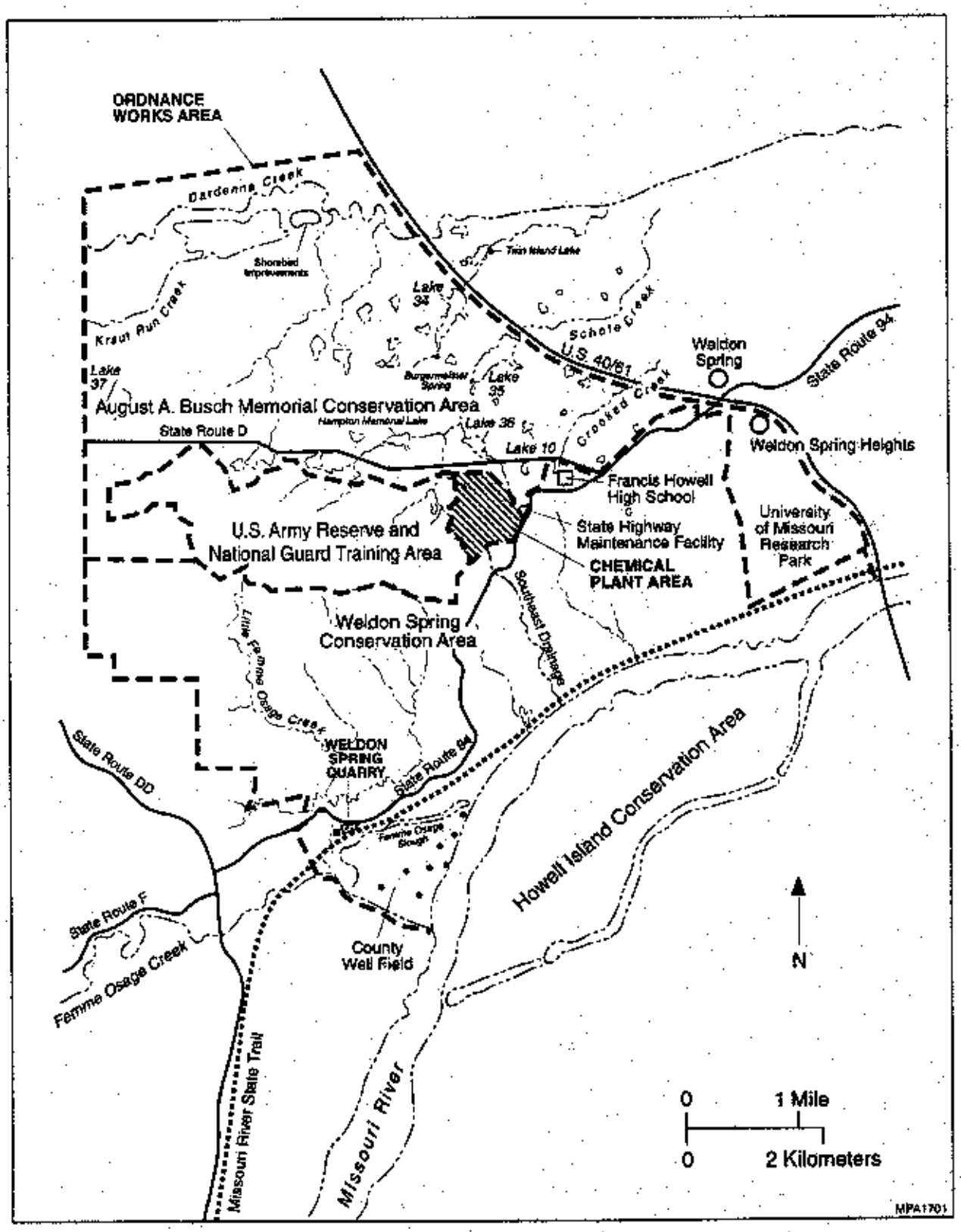


FIGURE 1.2 Current Disposition of the Properties Composing the Ordnance Works Area

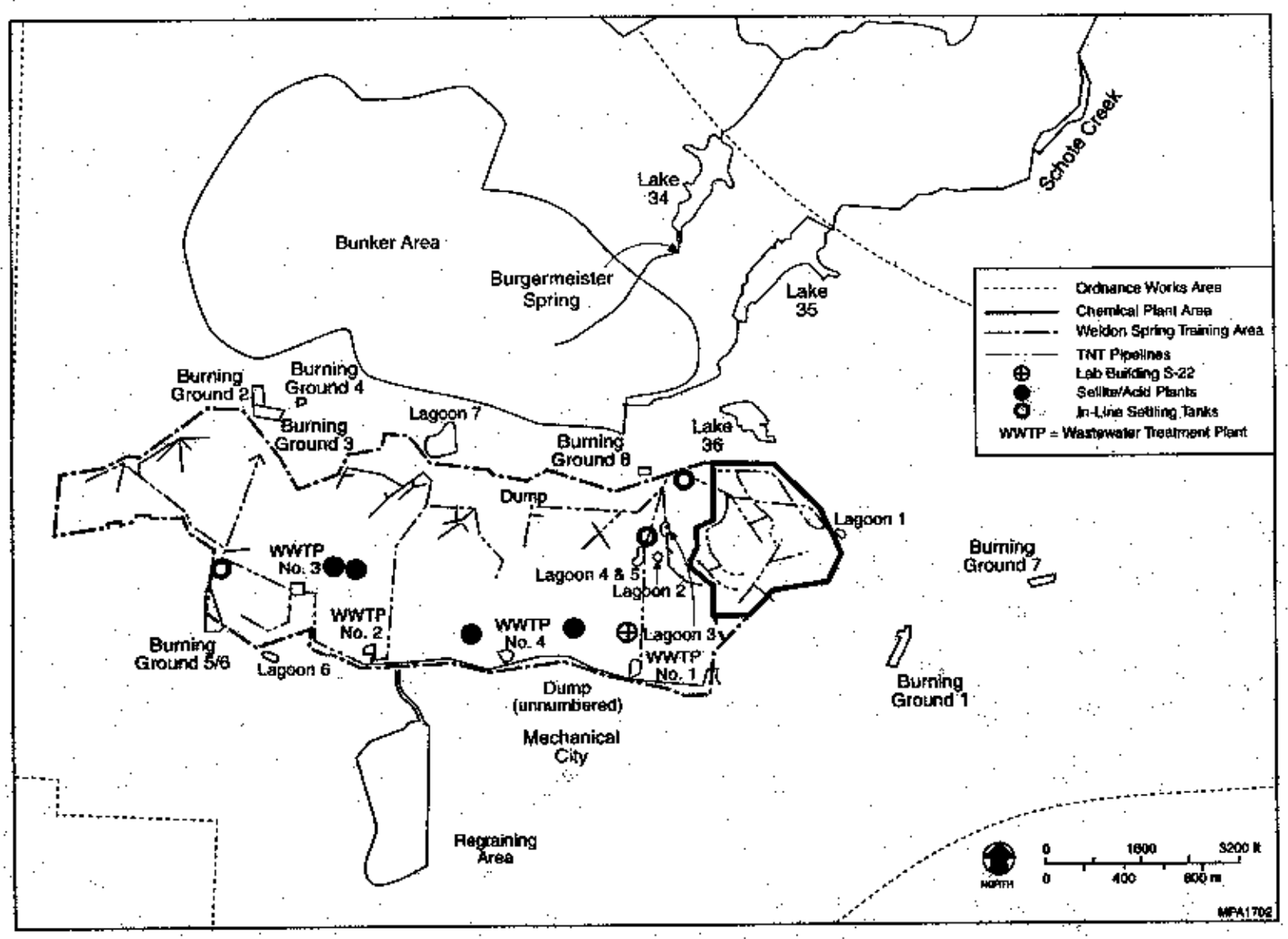


FIGURE 1.3 Locations of Waste Disposal Operations at the Ordnance Works Area

Potential historical source areas at the former ordnance works for groundwater contamination beneath the site include the TNT and DNT production lines, three wastewater treatment plants, in-line settling tanks, eight burning grounds, sellite/acid plants, laboratory buildings, Mechanical City (facility maintenance area), regraining areas, underground toluene and wooden wastewater transport pipelines, three dump areas, and seven wastewater lagoons (Figure 1.3). The burning grounds were used for waste products, general refuse, and waste from decontamination activities during the production period and subsequent cleanup.

The seven wastewater storage lagoons were constructed at the production area to store wastewater prior to constructing the water treatment facilities (IT Corporation 1993a). These wastewater lagoons have been drained and/or partially earth-filled by past decontamination activities. Six of the seven remnant lagoons (2 through 7) are located within the central portion of the former ordnance works area; the seventh lagoon, Lagoon 1, is located east of the chemical plant area. Currently, all lagoons except Lagoon 2 (completely earth-filled) are partially filled with ponded water (IT Corporation 1993a).

After completion of planned remedial activities at the ordnance works area, the following potential sources for groundwater contamination will remain: sorbed contaminants on soil particles under unsaturated conditions, contaminants sorbed onto material under saturated conditions, and contaminated sediment within the conduit to Burgermeister Spring.

Features remaining at the chemical plant area include the foundations of 40 process and nonprocess buildings, four raffinate pits, two former pond areas (Ash Pond and Frog Pond), and two former dump areas (north and south) (Figure 1.4). Soils in the dump areas and at scattered locations throughout the chemical plant are radioactively contaminated, and discrete locations also contain elevated concentrations of certain metals and organic compounds (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a).

Potential historical sources of groundwater contamination at the chemical plant area include process buildings, the raffinate pits, the Ash and Frog Pond areas, the former TNT processing lines, scattered pockets of contaminated soils, and subsurface materials surrounding the building foundations.

The four raffinate pits cover about 11 ha (26 acres) in the southwestern portion of the chemical plant area. They were used during the operational period of the chemical plant to receive waste slurry from processing operations. These pits constitute the most radiologically and chemically contaminated portion of the chemical plant area and at one time contained a maximum of about 152,911 m^3 (200,000 yd^3) of sludge and 215,768,476 L (57,000,000 gal) of water (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). In addition, drums and rubble from earlier decontamination activities at the chemical plant were disposed of in some of the pits (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a).

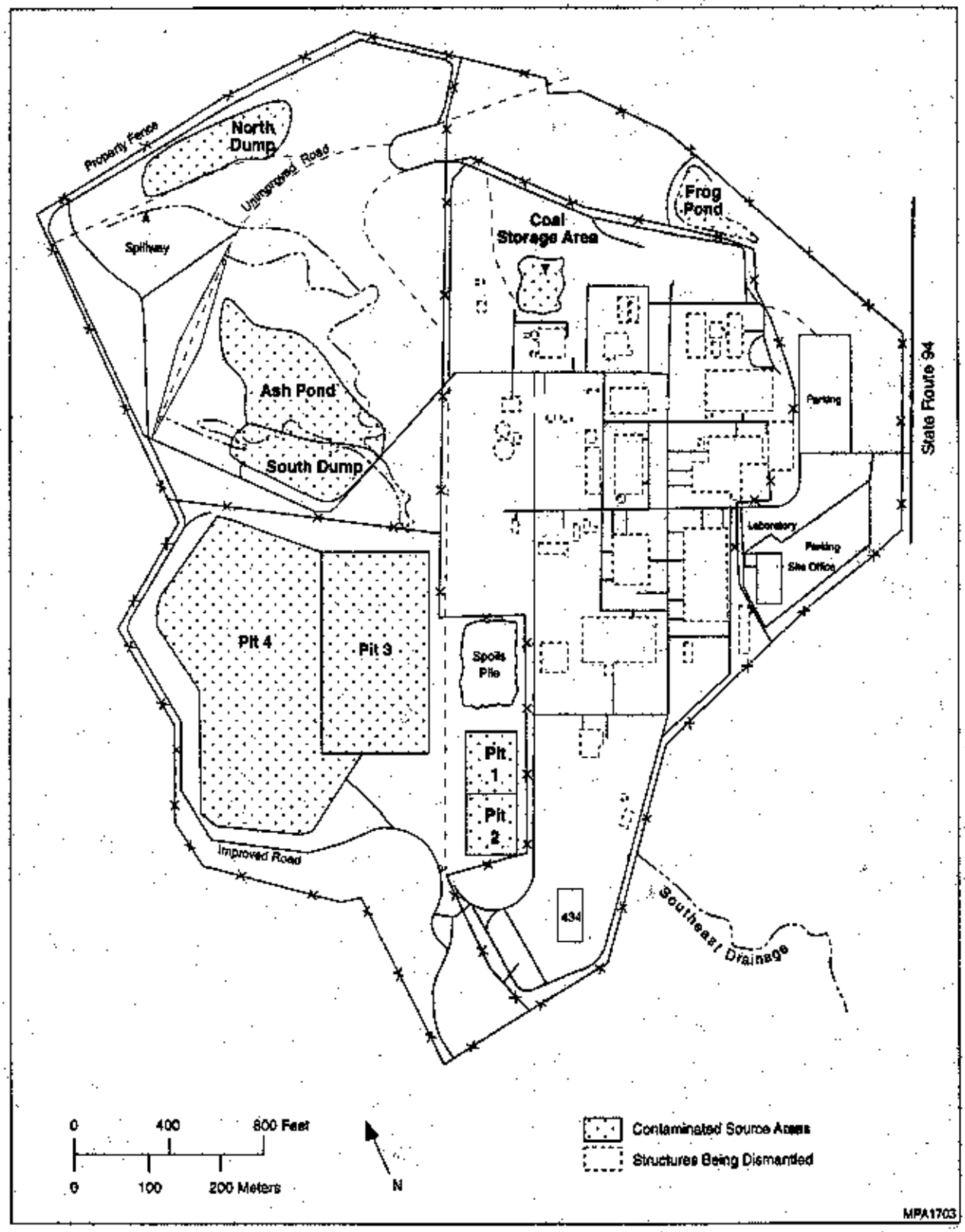


FIGURE 1.4 Original Layout of the Chemical Plant Area

After completion of remedial activities associated with previous decisions for the chemical plant area, three sources of contamination will remain: contaminated subsurface material in the vadose zone (contaminants sorbed onto soil particles under unsaturated conditions), contaminated consolidated rock and unconsolidated residuum in the phreatic zone (contaminants sorbed onto material under saturated conditions), and contaminated sediment within the conduit to Burgermeister Spring.

1.3.3 Environmental Setting

1.3.3.1 Land Use

The original Weldon Spring Ordnance Works site covered approximately 6,974 ha (17,233 acres) in St. Charles County. Current land use of the former ordnance works area includes the Weldon Spring Training Area, the DOE Weldon Spring Site, Missouri Department of Conservation and Missouri Department of Natural Resources-Division of State Parks–managed lands, the Francis Howell High School, a Missouri Department of Transportation maintenance facility, the village of Weldon Spring Heights, and a University of Missouri research park.

The Weldon Spring Training Area is located in the center of the former ordnance works area. The training area occupies approximately 670 ha (1,655 acres) and shares its eastern boundary with the chemical plant area. The training area is used by the U.S. Army Reserve, Missouri Army National Guard, and occasionally other military units for training exercises (IT Corporation 1993a). An average of 300 troops participate in training activities on weekends throughout the year. The 89th Regional Support Command, U.S. Army Reserve, has developed plans to construct a training center at the Weldon Spring Training Area. This facility would contain headquarters for several reserve units with about 30 full-time personnel. The units headquartered at the facility would conduct drills on assigned weekends and evenings at the facility and the training area.

The DOE Weldon Spring site consists of two geographically distinct areas, an 88-ha (217-acre) chemical plant area and a 4-ha (9-acre) limestone quarry. The chemical plant area is located in the central portion of the ordnance works area, and the quarry is located about 6 km (4 mi) south-southwest of the chemical plant area. Characterization and remediation activities are currently ongoing at both areas.

Most of the land of the ordnance works area consists of two state conservation areas. The August A. Busch Memorial Conservation Area, located in the northern portion of the ordnance works area and immediately adjacent to the chemical plant area and the training area, includes about 2,828 ha (6,987 acres) of actively managed grassland and forest. The Weldon Spring Conservation Area comprises about 2,977 ha (7,356 acres) of primarily forested land and is located in the southern

portion of the ordnance works area and south and east of the chemical plant and training areas. Both conservation areas are actively managed for fish and wildlife production and are used annually by more than 1,200,00 visitors for fishing, hunting, and hiking (Crigler 1992). The two conservation areas also annually host approximately 100,000 fishing trips. Although the conservation areas are used primarily for recreational activities, approximately 17% of the land area is leased to farmers for the production of domestic animal feed.

The Francis Howell High School occupies approximately 25 ha (61 acres) within the former Weldon Spring Ordnance Works site and is located about 1 km (0.6 mi) northeast of the chemical plant area (Figure 1.4). The school employs about 200 teachers and other staff and has a student enrollment of about 2,400. A State of Missouri Highway Department maintenance facility is located about 183 m (600 ft) northeast of the chemical plant area and employs nine full-time staff and one mechanic (Sizemore 1991). The former staff housing complex for the former Weldon Spring Ordnance Works site, located about 0.8 km (0.5 mi) southeast of the intersection of State Route 94 and U.S. Route 40/61, is currently a private housing development known as Weldon Spring Heights. This development occupies about 26 ha (63 acres) and has a population of about 80.

1.3.3.2 Groundwater Use

The aquifer as a whole beneath the boundaries of the chemical plant area and the ordnance works area is currently not used for drinking water or for irrigation. Drinking water is provided by the St. Charles County Water Department.

It is unlikely that the shallow aquifer beneath the ordnance works area and chemical plant area would be used by a future resident on the basis of the current and projected land use. The Army intends to continue using the training area for training activities in the future. The chemical plant area is currently being remediated, with all site waste being disposed of in an engineered disposal cell constructed on-site. The size of the cell is estimated to encompass approximately one third of the chemical plant area.

In addition, a large portion of the former ordnance works area has been converted into conservation areas. The August A. Busch Memorial Conservation Area and the Weldon Spring Conservation Area are managed by the Missouri Department of Conservation and are open throughout the year for recreational use. These areas are extensively used, as indicated by the estimated 1,200,000 visits each year (Crigler 1992).

A total of 45 old wells were identified on or very near to the ordnance works area as a result of a review of archival records from state files and interviews with persons familiar with the site. Many of the private wells identified were open to the deeper bedrock aquifers (i.e., Kimmswick and St. Peter) in order to obtain sufficient well yields. Although some of these private wells were open

to the shallow aquifer, in order to obtain sufficient yield most of these wells were open throughout the entire shallow aquifer (including all or part of the Fern Glen) rather than only the upper weathered part of the Burlington-Keokuk.

It is unlikely that a future resident would have a well open only to the upper part of the shallow aquifer because of the low transmissivity and low yield. A future resident would likely screen a private well in the deeper, more productive aquifers or, because of the 80-ft casing requirement, the well would be open to a larger portion of the shallow aquifer (rather than only the upper weathered unit of the Burlington-Keokuk). Finally, a municipal water supplier rather than individual wells would likely be the source of water for a future subdivision with multiple single family housing units.

No known shallow aquifer wells within the ordnance works area or chemical plant area are being used as sources of water. The closest private well to the former ordnance works site is located at Twin Island Lakes campground, approximately 0.20 km (0.12 mi) north of the August A. Busch Conservation Area. This well is estimated to be 70 to 91 m (230 to 300 ft) below the ground surface and is located downgradient from the site.

1.3.3.3 Ecological Resources

The ordnance works area and the chemical plant area are located along the boundary of the Ozark Border and Glaciated Plains physiographic provinces (based on physiographic provinces described in Johnson (1987). Land in the area varies from rolling hills to sloped forests to floodplain areas. This province possesses a variety of habitats that support a diverse flora and fauna (Missouri Department of Conservation 1991). The chemical plant area and portions of the ordnance works area are characterized by grasslands, old field habitat, and sparse to moderate woodland growth, primarily along creeks and drainages. Much of the chemical plant area is now cleared as a result of remedial actions in the area.

Sixty percent of the ordnance works area is forested and includes upland, slope, palustrine, and riparian forest habitats. Other terrestrial habitats found in the former ordnance works area are open fields, pastures, and cultivated farmlands.

A total of 29 mammal species have been reported in St. Charles County (DOE 1992a). Deer, squirrel, opossum, and racoon are common mammals and have been observed feeding and resting within the boundaries of the chemical plant area and the training area. Approximately 277 avian species have been reported from the conservation areas (Missouri Department of Conservation 1991), including wild turkey, great horned owl, red-tailed hawk, and several waterfowl and wading species, including wood duck, Canada goose, mallard, and great blue heron.

A total of 47 reptile species, 25 amphibian species, and 105 fish species have been reported in St. Charles County (DOE 1992a). Common herptofauna (reptiles and amphibians) found in this area include red-eared turtle, green frog, spring peeper, and central newt.

Surface water impoundments (lakes, reservoirs, and ponds) constitute the primary aquatic habitat present at the ordnance works area. Excluding the Missouri River, the principal stream habitat is Dardenne Creek, located in the Busch Conservation Area, and its larger tributaries. Numerous smaller streams and springs occur throughout the area, but the occurrence of surface water in many of these is ephemeral in nature and dependent on the precipitation regime and groundwater discharge. Many of the more than 105 species of fish reported in St. Charles County (Dickneite 1988) likely occur within suitable habitats in the conservation area. The reservoirs in the conservation areas are actively managed for recreational fishing and are stocked with such game species as bluegill, largemouth bass, black crappie, and channel catfish (Missouri Department of Conservation 1989). The larger stream habitats are known to support game and nongame fish species typically found in similar habitats throughout the Midwest and include a variety of centrarchids, minnows, shiners, and darters. Because of the ephemeral nature of flows, many of the small streams and springs provide limited year-round habitat for fish.

Five federal-listed threatened or endangered species, five federal candidate (C2) species, 13 state endangered species, and 19 state rare species have been reported from St. Charles County (DOE 1995b). Federal-listed species reported from or near the conservation areas or the ordnance works area include the bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco perigrinus*), interior least tern (*Sterna antillarum*), pallid sturgeon (*Scaphirhynchus albus*), and decurrent false aster (*Boltonia decurrens*) (DOE 1995b). The peregrine falcon and interior least tern only occur in the area as season migrants, and the pallid sturgeon is restricted to the Missouri River. The decurrent false aster occurs in slough habitats along the Missouri River but has not been reported in the area of the ordnance works area. Wintering bald eagles roost at the Howell Island Conservation Area and may forage in the ordnance works area. The sicklefin chub and sturgeon chub, both federal C2 species, and the paddlefish are large river species and if present in the area would be restricted to the Missouri River. Many of the C2 species, as well as the state-listed species, have been reported from the Busch or Weldon Spring Conservation areas and may utilize habitats receiving groundwater discharge (springs and seeps).

2 STUDY AREA INVESTIGATIONS

A number of investigations have been performed since 1987 to define the geological, hydrological, and contaminant profiles of the aquifer system at the chemical plant area and the ordnance works area. In addition, ecological surveys and sampling have also been performed to support the determination of environmental impacts from site-related contamination. Section 2.1 is a brief summary of the hydrological investigations relevant to the GWOUs. A description of the monitoring networks and data collected from these networks to delineate type and levels of site-related contamination is presented in Section 2.2. Section 2.3 describes activities performed as part of the ecological investigations.

2.1 HYDROGEOLOGIC INVESTIGATION

Numerous hydrogeological investigations have been conducted at the chemical plant area and the ordnance works area to develop a hydrogeological conceptual model for the GWOUs. The investigations that focused on characterizing the shallow aquifer system and identifying potential flow paths for contaminant migration included installation of a monitoring well, logging of bedrock and overburden core, measuring of static water levels, aquifer and tracer testing, and physical and chemical analyses of subsurface soils. Table 2.1 summarizes all relevant hydrogeological investigations.

Additional hydrogeological investigations were recently completed to further understand the groundwater flow system in the shallow aquifer. The studies performed in 1995 included installation of several additional monitoring wells and angled boreholes and aquifer testing in these wells. Aquifer testing was also performed for wells that had not been previously tested. More recent tracer tests were also performed (see Table 2.1). A detailed description of the hydrogeologic investigations listed in Table 2.1 is presented in Chapter 3.

2.2 NATURE AND EXTENT OF CONTAMINATION STUDIES

As discussed above, monitoring wells have been installed at the chemical plant area and the ordnance works area to provide geological, hydrological, and contaminant characterization data. Tables 2.2 and 2.3 list the groundwater monitoring wells and the completion intervals; the locations of the wells are shown in Figure 2.1.

Groundwater sampling and analysis have been ongoing at the chemical plant area since 1987. From 1987 to 1990, groundwater monitoring generally consisted of quarterly sampling of the wells composing the chemical plant monitoring network. In 1990, the monitoring frequency was

TABLE 2.1 Summary of Remedial Investigation Hydrogeologic Activities

Activity	Purpose	Organization/Report
Water-level measurements; sampling and analyses of groundwater and surface water samples.	To determine the extent and magnitude of groundwater and surface water contamination from chemical plant operation and the disposal of waste in the raffinate pits.	Kleeschulte and Emmett 1986, *Compilation and Preliminary Interpretation of Hydrologic Data for the Weldon Spring Radioactive Waste-Disposal Sites, St. Charles County, Missouri — A Progress Report.*
Description of monitoring equipment and methodology used, results summary, and discussion of significance of the results.	To consolidate documents prepared by Shell Engineering and Associates, Inc., on a water balance study conducted at the chemical plant area raffinate pits and to summarize the results.	Bechtel National, Inc. 1986, *Report on Water Balance Studies from 1983 to 1985, Weldon Spring Raffinate Pits, Weldon Spring, Missouri.*
Geophysical surveys, trenching, borehole drilling and sampling, installation of groundwater monitoring wells, laboratory soil property analyses, and groundwater sampling and analyses.	To determine if contaminants from site activities have impacted the groundwater and to evaluate the geology and hydrogeology, a hydrogeological characterization study was conducted at the chemical plant area.	Bechtel National, Inc. 1987, *Hydrogeological Characterization Report for Weldon Spring Chemical Plant, Weldon Spring, Missouri.*
Water-level measurements; streamflow measurements; dye tracing; and sampling and analyses of groundwater, springs, and the raffinate pits.	To determine the extent and magnitude of surface and groundwater contamination at the chemical plant area.	Kleeschulte and Emmett 1987, *Hydrology and Water Quality at the Weldon Spring Radioactive Waste-Disposal Sites, St. Charles County, Missouri.*
Water samples from 27 springs and seeps within a 3-km (2-mi) radius of the chemical plant area were collected and analyzed for nitroaromatic compounds, uranium, metals, and inorganic anions. Groundwater was also sampled at the chemical plant area.	To determine the extent of contamination in surface water and groundwater near the chemical plant area.	MK-Ferguson Company and Jacobs Engineering Group, Inc. 1989c, *Phase I Spring and Seep Report: Weldon Spring Site Remedial Action Project, Weldon Spring, Missouri.*
Three types of aquifer tests were performed: slug tests, pumping tests, and tracer tests.	To characterize the hydraulic properties of the shallow aquifer (i.e., Burlington-Keokuk Limestone) beneath the chemical plant area.	MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990b, *Aquifer Characteristics Data Report for the Weldon Spring Chemical Plant/Raffinate Pits and Vicinity Properties.*
Chemical analyses of groundwater and surface water samples, mineralogic and chemical analyses of overburden samples, laboratory sorption experiments, chemical and mineralogic characterization of sludge and interstitial samples from Raffinate Pit 3, and geochemical computer simulations.	To determine the geochemistry of the shallow aquifer and geochemical controls on the migration of uranium and other constituents from the raffinate pits.	Schumacher 1990, *Geochemical Data for the Weldon Spring Chemical Plant Site and Vicinity Property, St. Charles County, Missouri — 1989–90*; Schumacher 1993, *Geochemistry and Migration of Contaminants at the Weldon Spring Chemical Plant Site, St. Charles, Missouri — 1989–91.*
Literature search, classification of stream segments as gaining or losing, identification of spring locations, water tracing tests, continuous gauging of selected springs, and continuous water-level monitoring in selected monitoring wells.	To define the relationships between precipitation, surface runoff, groundwater recharge, and shallow groundwater discharge. The study area included most of the original ordnance works area and a small area to the northeast between U.S. Highway 40/61 and Dardenne Creek.	Missouri Department of Natural Resources 1991, *Shallow Groundwater Investigations at Weldon Spring, Missouri, Final Report for Fiscal Years 1988–1990.*
Classification of surface drainages into losing and gaining stream segments, locations of karst features (e.g., springs, caves, and sinkholes), water tracing tests, and continuous water-level monitoring of selected wells.	To identify the shallow groundwater discharge points that might be affected by runoff from the training area. The study area included the ordnance works area and the adjoining land to the west of it.	Price 1991, *Shallow Groundwater Investigations at the Weldon Spring Training Area, St. Charles County, Missouri.*

TABLE 2.1 (Cont.)

Activity	Purpose	Organization/Report
Laboratory batch experiments and geochemical modeling.	To determine the potential for migration of molybdenum, uranium, and other constituents from the raffinate pits, investigations were conducted at the chemical plant area.	Schumacher and Stollenwerk 1991, *Geochemical Controls on Migration of Molybdenum, Uranium, and Other Constituents at the Weldon Spring Chemical Plant Site.*
Installation of monitoring wells and measurement of static water levels.	To characterize the shallow aquifer system.	MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a, *Remedial Investigation for the Chemical Plant Area of the Weldon Spring Site.*
Exploratory trenching and soil borings to characterize the surficial material units, laboratory testing to determine engineering properties of each surficial material unit, and detailed mapping and cross-section development of the surficial material units.	To characterize and map the surficial units, define the types of soils, and determine their origins. The study area included the training area.	Rueff 1992, *Surficial Materials Investigation at the Weldon Spring Training Area, St. Charles County, Missouri.*
Installation of monitoring wells, logging of bedrock core, aquifer testing (i.e., slug tests), measurement of static water levels, and groundwater sampling and analysis.	To characterize the shallow aquifer system beneath the ordnance works area.	IT Corporation 1993a, *Final Remedial Investigation Report, Weldon Spring Training Area, Weldon Spring, Missouri.*
Water was collected and analyzed for nitroaromatic compounds from lysimeters installed in the unsaturated zone at locations along former TNT production lines and groundwater. Surface water, surficial soil samples, and subsurface soil core samples were also analyzed for nitroaromatic compounds. Soils samples were collected from various overburden units at the training area for physical, chemical, and mineralogic characterization.	To investigate the environmental fate of TNT at the training area.	Schumacher et al. 1993, *Geochemical Data for the Weldon Spring Training Area and Vicinity Property, St. Charles County, Missouri — 1990–92.*
Water-level measurements, sampling and analyses of groundwater and springs, and simulation of the groundwater flow system with a three-dimensional flow model.	To improve understanding of the geohydrology, to better define the extent of groundwater contamination, and to quantitatively assess the groundwater flow system in St. Charles County.	Kleeschulte and Imes 1994, *Geohydrology, Water Quality, and Simulation of Ground-Water Flow at the Weldon Spring Chemical Plant and Vicinity, St. Charles County, Missouri.*
Incorporation and interpretation of selected data collected by the DA, DOE, U.S. Geological Survey (USGS), and Missouri Department of Natural Resources. Relogging of bedrock and overburden core samples from DA wells and bedrock core samples from some of the DOE monitoring wells was a component of this investigation.	To present a geohydrologic description of the ordnance works area and chemical plant area that consists of descriptions of the geology and groundwater hydrology.	Mugel 1997, *Geohydrology of the Weldon Spring Ordnance Works, St. Charles County, Missouri.*
Physical and chemical analyses of soil and water samples from lysimeters installed in the unsaturated zone, groundwater and spring water quality data, discharge and water quality data collected during storm-water runoff events at two continuous record stream gauging stations and six ancillary stormwater runoff monitoring sites, and water-level data.	To collect hydrologic and water quality data at the ordnance works area.	Schumacher et al. 1996, *Hydrologic and Water-Quality Data for the Weldon Spring Ordnance Works, St. Charles County, Missouri — 1992–95.*

TABLE 2.1 (Cont.)

Activity	Purpose	Organization/Report
Installation of eight monitoring wells (six at the ordnance works area and two at the chemical plant area).	To provide information on groundwater elevation and flow direction and water quality in both the weathered and unweathered Burlington-Keokuk Limestone in areas where data were not available.	Additional activity performed by IT Corporation and MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.
Retrofit of one existing monitoring well at the ordnance works.	To provide data on the weathered Burlington-Keokuk Limestone, monitoring well USGS-7 was retrofitted from an open hole construction to that of a discrete monitoring interval and renamed MWD-112.	Additional activity performed by IT Corporation as part of this RI.
Core drilling of three angled borings at the chemical plant.	To further evaluate the areas of suspected highly conductive paleochannels on the basis of geological data and prior aquifer testing, three angled borings were drilled 30° from vertical to increase the likelihood of intersecting vertical fracture zones.	Additional activity performed by MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.
Packer testing of the bedrock during coring of monitoring wells and angled borings.	To evaluate the vertical variation of hydraulic conductivity in the weathered and unweathered Burlington-Keokuk Limestone and to identify any highly transmissive zones, packer (water pressure) tests were performed in the bedrock portion of each monitoring well and angled boring.	Additional activity performed by MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.
Injection of dye tracers in two angled borings and one monitoring well and monitoring for resurgence at nearby springs.	To determine if a subsurface hydraulic connection exists between the northern and western portions of the chemical plant area to Burgermeister Spring (Drainage 6300), tracer testing was performed.	Additional activity performed by MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.
Single well hydraulic conductivity testing (slug testing) on several existing monitoring wells at both the ordnance works area and the chemical plant area.	To provide a comprehensive data set for evaluation of the areal distribution of hydraulic conductivity in the weathered and unweathered Burlington-Keokuk Limestone, slug tests were performed on locations not previously tested.	Additional activity performed by MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.
Water-level monitoring of complete groundwater monitoring network.	To provide a regional picture of the potentiometric surface of the shallow aquifer, static water level measurements were obtained from the active monitoring well networks at both the ordnance works area and the chemical plant area.	Additional activity performed by MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.
Precipitation measurements.	To evaluate the response of the shallow aquifer system to precipitation events, daily precipitation measurements were obtained and compared to static groundwater levels in monitoring wells and discharge rates in springs.	Additional activity performed by MK-Ferguson Company and Jacobs Engineering Group, Inc., as part of this RI.

TABLE 2.2 Monitoring Wells Associated with the Ordnance Works Area

Location/Well Number	Completion Interval	Location/Well Number	Completion Interval
Training Area		***Ordnance Works Area***	
MWS- 01	Weathered/unweathered	USGS1	Unweathered
MWV-01	Overburden	USGS2[a,b]	Burlington-Keokuk
MWD-02	Unweathered	USGS2A	Overburden/Burlington-Keokuk
MWS-02	Weathered/unweathered	USGS3[a]	Burlington-Keokuk
MWV-02	Overburden	USGS4[a]	Burlington-Keokuk
MWS-03	Weathered/unweathered	USGS5[a]	?/Burlington-Keokuk
MWS-04	Weathered	USGS6[a]	Unweathered
MWD-05	Fern Glen/Chouteau	USGS7[c]	Burlington-Keokuk
MWS-05	Unweathered/Fern Glen	USGS8[a]	Burlington-Keokuk
MWD-06	Unweathered	USGS9[a]	Burlington-Keokuk
MWS-06	Unweathered	TIL-3	Unknown
MWS-07	Weathered	TIL-4[d]	Burlington-Keokuk/Fern Glen
MWS-08	Weathered	MWS-101	Kimmswick
MWV-08	Overburden	MWS-102	Decorah
MWD-09	Unweathered	MWS-103	Sulphur Springs/Kimmswick
MWS-09	Weathered	MWS-104	Weathered/unweathered
MWV-09[e]	Overburden	MWD-105	Unweathered/Fern Glen
MWS-10	Weathered	MWS-105	Unweathered
MWS-11	Weathered	MWD-106	Unweathered/Fern Glen
MWS-12	Weathered	MWS-106	Unweathered
MWS-13	Weathered	MWS-107	Weathered/unweathered
MWV-13[e]	Overburden	MWD-107	Unweathered
MWS-14	Weathered	MWS-108	Unweathered
MWD-15	Weathered	MWD-109	Unweathered/Fern Glen
MWS-15	Weathered	MWS-109	Unweathered
MWS-16	Weathered	MWS-110	Weathered/unweathered
MWV-16[e]	Overburden	MWS-111	Weathered
MWS-17	Weathered/unweathered	MWD-112	Weathered/unweathered
MWV-17	Overburden	MWS-112	Weathered
MWD-18	Kimmswick	MWGS-01[d]	Kimmswick
MWS-18	Chouteau/Bachelor/	MWGS-02[d]	Joachim/St. Peter
	Sulphur Springs	MWGS-03[d]	Burlington-Keokuk
MWV-18	Overburden	MWGS-04[d]	Kimmswick
MWS-19	Weathered	MWGS-05[d]	St. Peter
MWS-20	Weathered/unweathered	Army Well	?/Sulphur Springs Group/?
MWS-21	Weathered		
MWS-22	Weathered		
MWV-22[e]	Overburden		
MWD-23	Unweathered		
MWS-23	Weathered		
MWS-24	Weathered		
MWV-24[d]	Overburden		
MWV-24R	Overburden		
MWD-25	Weathered/unweathered		
MWS-25	Weathered		
MWS-26	Weathered		

[a] Completion interval is undifferentiated Burlington-Keokuk Limestone.

[b] Abandoned well.

[c] Retrofit well USGS7 replaced with MWD-112.

[d] Inactive monitoring well.

[e] Saturated overburden well.

TABLE 2.3 Monitoring Wells at the Chemical Plant Area

Location/Well Number	Completion Interval
Chemical Plant Area	
MW-2001	Weathered/unweathered
MW-2002	Weathered
MW-2003	Weathered
MW-2004[a]	Weathered/unweathered
MW-2005	Weathered
MW-2006	Weathered/unweathered
MW-2007	Weathered/unweathered
MW-2008[a]	Weathered/unweathered
MW-2009[a]	Weathered
MW-2010	Weathered
MW-2011[a]	Weathered/unweathered
MW-2012	Weathered/unweathered
MW-2013	Weathered/unweathered
MW-2014	Weathered
MW-2015	Weathered/unweathered
MW-2016	Weathered/unweathered
MW-2017	Weathered/unweathered
MW-2018	Weathered
MW-2019	Unweathered
MW-2020[c]	Weathered/unweathered
MW-2021	Unweathered
MW-2022	Unweathered
MW-2023	Unweathered
MW-2024	Unweathered
MW-2025[a]	Unweathered
MW-2026	Unweathered
MW-2027	Unweathered
MW-2028	Unweathered
MW-2029[a]	Unweathered
MW-2030	Weathered
MW-2031	Overburden/weathered
MW-2032	Overburden/weathered
MW-2033	Overburden/weathered
MW-2034	Weathered
Temporary Storage Area	
MW-2035	Weathered/unweathered
MW-2036	Weathered/unweathered
MW-2037	Weathered
MW-2038	Burlington-Keokuk[d]
MW-2039	Burlington-Keokuk[d]
Site Water Treatment Plant Equalization Basin	
MW-2040	Burlington-Keokuk[d]
MW-2041	Burlington-Keokuk[d]
MW-2042	Burlington-Keokuk[d]
MW-2043	Burlington-Keokuk[d]
MW-2044	Weathered/unweathered

Location/Well Number	Completion Interval
Raffinate Pits	
MW-3001[a]	Overburden/weathered
MW-3002[a]	Unweathered
MW-3003	Weathered/unweathered
MW-3004[a]	Overburden
MW-3005[b]	Overburden
MW-3006	Unweathered
MW-3007	Weathered/unweathered
MW-3008[c]	Weathered/unweathered
MW-3009[c]	Weathered/unweathered
MW-3010[a]	Weathered/unweathered
MW-3011[b]	Overburden
MW-3012[a]	Overburden
MW-3013[b]	Overburden
MW-3014[a]	Overburden
MW-3015[a]	Overburden
MW-3016[b]	Overburden
MW-3017[a]	Overburden
MW-3018[b]	Overburden
MW-3019	Weathered/unweathered
MW-3022[b]	Overburden/weathered
MW-3023	Weathered
MW-3024	Unweathered
MW-3025	Weathered
MW-3026	Unweathered
MW-3027	Weathered/unweathered
Off-Site Wells	
Chemical Plant Area	
MW-4001	Weathered/unweathered
MW-4002	Weathered/unweathered
MW-4003	Weathered
MW-4004	Unweathered
MW-4005	Weathered/Burlington-Keokuk[d]
MW-4006	Weathered
MW-4007	Unweathered
MW-4008	Unweathered
MW-4009	Unweathered
MW-4010	Weathered/unweathered
MW-4011	Unweathered
MW-4012	Unweathered
MW-4013	Weathered/unweathered
MW-4014	Weathered/unweathered
MW-4015	Weathered/unweathered
MW-4016	Weathered/unweathered
MW-4017[a]	Weathered/unweathered
MW-4018	Weathered/unweathered
MW-4019	Weathered/unweathered
MW-4020	Weathered/unweathered
MW-4021	Weathered/unweathered
MW-4022	Unweathered
MW-4023	Weathered
MW-4024	Weathered
MW-4025	Weathered

[a] Abandoned well.

[b] Inactive monitoring well.

[c] Retrofit well MW-2020 replaced with MW-2044; MW-3008 replaced with MW-3024; MW-3009 replaced with MW-3026.

[d] Completion interval is undifferentiated Burlington-Keokuk Limestone.

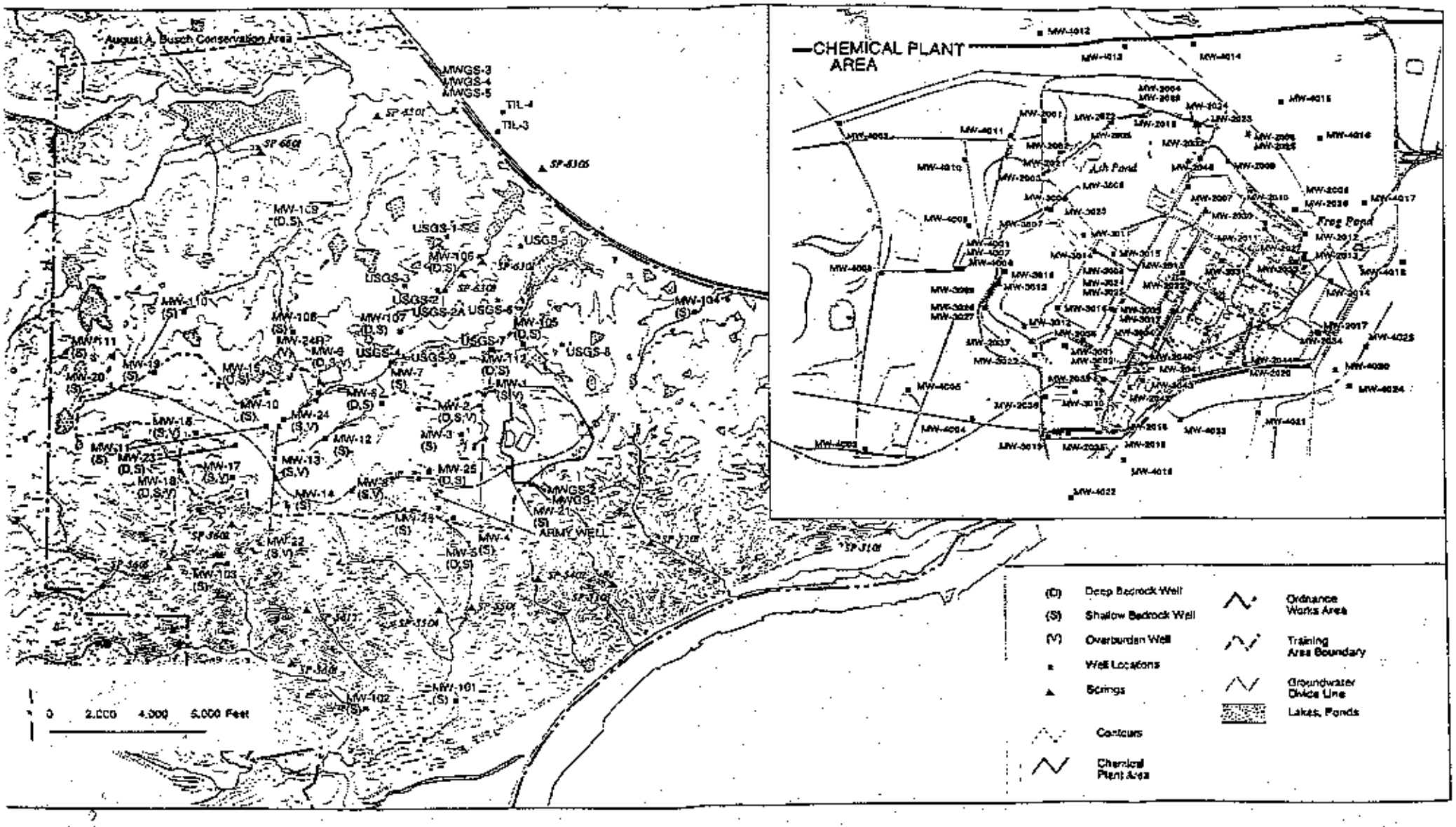


FIGURE 2-1 Location of Monitoring Wells and Springs at the Chemical Plant Area and the Ordnance Works Area

reduced to semiannually at monitoring locations where contaminants exceeded water quality criteria and to annually at remaining locations (DOE 1995b). Data collected prior to 1995 have been compiled and presented in various reports listed in Table 2.4.

Groundwater sampling was begun in the ordnance works area in 1989. Two sampling rounds in March and October of 1989 were conducted on the central portion of the ordnance works area (training area) wells. One sampling round was conducted in January 1990 on wells outside the training area; a round was conducted in May and June 1991 for all training area and ordnance works wells (IT Corporation 1995a). Quarterly sampling for analyses of nitroaromatics, metals, and inorganic anions was initiated in 1992. Since February 1993, quarterly samples have been analyzed only for nitroaromatics; metals and inorganic anions analyses are conducted annually (IT Corporation 1995a). Most of the wells completed in the overburden monitor perched water, except for five wells (MWV-09, MWV-13, MWV-16, MWV-22, and MWV-24R) that monitor the saturated overburden. Table 2.4 lists the reports in which groundwater data collected at the ordnance works area previous to 1995 have been compiled.

Several additional sampling activities were conducted in 1995 to provide further data to define the nature and extent of contamination in the shallow groundwater aquifer. Two wells completed in the weathered zone of the Burlington-Keokuk Limestone, MW-4024 and MW-4025, were installed southeast of the chemical plant area to delineate the extent of uranium contamination. Because of difficulties encountered during installation, MW-4024 was not completed until July 1995. The well was sampled at the time of well completion and was also sampled in August. Seven wells and one retrofit well installed on the ordnance works area for the hydrogeological investigation were sampled during both 1995 sampling events. MWS-24 is routinely not sampled because of previous well installation problems with an adjacent well. Samples for metals and anions analyses were not obtained from MWS-26 for the August round because the wells went dry prior to obtaining an adequate volume of water for analysis. Also, May and August samples were not obtained from MWV-8 and MWV-18 (located on the training area) because the wells were dry.

A joint sampling effort was conducted by DOE and the DA during May and August 1995; this sampling involved all currently monitored wells. In addition, in order to collect more recent data to determine groundwater discharge at the area springs, 15 springs were included for the joint sampling effort (Figure 2.1). Parameters evaluated under the joint sampling effort were those identified as COPC in the Work Plan (DOE 1995b) and are shown in Table 2.5. The list includes parameters that were not routinely analyzed at the ordnance works area (e.g., concentrations of uranium, lithium, molybdenum, and nitrate) and chemical plant area (e.g., degradation products of DNT and TNT). Because sampling methods, target analytes, and analytical procedures varied in the past, the joint sampling effort provided a unified sampling method, and target analyte list and specific analytical procedures to produce a set of comparable data between both areas.

TABLE 2.4 Summary of Groundwater Sampling and Analysis at the Chemical Plant Area and the Ordnance Works Area

Activity	Report
Groundwater monitoring 1987 — chemical plant area	*Water Quality Phase I Assessment Report*, MK-Ferguson and Jacobs Engineering Group, Inc. 1987
Groundwater monitoring 1988 — chemical plant area	*Phase II Groundwater Quality Assessment for the Weldon Spring Site, Chemical Plant, Raffinate Pits, and Surrounding Vicinity Properties*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1989d
Groundwater monitoring 1989 — chemical plant area	*Annual Site Environmental Report 1989*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1990a
Groundwater monitoring 1990 — chemical plant area	*Annual Site Environmental Report for Calendar Year 1990*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1991
Groundwater monitoring 1991 — chemical plant area	*Weldon Spring Site Environmental Report for Calendar Year 1991*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992b
Groundwater monitoring 1992 — chemical plant area	*Weldon Spring Site Environmental Report for Calendar Year 1992*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1993b
Groundwater monitoring 1993 — chemical plant area	*Weldon Spring Site Environmental Report for Calendar Year 1993*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1994
Groundwater monitoring 1994 — chemical plant area	*Weldon Spring Site Environmental Report for Calendar Year 1994*, MK-Ferguson Company and Jacobs Engineering Group, Inc. 1995
Groundwater monitoring, Rounds 1–3, March and October 1989 and June 1991 — ordnance works area	*Final Remedial Investigation Report, Weldon Spring Training Area, Weldon Spring, Missouri*, IT Corporation 1993a
Groundwater monitoring, Round 4, February 1992 — ordnance works area	*Quarterly Groundwater Monitoring, First Report (Revision No. 2, New Data)*, IT Corporation 1992b
Groundwater monitoring, Round 5, May/June 1992 — ordnance works area	*Quarterly Groundwater Monitoring, Second Report*, IT Corporation 1992c

TABLE 2.4 (Cont.)

Activity	Report
Groundwater monitoring, Round 6, August 1992 — ordnance works area	*Quarterly Groundwater Monitoring, Third Report*, IT Corporation 1992d
Groundwater monitoring, Round 7, December 1992 — ordnance works area	*Quarterly Groundwater Monitoring, Fourth Report*, IT Corporation 1993e
Groundwater monitoring, Round 8, February 1993 — ordnance works area	*1993: Groundwater Monitoring Report First Yearly Sampling Round, Weldon Spring Ordnance Works*, IT Corporation 1993b
Groundwater monitoring, Round 9, May 1993 — ordnance works area	*1993: Second Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1993c
Groundwater monitoring, Round 10, August 1993 — ordnance works area	*1993: Third Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1993d
Groundwater monitoring, Round 11, November 1993 — ordnance works area	*1993: Fourth Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1994d
Groundwater monitoring, Round 12, February 1994 — ordnance works area	*1994: Second Yearly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1994c
Groundwater monitoring, Round 13, May 1994 — ordnance works area	*1994: Second Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1994b
Groundwater monitoring, Round 14, August 1994 — ordnance works area	*1994: Third Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1994e
Groundwater monitoring, Round 15, November 1994 — ordnance works area	*1994: Fourth Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1995a
Groundwater monitoring, Round 16, February 1995 — ordnance works area	*1995: Third Yearly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1995c

TABLE 2.4 (Cont.)

Activity	Report
Groundwater monitoring, Joint Sampling Round 1 (Round 17) — chemical plant area and ordnance works area	*1995: Second Quarterly Groundwater Monitoring Report, Weldon Spring Ordnance Works*, IT Corporation 1995b
Groundwater monitoring, Joint Sampling Round 2 (Round 18) — chemical plant area and ordnance works area	*1995: Third Quarterly Groundwater Monitoring Report*, IT Corporation 1995c

TABLE 2.5 Contaminants of Potential Concern Evaluated in the Joint Sampling Effort

Human Health COPC	Ecological COPC
Uranium	Uranium[a]
Aluminum	Arsenic
Antimony	Chromium
Arsenic	Lead
Barium	Manganese
Cadmium	Mercury
Chromium	Molybdenum
Copper	Nickel
Iron	Selenium
Lead	Silver
Lithium	Thallium
Chloride	Nitrate
Fluoride	Nitroaromatic compounds[b]
Nitrate	
Sulfate	
Nitroaromatic compounds[b]	

[a] Retained on the basis of chemotoxicity only.

[b] Nitroaromatics include the following 11 compounds: 1,3-dinitrobenzene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, 1,3,5-trinitrobenzene, 2,4,6-trinitrotoluene, nitrobenzene, 2-amino-4,6-dinitrotoluene, 4-amino-2,6-dinitrotoluene, 2-nitrotoluene, 3-nitrotoluene, and 4-nitrotoluene.

Three springs — 5101, 5605, and 5612 — were not accessible during the May sampling event. The access to Spring 5101 was flooded, the discharge point for Spring 5605 could not be located because of high levels of water in the stream, and Spring 5612 was not flowing at the time of sampling. Samples were obtained from all locations during the August sampling event.

Toluene and carbon disulfide were also analyzed in samples from two ordnance works wells, MWS-5 and MWS-104. Toluene was detected in MWS-5 in a sample collected in 1989, and carbon disulfide was detected in MWS-104 in a 1990 sample. These detects were suspected to be due to laboratory contamination, and no detected concentrations of these compounds were found in the 1995 joint samples. Recent (1996 and 1997) data, collected from monitoring wells as part of a volatile organic compound (VOC) monitoring program at the chemical plant area, indicate the presence of very low levels of toluene in groundwater from some wells. These recent data are discussed in detail in Chapter 4.

2.2.1 Background Water Quality

Both the chemical plant area and the training area are located on a local surface water high and straddle a regional groundwater divide, and, therefore, it was not feasible to conduct upgradient/downgradient water quality comparisons to determine the extent of site-related contamination in the groundwater system. It was necessary to use existing on-site wells to estimate background levels of naturally occurring constituents (i.e., metals and anions). Organic compounds (primarily nitroaromatics compounds) are anthropogenic, and any detected concentration of these was assumed to be site related. Several wells open to the Burlington-Keokuk were identified in the Work Plan (DOE 1995b) as potential background locations since these areas had not shown detectable nitroaromatic compounds (a key contaminant at the training area) and were not believed to have been impacted from historical source areas. Monitoring well locations — MWS-13, MWS-23, and MWS-111 — were selected to represent background for the weathered zone of the Burlington Keokuk; MWD-105, MWD-106, MWS-108, and MWD-109 were selected to represent background for the unweathered zone. Monitoring wells MWD-105, MWS-108, and MWD-109 are located in the Busch Conservation Area north of the training area and the chemical plant area; MWS-13 and MWS-23 are located in the western portion of the training area; and MWS-111 is located northwest of the training area.

The background monitoring wells for this RI were selected on the basis of (1) completion in similar hydrostratigraphic units (e.g., weathered unit of the Burlington-Keokuk); (2) location outside of areas directly affected by contamination from the chemical plant area; and (3) location upgradient or at a distance from explosive production areas. Other factors evaluated for identifying background monitoring wells included groundwater sampling data (e.g., no impacts from past production operations indicated on the basis of no detectable concentrations of nitroaromatic compounds) and recognition, on the basis of dye tracing studies, of the potential for contaminant

migration from known or suspected source areas at the chemical plant area and the ordnance works area. Background well MWS-13 was eliminated from use because sulfate values were consistently higher than in other locations. Background well MWD-106 was also eliminated from use because it is located in the 6300 drainage basin near Burgermeister Spring. Because springs represent locations of groundwater discharge to the surface, the groundwater data collected from the background monitoring wells completed in the weathered zone of the Burlington-Keokuk were selected to represent background spring data. These data were compared with data collected from springs from across the ordnance works area and surrounding vicinity.

2.2.2 In Situ Sampling of Groundwater at the Southeast Drainage

Data requirements identified in the Work Plan (DOE 1995b) also include the need to collect preliminary information regarding contaminant levels in groundwater beneath the lower portion of the Southeast Drainage. Groundwater samples were obtained from six locations in August 1995. Boreholes were drilled using a hollow stem auger rather than the hydropunch technique specified in the Sampling Plan (DOE 1995a). This method was chosen because subsurface materials were believed to be too rocky for hydropunch methods. For each location, drilling was completed upon first encounter with groundwater; depths ranged from 1 to 3 m (3 to 10 ft). A water sample from an open borehole was then obtained with disposable bailers. The groundwater samples collected were very turbid because of the drilling methods used. These unfiltered groundwater samples were analyzed for metals, uranium, nitroaromatic compounds, nitrate, and sulfate.

These locations were resampled in April 1996 utilizing a hydropunch method. The hydropunch method was used because the push point could be advanced through the subsurface soils and because the method decreases the possibility of sediment disturbance such as that noted in the August 1995 sampling. Samples were obtained from boreholes with temporary casings and filtered using a 0.45-μm filter. The samples were obtained at depths where water was first encountered and deeper, where possible. Because depth to bedrock was unknown, deeper samples were collected by sampling at the depth where the push point was advanced to refusal (refusal at bedrock noted only for sample IS-4003) or to a depth of 9 to 12 m (30 to 40 ft). Temporary casings and 1-m (2-ft) screens were then installed at each point to allow an adequate sample to be gathered. The interval for two sampling locations (i.e., IS-4005 and IS-4006) did not yield enough water for laboratory analysis; therefore, samples obtained were analyzed for uranium only by using a Kinetic Phosphorescence Analyzer (KPA) method.

To better delineate contamination in the Southeast Drainage Area, a monitoring well was installed in May 1997. Data collected from this well will be evaluated and included in the FS.

2.3 ECOLOGICAL INVESTIGATION

A number of ecological investigations have been conducted to support the baseline ecological risk assessment for the groundwater operable units. Additional ecological investigations have been completed to evaluate potential or actual impacts of other site-related contamination and media. The investigations supporting the groundwater BRA focused on surface water habitats (springs) that receive direct groundwater discharge. The ecological investigations included biotic surveys, habitat assessments of selected surface waters, and toxicity testing of surface water and sediment from selected surface water habitats.

Groundwater from the chemical plant area and within the former Weldon Spring Ordnance Works site discharges to the surface at a number of springs and seeps. However, because of natural variations in groundwater discharge and precipitation, many of the springs and seeps do not provide suitable year-round habitat capable of supporting a diverse biota. Thus, the ecological investigations targeted Burgermeister Spring and downstream waters. Burgermeister Spring (SP-6301) is located within the 6300 drainage of the ordnance works area and receives groundwater discharge from the chemical plant area. Burgermeister Spring is within the Dardenne Creek watershed and represents the headwaters of Lake 34 in the Busch Conservation Area. Except for a small portion of the drainage immediately below the spring, Burgermeister Spring and the downstream waters provide year-round habitat for aquatic biota.

Surface water and sediment were collected from Burgermeister Spring and analyzed for nitroaromatic compounds, metals, and inorganic ions. Surface water and sediment were also collected for toxicity testing. Sampling locations and methods, analytical methods, and toxicity test methods are described in the Sampling Plan (DOE 1995a) and the Work Plan (DOE 1995b).

Macroinvertebrates and fish were collected from Burgermeister Spring and analyzed for contaminant levels. Biotic surveys of aquatic invertebrates, fish, and amphibians from Burgermeister Spring and downstream habitats were conducted to identify potential receptor species for the ecological risk assessment and to characterize the condition of the biotic communities currently inhabiting the spring and downstream habitats. The ecological investigations also included evaluations of habitat quality. These evaluations, employing EPA Rapid Bioassessment Protocol methods (EPA 1989b), characterize aquatic habitats and biotic communities on the basis of physical characteristics, such as water depth, current velocity, and siltation, independent of potential contamination.

The results of the ecological investigations (see Appendix A) were incorporated into the ecological risk portion of the baseline risk assessment (DOE and DA 1997), which is summarized in Section 6.2 of this RI. The Sampling Plan (DOE 1995a) and the Work Plan (DOE 1995b) identify similar ecological investigations for two springs within the 5300 drainage (Southeast Drainage); the results of these investigations are presented in a separate report (DOE 1996).

3 HYDROGEOLOGICAL INVESTIGATIONS OF THE STUDY AREA

This chapter summarizes the hydrogeological investigations performed at the ordnance works area and the chemical plant area to characterize the shallow aquifer and define potential pathways for contaminant migration. In addition to these investigations, those performed as part of this RI to refine the hydrogeologic conceptual model described in the Work Plan (DOE 1995b) are also discussed. Appendix B includes a discussion of the overburden and bedrock, as well as data summary tables, testing methods, figures, and geologic logs and well diagrams for the monitoring wells installed to complete the monitoring network to support this RI.

3.1 GEOLOGY

The geology of the Weldon Spring area can generally be divided into unconsolidated surficial material (overburden) and bedrock formations. Table 3.1 summarizes the generalized stratigraphy and hydrostratigraphy for the area. Additional information regarding the overburden and bedrock geology is provided in Section B.1 of Appendix B.

3.1.1 Overburden

The thickness of unconsolidated material or overburden ranges from 0 to 21 m (0 to 70 ft) in the vicinity of the chemical plant area and the ordnance works area on the basis of new and reinterpreted top of bedrock data (Mugel 1997). The actual thickness depends on topography and/or previous construction at each of the sites. Some of the thickest overburden occurs in the northern part of the training area and north of the training area (Mugel 1997). The overburden is thinnest along the topographic high on the southern edge of the training area and the chemical plant area because of erosion. South of the training area and the chemical plant area, many of the stream beds are in bedrock, thus the overburden is not present.

The seven principal overburden units found at the chemical plant area and the ordnance works area are (1) fill/topsoil, (2) Peoria Loess, (3) Roxana Silt, (4) Ferrelview Formation, (5) clay till, (6) basal till, and (7) residuum (see Figure 3.1). Section B.1.1 of Appendix B gives a more complete description of each overburden unit and a summary of physical characteristics on the basis of laboratory tests performed on soils from the chemical plant area and training area.

The Ferrelview Formation, the till units (basal and clay), and the residuum allow recharge to the shallow aquifer system because of the presence of hairline fractures and permeable zones (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a; Rueff 1992; Mugel 1997). The residuum and till units are saturated in localized portions of the ordnance works area and chemical

TABLE 3.1 Generalized Stratigraphy and Hydrostratigraphy for the Chemical Plant Area and the Ordnance Works Area

System	Series	Stratigraphic Unit	Thickness (ft)	Physical Characteristics	Hydrostratigraphic Unit[a]
Quaternary	Holocene	Alluvium	0–120	Silt, sand, gravel	Alluvial aquifer
	Pleistocene	Loess and glacial drift	0–11	Silty clay to silt	Not classified[b]
		Ferrelview Formation	0–22	Clay to silty clay	Glacial drift confining unit[c]
		Glacial till unit	0–47	Sandy and silty clay to clayey silt, with scattered rock fragments	Shallow aquifer
		Basal till unit	0–10	Sandy, clayey, silty gravel or gravelly silt	
Mississippian	Osagean	Residuum unit[d]	0–38	Clay, chert, silt; locally contains limestone fragments	
		Burlington-Keokuk Limestone	0–185	Limestone; silty, argillaceous, thickly bedded, cherty, fractured	Shallow aquifer
		Fern Glen Formation	0–67	Limestone; fine-grained, medium to thickly bedded, cherty	
	Kinderhookian	Chouteau Group	0–45 (+)	Dolomitic limestone; fine-grained, thinly to medium bedded	Upper confining
		Bachelor Formation	0–2	Sandstone; calcareous cement	
Devonian	Upper	Sulphur Springs Group			
		Bushberg Sandstone	0–20	Quartz sandstone; fine to medium-grained, friable	
		Glen Park Limestone	0–25	Calcareous siltstone, sandstone, oolitic limestone, and hard carbonaceous shale	
Ordovician	Cincinnatian	Maquoketa Shale[e]	0–11	Calcareous or dolomitic shale; typically thinly laminated, silty with shaley limestone lenses	
	Champlainian	Kimmswick Limestone	41–104	Limestone; coarsely crystalline, medium to thick bedded, cherty near base	Middle aquifer
		Decorah Group	25–36	Shale with thin interbeds of very finely crystalline limestone	Confining unit

TABLE 3.1 (Cont.)

System	Series	Stratigraphic Unit	Thickness (ft)	Physical Characteristics	Hydrostratigraphic Unit[a]
Ordovician (Cont.)	Champlainian (Cont.)	Plattin Limestone	70–125	Limestone; finely crystalline, thinly bedded	Lower confining unit (cont.)
		Joachim Dolomite	80–105	Dolostone; thin to thickly bedded, grades into siltstone, shales common	
		St. Peter Sandstone	120–150	Quartz sandstone; fine- to medium-grained, massively bedded	Deep aquifer
	Canadian	Powell Dolomite	50–60	Dolostone; fine to medium crystalline, minor chert and shale	
		Cotter Dolomite	200–250	Argillaceous, cherty dolomite; fine to medium crystalline; interbedded with shale	
		Jefferson City Dolomite	160–180	Dolomite; fine to medium crystalline	
		Roubidoux Formation	150–170	Dolomitic sandstone	
		Gasconade Dolomite	[f]	Cherty dolomite	
Cambrian	Upper	Eminence Dolomite	[f]	Dolomite; medium to coarsely crystalline, medium-bedded to massive	
		Potosi Dolomite	[f]	Dolomite; fine to medium crystalline, thick bedded to massive; drusy quartz common	

[a] When no hydrostratigraphic unit is listed, the unit is the same as for the preceding entry.

[b] These units are saturated in some places at the chemical plant area and the ordnance works area.

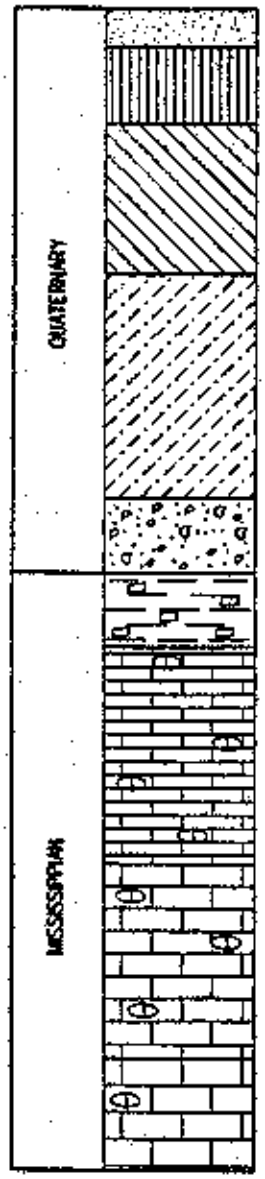
[c] A confining unit only where the base of the unit is below the potentiometric of the shallow aquifer, mainly in the August A. Busch Memorial Conservation Area.

[d] Residuum consists of the residual material from the weathering of the uppermost bedrock formation and possibly younger rocks. The uppermost bedrock formation in most places is the Burlington-Keokuk Limestone.

[e] Identified in monitoring well MWGS-2.

[f] Insufficient data to estimate thickness.

Sources: Data from Whitfield et al. (1989); DOE (1992a); Kleeschulte and Imes (1994); and Mugel (1997).



Stratigraphic Unit	Lithology	Thickness (ft)
Topsoil/Fill	Silt, Sand, Gravel	0–30
Loess (Including Roxana Silt overlying the Peoria Loess)	Silty Clay to Silt	0–11
Ferrelview Formation	Clay to Silty Clay	0–22
Clay Till	Sandy Silty Clay to Clayey Silt with Minor Gravel	0–47
Basal Till	Sandy, Clayey, Silty Gravel or Gravelly Silt	0–10
Residuum	Gravelly Clay to Clayey Gravel	0–38
Weathered Burlington-Keokuk Limestone	Limestone, Argillaceous Cherty, Porous, Vuggy, Fractured	0–113
Unweathered Burlington-Keokuk Limestone	Limestone-Cherty, Stylolitic, Locally Dolomite & Siltstone	0–113
Fern Glen Formation	Limestone to Dolomitic Limestone, Slightly Argillaceous	0–67

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FIGURE 3.1 Stratigraphic Column of the Overburden and Shallow Bedrock Aquifer

plant area. In the northern portion of the ordnance works area, saturation of these units becomes more predominant, and the units act as a leaky confining unit to the shallow aquifer (Mugel 1997). The glacially derived till units are not present south of the training area.

3.1.2 Bedrock

The uppermost bedrock unit beneath most of the ordnance works area and the chemical plant area is the Burlington-Keokuk Limestone. A detailed discussion of the bedrock units composing the regional shallow bedrock aquifer is provided in Section B.1.2 of Appendix B. Detailed and site-specific descriptions of each unit and subunit are provided in documents produced for each of the two areas (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a; IT Corporation, 1992a, 1993a; Mugel 1997).

The Burlington-Keokuk Limestone is a fine to coarse-grained, thinly to massively bedded limestone containing 60% chert as nodules and interbeds. The approximate thickness of this limestone ranges from 0 to 56 m (0 to 185 ft) in the ordnance works area (Mugel 1997), and from 12 to 56 m (40 to 185 ft) at the chemical plant area (Whitfield et al. 1989). In the southern portion of the ordnance works area, the Burlington-Keokuk Limestone is no longer present (because of erosion).

On the basis of stratigraphy and the degree of weathering, the Burlington-Keokuk Limestone has been characterized as having two different units. The weathered unit is the uppermost portion of the limestone formation and is characterized as generally having a higher hydraulic conductivity because of increased weathering. The lower unweathered unit is characterized as generally having a lower hydraulic conductivity because of a decrease in weathering. Most of the hydrologic discussion in Section 3.2 emphasizes the overburden units and the Burlington-Keokuk Limestone (Figure 3.1).

The present day topography (Figure 3.2) of the two areas reflects the subsurface topography (Figure 3.3) of the bedrock except in the northern portion of the ordnance works area where glacially derived materials were deposited over the existing topography. A bedrock high is present near the southern boundary of the training area and the chemical plant area and coincides with a topographic high.

Subsurface data indicate the presence of linear bedrock lows that are likely preglacial drainages in the top of the weathered Burlington-Keokuk Limestone near the northern and western boundaries of the chemical plant area (Figure 3.3). Geologic investigations have not identified any linear bedrock lows at the training area, but on the basis of the current understanding of the geology and groundwater flow, it is possible that such features exist. Large-scale closed depressions are not

exhibited on the bedrock surface, although swallow holes have been identified in several drainages in the nearby conservation areas (Missouri Department of Natural Resources 1991).

Beneath the Burlington-Keokuk Limestone is the Fern Glen Formation, a medium to thickly bedded, fine-grained dolomite and limestone with some layers of chert. On the basis of the rock core from the ordnance works area, the formation is estimated to range from 0 to 20 m (0 to 67 ft) thick. Erosion has eliminated this unit in the southern portion of the ordnance works area.

3.2 HYDROGEOLOGY

The principal aquifer systems identified in the Weldon Spring area are the alluvial aquifer and the three bedrock aquifers: shallow, middle, and deep (Kleeschulte and Emmett 1987). The relationship between the regional hydrostratigraphy and geologic units is presented in Table 3.1. The three regional bedrock aquifers are separated by thick sequences of bedrock that form confining units. The shallow aquifer is composed of saturated overburden, the Burlington-Keokuk Limestone and the Fern Glen Formation. The shallow bedrock aquifer is separated from the middle bedrock aquifer (Kimmswick Limestone) by 21 to 41 m (70 to 135 ft) of fine-textured limestone, shalely sandstone, and shale, which form a leaky confining unit over the middle bedrock aquifer. Beneath the middle aquifer is 64 to 90 m (210 to 295 ft) of shales and fine-grained limestones that form a confining unit over the deep aquifer (St. Peter Sandstone to Potosi Dolomite).

As discussed in Chapter 1, the focus of this RI is the shallow groundwater system, which includes the overburden units (i.e., residuum and till) in areas where these units are saturated, and the Burlington-Keokuk Limestone and the Fern Glen Formation (Mugel 1997). The overburden units and the weathered portion of the Burlington-Keokuk Limestone constitute the more permeable section of this aquifer where the groundwater flow can be characterized by Darcian diffuse flow with superimposed conduit flow. Although the Burlington-Keokuk Limestone is fractured, both horizontally and vertically, and has undergone dissolution that has enlarged the fractures, groundwater flow through the shallow aquifer can be described by the hydraulic head distribution in the aquifer; that is, groundwater will flow from areas of higher head toward areas of lower head (in accordance with Darcy's Law). The assumption is that if the bedrock has sufficiently high density of interconnected fractures, the bedrock unit will behave as a porous media, and Darcy's law may apply on a large scale. This assumption can be applied to portions of the chemical plant area and the ordnance works area, although discrete flow in large fractures or solution features must be taken into account in those areas that show evidence of preferential flow.

In the chemical plant area and in most of the ordnance works area, the shallow aquifer is an unconfined or water table aquifer. However, in the northern portion of the ordnance works area, it behaves as a confined aquifer because the potentiometric surface is above the base of the confining layer, which consists of glacial drift composed of clays and silts (Mugel 1997). The confining units

FIGURE 3.2 Surface Topography of the Chemical Plant Area and the Ordnance Works Area

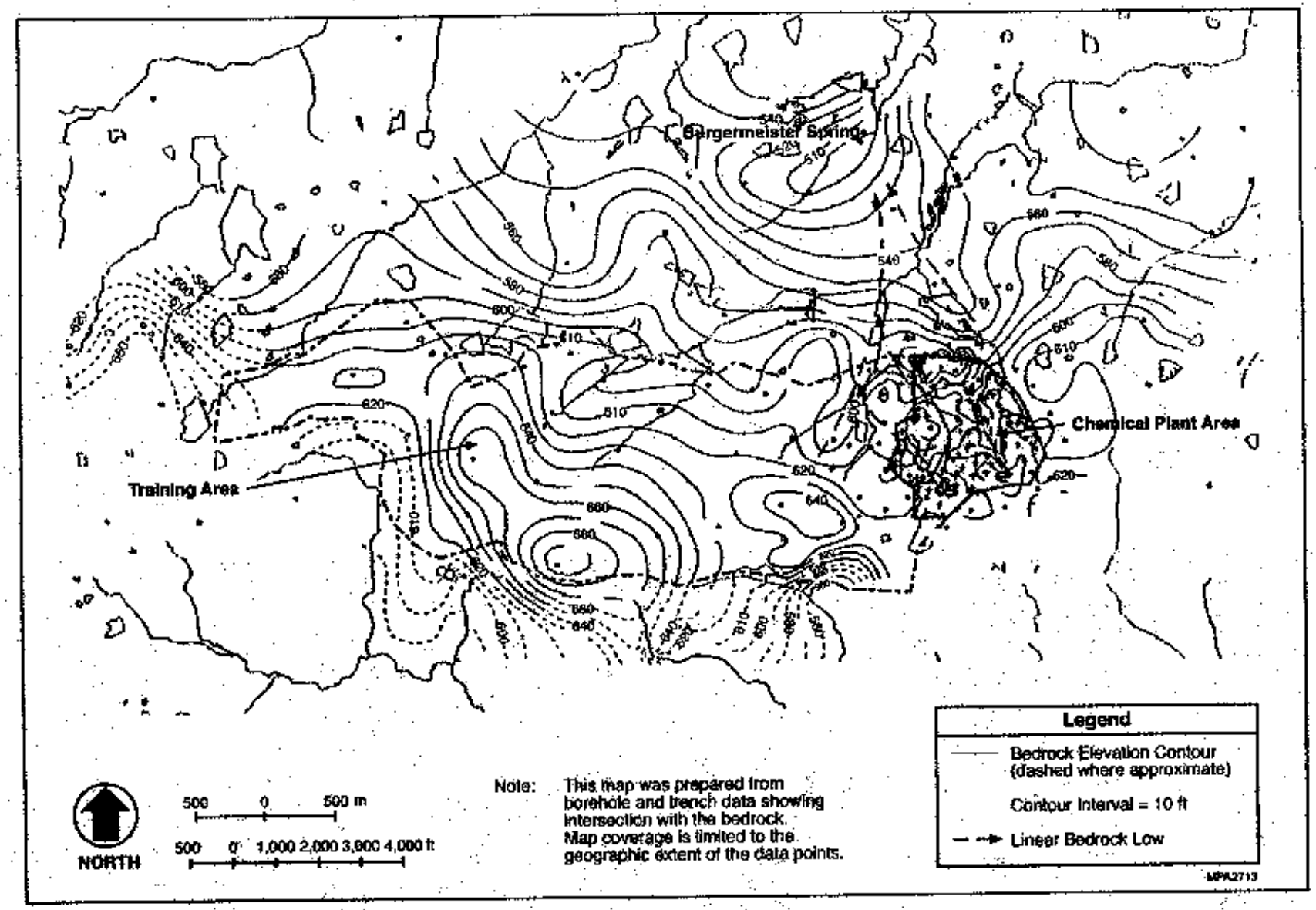


FIGURE 3.3 Bedrock Topography of the Chemical Plant Area and the Ordnance Works Area

with a low hydraulic conductivity retard groundwater movement through the unit as compared with the more permeable limestone and saturated residuum units. The glacial till unit does not confine groundwater at the chemical plant area, in the central and southern parts of the ordnance works area, or where the potentiometric surface occurs below the base of the unit (Mugel 1997).

3.2.1 Hydrostratigraphic Unit Determination

As discussed in Section 3.1, the Burlington-Keokuk Limestone has been divided into two units, an upper weathered zone that generally overlies a lower unweathered zone. The contact between these two units is gradational. The major observations made from previous hydrogeologic studies (Table 2.1) are as follows:

- In general, higher hydraulic conductivities have been measured in the weathered limestone unit than in the unweathered portion of the limestone;
- The weathered limestone unit exhibits relatively thin, highly conductive zones, consisting of fracture zones and solution features;
- The degree of weathering and intensity of fractures generally decrease with depth in the Burlington-Keokuk Limestone;
- Intervals of water loss during drilling activities diminish with depth; and
- The number and size of solution vugs and voids diminish with depth.

The upper hydrostratigraphic unit of the shallow aquifer is the saturated overburden and weathered unit of the Burlington-Keokuk Limestone; the lower unit is the unweathered unit and the Fern Glen Formation. Cross sections indicate that the weathered Burlington-Keokuk Limestone is typically saturated across most of the training area and the ordnance works area where the formation is present (Figures 3.4 and 3.5). Unsaturated weathered Burlington-Keokuk Limestone is present in some areas at the chemical plant area. As shown in these two figures, the thickness of the weathered unit varies across the site; the thickness generally is greater in areas where the bedrock topography is highest. In the northern portion of the ordnance works area, the weathered unit thins and/or disappears.

The depth to water varies from less than 3 to 18 m (10 to 60 ft) across the chemical plant area and the ordnance works area. The depth varies with difference in surface topography and/or bedrock topography. The vadose zone (unsaturated zone) generally occurs in the overburden, although in some areas it also includes parts of the weathered limestone. The vadose zone is generally thinner in stream segments where the surface topography is lowest. The thicker portions

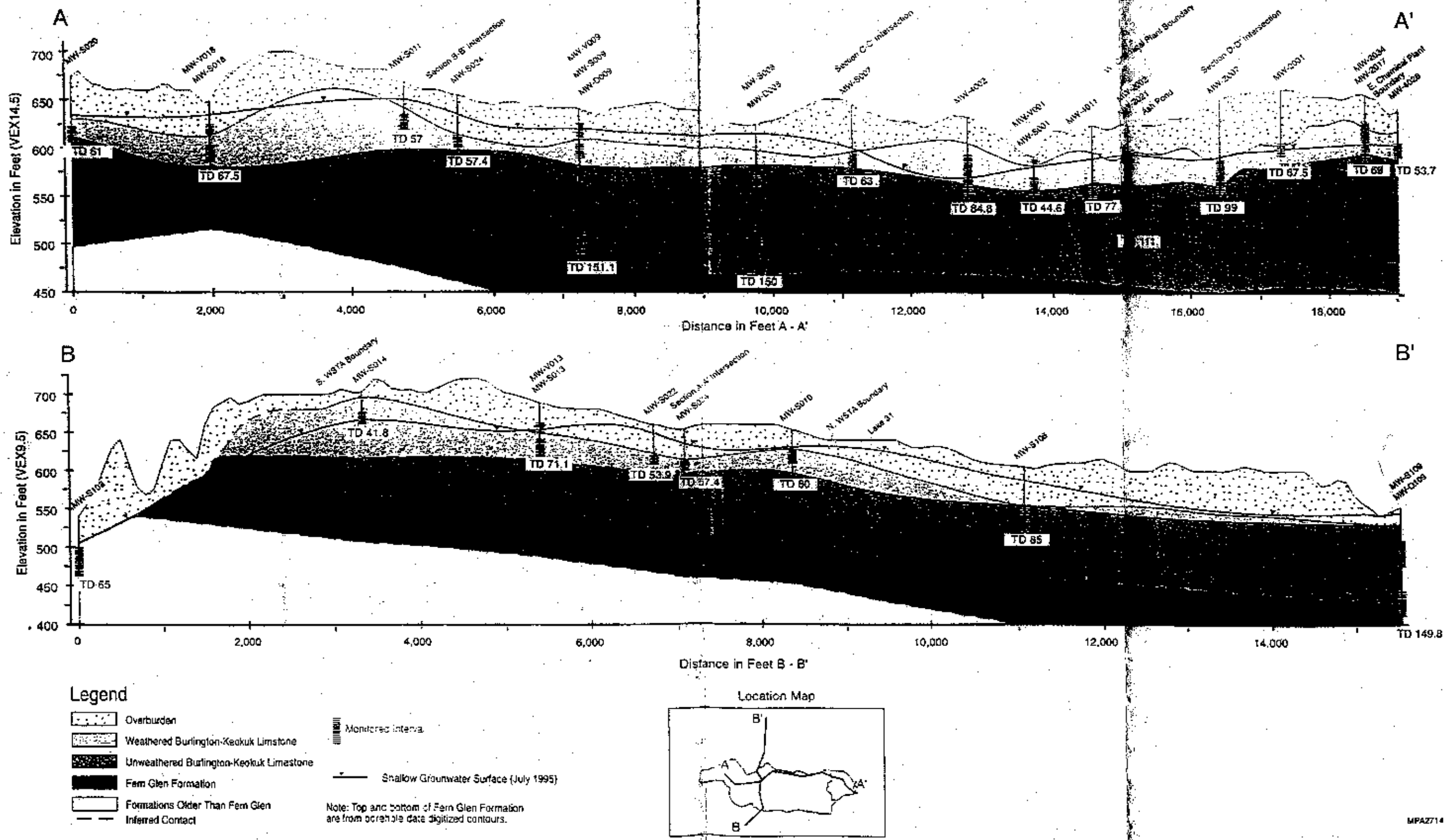


FIGURE 3.4 Hydrogeologic Cross Sections A and B

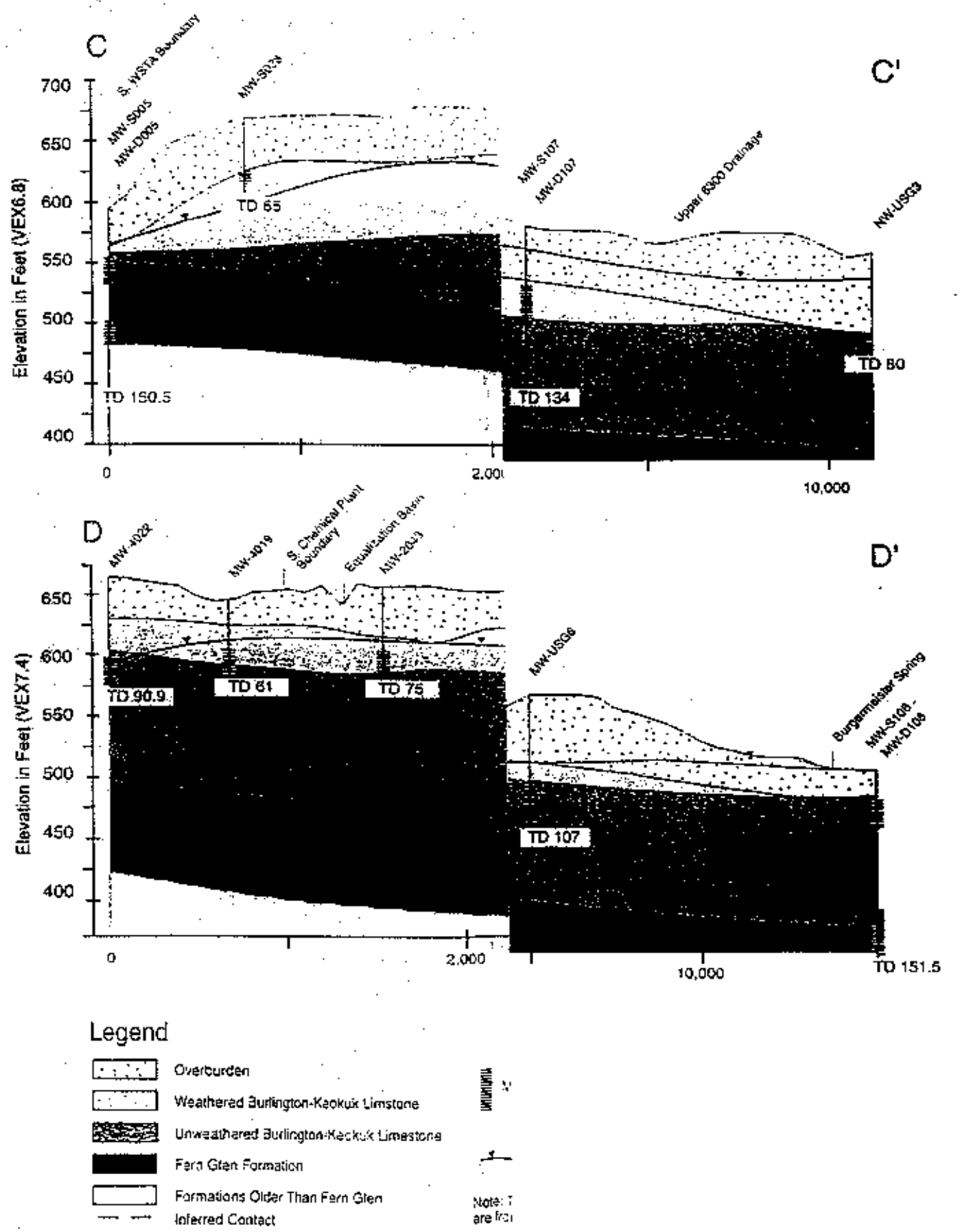


FIGURE 3.5 Hydrogeologic Cross Sections C and

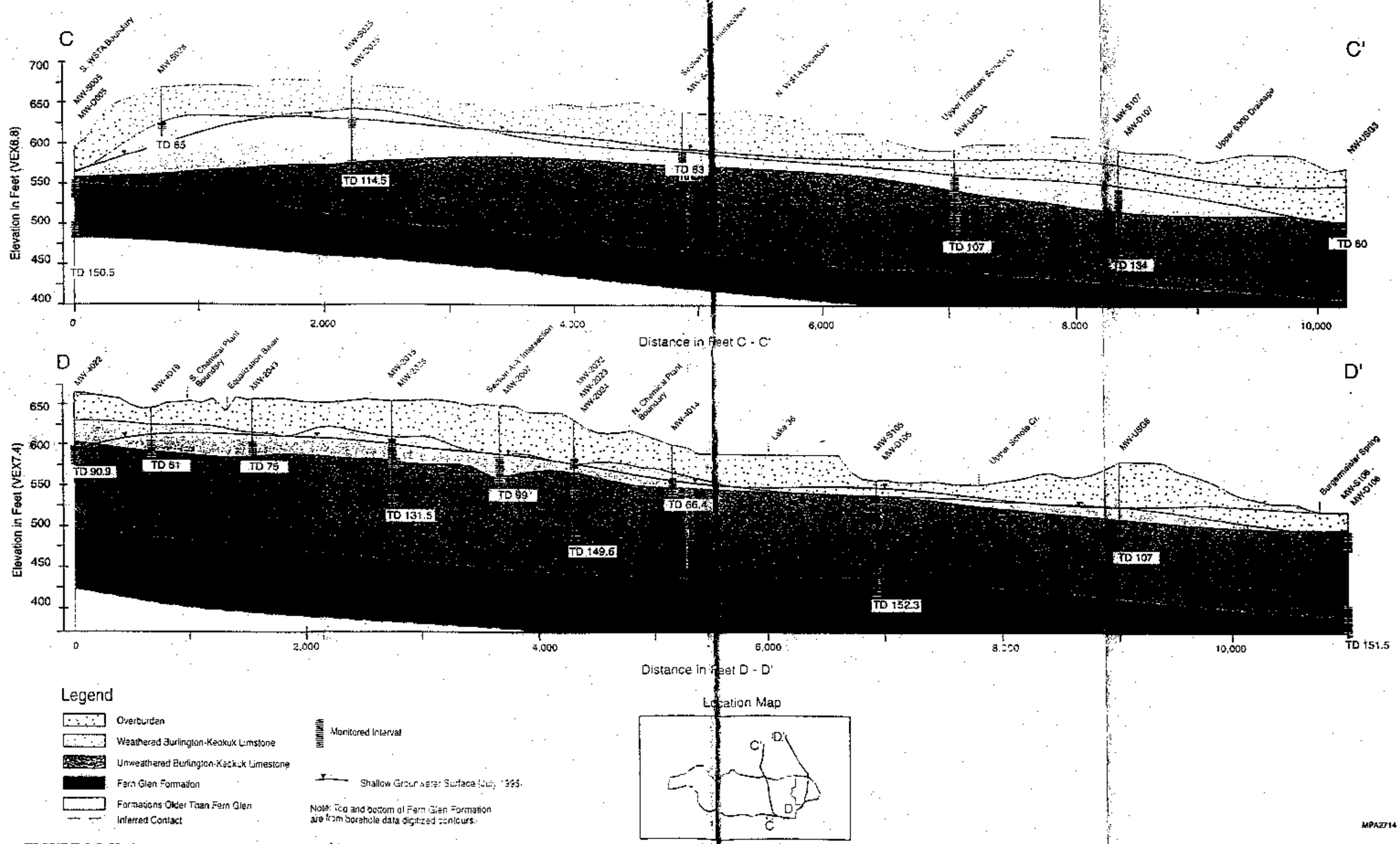


FIGURE 3.5 Hydrogeologic Cross Sections C and D

of the vadose zone occur along the topographic high along the southern edge of the training area and chemical plant area. The vadose zone is also thicker in bedrock lows and extends north from the chemical plant area where the static water level is generally lower.

Saturated overburden occurs in the northern and western portions of the ordnance works area and in several small, isolated locations within the chemical plant area. These areas coincide with the location of paleochannels or paleovalleys on the bedrock surface that have been identified from geologic investigations. Geologic logs from both sites indicate that saturation in the overburden is typically limited to the residuum at the chemical plant area and the training area where the static water level is above the top of bedrock. To the north, the till units become saturated where the static water level is above the top of bedrock.

3.2.2 Aquifer Characteristics

3.2.2.1 Hydraulic Conductivity

Hydraulic conductivity describes the rate at which groundwater can move through an aquifer. The hydraulic conductivity of the saturated overburden and Burlington-Keokuk Limestone has been estimated by in situ pressure (packer) tests and single-well hydraulic conductivity (slug) tests. The procedures for determining hydraulic conductivity by these methods are described in Sections B.2.3 and B.2.4 of Appendix B.

Slug tests were performed in 1987 in three of the overburden monitoring wells (MW-3004, MW-3005, and MW-3011) screened in the clay till unit around the perimeter of the raffinate pits (Table B.6). These tests indicated an average saturated hydraulic conductivity of 1.2×10^{-8} cm/s (3.9×10^{-10} ft/s) for the clay till unit, which is in general agreement with laboratory estimates (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a).

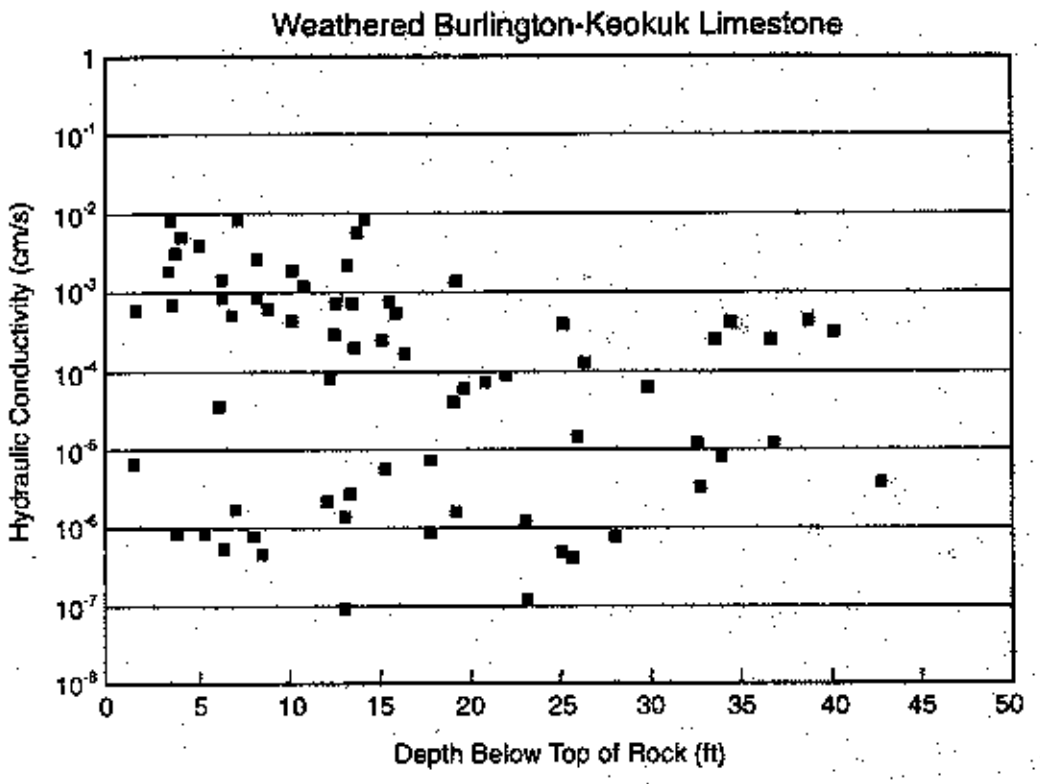
Slug testing was performed at the training area on four overburden monitoring wells that typically show saturated conditions (Table B.6). The remaining overburden wells were not tested because little water was present. The screened interval for three of these wells is in the saturated residuum near the top of bedrock; one well is screened in the till and residuum (IT Corporation 1993a). The hydraulic conductivities ranged from 1.05×10^{-7} to 4.17×10^{-4} cm/s (3.4×10^{-9} to 1.4×10^{-5} ft/s), indicating that the residuum is very heterogeneous. Locally in areas where the residuum is cohesive and clay rich, the hydraulic conductivity values are lower than in areas where the residuum is composed of noncohesive gravels. The higher hydraulic conductivity values in the overburden were at or near the bedrock interface (i.e., base of the residuum). Hydraulic conductivities near the overburden/bedrock interface are generally higher than those of the overlying overburden materials (clay, till).

Packer tests performed at both the chemical plant area and the training area provide further evidence that the hydraulic conductivity near the residuum/bedrock interface is generally much higher than in other overburden units. The average saturated hydraulic conductivity at the residuum/bedrock interface is 3.7×10^{-2} cm/s (1.2×10^{-3} ft/s) (Table B.9) (Bechtel National, Inc. 1987; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). Results of slug testing of wells screened at this interval indicate average hydraulic conductivities of 1.5×10^{-2} cm/s (4.9×10^{-4} ft/s) (Tables B.12 and B.13). This relatively high conductivity may indicate a preferential lateral flow zone where the interface is saturated. In saturated conditions, water entering this zone is likely to be diverted laterally rather than continuing to migrate vertically. Water will continue to migrate laterally until encountering a more permeable zone that allows vertical movement or until the preferential flow zone terminates.

Packer tests were performed during previous hydrogeologic investigations at the chemical plant area (Bechtel National, Inc. 1987; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a) and were also performed to support this RI. These tests were conducted to obtain hydraulic conductivity estimates for intervals of the weathered and unweathered units of the Burlington-Keokuk Limestone. The results of the packer tests are summarized in Tables B.10 and B.11.

Single-well hydraulic conductivity tests (slug tests) were performed to obtain information on the areal distribution of hydraulic conductivity values in the shallow aquifer. The slug testing results for the chemical plant area and the ordnance works area are summarized in Tables B.12 and B.13, respectively. Results of the slug testing indicate that although the hydraulic conductivity of the weathered and unweathered portions of the Burlington-Keokuk Limestone is highly variable, the hydraulic conductivity in the unweathered portion of the bedrock is generally higher than that in the unweathered unit. The variability of the conductivity values depends on the portion of the aquifer tested that corresponds to the screened depth of the well. The highest conductivity values in the weathered unit appear to correlate with areas of known preferential flow (e.g., in the northern parts of the chemical plant area and north of the training area).

Characteristics of the Burlington-Keokuk Limestone that influence groundwater flow include the primary porosity of the limestone, the distribution and interconnection of fractures, the presence of solution features, and the degree of clay filling within fractures and solution features. Although the hydraulic conductivity of the Burlington-Keokuk Limestone is highly variable on the basis of location and depth, the values become less variable with depth. In the weathered unit, the hydraulic conductivity ranges from 10^{-7} to 10^{-2} cm/s (10^{-9} to 10^{-4} ft/s). The upper part of the weathered unit shows a greater variation in hydraulic conductivity than does the lower part (see Figure 3.6). For example, within the top 5 m (15 ft), the range of hydraulic conductivity values is representative of the entire weathered unit; however, 11 m (35 ft) below bedrock, the hydraulic conductivity ranges from 10^{-6} to 10^{-4} cm/s (10^{-8} to 10^{-6} ft/s). In the unweathered unit, the hydraulic



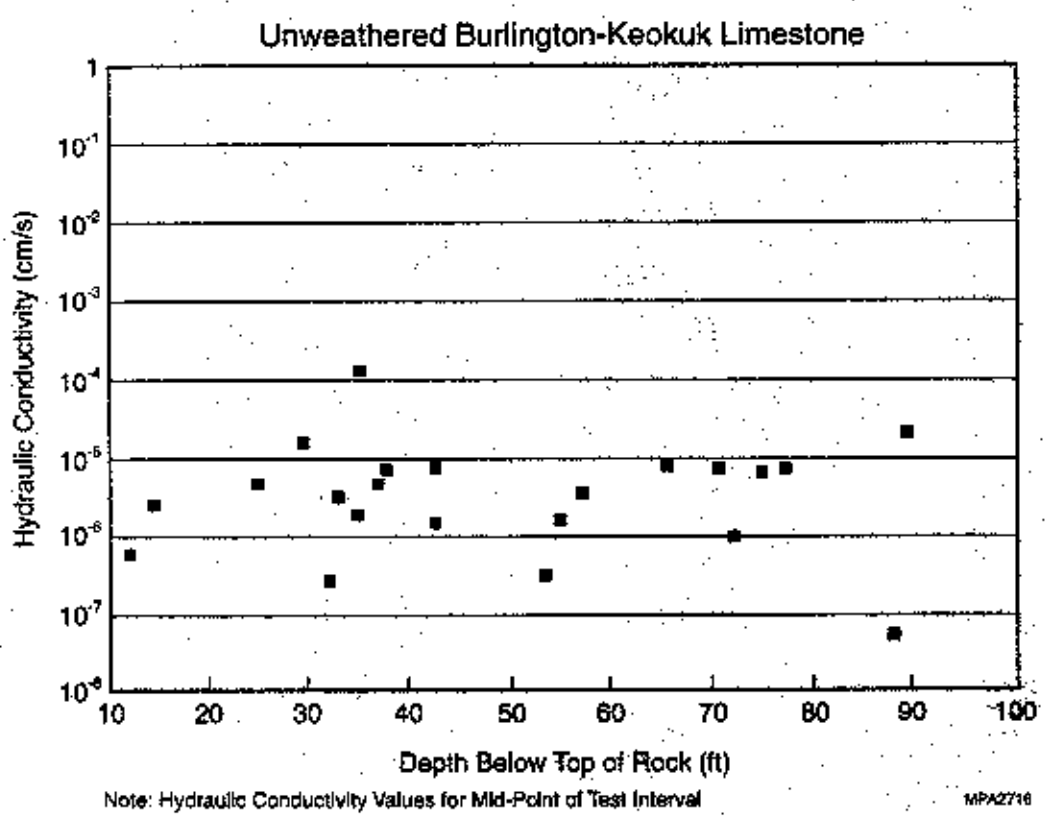


FIGURE 3.6 Comparison of Hydraulic Conductivity with Depth — Burlington-Keokuk Limestone

conductivity typically ranges from 10^{-7} to 10^{-5} cm/s (10^{-9} to 10^{-7} ft/s), with few exceptions through the entire thickness (Figure 3.6). Exceptions to these trends occur when a zone of greater fracture frequency or localized weathering is encountered at depth or when fracture zones in the upper portion of the bedrock are filled with clay. This condition was recently observed during testing on angled boring AH-2003 in the unweathered unit of the Burlington-Keokuk Limestone and in AH-2004, MWS-26, and MWD-107 in the weathered unit.

Comparison of packer test results and slug test results from locations where both tests methods were used indicates that the slug test values can be at least an order of magnitude lower than packer test values for a given location (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). This difference is probably the result of the length of the testing interval and the presence of discontinuities in the bedrock.

3.2.2.2 Primary and Secondary Porosity

The saturated Burlington-Keokuk Limestone in the shallow aquifer exhibits both primary porosity resulting from the presence of intergranular voids within the rock matrix and secondary porosity due to fracturing and solution activity within the rock. The secondary porosity component is a predominant factor in the weathered unit at the chemical plant area and the ordnance works area because of the extensive fracturing and weathering of the bedrock.

Packer testing in the weathered unit indicates thin zones of high conductivity encompassed in a less-conductive matrix (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). The higher hydraulic conductivity in this portion of the Burlington-Keokuk is influenced by the fracturing. Angled borings indicate that horizontal fractures along the bedding planes dominate vertical fracturing by approximately 20:1 within the weathered limestone. The unit is moderately to highly fractured, and 73% of the rock quality designation (RQD) values are in the poor to very poor category (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a).

The unweathered limestone unit is characterized by its lack of significant weathering or fracturing. An estimated 79% of the RQD values for this unit are in the fair to excellent category (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). Rock core logs indicate that large solution features are uncommon in this unit.

3.2.2.3 Anisotropy and Heterogeneity

The shallow bedrock aquifer is both anisotropic and heterogeneous. The weathered Burlington-Keokuk Limestone is characterized by significant secondary porosity and permeability derived from joints, fractures, and bedding planes that can control vertical and horizontal

groundwater flow. Data from rock core from the angled borings indicate that horizontal fractures are more predominant than vertical fractures, and thus contribute to preferential horizontal flow.

A general decrease in the degree of weathering, fracturing, and solution activity in the Burlington-Keokuk Limestone has established a heterogeneous trend in the vertical direction. Less weathering and solution activity with depth correlates to lower hydraulic conductivities and slower groundwater movement deeper in the Burlington-Keokuk Limestone.

3.2.3 Shallow Groundwater Surface

Groundwater levels fluctuate in elevation but generally remain within the weathered bedrock or overburden. Water-level elevations were measured from all active chemical plant area and ordnance works area monitoring wells in April and July 1995 to provide a regional perspective of the groundwater system. At each well, the measured water levels for both months were within the range of water-level elevations measured between 1987 and 1994. Table B.14 summarizes the static water-level measurements for April and July.

A potentiometric map (Figure 3.7) of the shallow aquifer was prepared on the basis of water-level elevations collected in July during the joint sampling effort. The potentiometric surface was derived with data from wells completed in the same hydrostratigraphic unit. Wells in the weathered unit were used preferentially over wells completed in the unweathered unit, and in the northern portion of the ordnance works area (where the weathered unit is absent), the depth of initial water was used. In areas where water-level measurements were available for two or more monitoring wells in a cluster, the measurement in the uppermost unit (e.g., typically the weathered unit) was used. Water-level measurements of known, existing perched water were not used to construct the map.

Evidence is present of a groundwater divide along the southern part of the training area and extending through the southern portion of the chemical plant area. In general, the shallow groundwater surface mimics the topography at the training area, chemical plant area, and the southern and eastern portions of the ordnance works area. The general flow direction is toward the Burgermeister Spring (6300 drainage) through a series of trough-like features that extend northward from both the eastern and central part of the training area and the chemical plant area. On the western part of the training area, groundwater flow is to the north. Groundwater flow in the southern portions of the chemical plant area and the training area exhibits steep gradients into the drainages to the south and southeast (drainages 5300–5600).

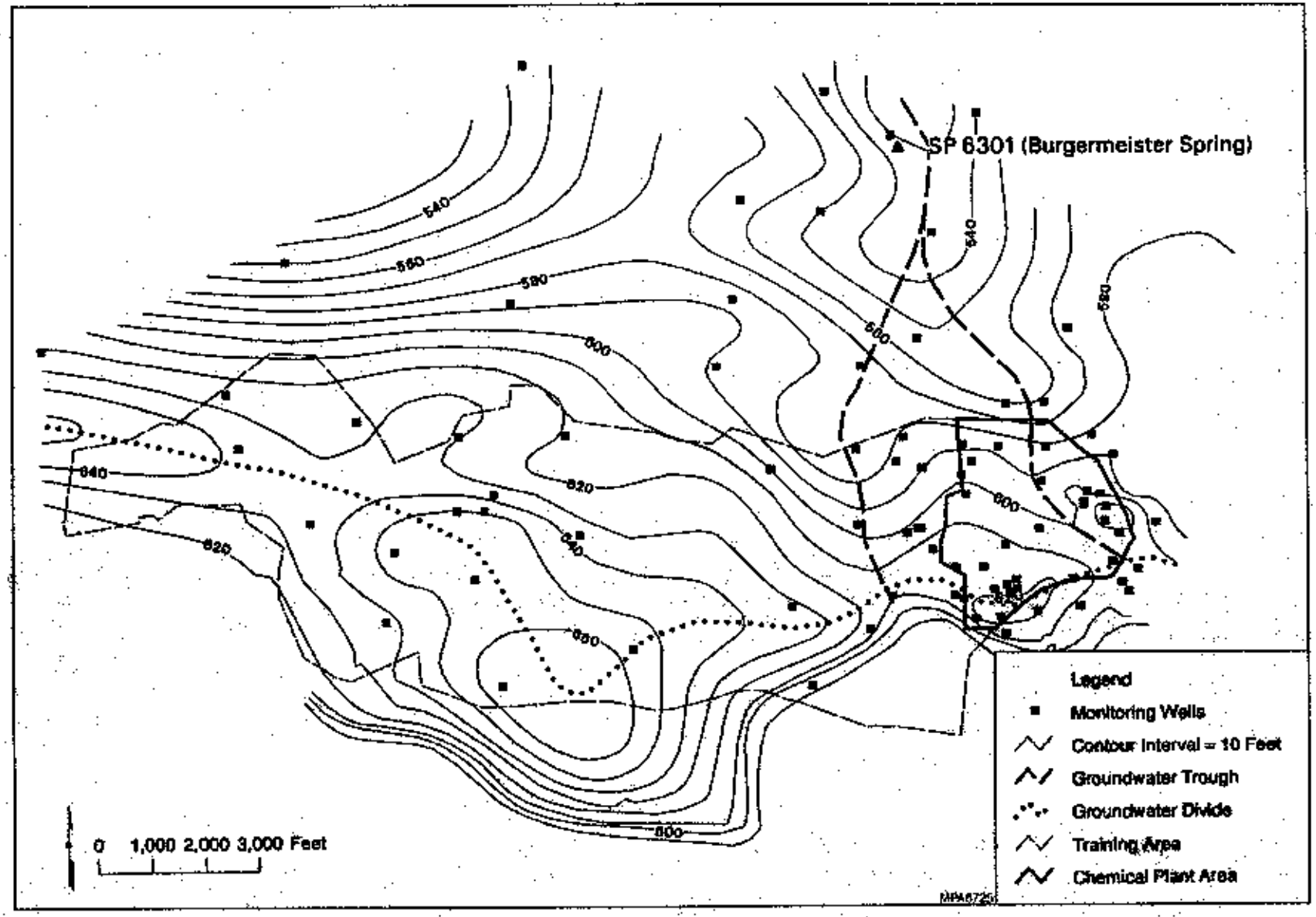


FIGURE 3.7 Hydraulic Head Distribution in the Shallow Groundwater

Groundwater levels fluctuate with time. Table B.15 summarizes the maximum static water-level fluctuations for each location. The smaller groundwater fluctuations were observed in several wells located at the southern and north-central portions of the chemical plant area. The larger fluctuations were observed at wells located on the western part of the training area, north of the training area, and in a few scattered locations within the chemical plant area. In general, small fluctuations typically occur in areas of larger hydraulic conductivities; for example MW-2032 and MW-4013 in the north part of the chemical plant area and MW-2037 and MW-2038 near Raffinate Pits 3 and 4 have hydraulic conductivities of 10^{-3} cm/s (10^{-5} ft/s) or greater and fluctuations less than 0.3 m (1 ft). The location-dependence of the water-level fluctuations may be attributed to the properties and the thickness of the vadose zone and the topographic surface. In general, the locations with greater fluctuation are in areas of thin overburden with potentially higher unsaturated hydraulic conductivities and also in areas such as stream valleys. In these locations, the greatest fluctuations are likely the result of quick movement of infiltration from precipitation and/or runoff into the groundwater system and the slow movement of water out of the well into the aquifer. Conversely, the locations with smaller groundwater fluctuation are in areas of thicker overburden and potentially lower unsaturated hydraulic conductivities.

Perched groundwater has been observed at several locations and is probably due to the presence of overburden materials with low hydraulic conductivity (see Section 1.1.2 of Appendix B). Perched conditions have consistently been encountered in the vicinity of the raffinate pits, as indicated by static water levels in MW-3004, MW-3005, MW-3011, MW-3013, and MW-3015 at the chemical plant area. These wells are completed in the overburden, and their water levels are at least 3 m (10 ft) above the elevation of the water table as determined from wells completed in the shallow aquifer. At the training area, perched water was detected in MWV-8, MWV-17, and MWV-18 (Figure 2.1). These three wells are completed in the overburden unit, and they are either dry or their water levels are consistently higher than the water table of the shallow aquifer.

3.2.4 Hydraulic Gradients

The direction of groundwater flow depends on the hydraulic head distribution, and the rate of flow depends on the hydraulic gradient. Horizontal hydraulic gradients were determined from the potentiometric surface of the shallow groundwater aquifer.

Except in the southern portion of the ordnance works area, the horizontal hydraulic gradients range from 0.001 to 0.04 across the chemical plant area and the ordnance works area in the shallow aquifer. The steeper gradients in the southern portion of the training area are likely a result of topographic controls on the groundwater system.

Vertical gradients within the shallow groundwater system have been evaluated in well clusters at both the chemical plant area and the ordnance works area (Table 3.2). These vertical

TABLE 3.2 Vertical Gradients within the Shallow Aquifer at the Chemical Plant Area and the Ordnance Works Area

Well Pair		Vertical Gradient[a]	Well Pair		Vertical Gradient[a]
Weathered and Unweathered Burlington-Keokuk Limestone					
MW-2002	MW-2021	↓	MW-3025	MW-3024[b]	↓
MW-2004	MW-2029	↓	MW-3027	MW-3026	↓
MW-2005	MW-2022	↓	MW-4006	MW-4007	↓
MW-2006	MW-2026	↓	MWS-2	MWD-2	↓
MW-2008	MW-2025	↓	MWS-23	MWD-23	↓
MW-2015	MW-2028	↓	MWS-107	MWD-107	↓
MW-2018	MW-2019	↓	MWS-9	MWD-9	↓
MW-2033	MW-2027	↓	MWS-25	MWD-25	↓
MW-3001	MW-3002	↓	MWS-112	MWD-112	↓
MW-3023	MW-3006	↓			
Burlington-Keokuk Limestone and Fern Glen Formation					
MWS-5	MWD-5	↑	MWS-106	MWD-106	↑
MWS-105	MWD-105	↑	MWS-109	MWD-109	↑↓
Overburden and Burlington-Keokuk Limestone					
MWV-1	MWS-1	↓↑	MWV-13	MWS-13	↑↓
MWV-2	MWS-2	↓	MWV-16	MWS-16	↓
MWV-9	MWS-9	↑	MWV-22	MWS-22	↑↓

[a] The arrow indicates the direction of the vertical gradient.

[b] Poor seal in deeper well resulted in false upward gradient. Subsequent data since reinstallation of deeper well indicated a downward gradient.

gradient directions were evaluated by examining the static water-level elevations measured from 1987 to 1996 for each well cluster. The majority of the well pairs exhibit downward vertical gradients, which suggests recharge within the Burlington-Keokuk Limestone.

Well pairs open to both the weathered and unweathered units of the Burlington-Keokuk Limestone at the chemical plant area and the ordnance works area exhibit downward gradients (Table 3.2). However, one well pair (MWS-02 and MWD-02) at the ordnance works area exhibits an upward gradient. This location is adjacent to a deeply eroded stream segment and shows evidence of discharge from the shallow groundwater in the northern portion of the training area. It is likely that this condition occurs elsewhere in the northern and southern portions of the ordnance works area where deeply incised valleys are present.

Vertical gradients between the Burlington-Keokuk Limestone and the underlying Fern Glen Formation were determined for well clusters in the northern and southern portions of the ordnance works area (Table 3.2). An upward gradient was determined for well pair MWS-05 and MWD-05, located adjacent to a steeply incised valley. This vertical gradient is the result of discharge of the shallow aquifer to this valley. Upward gradients were also determined for two well pairs (MWS-106 and MWD-106 and MWD-109 and MWS-109) located in drainage areas north of the training area. These upward gradients are the result of discharge of the shallow aquifer to Dardenne Creek, a regional groundwater drain for the shallow aquifer. Monitoring well MWD-106 has consistently exhibited artesian conditions since installation. Well pair MWS-109 and MWD-109 occasionally has shown both upward and downward gradients that are likely the result of seasonal groundwater fluctuations.

The vertical gradients between the saturated overburden and Burlington-Keokuk Limestone were evaluated on the basis of well clusters at the training area (Table 3.2). Downward gradients were observed in most of the well pairs, indicating recharge from the overburden to the underlying bedrock. Upward gradients were observed at well pair location MWV-09 and MWS-09, and occasionally at well pairs MWV-01 and MWS-01 and MWV-13 and MWS-13. The upward hydraulic gradients are probably a result of the topographic surface and the location of well pairs adjacent to streams. Groundwater discharges to gaining reaches of streams. In areas where the potentiometric surface is below the stream bed, groundwater can flow from the bedrock to the overburden where the overburden is permeable (Mugel 1997). In addition to well pairs MWV-01 and MWS-01, pairs MWV-13 and MWS-13 and MWV-22 and MWS-22 have shown both upward and downward gradients (IT Corporation 1995a). The difference in water levels between the overburden and weathered wells is less than 0.3 m (1 ft) and most likely is the result of seasonal fluctuations in groundwater levels and the lower hydraulic conductivity of the overburden.

Vertical gradients between the shallow, middle, and deep bedrock aquifers were evaluated with static water-level data from wells MW-4019, MWS-101, and MWGS-1 through MWGS-5 (Table 3.3) obtained in 1989 through 1995 (Kleeschulte 1995). Several of these wells are set in clusters, which allows evaluation of discharge/recharge conditions in different areas of the ordnance works (Figure 2.1). The cluster comprising wells MW-4019, MWGS-1, and MWGS-2 is located south of the chemical plant area near the groundwater divide. The vertical gradients between the three aquifers are downward and indicate recharge through the bedrock units.

The cluster consisting of wells MWGS-3, MWGS-4, and MWGS-5 is adjacent to Dardenne Creek in the northern portion of the ordnance works area. The vertical gradients indicate that the shallow and middle bedrock aquifers discharge to Dardenne Creek in this area because of upward gradients and artesian conditions exhibited in these wells. The potentiometric surface of the deep bedrock aquifer is significantly lower than that of the shallow and middle aquifers, which indicates a limited hydrogeologic connection between the deep and upper aquifers.

TABLE 3.3 Vertical Gradients in the Shallow, Middle, and Deep Bedrock Aquifers in the Weldon Spring Area

Well Pair		Location	Vertical Gradient[a]
Shallow and Middle Bedrock Aquifers			
MW-4019	MWGS-1	Groundwater Divide	↓
MWGS-3	MWGS-4	Dardenne Creek	↑
Middle and Deep Aquifers			
MWGS-1	MWGS-2	Groundwater Divide	↓
MWGS-4	MWGS-5	Dardenne Creek	No communication

[a] The arrow indicates the direction of the vertical gradient.

Well MWS-101, open to the Kimmswick Limestone, is located adjacent to the Little Femme Osage Creek in the southern portion of the ordnance works area. Artesian conditions observed in this well since installation indicate upward gradients from the middle aquifer. The artesian conditions are likely the result of regional discharge to the Little Femme Osage Creek. The shallow aquifer is not present in this portion of the area because of erosion of these units.

3.2.5 Aquifer Recharge and Discharge

Regionally, the principal source of recharge to the shallow aquifer is infiltration of precipitation in areas where glacial drift is not present or the shallow bedrock formations are near the surface (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). In the vicinity of the chemical plant area and the ordnance works area, recharge occurs by infiltration through the soil matrix and hairline fractures in some of the overburden materials and from water entering the aquifer through losing stream reaches and segments or where erosion has removed the less permeable overburden units. Results of lysimeter studies in the training area indicate recharge through the unsaturated overburden as evidenced by affected water quality of samples from beneath known surficial soil contamination. Recharge from the raffinate pits through the overburden is also indicated by the results from lysimeter studies (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a).

Groundwater discharges from the shallow aquifer can be observed as springs and seeps (Figure 3.8) in or near gullies both north and south of the groundwater divide. The final discharge points for groundwater flow are tributaries of the Mississippi River north of the divide (such as Dardenne Creek) and the Missouri River south of the divide.

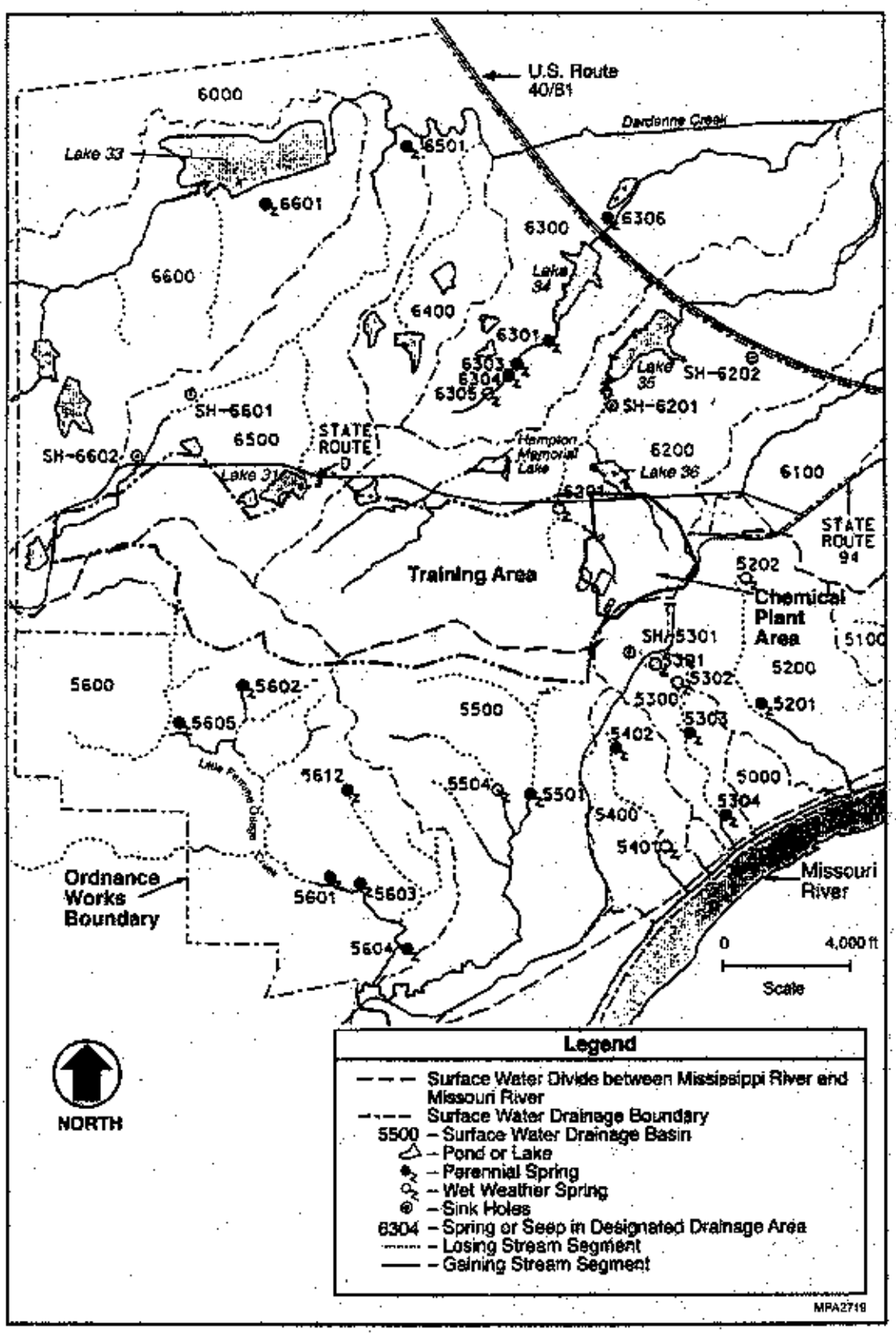


FIGURE 3.8 Gaining and Losing Stream Segments and Associated Springs and Seeps in the Ordnance Works Area

To address the concern about the potential for contaminated water to enter the deep aquifer from directly beneath the chemical plant area, the U.S. Geological Survey (USGS) completed a modeling study to quantitatively assess the groundwater flow system in St. Charles County. A regional three-dimensional groundwater flow model was developed to describe groundwater flow between the shallow, middle, and deep aquifers in the county. The study encompassed 725 km^2 (280 mi^2), which included most of St. Charles County. The results of the steady-state model simulations indicate that 21% of the groundwater flow out of the shallow aquifer beneath the chemical plant area has the potential to enter the middle aquifer. Approximately 80% of the groundwater flow out of the middle aquifer in the same area has the potential to infiltrate into the deep aquifer (Kleeschulte and Imes 1994). The quantity of water infiltrating from the shallow aquifer to the deep aquifer is small, and the time required for water to travel this distance is measured in hundreds of years (Kleeschulte 1991).

3.2.6 Groundwater and Surface Water Interaction

The Missouri Department of Natural Resources, Division of Geology and Land Survey, conducted a three-year investigation of the shallow groundwater in the Weldon Spring area (Missouri Department of National Resources 1991; Price 1991; IT Corporation 1992a). The investigation was conducted to inventory karst features (e.g., springs and sinkholes), identify the shallow groundwater discharge points for the chemical plant area and the training area, classify losing and gaining stream segments, perform stream run tracer tests, and monitor groundwater levels using continuous recorders. As part of the shallow groundwater investigations, a survey was performed in 1987 to locate springs and seeps that might be affected by groundwater or surface water discharges from the chemical plant area, the training area, and the ordnance works area. A total of 75 springs and seeps were located in the ordnance works area (Missouri Department of Natural Resources 1991). Three of these springs and seeps are perennial, and the larger wet-weather springs (considered the most significant hydrologically) and small intermittent springs and seeps only become active immediately following precipitation; these findings suggest very local recharge areas.

Within the ordnance works area, five sinkholes were identified (Figure 3.8). As with the springs, these sinkholes are small. Only one sinkhole, which periodically drains a portion of Lake 35, has exhibited any significant effect on the local hydrology. All others have a very limited internal drainage area and are not considered important hydrologic features. All of these sinkholes are located outside the chemical plant area and the training area (Price 1991).

Losing stream segments in the Missouri River watershed have been identified by visual observations (Missouri Department of Natural Resources 1991). Seepage runs on the drainages in the Mississippi River watershed were conducted to determine losing stream segments in that area. Swallow holes were also identified in both watersheds in the Weldon Spring area (Kleeschulte and Emmett 1987).

Twelve stream tracer injections were made during the final two years of the study, and 11 of these indicated at least one subsurface hydrologic connection (Figure 3.9). The dye tests showed two general patterns of subsurface drainage:

- Groundwater in drainages of the Missouri River watershed (south of the groundwater divide) does not cross into other drainages, and

- Groundwater in drainages of the Mississippi River watershed (north of the groundwater divide) can cross surface water divides and emerge in other drainages.

Examples of these differing hydrologic flow patterns are demonstrated by the dye traces south of Lake 35 and the Southeast Drainage (5200). Tracer was injected in a swallow hole near Lake 35 (Figures 3.8 and 3.9). Within six days of the injection, dye was detected in six locations at or downstream of Lake 34, which is in adjoining drainage 6300. The dye had traveled about 1.6 km (1 mi) in a northerly direction before surfacing in several seeps and springs in and downstream of Lake 34. Dye was not recovered further downstream in Schote Creek or in Burgermeister Spring, which are located a short distance northwest of the swallow hole.

A dye and water trace performed in the Southeast Drainage revealed a hydrologic connection between the head of the drainage and several springs within the drainage (Figure 3.9). Also, four losing sequences were identified within the drainage. A swallow hole was observed near the head of the drainage where all water was lost. Water was then observed to alternately seep into and surface from the streambed at four different points along the streambed. The short stretches of surface flow were separated by larger segments of dry streambed. Each losing stream segment in the valley appeared to be part of the recharge area for the next spring located farther downstream, until the reach at the end of the drainage became a gaining stream segment.

The results of the Missouri Department of Natural Resources investigations (Missouri Department of National Resources 1991; Price 1991) indicate that the shallow aquifer beneath the chemical plant area and the ordnance works area has characteristics typical of a carbonate groundwater system (e.g., weathered bedrock and solution-broadened joints and fractures). Studies performed by the Missouri Department of Natural Resources (1991) during 1989 found no effects of solution features such as subsurface conduits beneath the chemical plant area. Despite the lack of identified subsurface conduits at the time, overland flow from the northwestern portion of the chemical plant was lost in a losing reach of an unnamed tributary of Schote Creek about 305 m (1,000 ft) northwest of Ash Pond (Missouri Department of National Resources 1991; MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). The results of the Missouri Department of Natural Resources water-tracing studies indicate that a subsurface conduit is present between the unnamed tributary of Schote Creek and Burgermeister Spring. The travel time for the 1,981-m

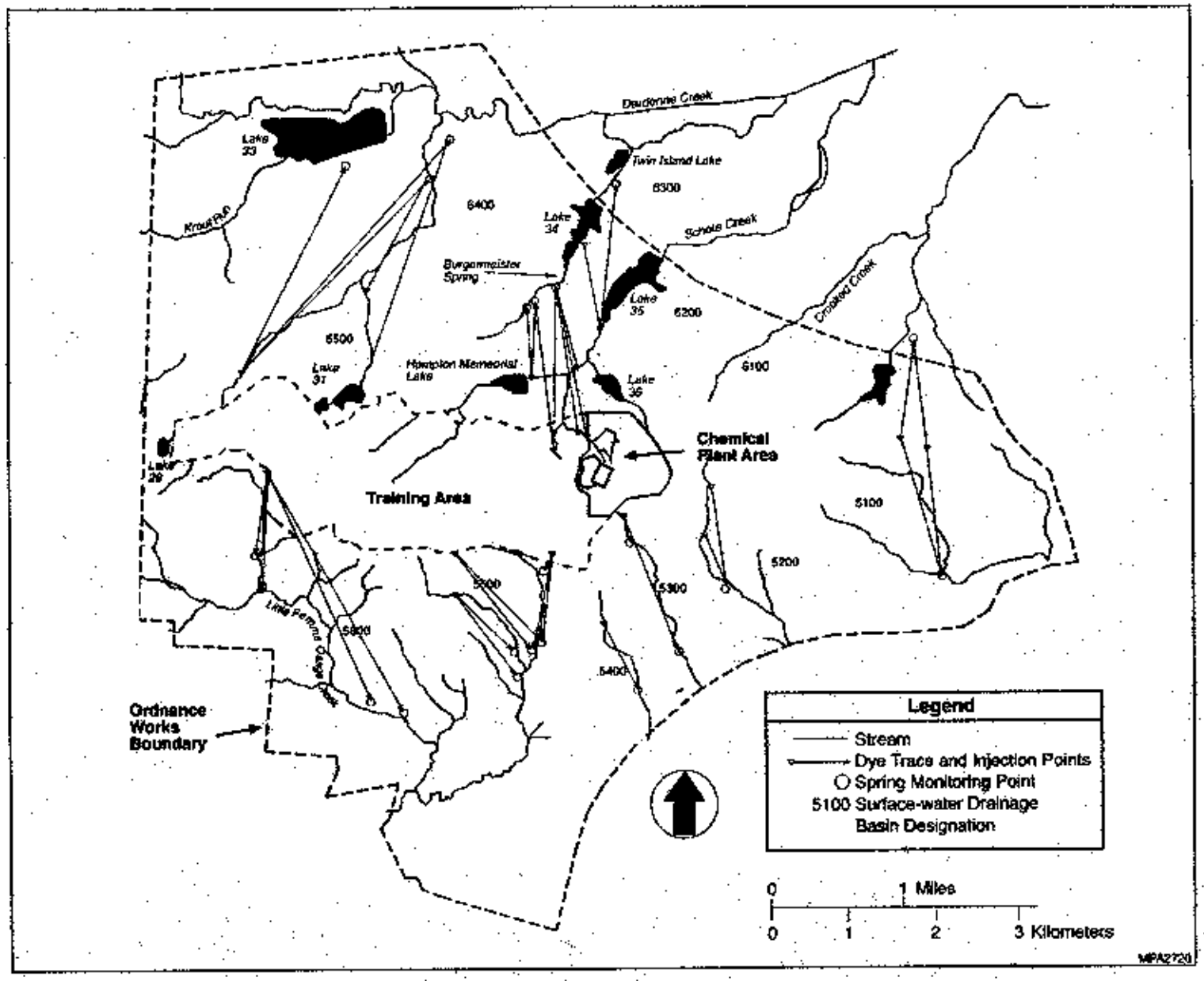


FIGURE 3.9 Water-Tracing Tests Performed at the Ordnance Works Area

(6,500-ft) straight-line distance was estimated to be 48 to 72 hours, depending on previous rainfall (Missouri Department of Natural Resources 1991).

As part of the angled borehole drilling performed under this RI, dye tracing was conducted to determine whether a subsurface hydraulic connection could be detected between Burgermeister Spring and the northern and western portions of the chemical plant area. On the basis of data from previous aquifer testing (high values of hydraulic conductivity) and the presence of specific contaminants detected at Burgermeister Spring, it was suspected that these sections of the chemical plant area are directly connected with the conduit system that discharges to Burgermeister Spring. Two angled borings and one monitoring well that had recently been slug tested were selected for injection of dye. Three springs in the 6300 drainage were monitored for resurgence of the dye; however, the dye was only detected in Burgermeister Spring (Figure 3.10). The time required for the tracer to travel from the injection point to the recovery point (i.e., Burgermeister Spring) was used to calculate estimated groundwater velocities. These velocities were specific to the prevailing flow conditions during each dye trace. The results of this tracer testing are summarized in Table 3.4.

The data at the springs were collected at close time intervals, along with precipitation data, in an effort to gain further insight into the flow characteristics of the aquifer. Plots of the average relative dye intensity at the springs with respect to time for two successful tracer tests are shown in Figures 3.11 and 3.12. These plots illustrate the fluctuation of the dye intensity throughout the monitoring period. Also indicated in these figures are precipitation events that occurred during the testing period. Review of these plots indicates that the increases in dye intensity typically coincided with precipitation events. This quick response of Burgermeister Spring to precipitation is illustrated in Figure 3.13 in a plot of discharge from the spring compared with precipitation.

Complex conduit systems typically showed multiple dye intensity peaks representative of the dye traveling different distances to the resurgence point (Jones 1984). The multiple peaks in the recovery curves for the tracer tests correlated with storm events. This correlation suggests remobilization and flushing of the stored tracer (i.e., dye) in the conduits as a result of the conduits' receiving infiltration from losing streams during recharge events. The results of the hydraulic conductivity testing of the overburden indicate that recharge from infiltration of precipitation through the overburden matrix is slow. However, in areas where surface water runoff from precipitation enters losing stream segments (and thinner overburden exists) residence time is shorter, resulting in faster response to precipitation events compared with infiltration from precipitation through the overburden.

The results of two water balance studies are presented below. The first is for the Southeast Drainage, and the second is for the 6200 and 6300 drainages at the chemical plant area and the ordnance works area. For the Southeast Drainage, the results of seepage runs performed for the drainage were analyzed as an alternative approach to a water balance (Missouri Department of

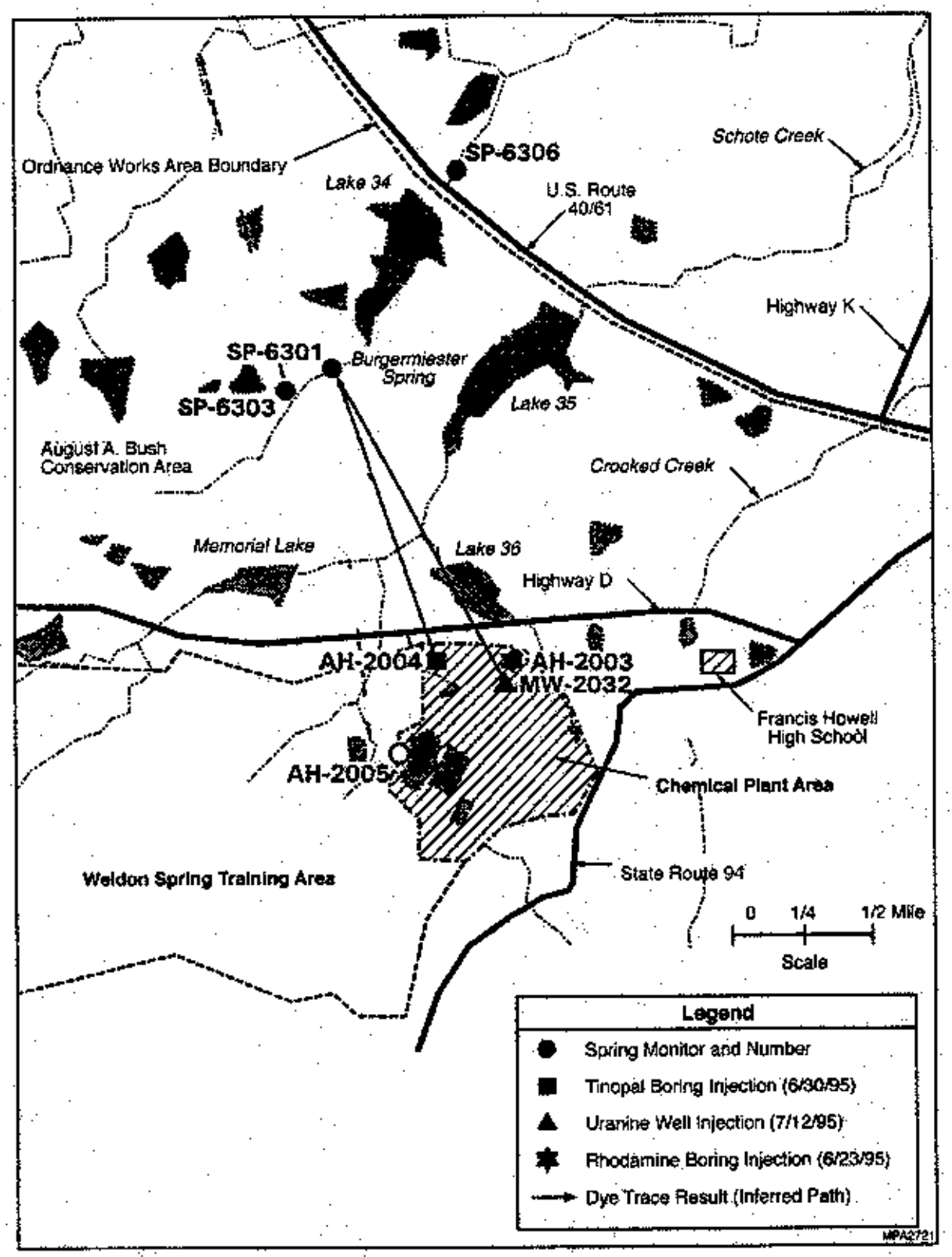


FIGURE 3.10 Flow Paths for Tracer Tests Performed at the Chemical Plant Area

TABLE 3.4 Summary of Tracer Testing Results

Location	Injection Interval[a] (ft)	Bedrock Interval[b]	Injection Date	Dye	Initial Detection Date	Minimum Distance (ft)	Calculated Groundwater Velocities (ft/min)
AH-2003	66.7 – 75.9	Weathered/ unweathered	6/23/95	Rhodamine WT	NA[c]	6,100	NA
AH-2004	26.8 – 44.4	Weathered	6/30/95	Tinopal	7/2/95 - 7/3/95	5,900	1.36 – 2.05
MW-2032	48.0 – 58.6	Residuum/ weathered	7/12/95	Uranine	7/19/95 - 7/21/95	6,500	0.50 – 0.64

[a] Injection intervals were measured as feet below ground surface (vertical).

[b] Bedrock intervals are within the Burlington-Keokuk Limestone.

[c] NA = data not available.

Natural Resources 1991). This method was used because there is no detailed information on the local precipitation or evapotranspiration. In addition to the seepage runs, on two occasions (October 29, 1987, and in September 1990), water was released at a rate of 379 L/m (100 gpm) from a hydrant located near the DOE fence at the head of the Southeast Drainage to determine the adequacy of the drainage to receive water from the proposed water treatment plant. Observations made in the drainage revealed results very similar to those previously obtained. That is, at each spring further downstream, the same flow resurfaced and stayed at the surface for a short distance before sinking again into the stream bed. Pyranine dye was also injected into the surface flow near the hydrant. For three weeks after the injection, dye was detected at the downstream springs; however, no dye was detected outside of the drainage.

On the basis of the results of the above seepage runs and dye tracer studies, the Southeast Drainage appears to be a closed system that has little observable loss to adjacent drainages or the underlying groundwater system. Because detailed information apparently was not collected on the actual flows at the downstream locations, it is not possible to quantify the losses of the surficial stream to the groundwater system. Recharge is, however, anticipated to be small (large values of recharge to groundwater would have produced observable changes in the downstream flows).

The topography of the Southeast Drainage also provides some insights into its hydrogeological behavior. Because the stream in the Southeast Drainage is surrounded by fairly steep wall, the bottom of the drainage is a likely place for groundwater discharge from the surrounding uplands. That is, the groundwater gradient in the vicinity of the stream bed is likely to be vertically up (Toth 1963). This groundwater discharge can provide the sustained base flow

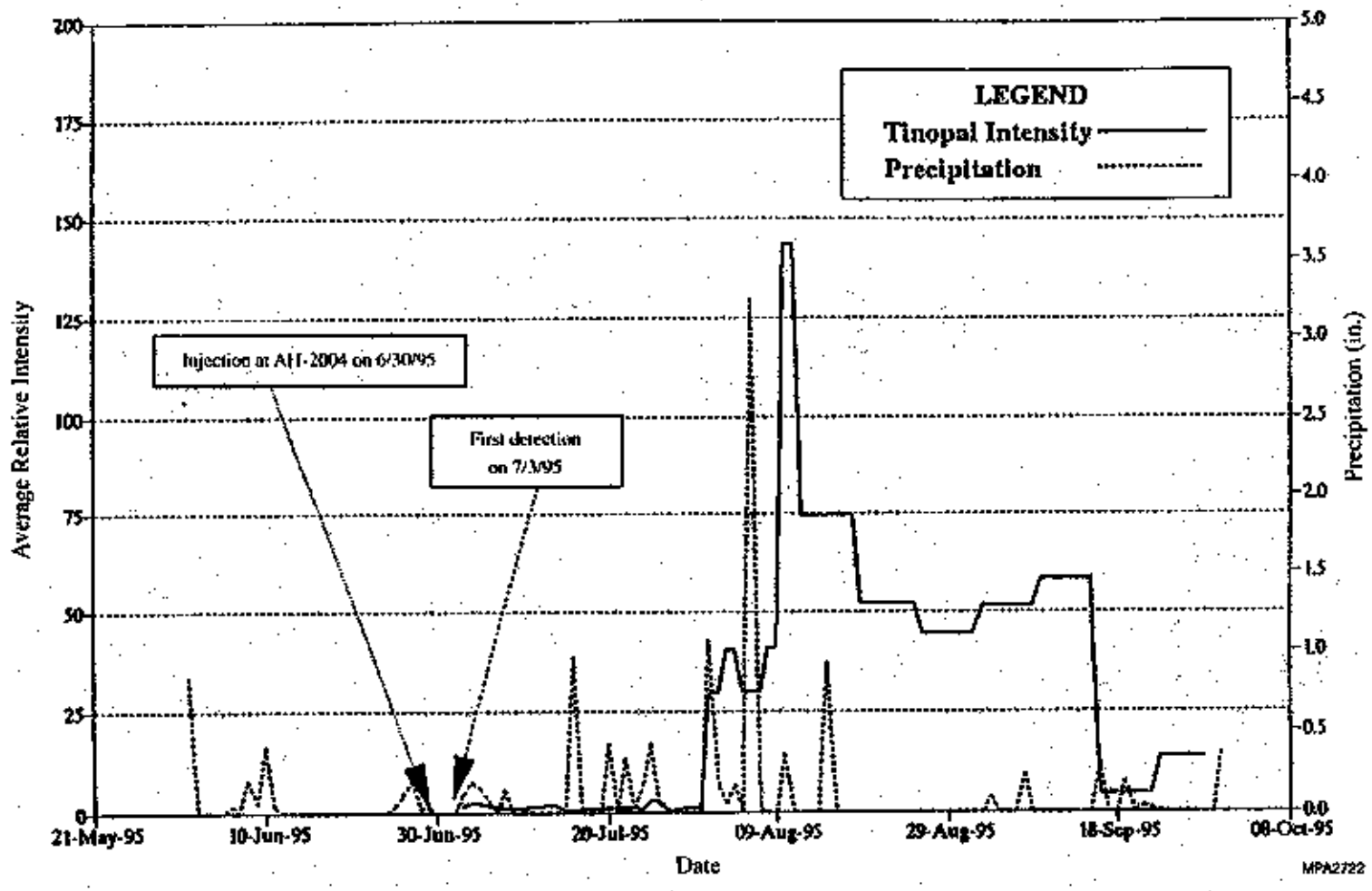


FIGURE 3.11 Tracer Test Results at Burgermeister Spring for the Dye Injection at AH-2004

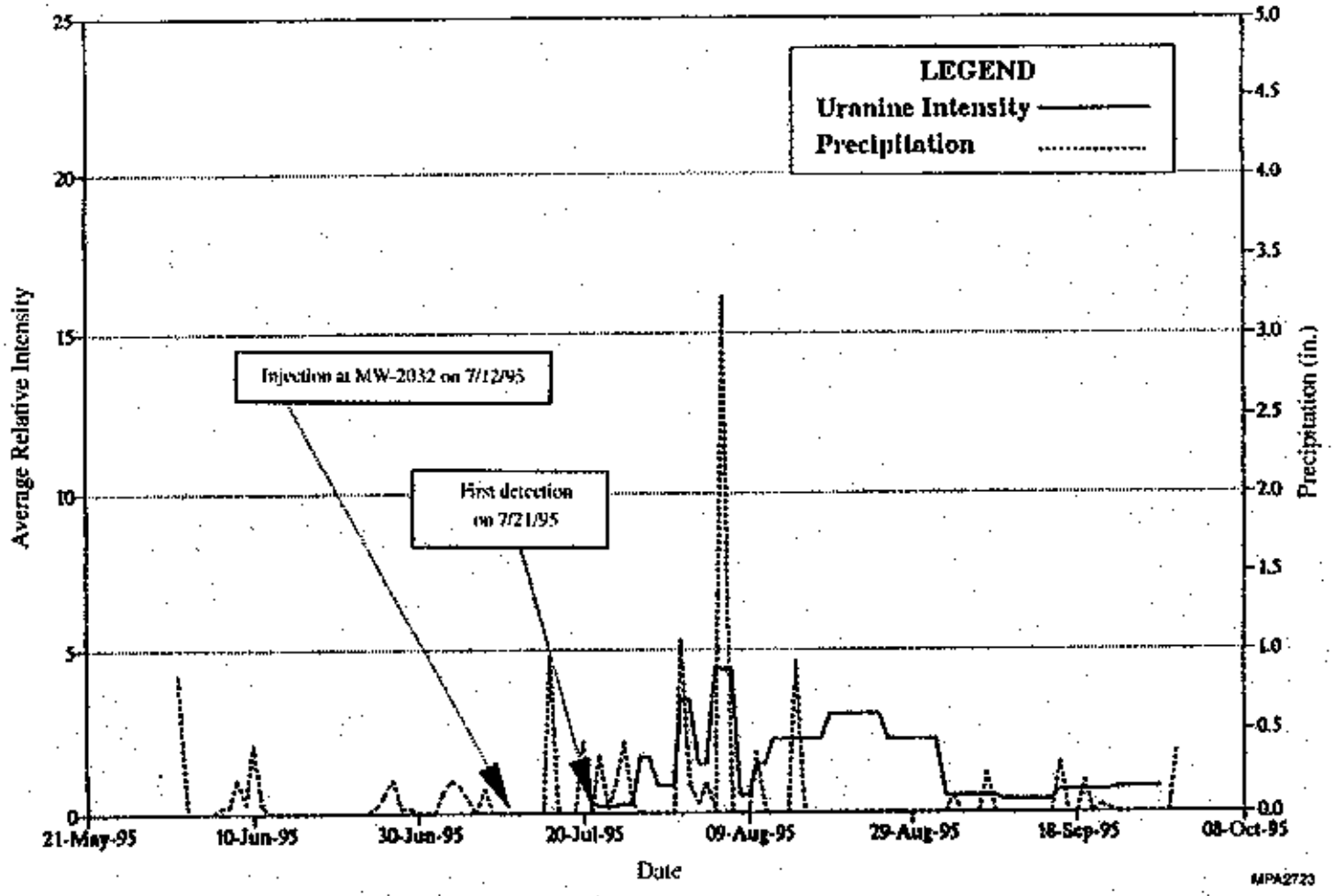


FIGURE 3.12 Tracer Test Results at Burgermeister Spring for the Dye Injection at MW-2032

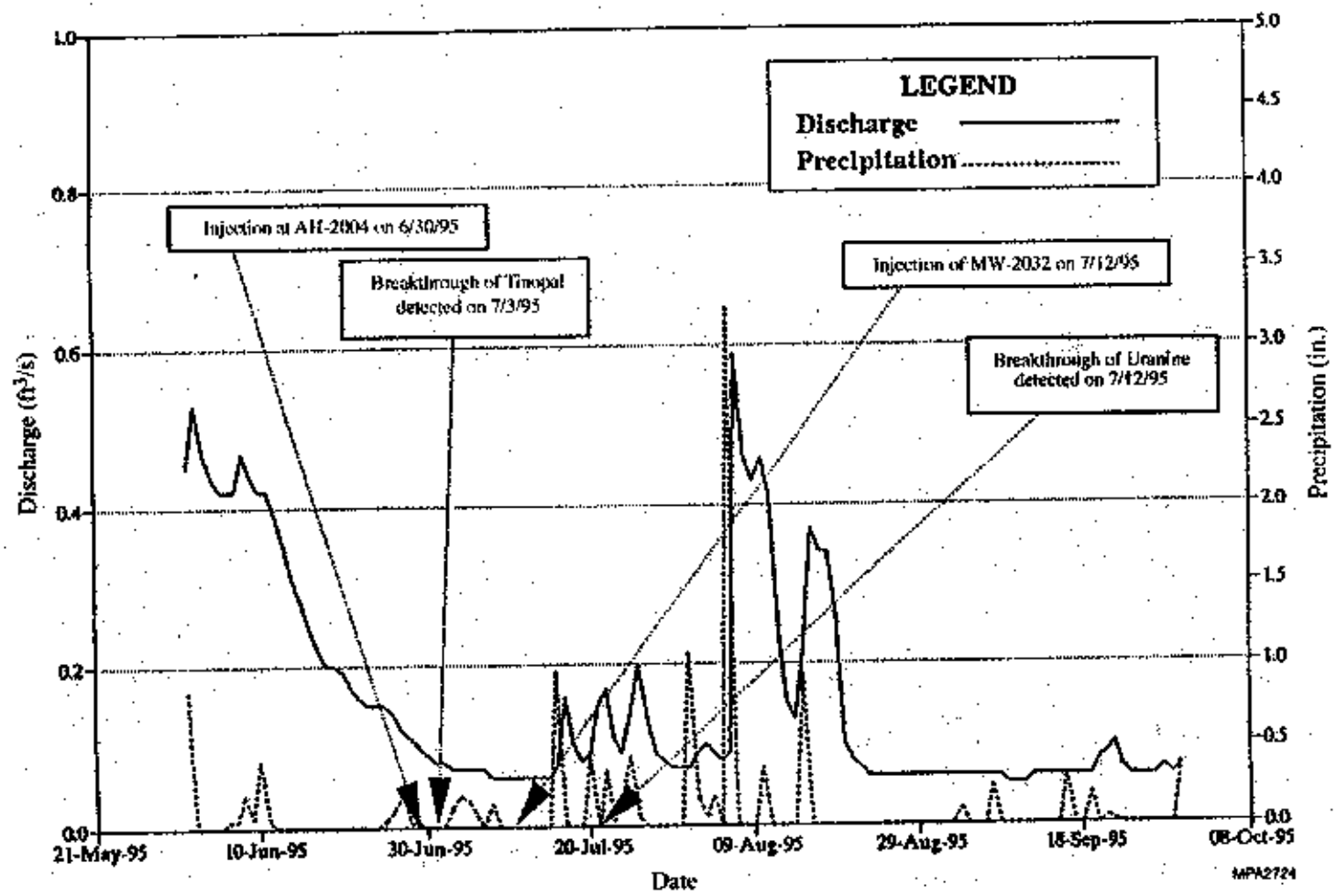


FIGURE 3.13 Discharge and Storm Event Comparison at Burgermeister Spring

observed in the lower reach of the stream and can also limit the amount of groundwater recharge from the surface.

In June 1987, 19 total-catch rain gages were installed over a 11.9-km^2 (4.6-mi^2) area that included the drainage basins of the unnamed tributary of which Burgermeister Spring is located and Schote Creek (Kleeschulte and Cross 1990); these streams are parts of the 6300 drainage and 6200 drainage, respectively. For the two-year USGS study that began in 1987, the drainages were combined because the northern portion of the chemical plant area (north of the surface water divide) is located in the Schote Creek drainage (6200), but interbasin transfer of water occurs from Schote Creek to the unnamed tributary containing Burgermeister Spring in the 6300 drainage (Kleeschulte and Emmet 1987). Daily total precipitation for the study area was calculated by the isohyetal method. In addition to the precipitation data, discharge data were also collected daily at Burgermeister Spring, the unnamed tributary at Twin Island Lake, and Schote Creek at U.S. Highway 40 and 61.

On the basis of the above information collected from August 1987 through September 1989, the USGS completed a water-balance study indicating that about 25% of the total precipitation to the study area leaves as surface water runoff via Schote Creek and the unnamed tributary (Kleeschulte and Imes 1994). For an average annual precipitation of 94 cm/yr (37 in./yr) (DOE 1992b), about 23 cm/yr (9 in./yr) would leave as surface runoff and 71 cm/yr (28 in./yr) would go to evapotranspiration and infiltration to the groundwater. Because the estimated potential evapotranspiration for the Weldon Spring area is about equal to the average annual precipitation (DOE 1992b), the estimated evapotranspiration and recharge values are within the range of the potential evapotranspiration.

Without additional information on recharge or evapotranspiration, the estimated sum of evapotranspiration and recharge cannot be further separated. However, in the modeling study performed by the USGS (Kleeschulte and Imes 1994), the maximum recharge to the shallow groundwater aquifer was 6.4 cm/yr (2.5 in./yr). For this value of recharge, the estimated average evapotranspiration would be 65 cm/yr (25.5 in./yr). This value is less than the potential evapotranspiration reported (DOE 1992b), and physically realistic.

Within the groundwater system, a second water balance can be performed. Under steady-state conditions (no net change in groundwater storage), inflow is equal to outflow. On the basis of the three-dimensional groundwater model developed by Kleeschulte and Imes (1994), 75% of the inflow to the upper, shallow aquifer (Burlington/Keokuk Limestones and the Fern Glenn Formation) in the immediate vicinity of the chemical plant area is derived from precipitation. The remaining 25% is derived from lateral inflow into the layer. For 6.4 cm/yr (2.5 in./yr) of infiltration from precipitation, the average total recharge to the shallow aquifer in the vicinity of the chemical plant area is, therefore, about 8.4 cm/yr (3.3 in./yr). About 21% of this recharge, that is, about 1.8 cm/yr (0.7 in./yr), leaks downward into the middle aquifer (Kimmswick Limestone) (Kleeschulte and Imes 1994).

About 94% of the total recharge to the middle aquifer in the immediate vicinity of the chemical plant area is derived from vertical leakage (Kleeschulte and Imes 1994). The remaining 6% is derived from lateral inflow. The average total recharge to the middle aquifer is, therefore, about 1.9 cm/yr (0.75 in./yr). Approximately 80% of this water recharges the deep aquifer (top of the St. Peter Sandstone to the base of the Potosi Dolomite); the other 20% is lateral outflow. On the basis of the above calculations, the vertical recharge to the deep aquifer is about 1.5 cm/yr (0.6 in./yr).

The above groundwater balance probably overestimates the amount of deep infiltration derived from precipitation, because the Kleeschulte and Imes model (1994) does not incorporate groundwater losses from the shallow aquifer to the conduit that discharges at Burgermeister Spring. During the two-year mini-water balance study (Kleeschulte and Cross 1990), about 430,000 m^3 (350 acre-ft) of water was discharged from Burgermeister Spring. This volume represents about 2% of the total precipitation on the combined 6200 and 6300 drainages. Most groundwater discharging at Burgermeister Spring, however, is likely to be derived from precipitation at the chemical plant area and adjacent training area.

In calendar year 1996, the total flow from Burgermeister Spring was about 210,000 m^3 (168 acre-ft) (Kleeschulte 1997). If this flow was derived primarily from precipitation on the chemical plant area and immediate vicinity north of the groundwater divide (approximately 405 ha [1,000 acres]), the discharge at Burgermeister Springs would represent about 80% of the surface infiltration of 6.4 cm/yr (2.5 in./yr) (the maximum value of USGS recharge used in the above calculations). If the drainage area of the conduit is less, the percentage of infiltration would increase correspondingly.

If 80% of the infiltration from rainfall is lost to Burgermeister Spring, the net recharge to the shallow aquifer would be 1.3 cm/yr (0.5 in./yr). If we then assume that the remainder (middle and deep aquifers) of the USGS model (Kleeschulte and Imes 1994) behaves as before, the amount of recharge to the middle aquifer would be 21% of the effective infiltration, or about 0.25 cm/yr (0.1 in./yr). If this recharge is still 94% of the total recharge to the middle aquifer, recharge to the middle aquifer would be about 0.28 cm/yr (0.11 in./yr). Approximately 80% of this water (0.25 cm/yr [0.1 in./yr]) would then go on to recharge the deep aquifer. This value is about a factor of six less than the value calculated above under the assumption that no groundwater is lost to Burgermeister Spring and represents about 0.3% of the total precipitation on the Burgermeister Spring catchment.

Because of uncertainties in the various input parameters and modeling assumptions, the effective average recharge to the deep aquifer is not known precisely, and may differ from the above estimated values by a factor of two. However, the amount of recharge to the deep aquifer is likely to be small (on the order of less than 1%) because of the small amount of effective surface infiltration, lateral losses to Burgermeister Spring, and presence of material of low hydraulic conductivity in the vertical soil column. Additional site-specific field work aimed at providing

specific evapotranspiration values, improved surface flow estimates, improved delineation of the Burgermeister Spring catchment, and estimates of total precipitation would improve these calculations. More detailed groundwater flow simulations would also reduce uncertainties in the estimates for lateral and vertical flows in the vicinity of the chemical plant area.

3.3 HYDROGEOLOGIC CONCEPTUAL MODEL

The hydrogeologic conceptual model (Figure 3.14) consists of several complex components: thinly bedded limestone, losing and gaining stream segments and sinkholes, preferential flow zones that discharge to springs, pronounced groundwater troughs in the shallow groundwater surface, solution-enlarged joints and fractures, and extensively weathered limestone bedrock. The shallow bedrock aquifer is unconfined and has locally semiconfining conditions as the result of the presence of a leaking confining glacial unit in the northern and central portions of the ordnance works area. The shallow aquifer is conceptualized to be a diffuse flow system with superimposed conduit flow. The matrix in which diffuse flow occurs is a storage reservoir with a low hydraulic conductivity that slows transfer to the conduit system. The superimposed conduit system allows for quick movement of water when it is released from the diffuse flow area to the system or is introduced from other sources (losing streams) directly into the conduit system.

Groundwater recharge occurs as infiltration from precipitation through the overburden, from surface water runoff, and from surface water impoundments. Infiltration through the overburden occurs through the soil matrix and hairline fractures observed in some of the overburden units, which have abundant near-vertical hairline fractures. Some of those fractures extend for more than 3 m (10 ft) (Rueff 1992). Many fractures in the loess are open and contain small roots and iron and magnesium oxides that indicate the movement of water. Hydraulic conductivity testing of these materials, lysimeter studies, and the presence of the groundwater mound beneath the chemical plant area and the training area all indicate that recharge through the overburden is slow. These lower hydraulic conductivities likely allow storage of water in the overburden. This stored water may provide a slow, constant recharge to the shallow groundwater system.

Recharge occurs as surface water runoff enters losing stream segments where thinner overburden areas exist at both the chemical plant area and the ordnance works area. This form of recharge has a shorter residence time in the system, as evidenced by the quick discharge response of Burgermeister Spring to precipitation events. It can be assumed that other large springs in the area (i.e., springs in drainages 5300, 5600, 6500, and 6600) behave similarly. This recharge is more rapid relative to infiltration through the overburden. Finally, recharge also occurs as infiltration from surface water bodies (impoundments), such as the raffinate pits, lakes, and lagoons.

Groundwater movement in the underlying limestone is controlled principally by horizontal fractures, bedding planes, and solution features. The lower section of the residuum near the bedrock contact has been identified as more permeable because of the presence of relic chert beds, gravels,

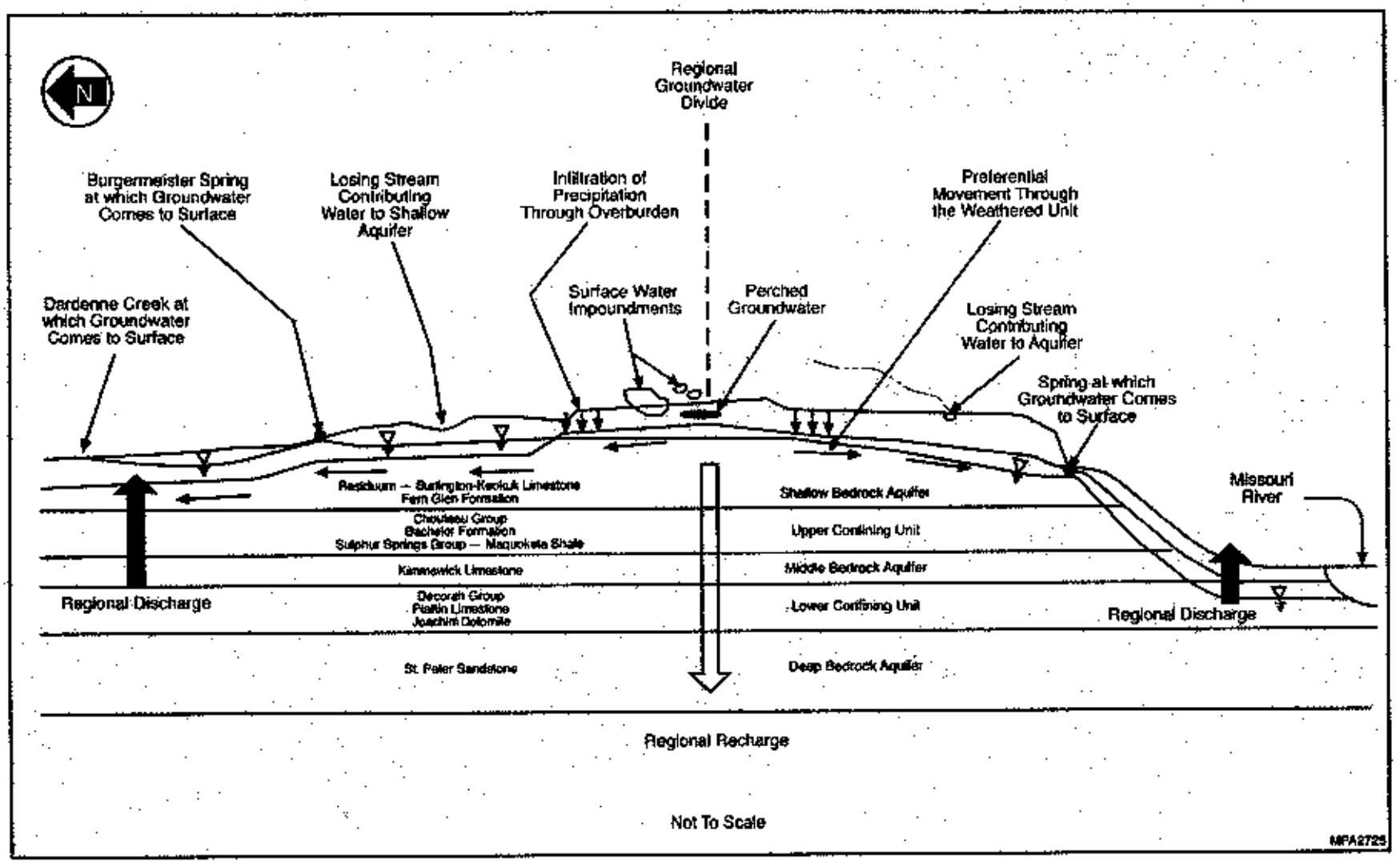


FIGURE 3.14 Hydrogeologic Conceptual Model

and weathered limestone. Preferential horizontal groundwater flow occurs along the contact of the saturated residuum with the underlying weathered limestone. Vertical movement occurs and is likely limited to areas that exhibit greater vertical weathering or fracturing. The downward vertical gradient within the overburden, Burlington-Keokuk Limestone, and Fern Glen Formation over most of the chemical plant area and the ordnance works area indicates recharge to the shallow aquifer system. The upward gradients that occur between these units represent groundwater discharge primarily along deeply eroded stream segments. Upward gradients are prevalent near Burgermeister Spring between the Burlington-Keokuk Limestone and the Fern Glen Formation and indicate discharge of the shallow aquifer to Dardenne Creek, a tributary to the Mississippi River.

Groundwater discharge also occurs at springs and seeps at the ordnance works area. Results of tracer tests indicate that groundwater flow is contained within surface water drainages south of the groundwater divide; north of the divide, groundwater crosses into other drainages. A primary point of resurgence for the chemical plant area north of the groundwater divide is Burgermeister Spring (SP-6301). Burgermeister Spring is also a primary point of resurgence for the ordnance works area north of the groundwater divide. South of the groundwater divide, resurgence occurs at numerous springs within smaller individual watersheds.

4 NATURE AND EXTENT OF CONTAMINATION

This chapter evaluates the nature and extent of contamination within the groundwater system for the chemical plant area and the ordnance works area. This evaluation is based on data collected under DOE and DA environmental monitoring programs from 1987 through 1995. In addition, a joint sampling effort was also conducted in May and August of 1995 to produce a comparable data set for both areas. The joint sampling involved all active monitoring wells and 15 springs. Groundwater and spring data for the joint sampling are presented in detail in Appendix C. These data, together with previously collected data for the evaluation of groundwater contamination, are evaluated in Section 4.1; data for contamination in groundwater discharge to area springs are evaluated in Section 4.2.

4.1 GROUNDWATER

For this RI, the groundwater contamination discussions are summarized on the basis of the well completions as in the Work Plan (DOE 1995b) for the GWOUs. The groundwater data were grouped into four stratigraphic units: the overburden, weathered Burlington-Keokuk Limestone, unweathered Burlington-Keokuk, and deeper units. The data from wells that monitor formations deeper than the Burlington-Keokuk were grouped together (there are no deep wells on the chemical plant area). Completion intervals for individual wells on the chemical plant area and the ordnance works area are provided in Chapter 2 (Tables 2.2 and 2.3) and in Appendix B. These groupings facilitate evaluation of the vertical distribution of contaminants.

Data for the chemical plant area and the ordnance works area were combined and evaluated together because the groundwater system is continuous beneath both areas. A summary of the data collected for the joint sampling and data collected prior to 1995 for metals and anions and nitroaromatic compounds is presented in Tables 4.1 and 4.2, respectively. Sampling for nitrite was not conducted as part of the joint sampling effort. Because early data indicated that nitrate levels are very low and nitrite readily oxidizes to nitrates, nitrite sampling was discontinued. For evaluation of the nature and extent of contamination, filtered and unfiltered metals data were combined on the basis of results from a study conducted by DOE on the effects of filtering water samples on contaminant concentrations (MK-Ferguson Company and Jacobs Engineering Group Inc. 1995). The results of this study indicated that sample filtering does not have a large impact on the results; the only metals that exhibited significantly higher concentrations (i.e., a relative percent difference of 20% or higher) in the unfiltered samples were aluminum, iron, lead, chromium, and manganese. Concentrations of antimony have been consistently higher for dissolved samples than in the unfiltered samples in wells associated with the ordnance works area and those wells sampled during the joint sampling effort. This problem has been attributed to antimony leaching from the filter used during groundwater sampling. Hence, dissolved antimony data from both the ordnance works area

TABLE 4.1 Summary of 1995 Joint Sampling Data and Data Collected from 1987–1994: Radionuclides and Metals

	Weathered Unit											
	1995 Joint Sampling Data						1987–1994 Data					
	Filtered			Unfiltered			Filtered			Unfiltered		
	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]
Radionuclides (pCi/L)												
Uranium, total	NS	NS	NS	151/156	0.0010 – 60	2.6	3/3	1.0 – 8.0	4.4	699/867	0.20 – 870	5.6
Metals (µg/L)												
Aluminum	57/158	2.5 – 280	24	111/158	3.8 – 27000	670	118/570	3 – 12,000	84	168/212	21 – 58,000	2,800
Antimony[b]	NS	NS	NS[c]	26/164	0.0050 – 5.6	0.74	NS	NS	NS	23/204	1.7 – 24	7
Arsenic	32/165	0.066 – 15	1.5	24/167	0.12 – 15	1.6	72/645	0.60 – 17	1.8	75/215	0.60 – 430	5.1
Barium	161/161	19 – 830	180	163/163	26 – 900	190	598/677	13 – 2,200	210	188/215	22 – 840	180
Cadmium	8/165	0.056 – 0.53	0.49	8/167	0.009 – 0.74	0.51	37/513	0.20 – 11	1.7	54/208	0.20 – 5	1.1
Chromium	118/164	0.91 – 23	2.8	127/167	1.1 – 120	5.1	90/664	0.90 – 250	7.0	56/216	2.0 – 90	6.8
Copper	45/165	0.69 – 42	2.8	87/165	1.1 – 85	5.6	84/488	0.40 – 75	6.2	105/204	1.0 – 150	11
Iron	96/138	7.6 – 610	84	118/139	16 – 32,000	850	302/617	1.7 – 22,000	190	195/212	9.0 – 42,000	3,800
Lead	23/163	0.026 – 23	1.1	93/164	0.009 – 46	3.4	141/603	0.70 – 65	2.6	103/216	0.80 – 200	7.6
Lithium	140/161	1.2 – 680	50	142/160	1.2 – 650	50	153/406	1.3 – 1,500	110	5/14	340 – 910	240
Manganese	95/163	0.088 – 240	15	131/161	1.2 – 1000	44	312/627	0.60 – 740	27	181/212	1.3 – 2,100	190
Mercury	5/162	0.29 – 3.8	0.14	9/164	0.20 – 4.5	0.16	54/513	0.05 – 44	0.26	16/208	0.2 – 1.0	0.11
Molybdenum	67/164	0.17 – 260	4.9	69/164	0.13 – 250	4.9	55/272	5.7 – 250	19	2/6	10 – 220	44
Nickel	148/161	0.30 – 95	8.4	156/161	0.010 – 170	12	97/622	0.70 – 330	17	64/212	6.0 – 260	22
Selenium	38/165	0.045 – 13	2.4	36/167	0.27 – 13	2.3	134/509	0.40 – 65	2.9	31/208	1.0 – 16	1.4
Silver	7/165	0.0050 – 3.2	0.5	15/167	0.0050 – 14	0.69	17/596	2.0 – 38	5.3	3/216	3.7 – 450	5.0
Thallium	5/165	0.020 – 2.2	0.67	5/165	0.069 – 1.9	0.67	29/447	0.10 – 5.8	2.3	22/204	1.0 – 4	1.9
Uranium, total	NS	NS	NS	151/156	0.0015 – 90	4.0	3/3	1.5 – 12	6.5	699/867	0.30 – 1,300	8.3

TABLE 4.1 (Cont.)

	Unweathered Unit											
	1995 Joint Sampling Data						1987–1994 Data					
	Filtered			Unfiltered			Filtered			Unfiltered		
	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[b]	Detection Frequency	Range	Mean[b]
Radionuclides (pCi/L)												
Uranium, total	NS	NS	NS	54/56	0.11 – 5.2	1.7	NS	NS	NS	262/314	0.20 – 17	2.4
Metals (µg/L)												
Aluminum	28/59	13 – 570	31	42/59	15 – 62,000	2,800	39/218	0.3 – 1,900	70	68/83	20 – 73,000	2,800
Antimony[b]	NS	NS	NS	10/60	0.23 – 4.4	0.70	NS	NS	NS	8/78	2.3 – 80	7.5
Arsenic	7/60	2.3 – 9.2	1.5	10/60	2.2 – 18	2.1	50/227	0.030 – 34	2.0	29/83	0.70 – 68	3.0
Barium	60/60	18 – 1,400	190	60/60	20 – 2,600	250	203/228	10 – 2,000	170	75/83	76 – 14,000	350
Cadmium	0/60	ND[d]	ND	4/60	0.028 – 3.0	0.58	12/193	0.20 – 18	1.7	23/78	0.20 – 6	1.0
Chromium	51/60	1.2 – 95	5.7	52/60	1.0 – 180	13	35/227	3.2 – 140	6.9	10/83	2.0 – 88	6.3
Copper	13/60	2.1 – 6.1	3.7	28/60	2.0 – 220	8.9	32/191	0.80 – 23	4.8	34/78	1.0 – 120	10
Iron	28/48	18 – 1,500	94	37/48	18 – 57,000	3,300	133/226	7.0 – 7,500	110	76/83	50 – 96,000	3,300
Lead	4/60	1.0 – 2.7	0.57	29/60	1.0 – 370	15	50/217	0.80 – 37	2.3	32/83	2.0 – 400	13
Lithium	57/60	0.30 – 210	19	58/60	0.90 – 200	20	41/150	3.7 – 280	29	2/6	33 – 78	39
Manganese	49/60	1.1 – 430	72	56/60	1.0 – 4,900	230	173/228	1.0 – 530	63	73/83	4.0 – 3,700	180
Mercury	2/59	0.93 – 0.94	0.13	3/59	0.21 – 1.5	0.15	10/189	0.030 – 2.5	0.12	5/78	0.10 – 1.1	0.10
Molybdenum	44/60	1.0 – 37	5.6	41/60	1.1 – 37	5.5	33/113	3.7 – 1,100	24	0/1	ND	ND
Nickel	57/60	1.0 – 90	7.0	59/60	1.2 – 290	18	13/227	0.40 – 27	8.9	20/83	6.4 – 580	19
Selenium	6/60	3.4 – 13	2.0	6/60	4.2 – 14	2.1	31/191	1.0 – 39	2.0	3/78	1.0 – 7.4	1.2
Silver	0/60	ND	ND	4/60	0.0070 – 22	1.2	9/215	2.0 – 10	3.3	1/83	9.1	2.9
Thallium	0/60	ND	ND	1/60	1.1	0.53	12/183	0.10 – 15	2.1	4/78	1.3 – 3.0	1.5
Uranium, total	NS	NS	NS	54/56	0.17 – 7.7	2.6	NS	NS	NS	262/314	0.30 – 25	3.6

TABLE 4.1 (Cont.)

	Overburden Unit											
	1995 Joint Sampling Data						1987–1994 Data					
	Filtered			Unfiltered			Filtered			Unfiltered		
	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]
Radionuclides (pCi/L)												
Uranium, total	NS	NS	NS	17/18	0.061 – 4.2	1.5	4/4	2.0 – 3.4	2.5	45/53	0.50 – 33	3.4
Metals (µg/L)												
Aluminum	13/20	0.25 – 570	55	18/20	23 – 2,200	470	16/65	3.0 – 1,300	73	40/50	90 – 57,000	6,400
Antimony[b]	NS	NS	NS	1/20	1.7	0.56	NS	NS	NS	3/46	6.0 – 17	11
Arsenic	1/20	4.5	1.2	5/20	0.26 – 7.6	1.5	14/65	0.70 – 4.0	2.1	22/50	0.60 – 16	3.8
Barium	20/20	26 – 310	110	20/20	37 – 340	120	53/66	23 – 660	140	40/50	35 – 960	200
Cadmium	3/20	0.043 – 0.15	0.44	4/20	0.071 – 1.2	0.47	9/60	0.26 – 4.0	1.6	18/46	0.20 – 10	1.7
Chromium	11/20	1.0 – 6.6	1.7	13/20	1.2 – 11	3.2	2/66	4.1 – 79	4.8	17/50	4.0 – 150	15
Copper	13/20	0.48 – 6.8	2.3	14/20	0.91 – 16	5.2	9/60	1.8 – 21	5.5	27/46	2.0 – 93	16
Iron	14/18	0.91 – 380	88	16/18	41 – 3,200	580	34/65	10 – 1,800	98	48/50	20 – 100,000	12,000
Lead	2/20	0.55 – 1.5	0.55	10/20	0.074 – 19	3.0	18/66	1.2 – 37	2.4	27/50	3.5 – 96	13
Lithium	17/20	0.25 – 13	4.0	17/20	0.26 – 14	4.3	3/22	7.1 – 64	17	1/8	35	29
Manganese	18/20	0.42 – 53	6.7	20/20	2.4 – 190	46	34/65	1.0 – 300	28	42/50	2.2 – 4,300	460
Mercury	0/20	ND	ND	1/20	0.35	0.11	5/60	0.11 – 1.8	0.14	3/46	0.20 – 0.30	0.11
Molybdenum	5/20	0.34 – 1.4	0.61	5/20	0.49 – 1.8	0.69	2/17	22 – 58	14	0/4	ND	ND
Nickel	20/20	0.64 – 55	6.8	20/20	0.94 – 51	8.5	4/65	9.0 – 60	11	23/50	8.0 – 170	26
Selenium	3/20	0.14 – 4.6	1.7	3/20	0.39 – 4.8	1.7	12/60	1.0 – 20	2.1	1/46	2.0	1.3
Silver	0/20	ND	ND	1/20	2.9	0.62	1/65	17	3.5	0/49	ND	ND
Thallium	0/20	ND	ND	0/20	ND	ND	4/60	1.1 – 6.0	2.3	3/46	2.0 – 9.0	2.3
Uranium, total	NS	NS	NS	17/18	0.091 – 6.3	2.3	4/4	3.0 – 5.1	3.8	45/53	0.75 – 49	5.1

TABLE 4.1 (Cont.)

	Deep Well											
	1995 Joint Sampling Data						1987–1994 Data					
	Filtered			Unfiltered			Filtered			Unfiltered		
	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]
Radionuclides (pCi/L)												
Uranium, total	NS	NS	NS	12/14	0.068 – 2.6	0.79	NS	NS	NS	NS	NS	NS
Metals (µg/L)												
Aluminum	7/14	16 – 890	85	13/14	19 – 8,200	1,100	14/47	20 – 3,300	160	38/47	30 – 16,000	3,000
Antimony[b]	NS	NS	NS	3/14	1.1 – 1.7	0.71	NS	NS	NS	7/46	2.7 – 6.6	7.1
Arsenic	6/14	2.9 – 14	4.1	9/14	2.4 – 56	12	20/46	1.0 – 12	3.5	26/46	0.60 – 230	16
Barium	14/14	50 – 460	190	14/14	60 – 450	200	41/47	23 – 470	180	41/47	38 – 480	220
Cadmium	0/14	ND	ND	1/14	1.6	0.58	6/46	0.3 – 2.0	1.1	26/47	0.20 – 8.7	1.4
Chromium	8/14	1.0 – 4.9	1.5	10/14	1.2 – 5.9	2.4	5/47	2.0 – 18	4.1	9/46	3.0 – 40	5.1
Copper	4/14	2.3 – 7.3	1.9	11/14	2.0 – 33	8.8	9/46	1.0 – 18	4.1	28/46	2.0 – 50	12
Iron	11/14	34 – 6,300	1800	14/14	34 – 18,000	5,900	25/47	15 – 8,900	1,200	46/47	130 – 51,000	7,200
Lead	1/14	1.9	0.6	8/14	1.5 – 180	22	9/46	1.1 – 19	2.5	27/46	2.0 – 270	18
Lithium	11/14	1.0 – 20	6.2	13/14	1.1 – 20	6.8	NS	NS	NS	NS	NS	NS
Manganese	13/14	1.4 – 880	210	14/14	6.1 – 880	270	41/47	4.1 – 870	220	44/47	6.2 – 1,800	380
Mercury	0/14	ND	ND	0/14	ND	ND	1/47	5.5	0.20	3/46	0.20 – 7.7	0.26
Molybdenum	7/14	1.1 – 7.2	2.3	7/14	1.3 – 7.6	2.3	NS	NS	NS	NS	NS	NS
Nickel	12/14	1.1 – 5.1	2.5	12/14	1.6 – 13	4.9	5/46	10 – 37	8.8	11/46	8.0 – 130	15
Selenium	0/14	ND	ND	0/14	ND	ND	4/46	0.8 – 2.0	1.1	2/46	1.0 – 1.4	1.1
Silver	0/14	ND	ND	0/14	ND	ND	2/46	2.0 – 2.0	2.9	0/46	ND	ND
Thallium	0/14	ND	ND	0/14	ND	ND	1/46	2.0	2.4	3/46	1.2 – 2.0	1.7
Uranium, total	NS	NS	NS	12/14	0.10 – 3.9	1.2	NS	NS	NS	NS	NS	NS

[a] The mean concentrations were calculated by substituting half the detection limit for values reported as nondetects.

[b] Filtered antimony data for the ordnance works area and joint data were excluded from data summaries because of possible contamination from field filters.

[c] NS = not sampled.

[d] ND = not detected.

TABLE 4.2 Summary of 1995 Joint Sampling Data and Data Collected from 1987–1994: Anions and Nitroaromatic Compounds

	Weathered Unit						Unweathered Unit					
	1995 Joint Sampling Data			1987–1994 Data			1995 Joint Sampling Data			1987–1994 Data		
	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]
Anions (mg/L)												
Chloride	79/85	0.81–49	7.6	896/927	0.4–1,700	18	26/30	1–12	2.3	328/346	0.49–29	2.6
Fluoride	65/86	0.055–0.34	0.15	326/559	0.050–54	0.58	29/30	0.066–0.99	0.23	121/208	0.050–2.1	0.28
Nitrate	136/162	0.040–900	41	790/863	0.020–310,000	620	19/59	0.0050–370	25	144/307	0.020–1,200	21
Nitrite-N	NS	NS	NS	33/255	0.010 – 97[c]	1.5	NS	NS	NS	NS	NS	NS
Sulfate	80/90	1.9–1,100	65	1037/1073	0.70–1,800	78	32/32	5.3–130	28	387/398	0.80–9,100	53
Nitroaromatics (µg/L)												
1,3,5-TNB	57/165	0.035–39	1.7	450/1232	0.016–89	2.8	6/59	0.044–0.14	0.021	33/426	0.020–17	0.38
1,3-DNB	3/168	0.17–0.86	0.052	69/1232	0.047–35	0.3	2/59	0.12–0.14	0.048	2/426	0.40–1.1	0.35
2,4,6-TNT	29/167	0.028–29	0.49	241/1230	0.016–65	0.85	0/60	ND[b]	ND	3/426	1.5–7.8	0.37
2,4-DNT	78/167	0.020–8.8	0.25	399/1226	0.014–940	2.5	8/57	0.036–0.13	0.023	13/425	0.029–0.59	0.33
2,6-DNT	80/162	0.0071–15	0.73	498/1222	0.0052–950	3.8	10/60	0.021–0.45	0.028	17/426	0.012–2.9	0.36
2-Amino-4,6-DNT	74/158	0.016–16	0.99	171/329	0.025–24	1.6	9/58	0.031–0.77	0.046	0/129	ND	ND
4-Amino-2,6-DNT	80/158	0.020–22	1.5	131/329	0.056–71	3.0	10/58	0.017–1.8	0.099	4/129	0.30–0.56	0.15
2-Nitrotoluene	30/161	0.083–100	1.3	15/371	0.30–900	3.0	3/58	0.054–0.3	0.028	0/147	ND	ND
3-Nitrotoluene	14/166	0.032–7.7	0.13	18/388	0.08–480	3.5	1/59	0.041	0.016	0/152	ND	ND
4-Nitrotoluene	8/166	0.15–30	0.27	29/388	0.13–2,600	7.3	0/60	ND	ND	1/152	1.1	0.14
Nitrobenzene	4/168	0.042–0.062	0.021	78/1231	0.017–22	0.3	0/60	ND	ND	8/425	0.030–6.0	0.39
Volatile Organic Compounds (µg/L)[e]												
Trichloroethylene	–	–	–	29/83	1.0 – 9,000	270	–	–	–	2/17[d]	48 – 60	6.7
1,2-Dichloroethene	–	–	–	17/83	1.0 – 39	3.2	–	–	–	1/16[d]	0.97	0.065

TABLE 4.2 (Cont.)

	Overburden Unit						Deep Unit					
	1995 Joint Sampling Data			1987–1994 Data			1995 Joint Sampling Data			1987–1994 Data		
	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]	Detection Frequency	Range	Mean[a]
Anions (mg/L)												
Chloride	8/10	1.1–17	4.2	83/86	0.5–43	6.8	7/7	1.8–9.1	3.6	44/46	0.50–13	3.2
Fluoride	8/10	0.090–0.26	0.14	50/67	0.12–1.7	0.39	7/7	0.090–1.5	0.66	42/45	0.12–13	0.94
Nitrate	19/20	0.18–56	5.4	52/52	0.38–2,200	250	4/14	0.12–0.33	0.099	1/1	1.2	1.2
Nitrite-N	NS	NS	NS	3/16	0.010 – 0.12	0.047	NS	NS	NS	NS	NS	NS
Sulfate	10/10	14–360	64	88/94	1.2–920	130	7/7	8.4–100	32	41/46	3.2–100	29
Nitroaromatics (µg/L)												
1,3,5-TNB	11/20	0.038–14	2.4	64/147	0.036–29	3.3	0/14	ND	ND	2/97	0.9–1.6	0.16
1,3-DNB	2/20	0.32–0.40	0.077	10/147	0.25–2.2	0.21	0/14	ND	ND	1/97	0.35	0.14
2,4,6-TNT	13/20	0.035–30	4.3	70/147	0.082–57	5.3	0/14	ND	ND	3/97	0.46–6.8	0.22
2,4-DNT	10/20	0.059–20	1.9	54/147	0.033–84	3.2	0/14	ND	ND	1/97	0.35	0.14
2,6-DNT	16/20	0.018–4.9	1.3	63/146	0.03–1,200	17	0/14	ND	ND	1/97	0.36	0.14
2-Amino-4,6-DNT	16/20	0.04–35	4.3	31/80	0.40–44	4.8	0/14	ND	ND	0/81	ND	ND
4-Amino-2,6-DNT	16/20	0.18–26	3.8	36/80	0.30–53	5.0	0/14	ND	ND	1/81	0.42	0.15
2-Nitrotoluene	7/17	0.13–0.65	0.13	2/92	0.30–0.76	0.16	0/14	ND	ND	0/94	ND	ND
3-Nitrotoluene	5/19	0.032–0.13	0.029	6/96	0.05–1.7	0.18	0/14	ND	ND	3/97	0.060–0.63	0.15
4-Nitrotoluene	5/20	0.063–0.22	0.041	5/96	0.30–1.4	0.17	0/14	ND	ND	1/97	1.2	0.15
Nitrobenzene	0/20	ND	ND	17/148	0.40–31	1.2	0/14	ND	ND	0/97	ND	ND
Volatile Organic Compounds (µg/L)[c]												
Trichloroethylene	–	–	–	1/9	1.0	0.11	–	–	–	–	–	–
1,2-dichloroethene	–	–	–	3/9	1.0 – 5.0	1.0	–	–	–	–	–	–

[a] The mean concentrations for anions were calculated by substituting half the detection limit for values reported as nondetects. For nitroaromatics, concentrations were calculated by substituting a zero for nondetects. No mean concentrations were calculated for nitroaromatics, which had a 0% detection frequency.

[b] ND = not detected.

[c] Data for volatile organic compounds collected from 1996-1997.

[d] Detections reported for only one were (MW-3024); this well was retrofit at the of 1996; there were no detections in the retrofitted well.

[e] Suspected outlier values for nitrite were reported for two wells: 97 mg/L for MW-2003 and 61 mg/L for MW-3009. The next highest level of nitrite reported was 1.4 mg/L.

and the joint sampling were excluded from evaluation for this RI because of potential contamination from filters.

The results of the joint data are generally consistent with the data collected prior to 1995. For most of the constituents, the range and means for the joint data are lower. This observation is most pronounced for nitrates and uranium detected in the weathered unit. Some of this variability can be attributed to suspected outliers in the pre-1990 data. More recent data are believed to be representative of current conditions in the groundwater system. Overall, the highest contaminant concentrations for nitroaromatic compounds, anions, and some metals (such as uranium) are found in the shallow portions of the aquifer (weathered unit and overburden).

Recent (1996 and 1997) sampling of monitoring wells and springs at the chemical plant area and vicinity was conducted as part of a VOC monitoring program. Results indicated the presence of trichloroethylene (TCE) and 1,2-dichloroethene (1,2-DCE) in a few wells located near the raffinate pits. Results also indicated the presence of very low levels of toluene. Estimated values were reported for nine wells, with concentrations ranging from 0.33–2.0 µg/L. This finding is consistent with earlier data collected for toluene when wells were first installed; toluene was detected in five wells at levels ranging from 1.0 to 2.3 µg/L. Soil characterization activities done in support of the RI for the chemical plant area resulted in a few (i.e., 9 out of 252) low-level detections of toluene in soils adjacent to the process buildings. Levels ranged from 11 to 160 ppb. These low concentrations in soil are attributed to decontamination activities that involved use of toluene to decontaminate sampling equipment. No other VOCs were detected in groundwater or springs.

Section 4.1.2 discusses the nature and extent of contamination in groundwater. For the naturally occurring constituents (metals and anions), a background comparison was conducted to determine the list of contaminants that are present at levels above background. The discussion on the nature and extent of contamination of naturally occurring constituents focuses on the list of COPC identified by the background comparison presented in Section 4.1.1.

4.1.1 Background Comparison for Naturally Occurring Constituents

A background comparison was performed for all naturally occurring constituents to determine whether site concentrations of potential contaminants differ from naturally occurring background concentrations. As discussed in Chapter 2, five wells were identified as representative of background groundwater quality: MWS-23 and MWS-111 for the weathered Burlington-Keokuk Limestone; MWS-105, MWS-108, and MWS-109 for the unweathered Burlington-Keokuk. It was not possible to identify background wells representative of the overburden and deeper formations. Therefore, contaminant concentrations in the overburden unit were compared with the statistically derived background for the weathered unit, while contaminant concentrations in the deeper formations were compared with the statistically derived background levels for the unweathered unit.

Since most of the stratigraphically deeper formations are predominantly limestone and all the wells are relatively shallow, it was expected that the groundwater quality of individual formations would be similar. A summary of the statistically derived background groundwater concentrations for potential contaminants is presented in Table 4.3. Because uranium, lithium, and molybdenum are not associated with materials that were processed at the ordnance works, these parameters were not included in the DA monitoring program.

For background comparison, data for the chemical plant area and the ordnance works area were combined within each hydrostratigraphic unit and compared to the appropriate background data set. A 95% upper confidence limit of the arithmetic average (UCL) was calculated for each parameter in the background and site groundwater data sets, and these UCL values were then compared with one another. The results of this comparison are presented in Table 4.4 and discussed below. Table 4.4 also provides available regulatory limits for groundwater quality (maximum contaminant levels [MCLs] and secondary maximum contaminant levels [SMCLs]) for use as points of reference in the discussion.

The UCLs for many of the metals and anions detected in the unweathered Burlington-Keokuk and deep formations exceeded the statistically derived background levels for the unweathered unit (Table 4.4), although many of these exceedances were less than a factor of 2. Metals present in the unweathered unit with UCL concentrations at or below background levels were antimony, arsenic, cadmium, silver, and thallium; fluoride was the only anion present below background levels. In the deep unit, antimony, cadmium, selenium, and silver exhibited UCL concentrations at or below background levels.

Within the weathered hydrostratigraphic unit, only lithium, molybdenum, uranium, chloride, nitrate, and sulfate had UCL concentrations that exceeded statistically derived background levels by more than a factor of about 2 (Table 4.4). Among these contaminants and for which MCL or SMCL values are available, only the nitrate UCL concentration exceeded an MCL or SMCL value. Among the metals and anions in the overburden unit, only molybdenum, uranium, chloride, nitrate, and sulfate exhibited UCL concentrations that exceeded the background levels by more than a factor of about 2 (Table 4.4). Among these contaminants and for which MCL or SMCL values are available, only nitrate exceeded an MCL or SMCL concentration.

Within the unweathered unit, UCL concentrations exceeding the statistically derived background levels by more than a factor of about 2 were calculated for aluminum, chromium, iron, lead, lithium, molybdenum, uranium, nitrate, and sulfate (Table 4.4). Among these, only the aluminum, iron, and nitrate UCL concentrations exceeded available MCL or SMCL levels. Within the deep hydrostratigraphic unit, aluminum, arsenic, iron, lead, manganese, molybdenum, chloride, fluoride, and nitrate exhibited UCL concentrations that exceeded background levels by more than a factor of about 2 (Table 4.4). The UCL values for aluminum, iron, lead, and manganese exceeded MCL or SMCL levels.

TABLE 4.3 Background Groundwater Concentrations of Potential Contaminants

	Weathered Unit					Unweathered Unit				
	Detection Frequency	Range	Mean[a]	Standard Deviation	95% UCL[a]	Detection Frequency	Range	Mean[a]	Standard Deviation	95% UCL[a]
Radionuclides (pCi/L)										
Uranium, total	4/4	0.41 – 0.94	0.64	0.25	0.93	4/6	0.28 – 0.56	0.34	0.18	0.48
Metals (µg/L)										
Aluminum	20/34	45 – 16,000	2,000	3,900	3,100	29/54	16 – 2,600	220	490	330
Antimony	7/34	1.1 – 6.3	5.1	9.4	6.3	10/54	1 – 20	5.3	9.3	7.5
Arsenic	7/34	0.9 – 13	2.5	2.9	3.4	14/54	0.6 – 9.7	2.0	1.9	2.5
Barium	32/34	89 – 490	270	140	310	48/54	81 – 310	130	32	140
Cadmium	8/34	0.20 – 0.70	0.67	0.73	0.70	8/54	0.28 – 1.8	0.96	1.4	1.3
Chromium	10/34	1.6 – 22	4.8	5.1	6.2	12/54	1.0 – 3.1	2.9	2.8	3.1
Copper	17/34	1.0 – 58	10	14	14	17/54	1.0 – 62	4.5	8.8	6.5
Iron	26/34	10 – 21,000	3,000	5,200	4,500	39/53	22 – 3,000	250	480	360
Lead	19/34	0.70 – 15	4.1	4.1	5.2	10/54	1.1 – 16	2.4	3.4	3.2
Lithium	5/8	2.0 – 11	3.9	4.1	6.6	12/12	3.3 – 4.7	3.9	0.48	4.1
Manganese	24/33	3.9 – 900	200	280	290	53/54	1.7 – 290	78	73	95
Mercury	2/34	0.1 – 2.0	0.15	0.33	0.25	3/54	0.10 – 0.50	0.098	0.059	0.11
Molybdenum	0/8	–	0.5	0	0.50	4/12	1.3 – 2.4	0.91	0.66	1.3
Nickel	17/34	1.8 – 920	39	160	84	15/54	1.9 – 20	6.6	5.7	7.9
Selenium	2/34	1.0 – 1.1	1.2	0.98	1.1	4/54	1.0 – 2.0	1.3	1	1.5
Silver	0/34	–	2.3	1.8	2.9	1/54	3.0	2.4	1.7	2.7
Thallium	0/34	–	1.3	1.5	1.8	3/54	3.0 – 7.0	1.5	1.6	1.9
Uranium, total	4/4	0.61 – 1.4	0.95	0.38	1.4	4/6	0.41 – 0.83	0.5	0.26	0.72
Anions (mg/L)										
Chloride	12/15	0.98 – 3.0	1.2	0.72	1.6	22/24	0.4 – 2.6	1.1	0.62	1.4
Fluoride	10/15	0.15 – 1.1	0.31	0.28	0.44	21/24	0.19 – 0.84	0.4	0.21	0.48
Nitrate	3/4	0.20 – 0.25	0.19	0.093	0.25	0/6	–	0.050	0	0.050
Sulfate	10/15	0.42 – 22	8.5	7.7	12	24/24	9.5 – 61	22	11	26

[a] The mean concentration and 95% UCL values were calculated by using half the sample detection limits for values reported as nondetect. For contaminants where the UCL is greater than the maximum reported concentration, the maximum was reported as the UCL.

TABLE 4.4 Comparison of Site Data with Statistically Derived Background Concentrations of Naturally Occurring Contaminants[a]

	Weathered Background UCL	Weathered Site UCL	Overburden Site UCL	Unweathered Background UCL	Unweathered Site UCL	Deep Site UCL	MCL
Radionuclides (pCi/L)							
Uranium, total	0.93	6.5	3.7	0.48	2.5	1.2	14
Metals (μg/L)							
Aluminum	3,100	870	3,100	330	1,500	1,800	50 – 200[b]
Antimony	6.3	5.1	10	7.5	6.2	6.6	6
Arsenic	3.4	2.1	2.8	2.5	2.4	13	50
Barium	310	210	170	140	280	220	2,000
Cadmium	0.70	1.3	1.5	1.3	1.3	1.3	5
Chromium	6.2	6.8	9.7	3.1	8.8	4.7	100
Copper	14	6.9	9.9	6.5	7.2	9.0	1,000[b]
Iron	4,500	1,200	5,800	360	1,700	5,100	300[b]
Lead	5.2	3.8	7.3	3.2	8.3	16	15[c]
Lithium	6.6	100	14	4.1	31	8.3	–
Manganese	290	65	230	95	140	340	50[b]
Mercury	0.25	0.29	0.14	0.11	0.15	0.33	2
Molybdenum	0.50	14	6.8	1.3	22	3.2	–
Nickel	84	17	18	7.9	15	12	100
Selenium	1.1	2.8	2.0	1.5	2.1	1.3	50
Silver	2.9	5.3	3.0	2.7	2.7	2.0	100[b]
Thallium	1.8	1.8	2.0	1.9	1.6	2.0	2[b]
Uranium, total	1.4	9.7	5.5	0.72	3.7	1.7	20[d]
Anions (mg/L)							
Chloride	1.6	21	7.6	1.4	2.8	3.8	250[b]
Fluoride	0.44	0.67	0.42	0.48	0.30	1.3	2
Nitrate	0.25	1,000	270	0.050	34	0.31	10
Sulfate	12	84	160	26	85	37	250[b]

[a] Background comparisons performed by comparing the UCL for the weathered background wells with the UCL for the weathered and overburden site wells, and the UCL for the unweathered background wells with the UCL for the unweathered and deeper unit site wells.

[b] SMCL

[c] Action level.

[d] The proposed MCL for uranium is 20 μg/L, which corresponds to 14 pCi/L on the basis of the ratio of uranium isotopes in site soil.

Although statistically derived background concentrations were exceeded for a number of contaminants, most exceedances were within a factor of about 2 or less and the differences were generally less than 5 μg/L in magnitude. Within the weathered unit, contaminants for which the UCL exceeded the weathered background UCL by a factor of 5 or more included lithium, molybdenum, uranium, chloride, nitrate, and sulfate. Within the overburden unit, only the UCL values for molybdenum, chloride, nitrate, and sulfate exceeded background levels by a factor of 5 or more. Within the deeper units, the background UCL levels were exceeded by a factor of 5 or more only by aluminum, iron, lithium, molybdenum, uranium, and nitrate in the unweathered unit, and by aluminum, arsenic, iron, lead, and nitrate in the deep unit. Contaminants for which the UCL exceeded the appropriate background UCL by a factor of 10 or more included lithium, molybdenum, chloride, and nitrate in the weathered unit; molybdenum, nitrate, and sulfate in the overburden unit; molybdenum and nitrate in the unweathered unit; and iron in the deep unit.

The comparison of background and site groundwater data indicates that most of the COPC in groundwater are present at concentrations that differ little from background levels. In contrast, only a few of the COPC are present at levels moderately or greatly exceeding background levels. Contaminants indicated to moderately exceed background (UCL exceeds background UCL by a factor of 5 to 10) include aluminum, arsenic, lead, and uranium, while contaminants greatly exceeding background (exceeding the background UCL by a factor of 10 or more) include iron, lithium, molybdenum, chloride, nitrate, and sulfate.

None of the UCL values for these COPC exceeded the background UCL levels by the same magnitude among all the stratigraphic units, and no apparent regular trend exists for contaminant concentrations among the stratigraphic units. For example, the UCL value for iron is about equal to background for the overburden unit, below the background UCL level in the weathered unit, about 5 times greater for the unweathered unit, and about 14 times greater for the deep unit. For arsenic, the UCL values were below the background UCL value for the weathered, overburden, and unweathered units, but about 5 times above background for the deep unit. In contrast to these contaminants, the UCL value for nitrate differed the most from background in the weathered unit and the least in the deep unit.

Two additional statistical evaluations (the Gehan rank-sum test and the Quantile test) were conducted on the site and background data sets in order to identify metals and anions that are present at the site at concentrations that differ significantly from background.

The Gehan (Wilcoxon) rank-sum test was used to compare the distribution of the site and background data sets. The null (default) hypothesis for this test is that the site data set distribution is equal to the background data set distribution. The alternative hypothesis is that the distributions differ.

The Gehan test first ranks the data by concentration value, then uses this ranking to determine the probability of the site distributions exceeding the background distribution. The two data sets are combined and ordered from smallest to largest on the basis of concentration; the smallest observation gets rank 1; the second smallest, rank 2; and so on. The two data sets are then separated by origin (site or background), and a test statistic is calculated on the basis of the sum of the ranks associated with each data set. If the site sum is greater than the background sum, higher concentrations are present at the site than in the background.

The significance level and *p*-value determine how different the two sums are; the significance level is a value between 0 and 1 that is chosen before sampling for statistical testing begins; *p*-values originate from the statistical test using actual data. A *p*-value that is smaller than the significance level indicates that at the site, the sum is significantly greater than the background sum.

The Quantile test determines whether the tails of the data set distributions are different. As in the Gehan test, the two data sets are combined and ranked; however, they are not separated. Rather, the 80th percentile of the combined data set is determined, and the number of site and background values greater than this value are counted separately. The 80th percentile is the value that exceeds 80% of the data values. The *p*-value is a comparison of the counts; if the number of the site values sufficiently exceeds the number of background concentrations, the *p*-values will be less than the significance level, and it can be concluded that the concentration at the site significantly exceeds the background concentration.

The results of the Quantile and Gehan tests indicated that concentrations of barium, chloride, lead, lithium, and nickel differed significantly from background only in the unweathered and deep units at both the chemical plant area and the ordnance works area (Tables 4.5 and 4.6). In contrast, aluminum, arsenic, cadmium, copper, iron, manganese, and fluoride concentrations are significantly different from background levels only in the deep unit and only beneath the ordnance works area. Chromium concentrations differ significantly from background levels at both the chemical plant area and ordnance works area only in the weathered unit.

Within the weathered and overburden units, chloride, sulfate, molybdenum, and uranium concentrations differed significantly from background levels at both the chemical plant area and the ordnance works area; selenium concentrations differed from background levels only at the chemical plant area. Chloride and sulfate concentrations differed from background only at the chemical plant area. Chloride and sulfate concentrations in the unweathered unit beneath the ordnance works area did not significantly differ from background levels (Table 4.7). The Quantile test indicated that nitrate did not exceed background levels within any of the stratigraphic units beneath the chemical plant area and the ordnance works area. Nitrate concentrations were indicated by the Gehan test to significantly exceed background at the chemical plant area and the ordnance works area in all stratigraphic units except the unweathered unit beneath the ordnance works area.

TABLE 4.5 Quantile Test Results by Stratigraphic Unit (Overburden, Weathered, Unweathered, and Deep) of Metals Concentrations in Groundwater at the Chemical Plant Area (Chemical) and the Ordnance Works Area (Army)[a]

Quantile Test

Well	Al	Sb	As	Ba	Cd	Cr	Cu	Fe	Pb
C/W	0.9982	0.4772	NVT[b]	0.7255	NVT	0.3442	0.6733	1.00	0.8431
C/U	0.9977	0.4559	0.9163	0.0[c]	NVT	0.0[c]	0.1846	0.9973	0.0175[c]
C/O	0.9917	NVT	NVT	0.9823	NVT	0.4122	0.8393	0.9413	0.6390
A/W	0.9992	0.2978	0.1574	1.00	NVT	0.9839	0.9773	0.9998	0.9992
A/U	0.4659	0.3222	0.6114	0.0[c]	NVT	0.0490[c]	0.3183	0.0490[c]	0.3183
A/O	0.9035	NVT	0.2690	1.00	0.4527	0.7988	0.9035	0.9865	0.9608
A/D	0.0129[c]	NVT	0.0[c]	0.0[c]	0.0859[c]	0.1739	0.0030[c]	0.0	0.0001[c]

Well	Li	Mn	Hg	Mb	Ni	Se	Ag	Tl	U
C/W	0.7599	1.00	NVT	0.2920	0.8720	NVT	NVT	NVT	0.4612
C/U	0.0665[c]	0.8496	NVT	0.0[c]	0.0469[c]	NVT	NVT	NVT	0.2594
C/O	0.8238	0.9844	NVT	0.9767	0.9626	0.0002[c]	NVT	NVT	0.3999
A/W	0.8081	1.00	NVT	0.0002[c]	0.9916	NVT	NVT	NVT	0.4065
A/U	0.0545[c]	0.9100	NVT	0.0[c]	0.0490[c]	NVT	NVT	NVT	0.2361
A/O	0.8168	0.9865	NVT	0.0864[c]	0.9608	NVT	NVT	NVT	0.3756
A/D	0.0404[c]	0.0[c]	NVT	0.0[c]	0.0820[c]	NVT	NVT	NVT	0.2066

[a] C/W = chemical weathered; C/U = chemical/unweathered; C/O = chemical/overburden; AW = Army/weathered; A/U = Army/unweathered; H/O = Army overburden; and A/D = Army Deep.

[b] NVT = not a valid test; 80% of the combined data are below the detection limit.

[c] Significantly different from background.

TABLE 4.6 Wilcoxon (Gehan) Rank-Sum Test Results by Stratigraphic Unit (Overburden, Weathered, Unweathered, and Deep) of Metals Concentrations in Groundwater at the Chemical Plant Area (Chemical) and the Ordnance Works Area (Army)[a]

Wilcoxon (Gehan) Rank-Sum Test

Well	Al	Sb	As	Ba	Cd	Cr	Cu	Fe	Pb
C/W	0.9777	0.2908	0.9824	0.7255	0.4484	0.3130	0.6733	0.9999	0.9389
C/U	0.9571	0.2777	0.7348	0.3044	0.3964	0.0002[b]	0.2361	0.9987	0.1087
C/O	0.8239	0.3686	0.5431	0.9195	0.4188	0.2825	0.5647	0.7923	0.5841
A/W	0.9811	0.2849	0.3740	1.00	0.6053	0.6198	0.9491	0.9735	0.9892
A/U	0.5243	0.3014	0.5223	0.0029[b]	0.5748	0.2298	0.4207	0.8042	0.2607
A/O	0.8465	0.7887	0.5198	1.00	0.5216	0.7837	0.9231	0.8364	0.9805
A/D	0.0662[b]	0.5252	0.0016[b]	0.0002[b]	0.2798	0.3862	0.0607[b]	0.0[b]	0.0167[b]

Well	Li	Mn	Hg	Mb	Ni	Se	Ag	Tl	U
C/W	0.2121	1.00	0.4191	0.0899[b]	0.5396	0.3154	0.5262	0.5121	0.0190[b]
C/U	0.0447[b]	0.9862	0.3227	0.0[b]	0.1280	0.0408[b]	0.4276	0.5521	0.0004[b]
C/O	0.1747	0.9808	0.2893	0.2509	0.6326	0.0119[b]	0.3715	0.4056	0.0028[b]
A/W	0.2812	0.9986	0.3778	0.0[b]	0.9136	0.2573	0.4756	0.3342	0.0925[b]
A/U	0.8081	0.9966	0.3662	0.0[b]	0.1109	0.4239	0.7810	0.5969	0.0009[b]
A/O	0.4528	0.9882	0.6137	0.0113[b]	0.9553	0.5734	0.5078	0.3390	0.0490[b]
A/D	0.1672	0.0023[b]	0.5812	0.0[b]	0.3209	0.6744	0.5505	0.6661	0.3550

[a] C/W = chemical weathered; C/U = chemical/unweathered; C/O = chemical/overburden; AW = Army/weathered; A/U = Army/unweathered; H/O = Army overburden; and A/D = Army Deep.

[b] Significantly different from background.

TABLE 4.7 Statistical Evaluation by Stratigraphic Unit (Overburden, Weathered, Unweathered, and Deep) of Anion Concentrations in Groundwater at the Chemical Plant Area (Chemical) and the Ordnance Works Area (Army)[a]

Quantile Test

Well	Cl^-	F^-	NO_3^-	SO_4^-
C/W	0.0341[b]	0.6541	0.4098	0.0346[b]
C/U	0.0040[b]	1.00	0.2616	0.0287[b]
C/O	0.0223[b]	0.1317	0.3990	0.0210[b]
A/W	0.0320[b]	0.3948	0.4065	0.0325[b]
A/U	0.4742	0.2548	NVT	0.9836
A/O	0.0216[b]	0.3714	0.3756	0.0216[b]
A/D	0.0016[b]	0.0016[b]	0.2066	0.0198[b]

Wilcoxon (Gehan) Rank-Sum Test

Well	Cl^-	F^-	NO_3^-	SO_4^-
C/W	0.0[b]	0.8854	0.0028[b]	0.0[b]
C/U	0.0[b]	1.00	0.0237[b]	0.2068
C/O	0.0[b]	0.3959	0.0005[b]	0.0[a]
A/W	0.0012[b]	0.4352	0.0729[b]	0.0001[b]
A/U	0.4096	0.8441	0.1335	0.9987
A/O	0.0006[b]	0.3570	0.0148[b]	0.0[b]
A/D	0.0[b]	0.0148[b]	0.0979[b]	0.3053

[a] C/W = chemical weathered; C/U = chemical/unweathered; C/O = chemical/overburden; AW = Army/weathered; A/U = Army/unweathered; H/O = Army overburden; and A/D = Army Deep; NVT = not a valid test.

[b] Significantly different from background.

The results of the comparisons using UCL values were comparable to the results obtained from the Quantile and Gehan tests; for most of the metals, minimal differences occurred between the background and site data. The Quantile and Gehan tests indicated differences for aluminum, arsenic, barium, cadmium, copper, iron, lead, lithium, manganese, molybdenum, nickel, and uranium. In contrast, the comparison of site and background UCL concentrations indicated that barium, cadmium, copper, manganese, and nickel differed only slightly between site and background data.

Arsenic is associated with the ores that were processed at the chemical plant and is a contaminant in the raffinate pits. However, arsenic was only detected at levels below background concentrations from those wells downgradient of the raffinate pits. In addition, arsenic was detected to the southwest of the training area. The high UCL value calculated for arsenic for the deep unit was the result of a very high concentration detected from well MWS-103 from this area. It is hydrologically not possible that the wells in this area could have been impacted by contaminants from the chemical plant area, and arsenic is not associated with past activities at the ordnance works. In addition, the Burlington-Keokuk Limestone is absent from the southwestern portion of the former ordnance works area due to erosion. The uppermost bedrock in this area consists of the Kimmswick and Decorah formations; MWS-103 is open to these formations. Thus, it is likely that the reported arsenic concentrations are indicative of background levels for this area.

Similarly, the site concentrations of aluminum, iron, and lead may actually reflect local background levels. The data indicate a very heterogeneous distribution of these metals among the stratigraphic units at the chemical plant area and the ordnance works area. The UCL values for aluminum, iron, and lead exceeded background UCL values by more than a factor of 2 only in the unweathered and/or deep units (Table 4.4). However, the unweathered background UCL values of these metals were less than the background UCL values for the weathered unit. In addition, the UCL values for aluminum and iron for the unweathered and deep units were less than or about equal to their respective background UCL values for the weathered unit.

In contrast to the aforementioned metals, lithium, molybdenum, and uranium were detected at levels above background in a large percentage of wells on both the chemical plant area and the ordnance works area, and especially at the chemical plant area. The higher frequency of detection for uranium was expected, since this metal is a known contaminant at the raffinate pits and in soils at the chemical plant area. Lithium and molybdenum are associated with uranium ores, and both of these metals were contaminants in the raffinate pit sludges and surface water.

The differences between the site and background concentrations indicated for lithium, molybdenum, and uranium could be a function of the smaller background sample size compared to the site sample size. The background wells were sampled less frequently for these metals. Elevated nitrate, chloride, and sulfate were indicated from the Quantile and Gehan tests and the UCL comparisons.

4.1.2 Distribution of Site Contaminants

On the basis of a review of groundwater quality data and the background comparison, lithium, molybdenum, uranium, nitrate, chloride, sulfate, nitroaromatic compounds, TCE and 1,2-DCE were identified as site contaminants. The distribution of site contaminants is illustrated in Figures 4.1 through 4.4 for metals (including uranium), Figures 4.5 through 4.8 for the anions; Figures 4.9 through 4.19 for the nitroaromatic compounds, and Figure 4.20 for TCE and 1,2-DCE. The UCL values for each well, calculated on the basis of all data collected from 1987 to 1995, are shown in the figures. Additional figures for nitrate and uranium are also provided for which UCL values for each well are calculated on the basis of more recent data only (1995-1997). Data from quarterly sampling were averaged to calculate the UCL for each well. This procedure is appropriate because no time trending has been observed. UCLs are posted for each well rather than drawing isopleths because no plume has been identified. For metals and anions, only those wells that exceeded the statistically derived background are shown. The distribution maps for nitroaromatic compounds show all the locations where these compounds were detected. Contaminants for which an MCL or SMCL is available include chloride (250 mg/L), nitrate (10 mg/L), and sulfate (250 mg/L). Wells that had UCL values above the MCL or SMCL values are designated in the figures.

4.1.2.1 Metals

Contaminant distributions for uranium are shown in Figures 4.1 and 4.2. Figure 4.1 illustrates the UCLs for each well based on data collected since 1987. An additional map is also presented using more recent data (Figure 4.2) that provide a more current indication of contaminant levels for each well. Wells that are considered to be impacted by uranium processing activities are designated in the distribution maps; these wells were determined on the basis of data evaluation, existing or previous source areas, and groundwater flow. Concentrations are also compared with the proposed MCL of 20 µg/L, which corresponds to an activity concentration of 14 pCi/L on the basis of the ratio of uranium isotopes measured in soil at the chemical plant area (i.e., an activity ratio of 1 to 1 between U-234 and U-238).

In general, the areas with uranium contamination include the area around the raffinate pits and Ash Pond, the Frog Pond area, south and southeast portions of the chemical plant area and adjacent boundary, and west of the chemical plant area boundary extending north to Burgermeister Spring. Uranium contamination is primarily limited to the overburden and weathered units of the aquifer. Uranium levels are much lower in the unweathered and deeper units (0.028 to 6.6 pCi/L in the unweathered, and less than 3.0 pCi/L in the deeper unit).

The highest UCLs for uranium (as shown on Figure 4.1) are indicated for wells MW-3009, MW-3008, MW-4010, and MW-4024. The well with the highest UCL is MW-4010 (130 pCi/L),

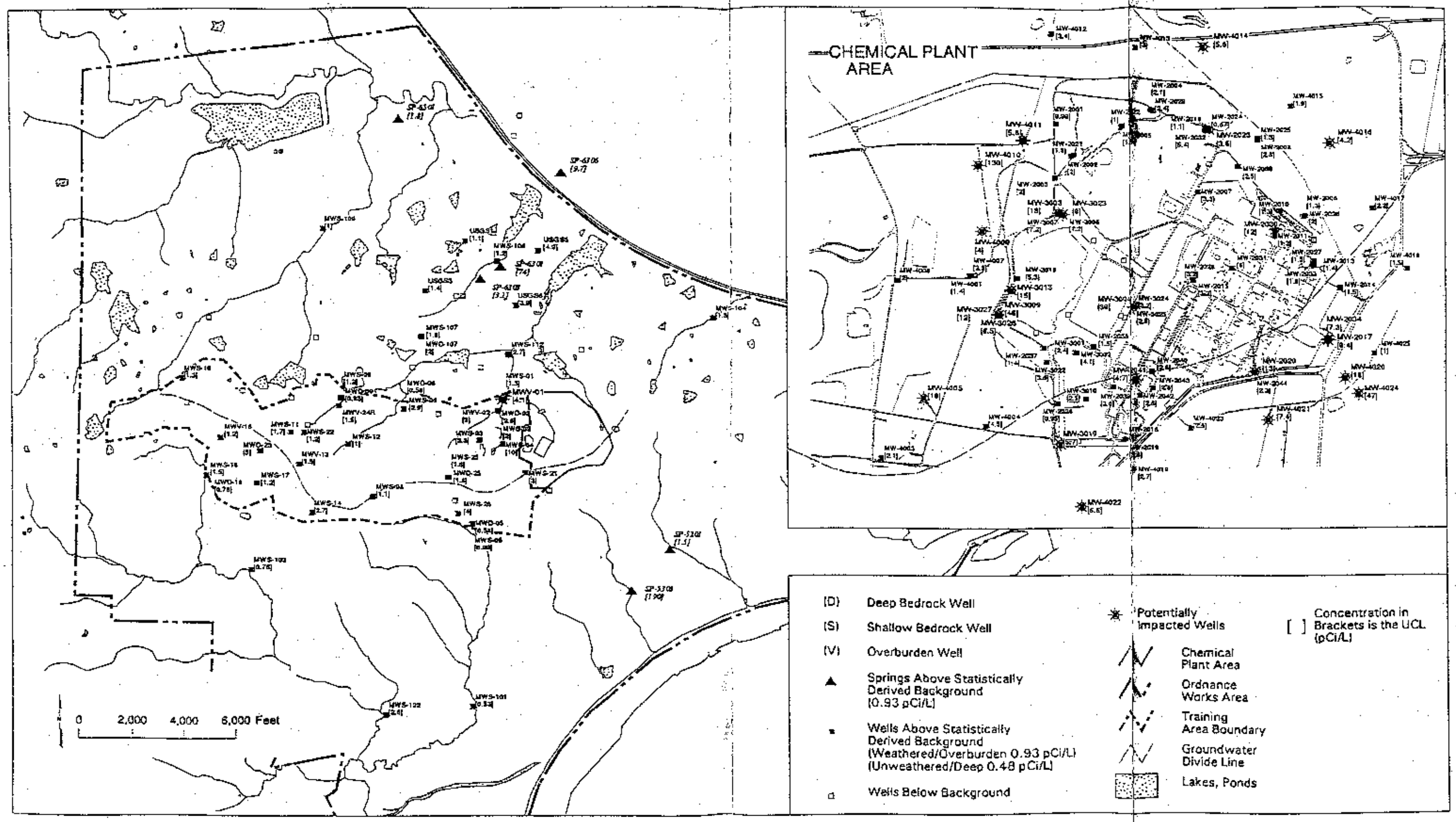


FIGURE 4.1 Distribution of Uranium Based on Data Collected Since 1987 at the Chemical Plant Area and the Ordnance Works Area

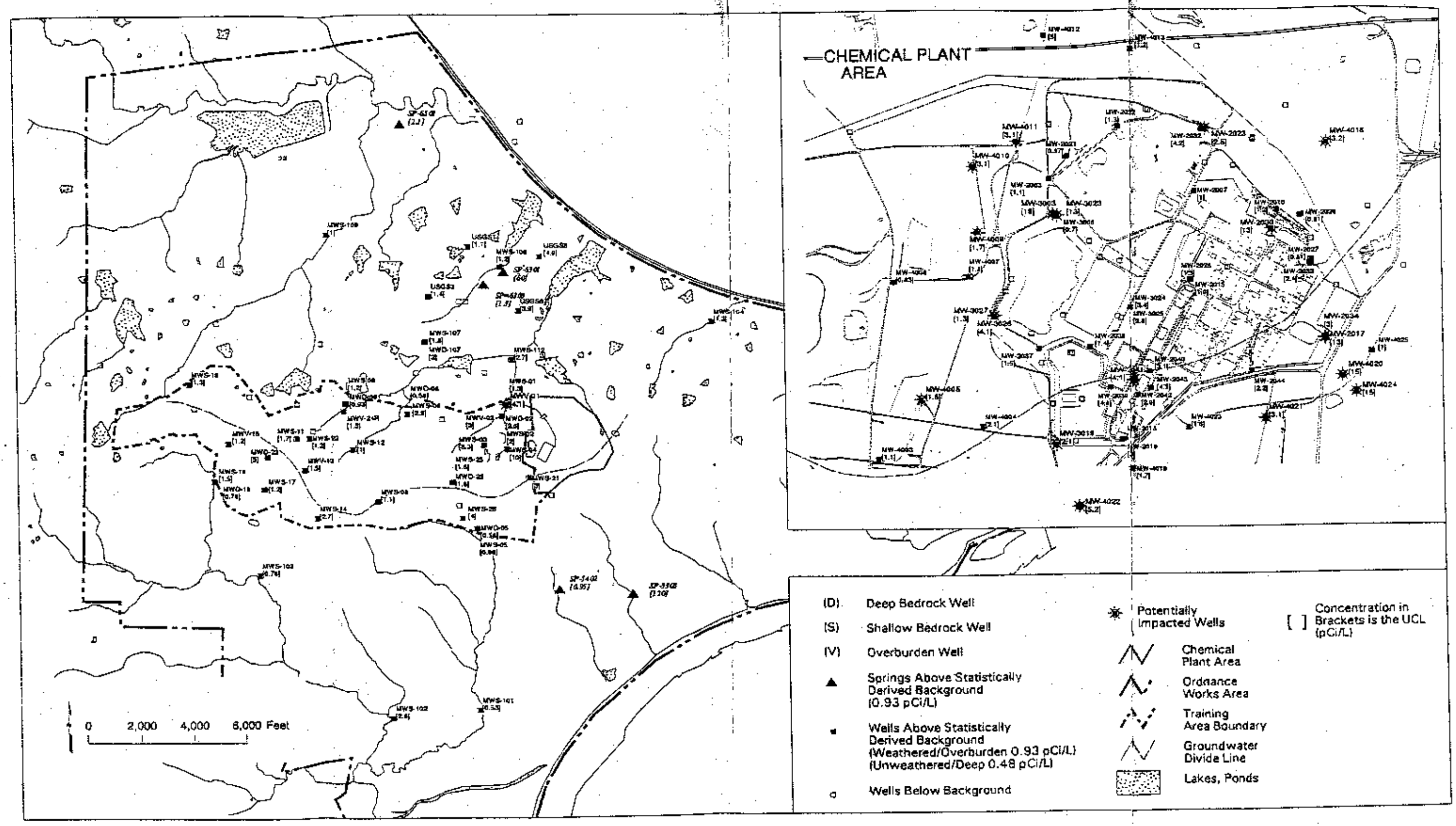


FIGURE 4.2 Distribution of Uranium Based on Data Collected Since 1995 at the Chemical Plant Area and the Ordnance Works Area

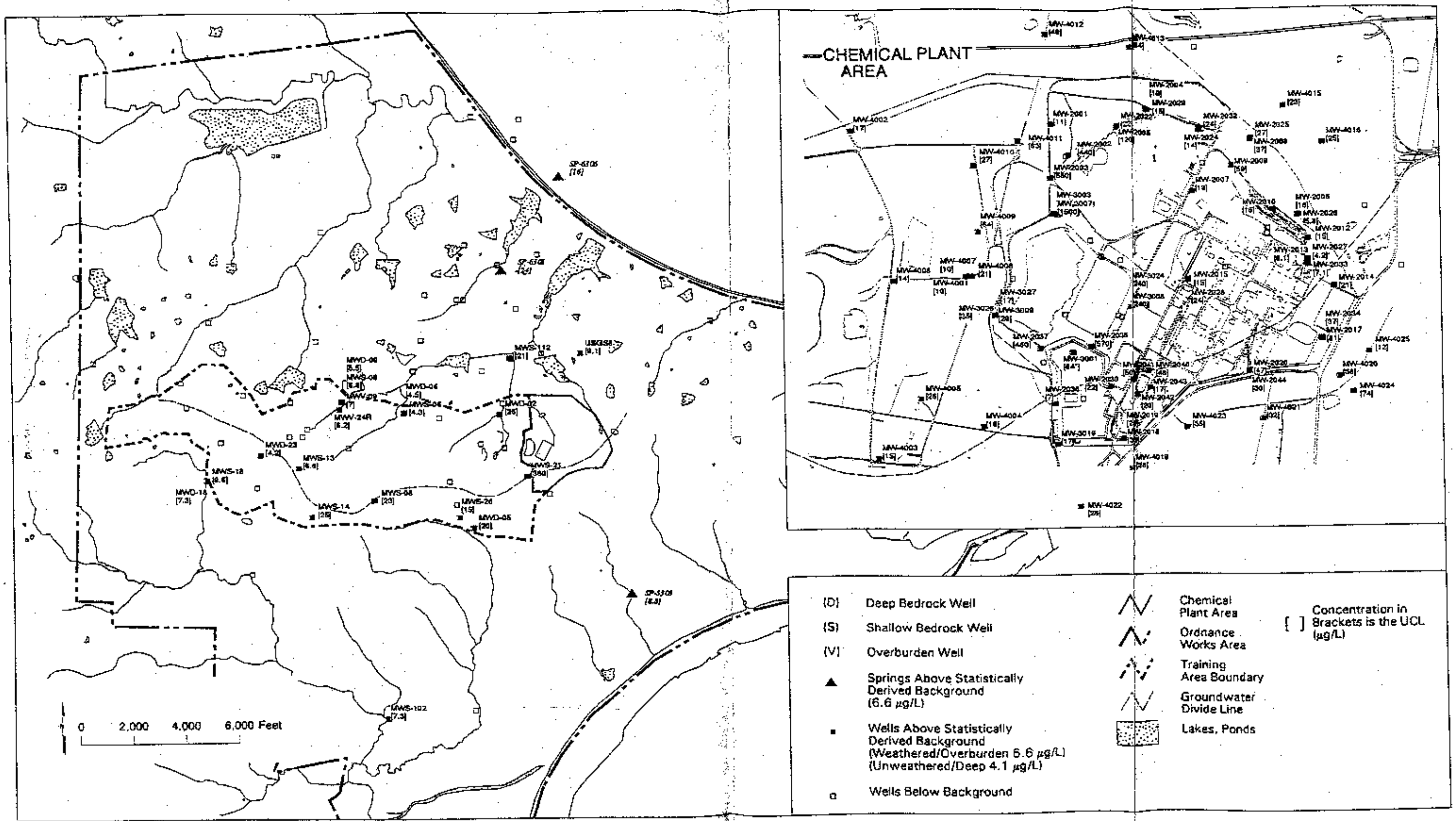


FIGURE 4.3 Distribution of Lithium at the Chemical Plant Area and the Ordnance Works Area

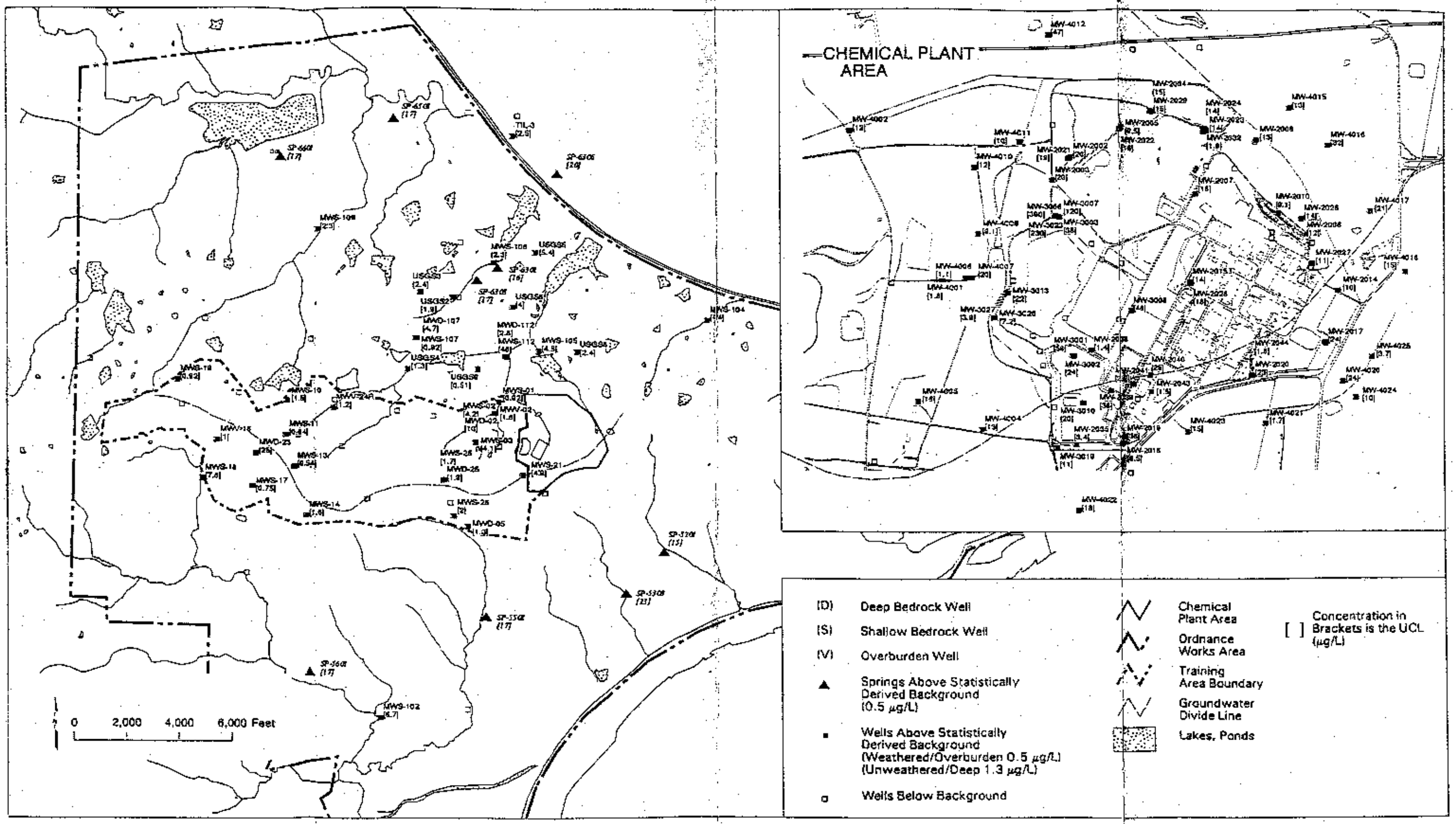


FIGURE 4.4 Distribution of Molybdenum at the at the Chemical Plant Area and the Ordnance Works Area

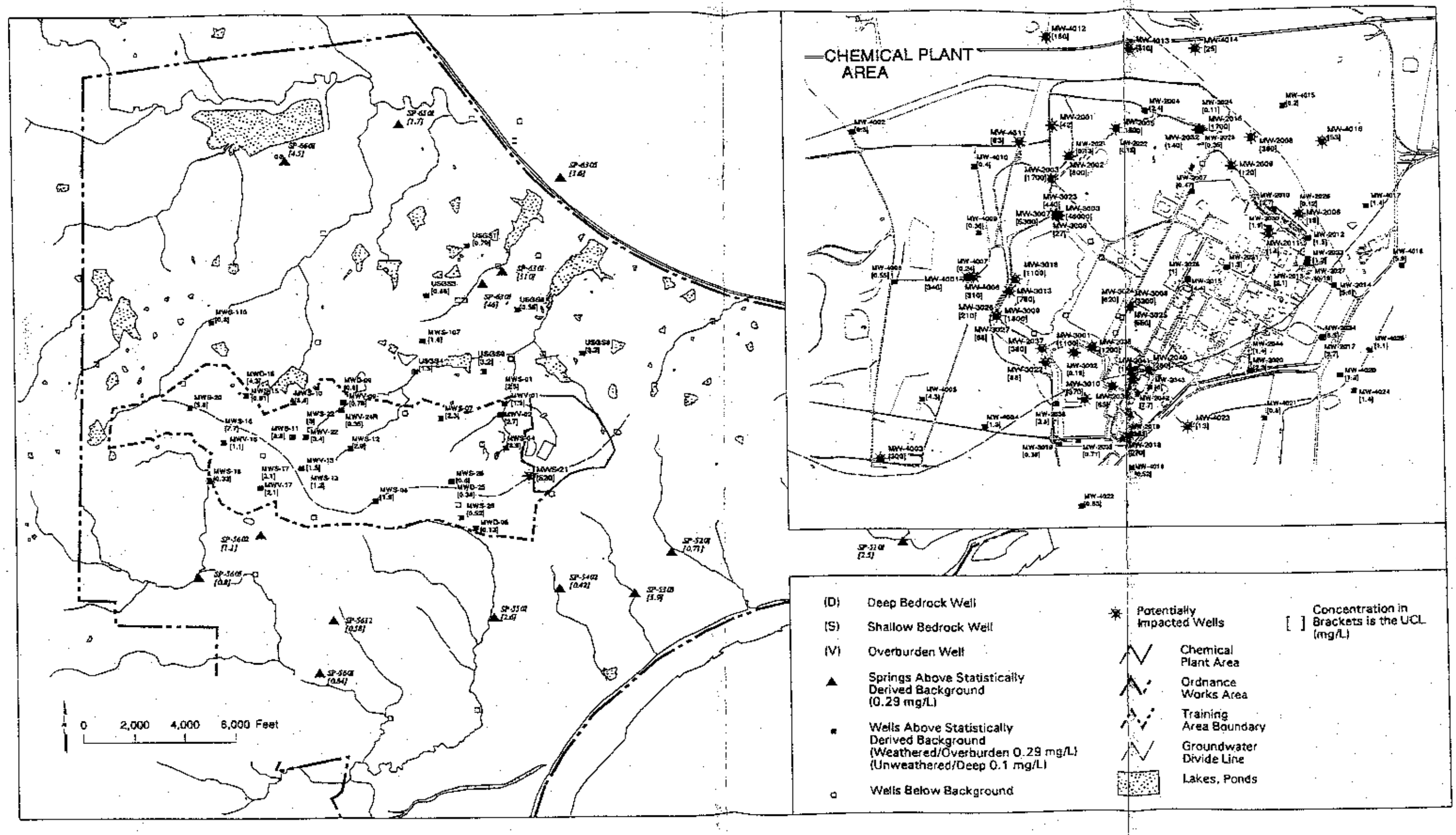


FIGURE 4.5 Distribution of Nitrate Based on Data Collected Since 1987 at the Chemical Plant Area and the Ordnance Works Area

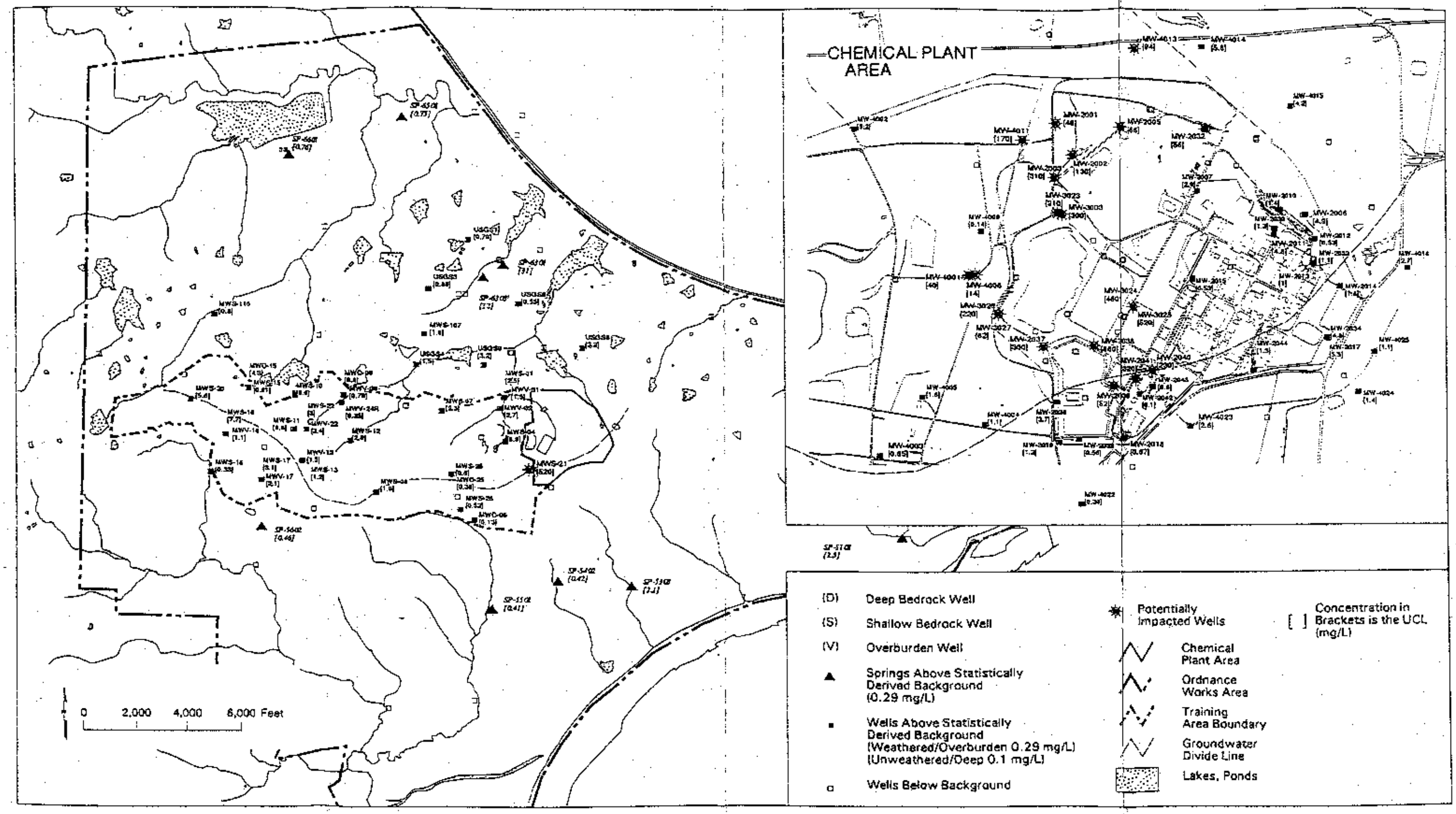


FIGURE 4.6 Distribution of Nitrate Based on Data Collected Since 1995 at the Chemical Plant Area and the Ordnance Works Area

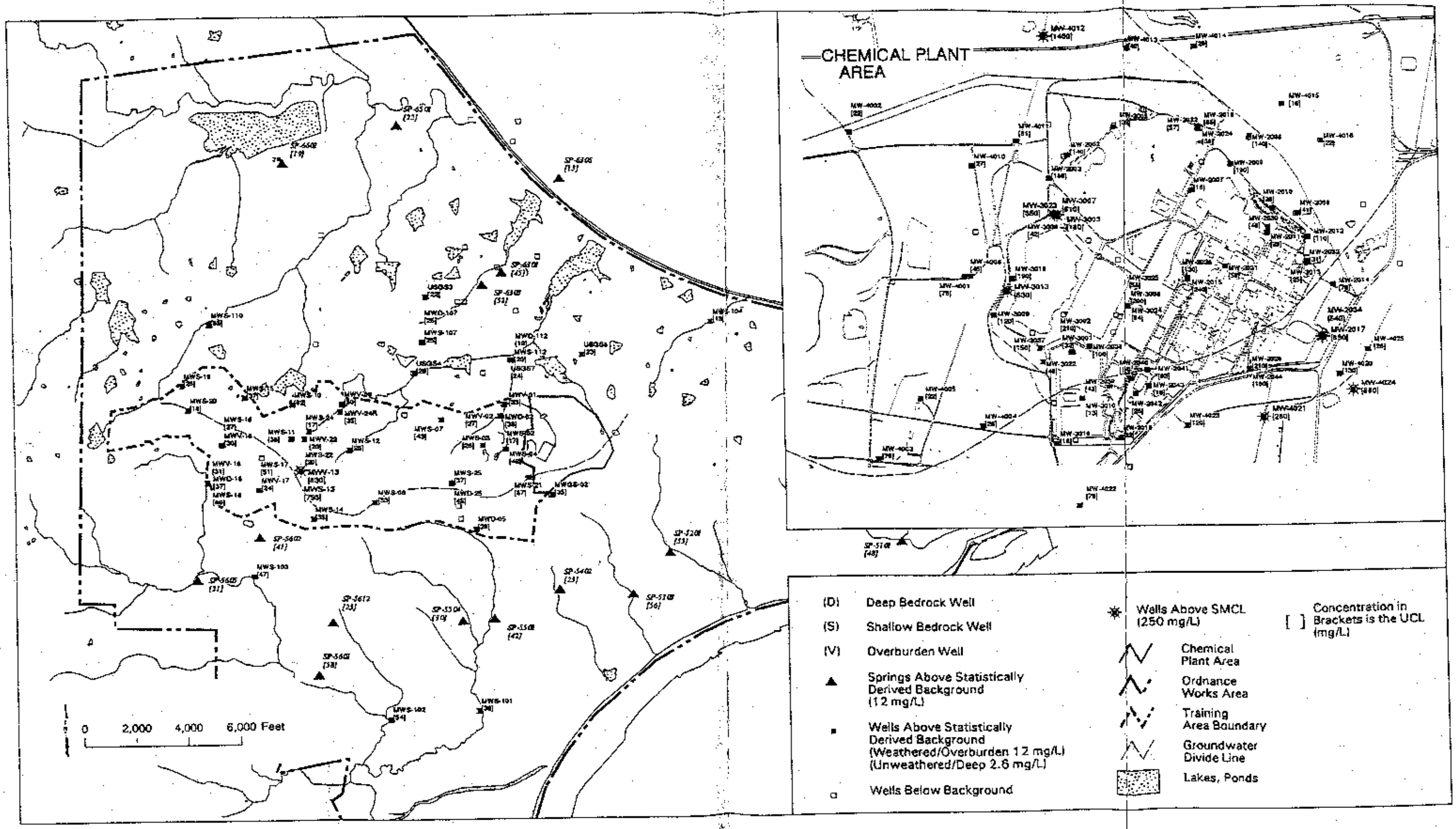


FIGURE 4.7 Distribution of Sulfate at the Chemical Plant Area and the Ordnance Works Area

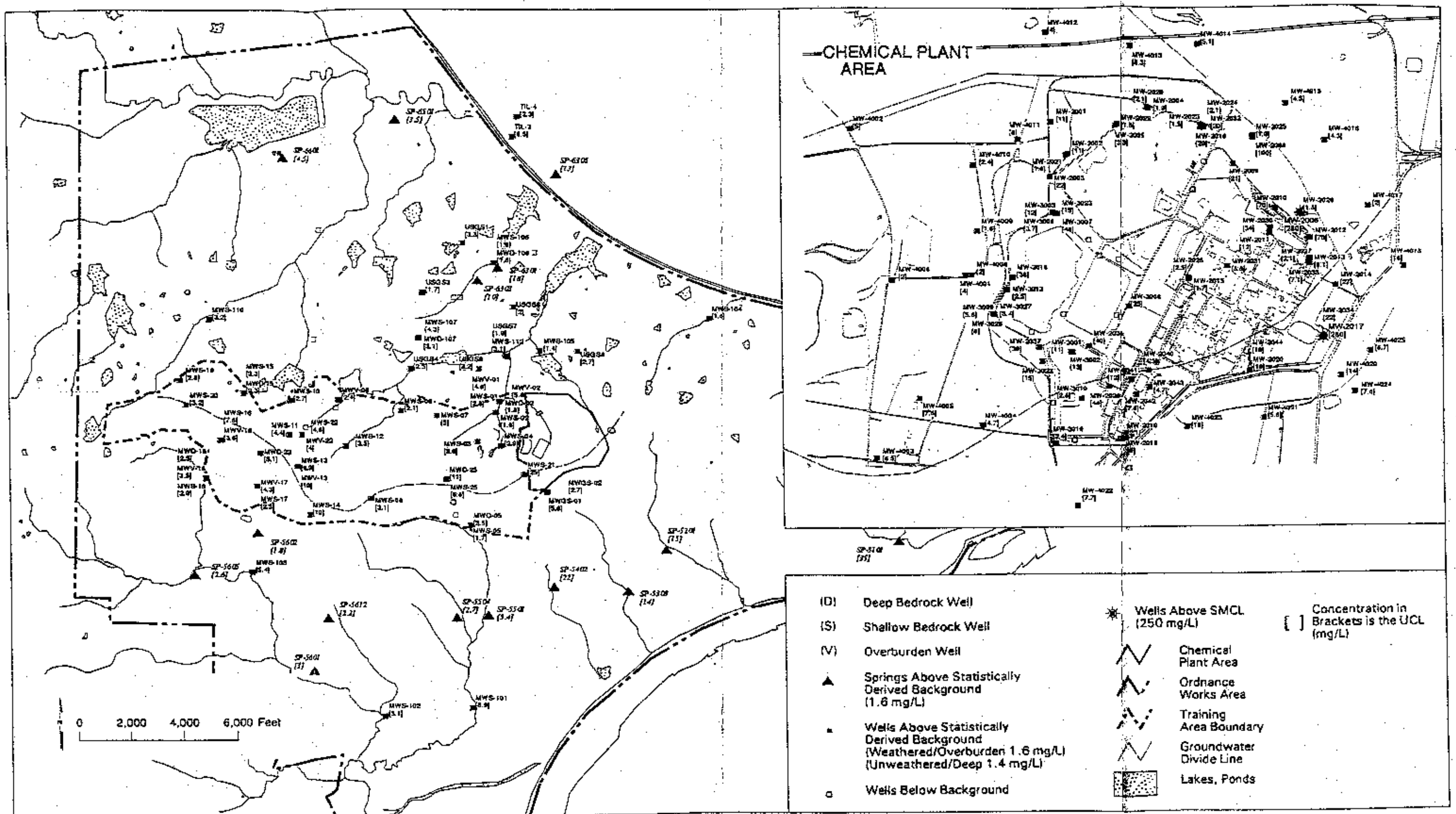


FIGURE 4.8 Distribution of Chloride at the Chemical Plant Area and the Ordnance Works Area

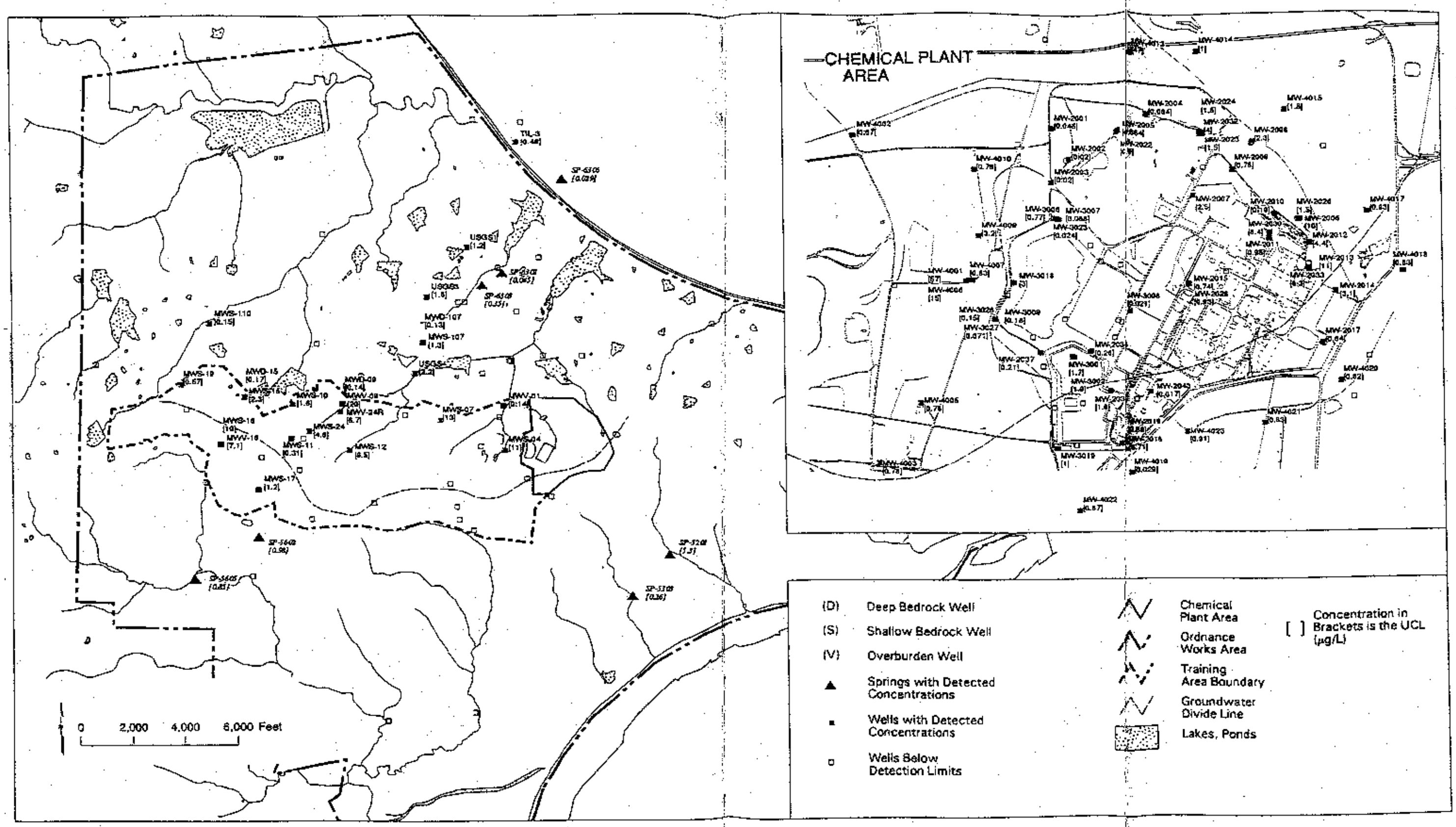


FIGURE 4.9 Distribution of 1,3,5-TNB at the Chemical Plant Area and the Ordnance Works Area

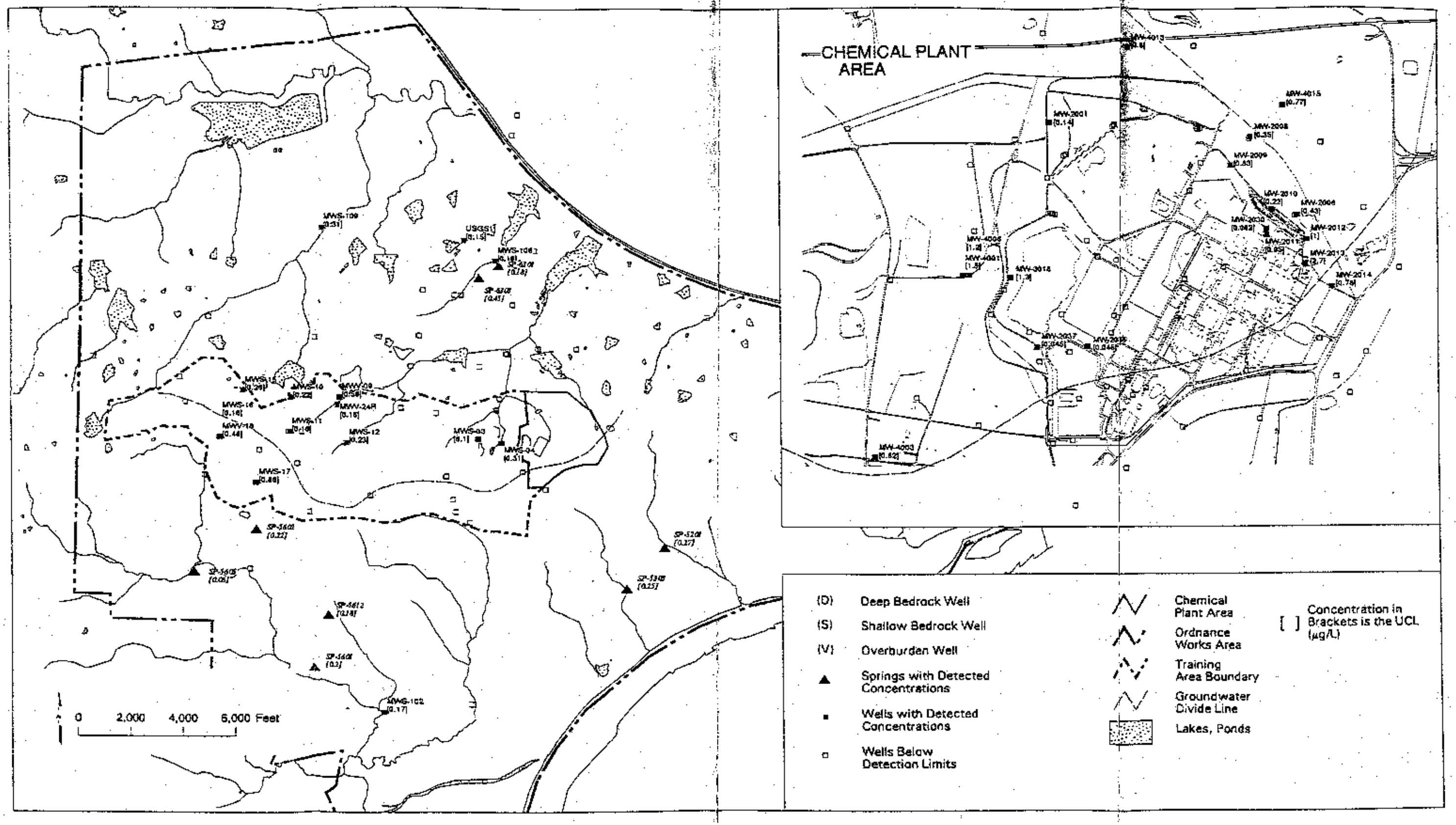


FIGURE 4.10 Distribution of 1,3-DNB at the Chemical Plant Area and the Ordnance Works Area

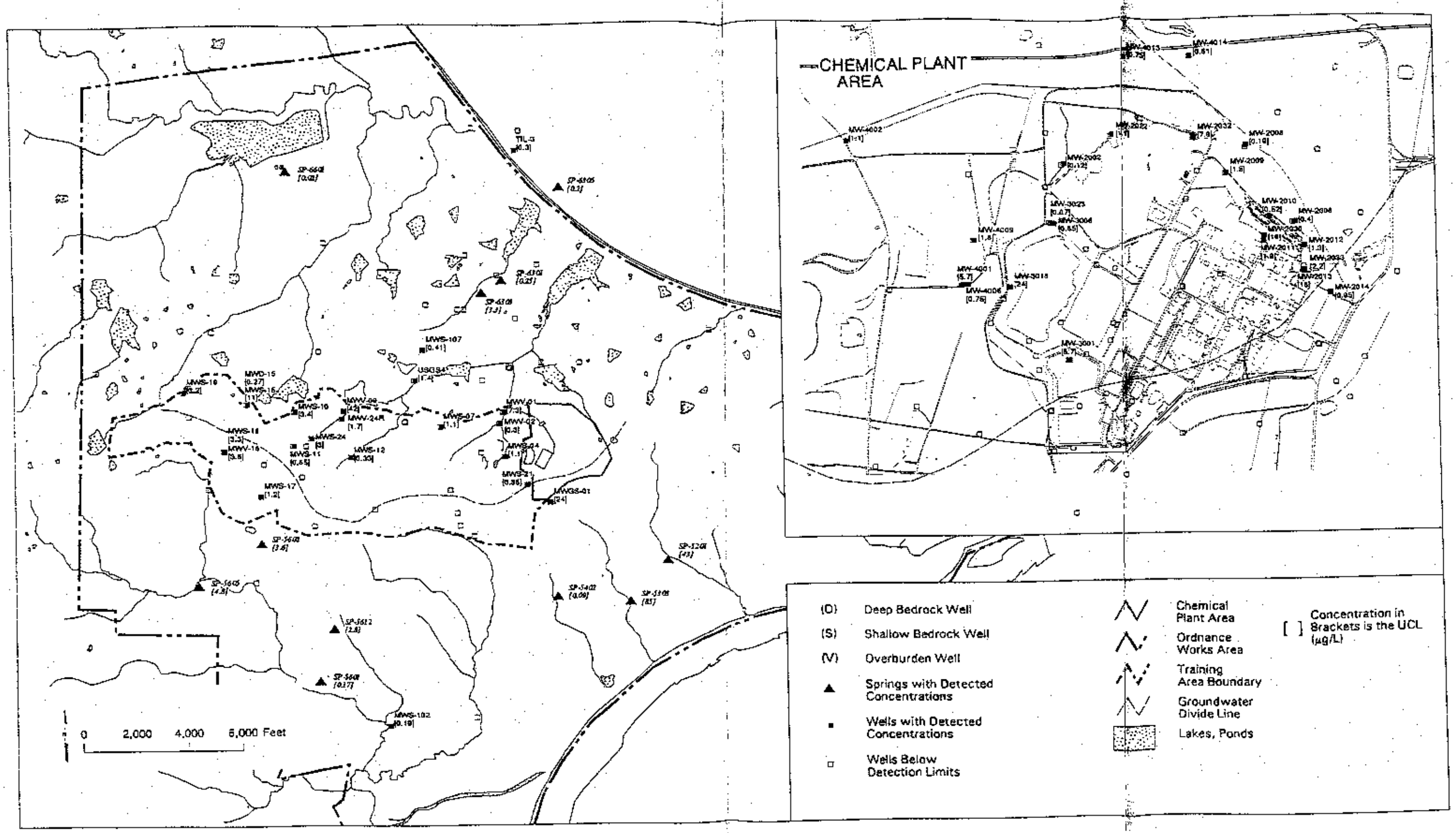


FIGURE 4.11 Distribution of 2,4,6-TNT at the Chemical Plant Area and the Ordnance Works Area

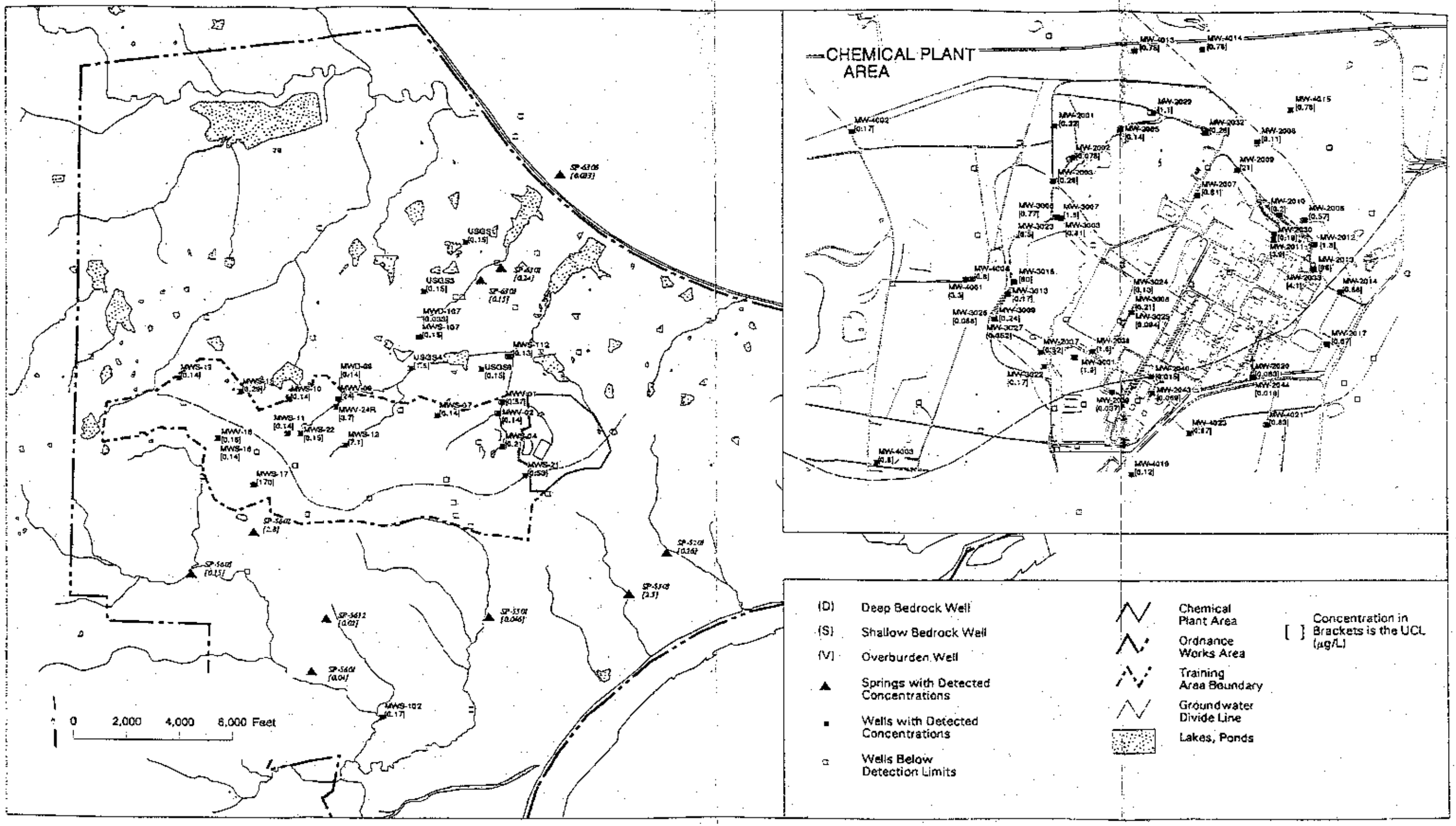


FIGURE 4.12 Distribution of 2,4-DNT at the Chemical Plant Area and the Ordnance Works Area

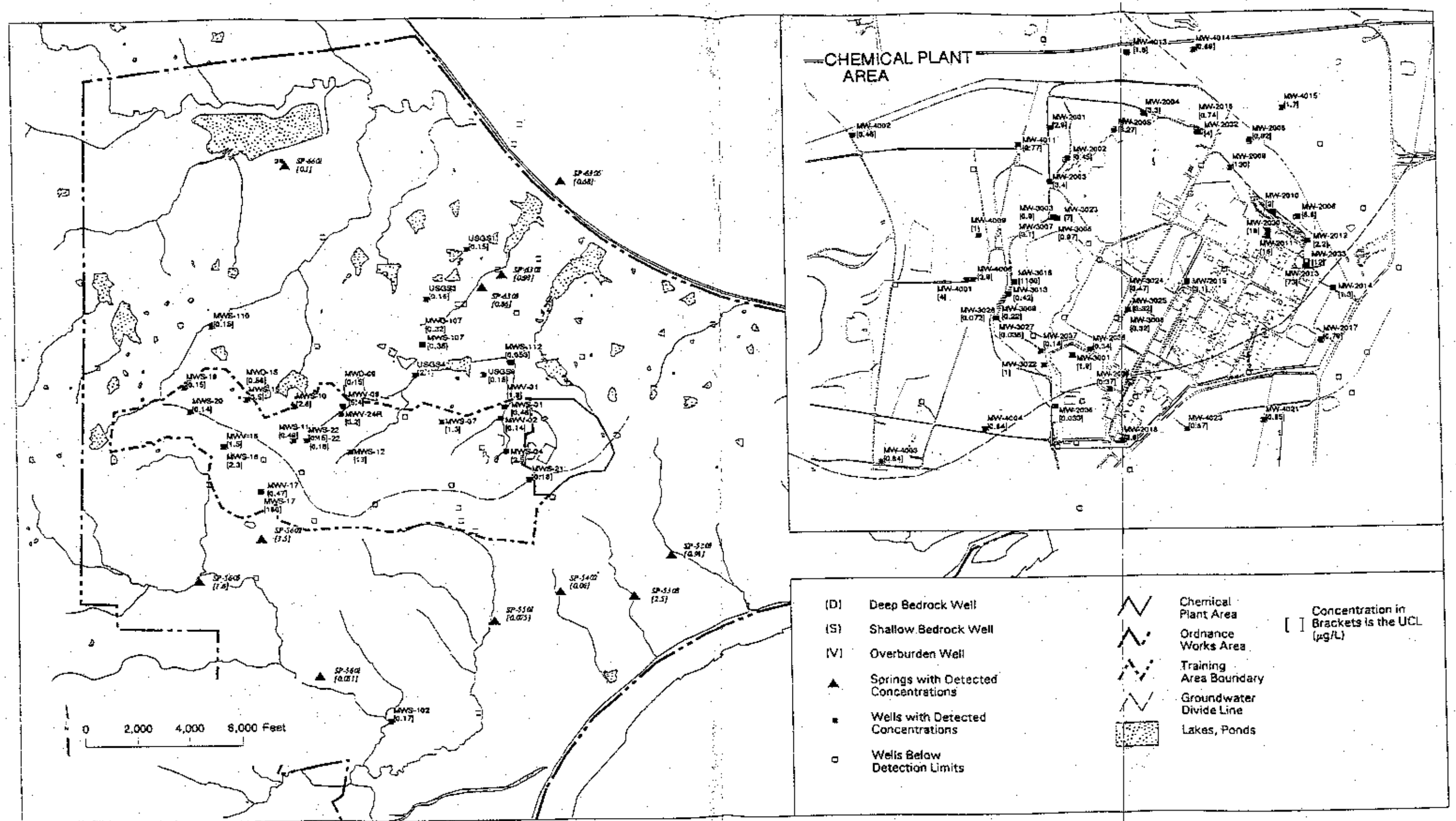


FIGURE 4.13 Distribution of 2,6-DNT at the Chemical Plant Area and the Ordnance Works Area

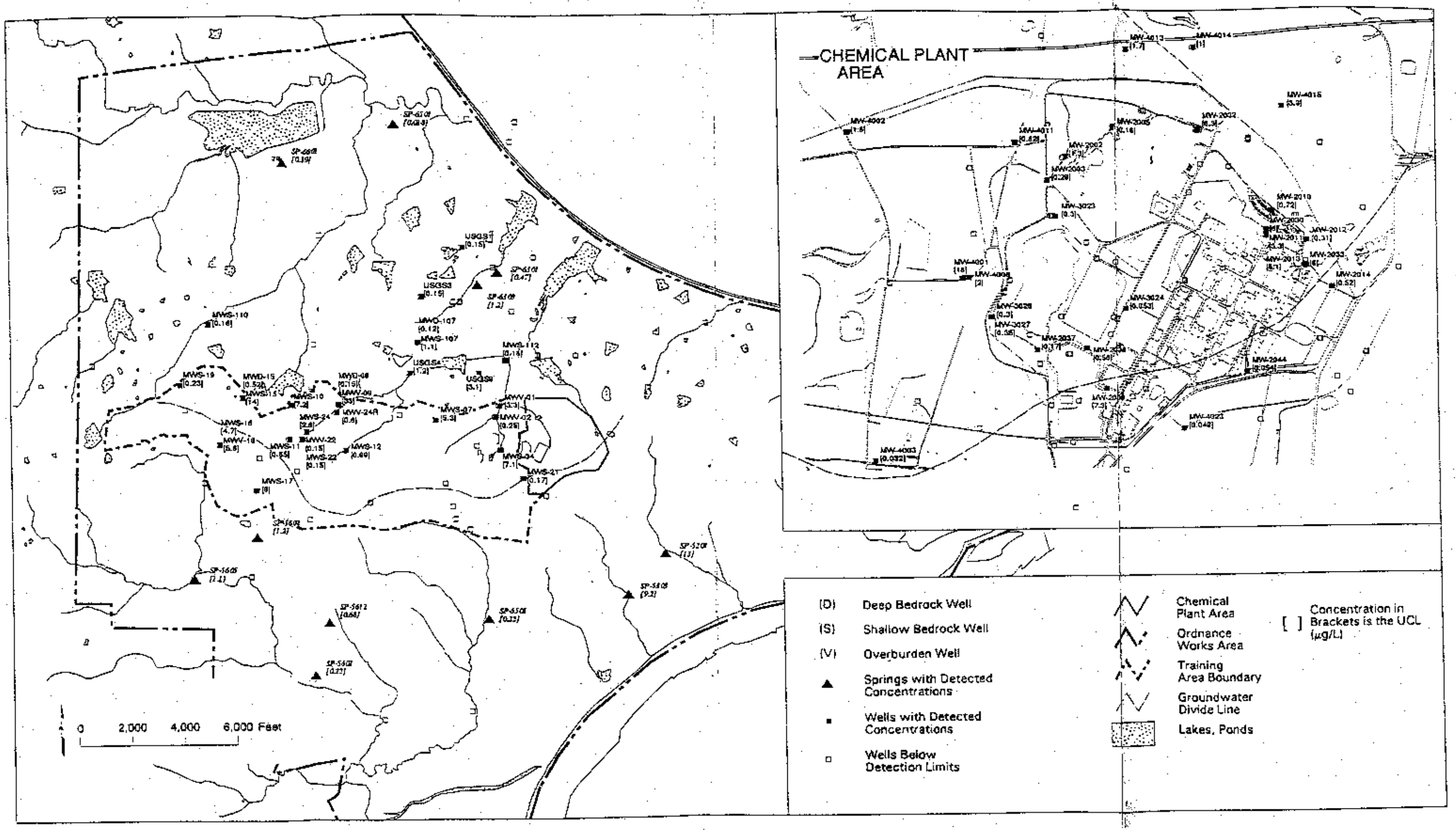


FIGURE 4.14 Distribution of 2-Amino-4,6-DNT at the Chemical Plant Area and the Ordnance Works Area

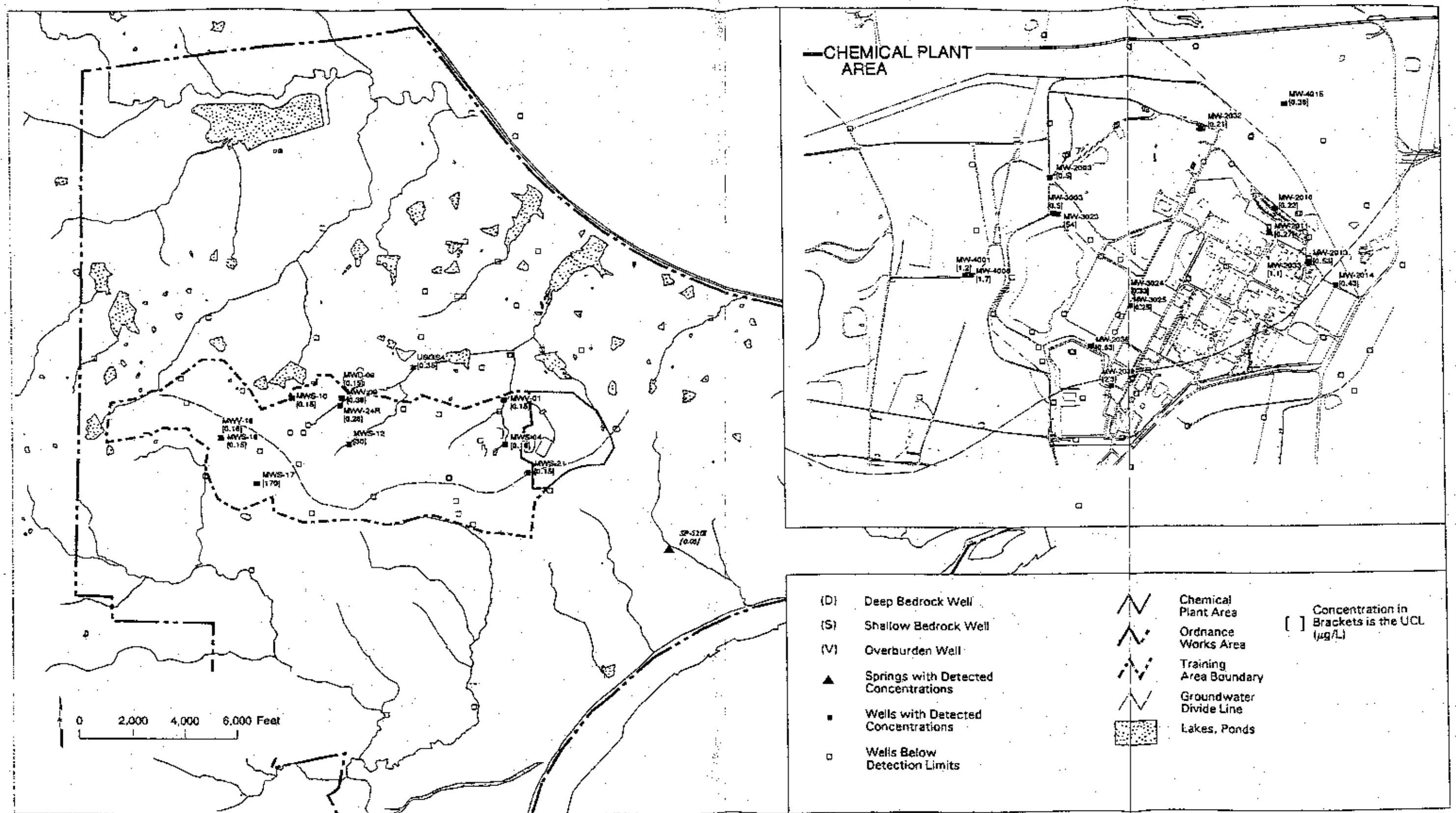


FIGURE 4.15 Distribution of 2-Nitrotoluene at the Chemical Plant Area and the Ordnance Works Area

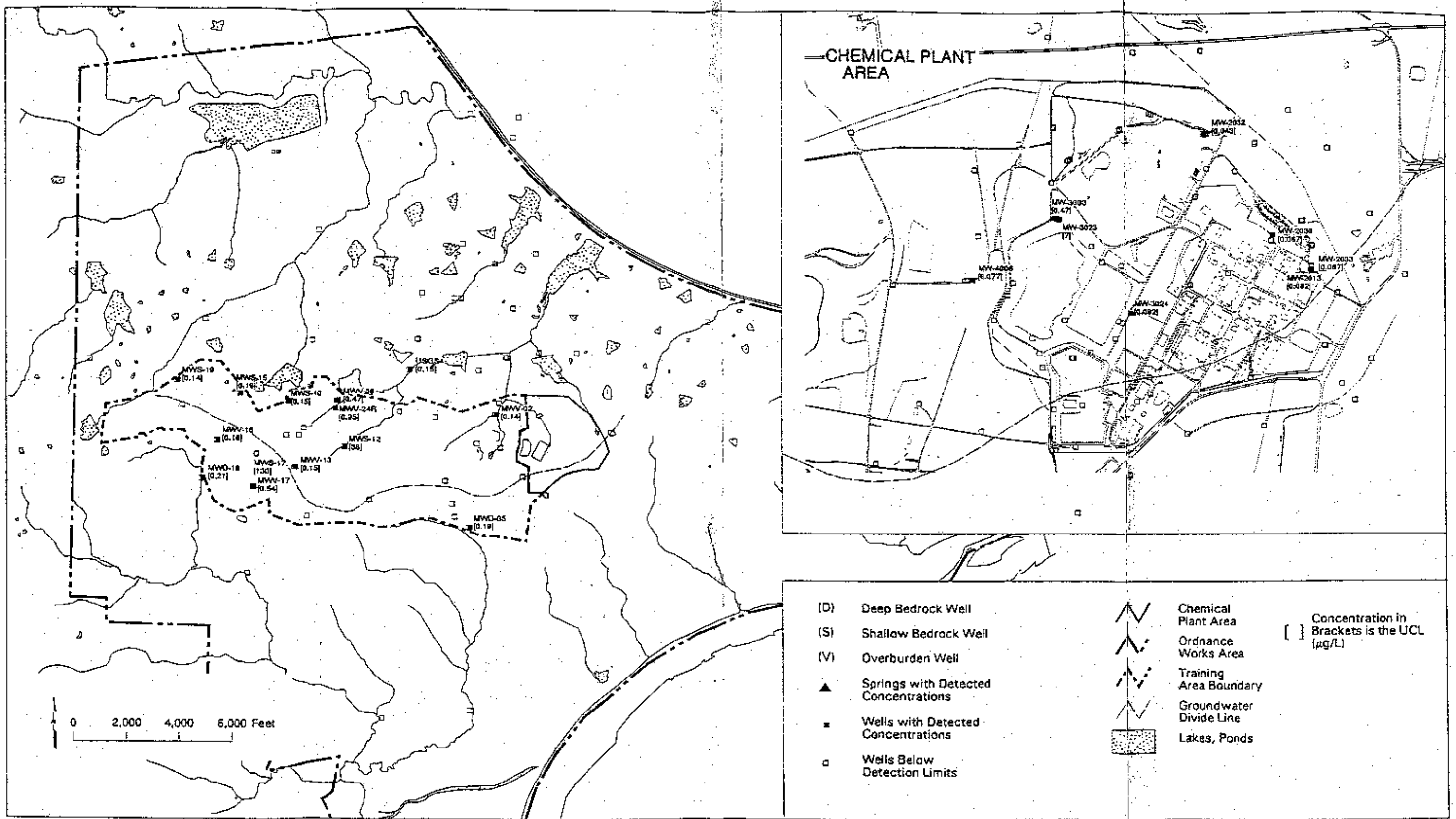


FIGURE 4.16 Distribution of 3-Nitrotoluene at the Chemical Plant Area and the Ordnance Works Area

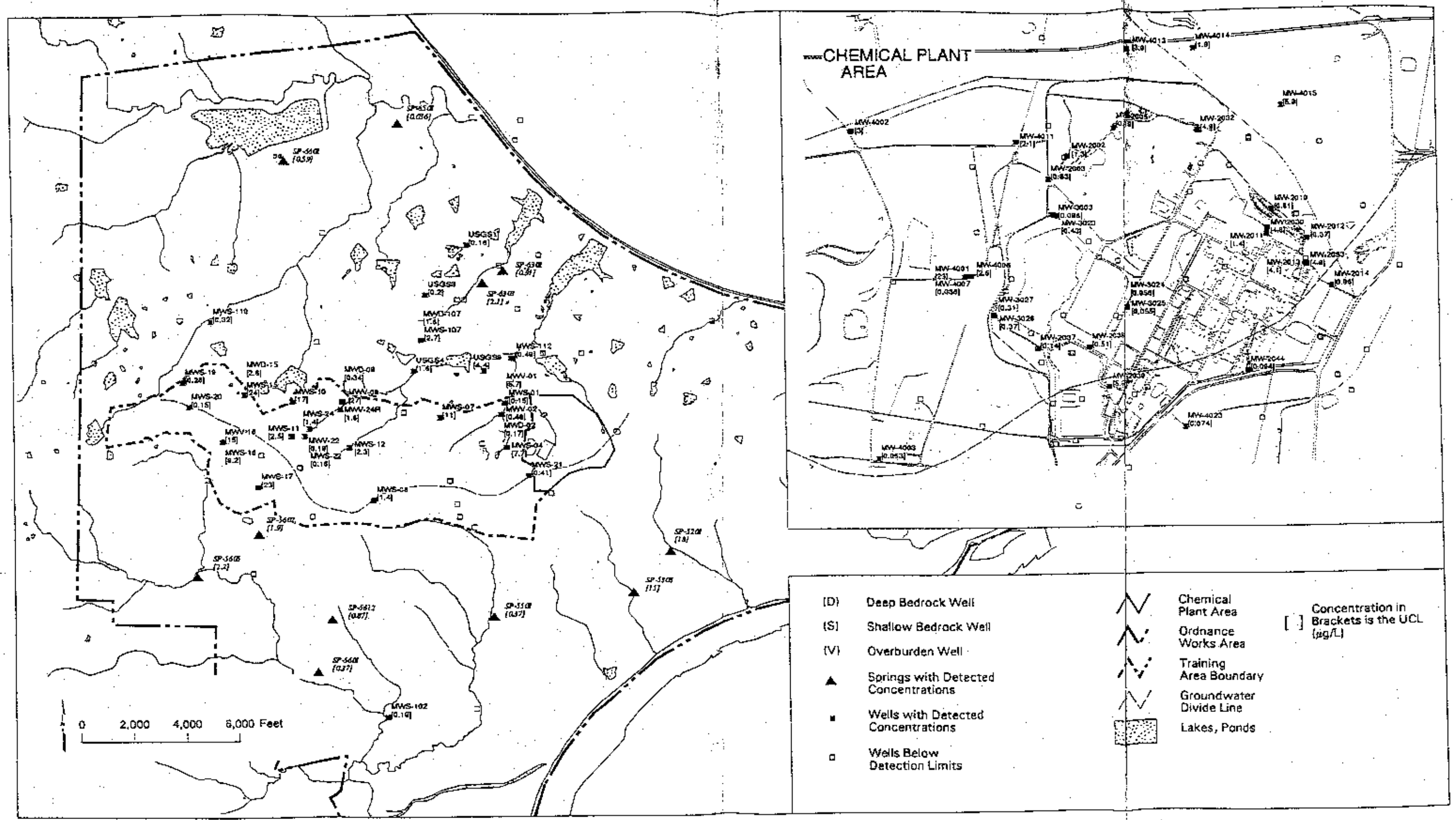


FIGURE 4.17 Distribution of 4-Amino-2,6-DNT at the Chemical Plant Area and the Ordnance Works Area

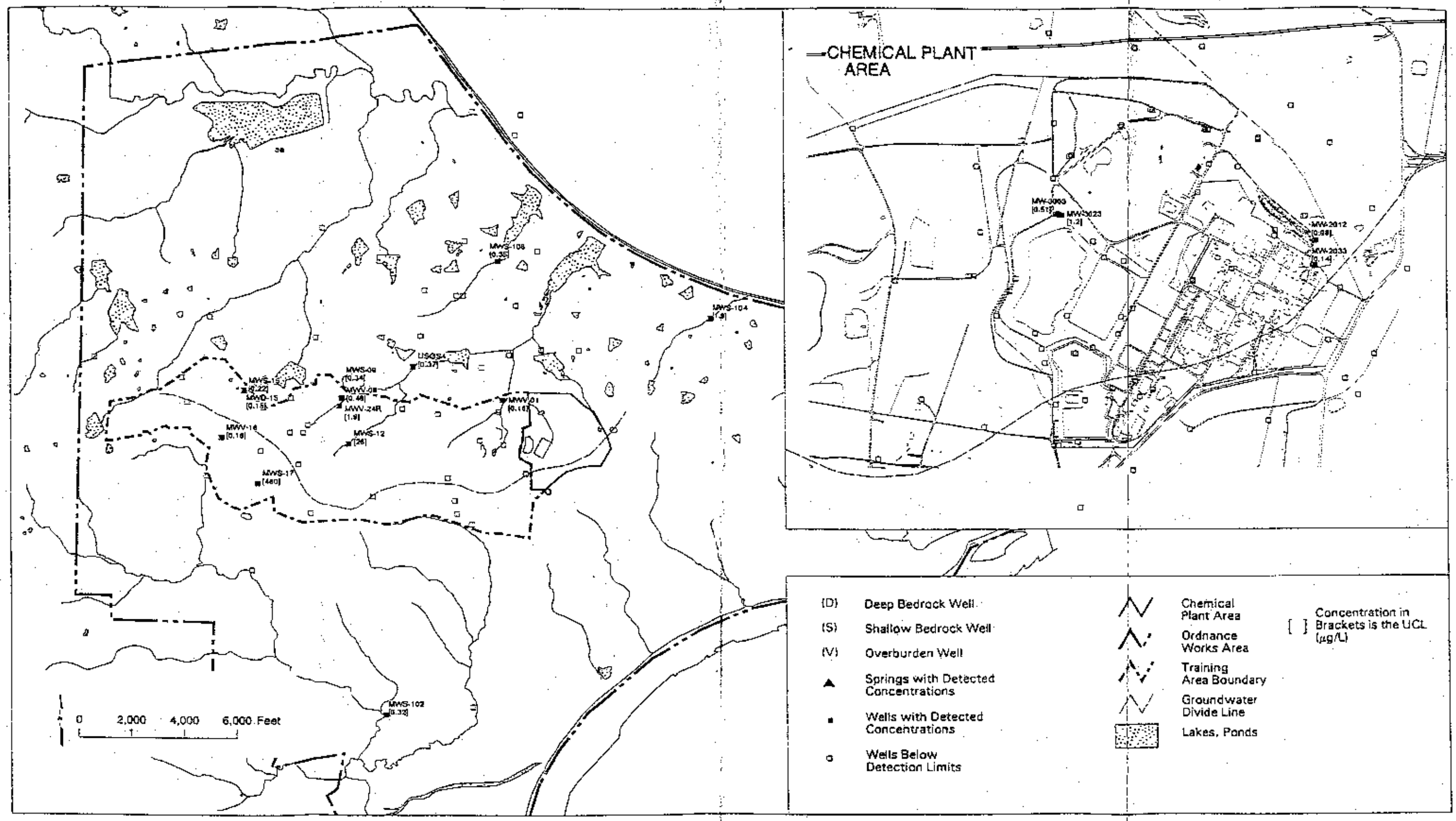


FIGURE 4.18 Distribution of 4-Nitrotoluene at the Chemical Plant Area and the Ordnance Works Area

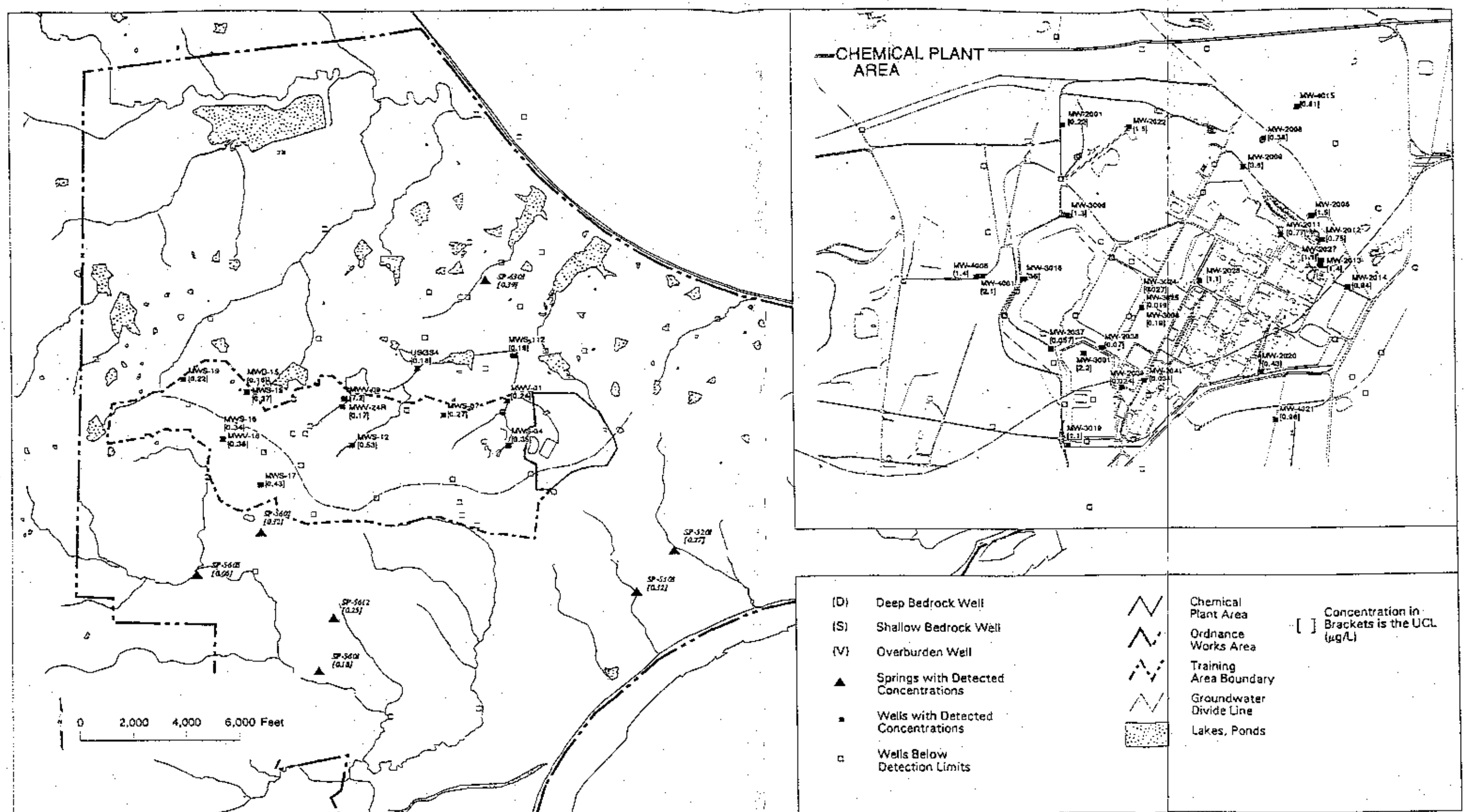


FIGURE 4.19 Distribution of Nitrobenzene at the Chemical Plant Area and the Ordnance Works Area

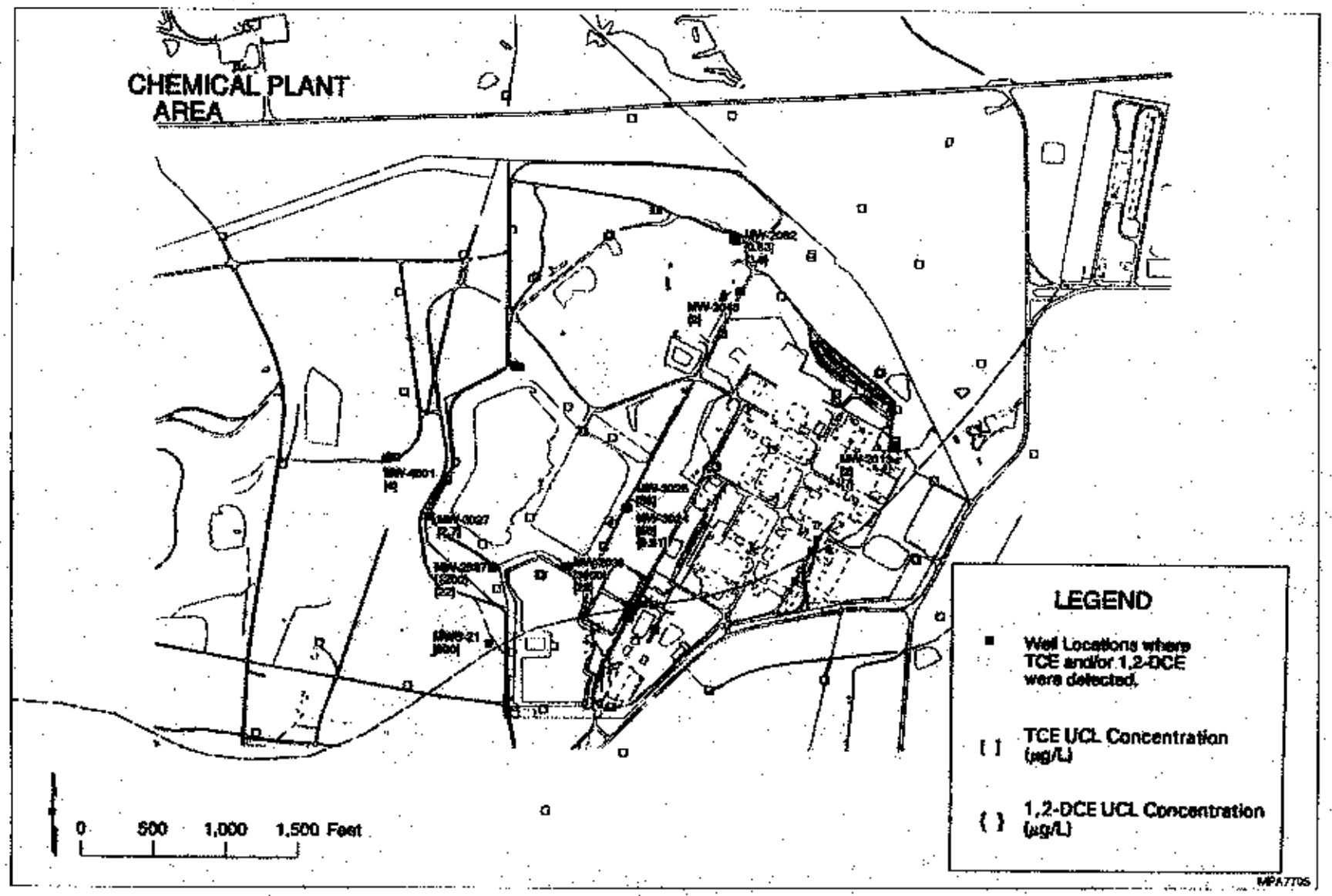


FIGURE 4.20 Distribution of TCE and 1,2-DCE at the Chemical Plant Area and the Ordnance Works Area

located just west of the chemical plant area downgradient of the raffinate pits. However, the UCL for this well is biased high due to an anomalous uranium concentration detected during the early stages of the monitoring program. A similar outlier was also detected for MW-4005. Recent data collected for these wells are similar to background levels. Monitoring wells MW-3009 and MW-3008, located adjacent to the raffinate pits, were originally constructed as open hole wells and open to both the weathered and unweathered units. In 1994, these wells were both retrofitted. Monitoring well MW-3008 was retrofitted with MW-3024, which is only open to the unweathered unit. In addition, a new well, MW-3025, was installed adjacent to MW-3024 and is open only to the weathered unit. Similarly, MW-3009 was retrofitted with MW-3026, which is open only to the unweathered unit. A new well, MW-3027, was installed adjacent to MW-3026 and is open primarily to the unweathered unit. Concentrations in these retrofit wells have been much lower (maximum concentration of 12 pCi/L in the weathered wells and 6.5 pCi/L in the unweathered) than before the wells were retrofitted. Monitoring well MW-4024, located on the southeastern boundary of the chemical plant, is a new well installed to delineate the boundary of contamination flowing south from MW-4020. The maximum uranium level detected in this well was 60 pCi/L, which may be a result of contamination from the bentonite grout used in the well installation (see Chapter 7). Concentrations in this well have declined since installation; the most recent data collected indicated low levels (i.e., 4.1 and 7.1 pCi/L).

Recent data indicate the highest levels of uranium located in MW-3003, located downgradient of the raffinate pits. Only three wells (including MW-4024) have UCLs which are greater than the proposed MCL for uranium of 14 pCi/L.

The contaminant distribution for lithium is shown in Figure 4.3. Lithium was detected throughout the groundwater system; higher concentrations were detected in the vicinity of, or downgradient from, the raffinate pits and the Ash Pond area. Monitoring wells with UCL lithium concentrations greater than 100 µg/L include MW-3003, MW-3007, MW-3008, MW-3023, MW-2002, MW-2003, MW-2005, MW-2037, MW-2038 , and MWS-12 (Figure 4.3). All of these wells are open to the weathered unit, and the maximum lithium concentration detected from these wells was 1,500 µg/L in MW-3007. The UCL lithium concentrations on the training area (with the exception of MWS-21 and MWD-02) ranged from 1.2 to 21 µg/L in the weathered unit, from 2.2 to 26 µg/L in the unweathered unit, and from 1.1 to 20 µg/L in the deeper unit. Because lithium is associated with the ores that were processed at the chemical plant, it is reasonable that elevated levels of lithium would be detected downgradient of the raffinate pits where elevated levels of lithium have been found in the sludges and surface water. Lithium detected in other areas of the groundwater system may be representative of background levels. Although some wells contain high levels of lithium, these levels must be viewed in the context of the limited background data collected for lithium.

The contaminant distribution for molybdenum is shown in Figure 4.4. Molybdenum concentrations are also widespread in the groundwater system but unlike lithium and uranium,

molybdenum was not detected in a large percentage of wells (only in about 30% of the wells). At the chemical plant area, the highest molybdenum concentrations were detected from MW-3023 (UCL concentration of 230 µg/L), MW-3006 (UCL concentration of 390 µg/L), and MW-3007 (maximum concentration of 120 µg/L). Among the other wells on the chemical plant area, the UCL molybdenum concentrations ranged from 1.4 to 58 µg/L. On the ordnance works area, the UCL molybdenum concentrations ranged from 0.50 to 25 µg/L; the highest UCL concentration was from well MWS-112 (47 µg/L), which is located downgradient of the raffinate pits.

4.1.2.2 Inorganic Anions

Contaminant distributions for nitrate are depicted in Figures 4.5 and 4.6. As was done for uranium, a separate map is presented based on recent data (Figure 4.6). The recent data are believed to represent a more accurate presentation of current contamination levels. Wells that are considered to be impacted are designated in the distribution maps; these wells were determined on the basis of data evaluation, source areas, the MCL for nitrate (10 mg/L), and groundwater flow.

Very high levels of nitrate are present in areas near the raffinate pits and Ash Pond; the highest nitrate levels were detected from wells MW-3003 (UCL of 46,000 mg/L) and MW-3007 (UCL of 5,300 mg/L). The UCL for MW-3003 is exceptionally high because of an anomalous, high concentration detected prior to 1990. In areas where nitrate is elevated, concentrations tend to decrease with depth. At the chemical plant area, nitrate levels in wells open to the unweathered unit were all below the nitrate MCL concentration of 10 µg/L, with the exception of four wells; MW-3024, MW-3026, MW-3006, and MW-4012 (Figure 4.5). Recent data indicate background levels of nitrate in MW-4012. The extent of nitrate contamination is primarily limited to the chemical plant area; contamination also extends beyond the site boundaries to the north and west. Wells on the middle and western portions of the training area have very low levels of nitrate, and are not considered to be impacted.

The contaminant distribution for sulfate is shown in Figure 4.7. Sulfate contamination is widespread throughout the groundwater system. Ten wells had UCL sulfate concentrations greater than the sulfate SMCL of 250 mg/L. Two of these wells, MWV-13 (830 mg/L) and MWS-13 (750 mg/L), are located on the ordnance works area about 50 yards downgradient of Sellite Plant 2. Wells on the chemical plant area and the adjacent area for which the UCL for sulfate exceeded the sulfate SMCL concentration included MW-3013 (830 mg/L), MW-4012 (1,400 mg/L), MW-2017 (850 mg/L), MW-2034 (540 mg/L), MW-3007 (610 mg/L), MW-3023 (350 m/L), MW-4021 (280 mg/L), and MW-4024 (680 mg/L) (Figure 4.7).

The contaminant distribution for chloride is shown in Figure 4.8. Chloride contamination in groundwater is generally low; higher concentrations were found predominately in wells open to the weathered unit near the eastern boundary of the chemical plant area. The highest levels were

found in MW-2006 (280 mg/L), MW-2008 (190 mg/L), MW-2012 (70 mg/L) and MW-2017 (280 mg/L). Chloride levels on the ordnance works area are low.

4.1.2.3 Nitroaromatic Compounds

The distribution of nitroaromatic compounds in groundwater beneath the chemical plant and ordnance works areas is shown in Figures 4.9 to 4.19. Nitroaromatics do not appear to be distributed throughout the groundwater system but rather occur sporadically at low levels across the system; higher levels generally occur in the overburden and weathered units. Within the overburden unit, the highest levels of nitroaromatic contamination were found primarily in MW-3018 and MWV-09. The highest UCL concentrations of the primary nitroaromatic compounds were estimated for well MW-3018, which is located on the chemical plant area (80 µg/L 2,4-DNT; 1,100 µg/L 2,6-DNT; and 31 µg/L nitrobenzene). Lower UCL concentrations were detected in MWV-09 (24 µg/L 2,4-DNT; 5.4 µg/L 2,6-DNT; and 7.2 µg/L nitrobenzene). Well MWV-09 also had the highest UCL concentrations of 2-amino-4,6-DNT (33 µg/L) and 4-amino-2,6-DNT (27 µg/L).

Within the weathered unit, the most frequently detected nitroaromatic compounds were 2,4-DNT; 2,6-DNT; 1,3,5-TNB; 2,4,6-TNT; and the amino-DNT degradation compounds. The distribution patterns are relatively similar among the DNT compounds (Figures 4.9 to 4.19). The highest concentrations of these compounds were found at the chemical plant in the Frog Pond area and in the central portion of the training area. The highest UCL concentrations were found in MWS-17 (170 µg/L 2,4-DNT and 180 µg/L 2, 6-DNT). At the chemical plant area, the highest concentrations were detected in the Frog Pond area in MW-2013 (96 µg/L 2,4 -DNT) and MW-2009 (130 µg/L 2,6-DNT). These wells are located where both wash and grainer houses previously existed. On the training area, the highest UCL concentrations of the amino-DNT degradation compounds were found in MWS-15 (14 µg/L 2-amino-4,6-DNT and 24 µg/L 4–amino-2,6-DNT) and MW-4001 (18 µg/L 2-amino-4,6-DNT and 23 µg/L 4-amino-2,6-DNT).

The highest concentrations of 1,3,5 -TNB (Figure 4.9) and 2,4,6,-TNT (Figure 4.11) were found in wells at the training area and at the chemical plant area in the vicinity of Frog Pond. The highest UCL for 1,3,5,-TNB was estimated for MW-4001 (57 µg/L); the highest UCL for 2,4,6,-TNT was estimated for MW-2030 (19 µg/L).

Highest concentrations of the remaining nitroaromatic degradation products were detected primarily in wells MWS-12 and MWS-17, which are located on the central portion of the training area. The UCL concentrations of 2-NT, 3-NT, and 4-NT were 170 µg/L, 130 µg/L, and 460 µg/L, respectively, at MWS-17, and 30 µg/L, 38 µg/L, and 26 µg/L, respectively, at MWS-12.

In the unweathered and deeper units of the aquifer, nitroaromatic compounds were detected at much lower frequencies and concentrations than in the more shallow units.

4.1.2.4 Volatile Organic Compounds

Sampling of VOCs in groundwater was initiated in response to detection of hexane during workplace monitoring in the headspace of sludge tanks at the Chemical Stabilization\Solidification Pilot Plant, to determine whether contamination in sludge may have migrated into groundwater. Two monitoring wells near the raffinate pits (i.e., MW-3025 and MW-2038) were sampled. Results indicated the presence of trichloroethylene (TCE) and 1,2-dichloroethene (1,2-DCE); no other VOCs were detected. A sitewide sampling was conducted starting in mid-1996 for VOCs in monitoring wells and three springs (i.e., Burgermeister Spring, and SP-5303 and SP-5304 in the Southeast Drainage) at the chemical plant area. TCE was detected in four of the 45 wells monitored. A maximum concentration of 9,000 µg/L was detected in MW-2038. Estimated values below the detection limit were also indicated for three other wells. Concentrations of 1,2-DCE were detected in two wells in the vicinity of the raffinate pits; a maximum concentration of 39 µg/L was detected in MW-2038. Samples from MW-2013, located near Frog Pond, also contained 1,2-DCE at levels ranging from 7 to 16 µg/L. Estimated values ranging from 1 to 5 µg/L were reported for two additional wells. Four newly installed compliance wells for the disposal cell were also monitored for VOCs as part of the baseline sampling program for the disposal cell. An estimated 1,2-DCE value of 2 µg/L was reported for one of the wells (MW-2046).

In 1997, six wells located southwest of the chemical plant area were added to the monitoring program. TCE was detected in MWS-21, located on the training area adjacent to the southwestern boundary of the chemical plant area. No other VOCs were detected in groundwater. In addition, no VOCs were detected in the springs. The presence of TCE and DCE is believed to be a recent occurrence; sampling for VOCs before 1990 indicated only one low-level detection of TCE in MW-2030 (7 µg/L).

The distribution of contamination in groundwater is illustrated in Figure 4.20 for TCE and 1,2-DCE. In general, detections were limited to the area south and southeast of Raffinate Pits 3 and 4. The contamination is contained in the saturated overburden and weathered portion of the aquifer and appears to be migrating to the southwest. On the basis of the monitoring data, it appears that additional releases are not now occurring. Monthly sampling of groundwater wells in the vicinity of the raffinate pits (including wells on the southwestern portion of the training area) is planned through the end of 1997 to monitor the migration of these compounds. The springs (e.g., Burgermeister Spring, SP-6303, SP-5303, and SP-5304) will also continue to be monitored.

Possible sources of groundwater contamination include waste drums recently removed from the southeastern corner of Raffinate Pit 4 and contaminated soils and sludges in Raffinate Pits 3 and 4. Oil residues from some of the drums contained TCE at levels up to 280,000 µg/kg. Sampling of soil and sludge in the pits has not indicated the presence of any significant source of VOC contamination; two samples from Raffinate Pit 3 indicated low levels of TCE, ranging from 12 to 23 µg/L. It is suspected that TCE occurs in isolated pockets, and it is possible that the source may

already have been depleted. Additional sampling with a soil gas technology was done to investigate the presence of remaining sources (MK-Ferguson Company and Jacobs Engineering Group 1997b). Soil gas within the overburden material was analyzed to determine if the soils or underlying groundwater is contaminated with TCE. The results of the soil gas sampling did not identify the presence of remaining sources that would have contributed to the groundwater contamination. A few low-level concentrations of TCE were detected at five locations on the training area, west and south of the raffinate pits. Concentrations ranged from 1.2 to 2.9 ppb. Soil samples were also collected in these locations for analysis in the laboratory. Volatiles were not detected in any of the samples. The soil gas technology was also employed to sample groundwater in areas where saturated overburden is present. Groundwater was obtained at only one location west of Raffinate Pit 4, and volatiles were not detected above the detection limit (i.e., 1 ppb).

4.1.3 In Situ Sampling of Groundwater at the Southeast Drainage

Groundwater contamination in the Southeast Drainage (5300 drainage) was evaluated using in situ data collected from six locations in the lower portion of the drainage. The locations of the in situ samples are depicted in Figure 4.22, and the results of the in situ groundwater sampling are presented in Table 4.8. Samples were collected at the depth where water was first encountered and at depth; concentrations detected in the samples were compared with levels detected at the nearest discharge points, Springs 5303 and 5304 (Figures 3.9 and 4.21).

Uranium concentrations detected in the shallow groundwater samples (at the depth where groundwater was first encountered) ranged from 24 to 160 pCi/L. In deeper samples, lower levels of uranium were detected and ranged from 2.1 to 80 pCi/L. These concentrations were lower than the maximum concentrations but within the ranges detected in both Spring 5303 (67 to 370 pCi/L) and Spring 5304 (40 to 310 pCi/L). Sulfate was also detected in all samples; concentrations ranged between 30 and 220 mg/L. Sulfate levels were higher than concentrations detected in Springs 5303 and 5304 (i.e., a maximum of 67 mg/L), but were similar to levels detected further upstream in the drainage at Spring 5302.

Nitroaromatic compounds were only sampled at depths where groundwater was first encountered (Table 4.8). The nitroaromatic compounds 2,4-DNT, 2,6-DNT, and the amino-DNT compounds were detected in all samples at low levels ranging from 0.0080 to 3.3 µg/L. The compounds 1,3,5-TNB, 1,3-DNB, and 2,4,6-TNT were detected in three samples at levels ranging from 0.024 µg/L for 2,4,6-TNT to 0.12 µg/L for 1,3,5-TNB and 1,3-DNB. The concentrations were within or lower than the range of concentrations measured in Springs 5303 and 5304. For these springs, the highest concentrations were detected in Spring 5303; the maximum concentration for 2,4,6-TNT was 280 µg/L, and for both 2,4-DNT and 2,6-DNT it was 11 µg/L. Nitrobenzene and the nitrotoluene compounds were not detected in any of the in situ samples.

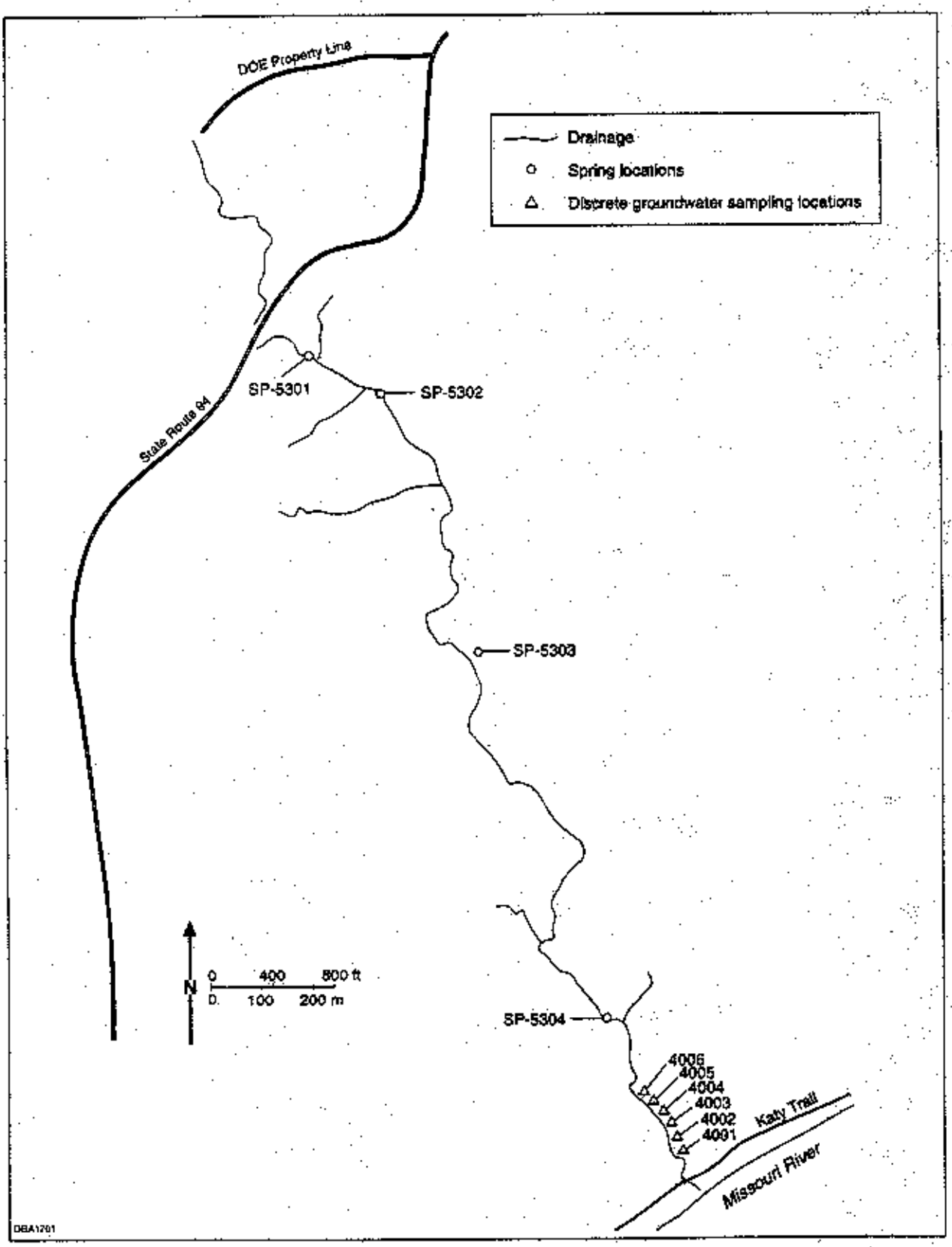


FIGURE 4.21 Location of In Situ Groundwater Sampling Sites in the Southeast Drainage

TABLE 4.8 Radiological and Chemical Concentrations for In Situ Groundwater Samples from the Southeast Drainage

Parameter	IS-4001[a] (15.0 ft)	IS-4001B[b] (34–38 ft)	IS-4002[a] (9.0 ft)	IS-4002B[b] (28–31.5 ft)	IS-4003[a] (5.0 ft)	IS-4003B[b] (7.5-9.0 ft)
Radiological (pCi/L)						
Uranium	87	2.1	140	6.1	160	71
Metals (µg/L)						
Antimony	ND[c]	3.2	ND	ND	6.2	ND
Arsenic	ND	ND	ND	ND	ND	3.4
Cadmium	ND	ND	ND	ND	ND	ND
Lithium	14	11	18	8.0	6.9	6.4
Lead	ND	ND	ND	ND	ND	ND
Nickel	ND	ND	ND	ND	ND	ND
Molybdenum	30	67	38	47	30	75
Thallium	ND	ND	ND	ND	ND	ND
Anions (mg/L)						
Nitrate	ND	-[d]	ND	-	0.16	-
Sulfate	53	79	53	66	40	55
Nitroaromatics (µg/L)						
1,3,5-TNB	ND	-	0.04	-	ND	-
1,3-DNB	ND	-	0.12	-	ND	-
2,4,6-TNT	ND	-	0.098	-	0.024	-
2,4-DNT	0.11	-	3.3	-	0.11	-
2,6-DNT	0.0080	-	0.53	-	0.019	-
2-Amino-4,6-DNT	0.19	-	0.50	-	0.49	-
4-Amino-2,6-DNT	0.32	-	0.95	-	0.87	-
2-Nitrotoluene	ND	-	ND	-	ND	-
3-Nitrotoluene	ND	-	ND	-	ND	-
4-Nitrotoluene	ND	-	ND	-	ND	-
Nitrobenzene	ND	-	ND	-	ND	-

TABLE 4.8 (Cont.)

Parameter	IS-4004[a] (6.0 ft)	IS-4004B[b] (20.5 ft)	IS-4005[a] (8.0 ft)	IS-4005B[b] (34–37 ft)	IS-4006[a] (15.0 ft)	IS-4006B[b] (28–30 ft)
Radiological (pCi/L)						
Uranium	137	9.1	32	80	24	27
Metals (µg/L)						
Antimony	3.1	12	4.4	-	ND	-
Arsenic	ND	4.7	ND	-	6.1	-
Cadmium	ND	ND	ND	-	ND	-
Lithium	5.0	ND	7.5	-	8.0	-
Lead	ND	ND	ND	-	6.2	-
Nickel	ND	ND	ND	-	ND	-
Molybdenum	ND	20	14	-	38	-
Thallium	ND	ND	ND	-	ND	-
Anions (mg/L)						
Nitrate	ND	-	0.46	-	ND	-
Sulfate	42	30	40	-	220	-
Nitroaromatics (µg/L)						
1,3,5-TNB	ND	-	0.12	-	ND	-
1,3-DNB	ND	-	ND	-	ND	-
2,4,6-TNT	ND	-	0.053	-	ND	-
2,4-DNT	0.32	-	0.25	-	0.16	-
2,6-DNT	0.12	-	0.31	-	0.0070	-
2-Amino-4,6-DNT	0.52	-	0.36	-	0.036	-
4-Amino-2,6-DNT	0.91	-	0.52	-	0.055	-
2-Nitrotoluene	ND	-	ND	-	ND	-
3-Nitrotoluene	ND	-	ND	-	ND	-
4-Nitrotoluene	ND	-	ND	-	ND	-
Nitrobenzene	ND	-	ND	-	ND	-

[a] The sample was collected at the depth where the groundwater was first encountered; the sample depth is in parentheses.

[b] The sample was collected at a depth greater than where the groundwater was first encountered; the sample depth is in parentheses.

[c] ND = not detected.

[d] A hyphen indicates that the parameter was not analyzed.

The concentrations of the metals in the groundwater are consistent with levels that are discharging from the springs within the drainage. Thallium, nickel, and cadmium were not detected in the in situ samples; antimony, arsenic, and lead were detected in less than 40% of the samples and at only very low concentrations. Only two metals were detected at concentrations higher than levels detected in the springs. Within the groundwater, lithium and molybdenum were detected at maximum concentrations of 18 µg/L and 76 µg/L, respectively, which are a factor of 2 higher than the maximum concentrations detected in the springs. The detected concentrations of lithium and molybdenum are within the range of detected concentrations in site groundwater.

The results of the in situ groundwater sampling indicate that, in general, groundwater concentrations are similar to or less than concentrations discharging from the lower springs in the Southeast Drainage. The major contaminant in groundwater is uranium, with low levels of nitroaromatic compounds, lithium, molybdenum, and sulfate. The probable sources of groundwater contamination are the contaminated sediments along the length of the drainage.

To better delineate the extent of uranium contamination in the area, a monitoring well was installed in the lower portion of the Southeast Drainage in May 1997 (MK-Ferguson Company and Jacobs Engineering Group 1997a). Quarterly sampling and analysis for site contaminants are planned over the next year. Sampling will also include thallium, at a detection limit of 1.0 µg/L, to resolve issues with the in situ sampling that used a detection limit of 5.0 µg/L. The first quarter sampling was conducted on May 12, 1997. Results indicated very low levels of nitrate (0.12 mg/L). Thallium, uranium, nitroaromatic compounds, TCE, and 1,2-DCE were not detected. Subsequent sampling for this monitoring well will be reported in the annual site monitoring report and/or the FS, as appropriate.

4.2 SPRINGS

Fifteen springs were sampled as part of the joint sampling for the groundwater remedial investigation and included 5101, 5201, 5303, 5402, 5501, 5504, 5601, 5602, 5605, 5612, 6301, 6303, 6306, 6501, and 6601. The results of the 1995 joint sampling are presented in Appendix C. Table 4.9 summarizes these data, together with previous data collected since 1987 for the fifteen springs.

For naturally occurring contaminants, the UCL and range of concentrations were compared with the statistically derived background concentrations calculated for the weathered unit of the Burlington-Keokuk Limestone. This comparison indicated concentrations above background for chloride, nitrate, sulfate, antimony, cadmium, iron, lithium, manganese, mercury, molybdenum, silver, and uranium.

Antimony was detected infrequently, although values ranged up to 95 µg/L at Spring 5601. several of these samples were filtered prior to analysis and, therefore, are currently being evaluated to determine if data should be rejected because of filter contamination as discussed in Section 4.1.

TABLE 4.9 Summary of Spring Data[a]

	Detection Frequency	Range	Mean[b]	95% UCL	Background[c]
Anions (mg/L)					
Chloride	89/89	1.11 – 42	10	12	1.6
Fluoride	39/64	0.10 – 0.60	0.23	0.26	0.44
Nitrate	150/166	0.06 – 10,000	76	180	0.29
Sulfate	109/113	3.2 – 86	34	37	12
Metals (µg/L)					
Aluminum	121/190	15 – 2,800	200	250	3,100
Antimony	42/155	1.1 – 95	12	14	6.3
Arsenic	39/186	0.60 – 290	3.7	6.2	3.4
Barium	211/234	61 – 3,200	140	160	310
Cadmium	6/170	0.60 – 25	1.2	1.4	0.70
Chromium	73/206	0.80 – 30	5.0	5.8	6.2
Copper	53/166	1 – 30	4.6	5.3	14
Iron	170/192	10 – 400,000	2,800	6,200	4,500
Lead	21/190	0.80 – 60	4.5	5.9	5.2
Lithium	18/112	2.2 – 52	12	14	6.6
Manganese	114/150	1.3 – 20,000	1,200	1,600	290
Mercury	35/208	3.7 – 6,100	37	86	0.25
Molybdenum	22/108	2.5 – 38	9.0	11	0.50
Nickel	62/165	0.0080 – 44	6.1	7.0	84
Selenium	27/209	0.0005 – 6.5	1.1	1.2	1.1
Silver	11/208	1.5 – 240	3.2	5.3	2.9
Thallium	13/171	0.0010 – 6.1	1.3	1.6	1.8
Uranium, total	213/249	0.07 – 540	74	84	1.4
Nitroaromatics (µg/L)					
1,3,5–TNB	61/278	0.020 – 15	0.40	0.56	-[d]
1,3–DNB	17/276	0.56 – 1.2	0.022	0.033	-
2,4,6–TNT	136/279	0.020 – 280	5.8	8.1	-
2,4–DNT	81/279	0.020 – 11	0.12	0.20	-
2,6–DNT	111/277	0.007 – 18	0.35	0.49	-
2–Amino–4,6–DNT	68/85	0.017 – 19	1.4	2.0	-
2–Nitrotoluene	3/126	0.080 – 0.080	0.0013	0.0023	-
3–Nitrotoluene	0/127	ND	ND	ND	-
4–Amino–2,6–DNT	67/85	0.030 – 24	2.0	2.8	-
4–Nitrotoluene	0/127	ND	ND	ND	-
Nitrobenzene	11/278	0.060 – 1.4	0.016	0.027	-
Radiological (pCi/L)					
Uranium	213/249	0.048 – 370	50	57	0.93

[a] Includes data collected from 1987–1995 for Springs 5101, 5201, 5303, 5402, 5501, 5504, 5601, 5602, 5605, 5612, 6301, 6303, 6306, 6501, and 6601.

[b] The mean and 95% UCL concentrations were calculated by substituting half the detection limit for values reported as nondetected. For nitroaromatic compounds, the mean was calculated by substituting a zero for values reported as nondetects.

[c] The groundwater data collected from the background wells representing the weathered Burlington-Keokuk are used as background data for the springs.

[d] Background for nitroaromatics considered to be zero.

Arsenic was detected in about 20% of the samples but was found in 62% of the samples taken at Spring 6306; values ranged from 0.6 to 290 µg/L. With the exception of the maximum arsenic concentration of 290 µg/L detected from Well 6306 in 1996, arsenic concentrations were all less than 16 µg/L. This suggests that the single, maximum reported concentration is an outlier. Excluding this maximum concentration from the estimation of the UCL concentration, arsenic was below the background 95% UCL concentration.

Cadmium was detected once at Springs 5201, 5602, and 6301 and three times at Spring 6306; concentrations ranged from 0.60 to 25 µg/L. Iron was detected in 88% of the samples. Although the UCL iron concentrations exceeded the background 95% UCL level, this was due to a single high concentration (400,000 µg/L) detected at Spring 6306 in 1991. Including this data point, the iron UCL slightly exceeded the background level (by a factor of about 1.3). Excluding this single data point results in the UCL iron value being less than the background 95% UCL concentration by a factor of about 5 (860 µg/L for the springs and 4,500 µg/L for background).

Lithium was detected infrequently (only 16% of all samples) at Springs 5303 and 5501 and primarily from the springs in the 6300 drainage: the highest concentration was reported from Burgermeister Spring (6301) at 52 µg/L. Manganese was detected frequently (76% of all samples) in all springs sampled; the highest concentrations (20,000 µg/L) were reported from Spring 6306. Mercury was detected in 17% of the samples, primarily only at Springs 5602, 6301, 6303, 6306, 6501, and 6601. The highest concentrations were reported from springs located in the 5600 and 6300 drainages. Mercury concentrations ranged from 0.37 µg/L to 6,100 µg/L; the UCL concentration exceeded the background level by a factor of about 340. This magnitude of exceedance, however, is misleading and is due to a single high mercury concentration of 6,100 µg/L detected in Spring 6306. Excluding this value, the maximum reported mercury concentration was 340 µg/L, with a mean value of 8 µg/L. The UCL concentration (12 µg/L) exceeded background (0.25 µg/L) by a factor of 48. Molybdenum was detected in a few springs from the 5300 and 6300 drainages at concentrations up to 38 µg/L. Selenium and silver were detected in only 5% and 8%, respectively, of the spring samples and were absent from most springs. The UCL concentrations of these metals only slightly exceeded background levels (1.2 µg/L versus 1.1 µg/L) for selenium and (5.3 µg/L versus 2.9 µg/L) for silver. Elevated levels of iron were detected in many of the springs. Levels of iron exceeded the SMCL of 300 µg/L at 10 springs. Levels of manganese exceeded the SMCL of 50 µg/L at six springs. For comparison, the statistically derived background levels for iron and manganese also exceed the SMCL

Uranium was detected in all springs at low concentrations except in the springs in the 5300 and 6300 drainages. Uranium concentrations ranged from 0.048 to 370 pCi/L; the maximum uranium concentration was reported from Spring 5303 in the Southeast Drainage.

Nitrate was detected at levels ranging from 0.06 to 10,000 mg/L. Springs with the highest average nitrate concentrations were 6301 (Burgermeister Spring) (210 mg/L) and 6303 (21 mg/L).

Average concentrations at other springs ranged from 0.26 to 3.6 mg/L. The high 95% UCL (180 mg/L) estimated for nitrate was the result of a single high nitrate concentration of 10,000 mg/L reported from Spring 6301 in 1988. This value may be an outlier, since the next highest reported nitrate concentration is only 210 mg/L, reported in 1991 from Spring 6301. This concentration is approximately 50 times less than the 1988 concentration. Excluding the 1988 concentration, the UCL concentration was 18 mg/L, which is an order of magnitude less than the UCL estimated using the 1988 value. Sulfate was detected in all springs and in 96% of all samples; the highest concentrations were found in Springs 5101, 5201, 5303, 6301, and 6303. Chloride was detected in 100% of the spring samples; concentrations ranged from 1.1 to 42 mg/L (Table 4.9).

The highest nitroaromatic concentrations were detected at four locations: Spring 5201 (downstream of Burning Ground 1), Spring 5303 (Southeast Drainage), Spring 6301 (Burgermeister Spring), and Spring 5602 (south of the training area). Springs 5201 and 5303 had the highest nitroaromatic concentrations, with concentrations of 120 and 280 µg/L, respectively, for 2,4,6-TNT. Concentrations of other nitroaromatics detected in these four springs ranged from 3 µg/L to 17 µg/L. Six nitroaromatic compounds (1,3,5-TNB; 2,4,6-TNT; 2,4-DNB; 2,6-DNB; and the two amino-DNT compounds) were detected frequently at 11 spring locations. All six of these nitroaromatic compounds were also detected at Springs 5201, 5303, 5602, 5605, 6301 and 6303. At Springs 5501, 5601, 5612, and 6601, all nitroaromatics except 1,3-TNB were detected in collected samples.

Nitrobenzene, 2-nitrotoluene, 3-nitrotoluene, and 4-nitrotoluene were not detected in any of the springs sampled and were detected in fewer than 6% of all samples. Nitroaromatics were not detected in two of the 15 springs sampled (Springs 5101 and 5504), and only 2-amino-4,6-DNT and 4-amino-2,6-DNT have been detected at Spring 6501. Concentrations of 2,4,6-TNT and 2,6-DNT have been detected only twice in Spring 5402 at low levels (0.09 µg/L).

Three springs were also sampled for VOCs in August and October of 1996. The springs included Burgermeister Spring and two springs in the Southeast Drainage (5303 and 5304). No VOCs were detected in these springs. These springs (including 6303) will continue to be monitored monthly for VOCs through the end of 1997.

4.3 SUMMARY OF CONTAMINATION

In summary, the site contaminants identified for groundwater include uranium, lithium, molybdenum, chloride, nitrate, sulfate, nitroaromatic compounds, trichloroethylene, and 1,2-dichloroethylene. For groundwater beneath the chemical plant area and the ordnance works area, the greatest extent and highest concentrations of contaminants are in the overburden and weathered units. Groundwater in the vicinity of the raffinate pits and Ash Pond exhibits the highest concentrations of lithium, molybdenum, nitrate, and uranium. In the Frog Pond area, groundwater has been impacted primarily by sulfate and nitroaromatic compounds. Nitroaromatic compounds are

also present in groundwater in scattered locations across the chemical plant area and central portion of the training area. Some contamination from nitroaromatic compounds is also evident in groundwater beneath the former bunker area on the northern ordnance works area. Nitroaromatic compounds were detected at much lower frequencies and at lower levels in wells screened in the unweathered and deeper units of the aquifer.

The site contaminants identified for springs include uranium, antimony, cadmium, iron, lithium, manganese, mercury, molybdenum, silver, chloride, nitrate, sulfate, and nitroaromatic compounds. Uranium and nitrate were routinely detected above background levels in spring samples from two drainages, 5300 and 6300. Elevated sulfate levels were found in springs in the 5100, 5200, 5300, and 6300 drainages. Nitroaromatics were detected in springs from most of the drainages in the former ordnance works area, except for the 5100 drainage, and infrequently (twice) in the 5400 drainage.

5 CONTAMINANT FATE AND MIGRATION

Analysis of the fate and migration of contaminants in an aquifer involves determining the behavior of a chemical released into the environment. This behavior can be described by three environmental processes: transformation, transfer, and transport (Mackay et al. 1985). Table 5.1 summarizes and gives examples of each process.

Migration is the combination of transfer and transport processes and governs the spatial and temporal distribution of a chemical in groundwater. The migration of contaminated water in the aquifer is controlled by a combination of hydrologic, geochemical, and biological factors. Principal among the hydrologic factors affecting migration at the chemical plant area and the ordnance works area are heterogeneity of the aquifer, preferential flow in fracture systems, locations of saturated and unsaturated zones with reference to historic and current sources, and interaction between surface water and the shallow groundwater aquifer.

TABLE 5.1 Summary of Environmental Processes Affecting Contaminant Fate and Migration

Process	Process Description with Example
Transformation	Alteration of the form of a chemical through physical, chemical, and/or biological reactions. This process reduces the concentration of a chemical (attenuation) but does not necessarily slow its rate of transport (retardation). While the transport rate of the original chemical species is unlikely to change, the daughter products of the transformational processes are likely to exhibit their own transport rates. Examples of transformation processes potentially affecting the fate of COPC include hydrolysis, photolysis, oxidation/reduction, chemical precipitation, radioactive decay, and biodegradation.
Transfer	Redistribution of a chemical between media. Examples of transfer are adsorption/desorption and dissolution in soil/water systems. Dissolution is a process by which a material changes from the solid to aqueous phase. Adsorption is the reversible adhesion of a solute to the aquifer matrix. Desorption is the release of a solute from the aquifer matrix into the soil/water system.
Transport	Redistribution of a chemical within a single medium. Solute transport in groundwater occurs in response to hydraulic and chemical gradients and can be described with the advection/dispersion model. Advection is the process by which a solute is transported by the bulk motion of flowing groundwater; dispersion is produced by unequal velocities in the porous medium and causes spreading of the solute. The spreading of dissolved contaminants by dispersion produces dilution and attenuation.

The discussion in this chapter of fate and migration integrates information from a number of sources, the primary ones being *Baseline Assessment for the Chemical Plant Area of the Weldon Spring Site* (DOE 1992a), *Remedial Investigation of the Chemical Plant Area* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a), *Work Plan for the Remedial Investigation/Feasibility Study for the Groundwater Operable Unit at the Chemical Plant Area and the Ordnance Works Area* (DOE 1995b), and *Final Remedial Investigation, Weldon Spring Training Area* (IT Corporation 1993a). The discussion of persistence and attenuation relies on site-specific research performed by the USGS (Schumacher and Stollenwerk 1991; Schumacher 1993). Information published by the USGS (Schumacher et al. 1996) also was used in the discussion of the fate and transport of nitroaromatic compounds.

5.1 CONTAMINANT SOURCES AND ROUTES OF MIGRATION

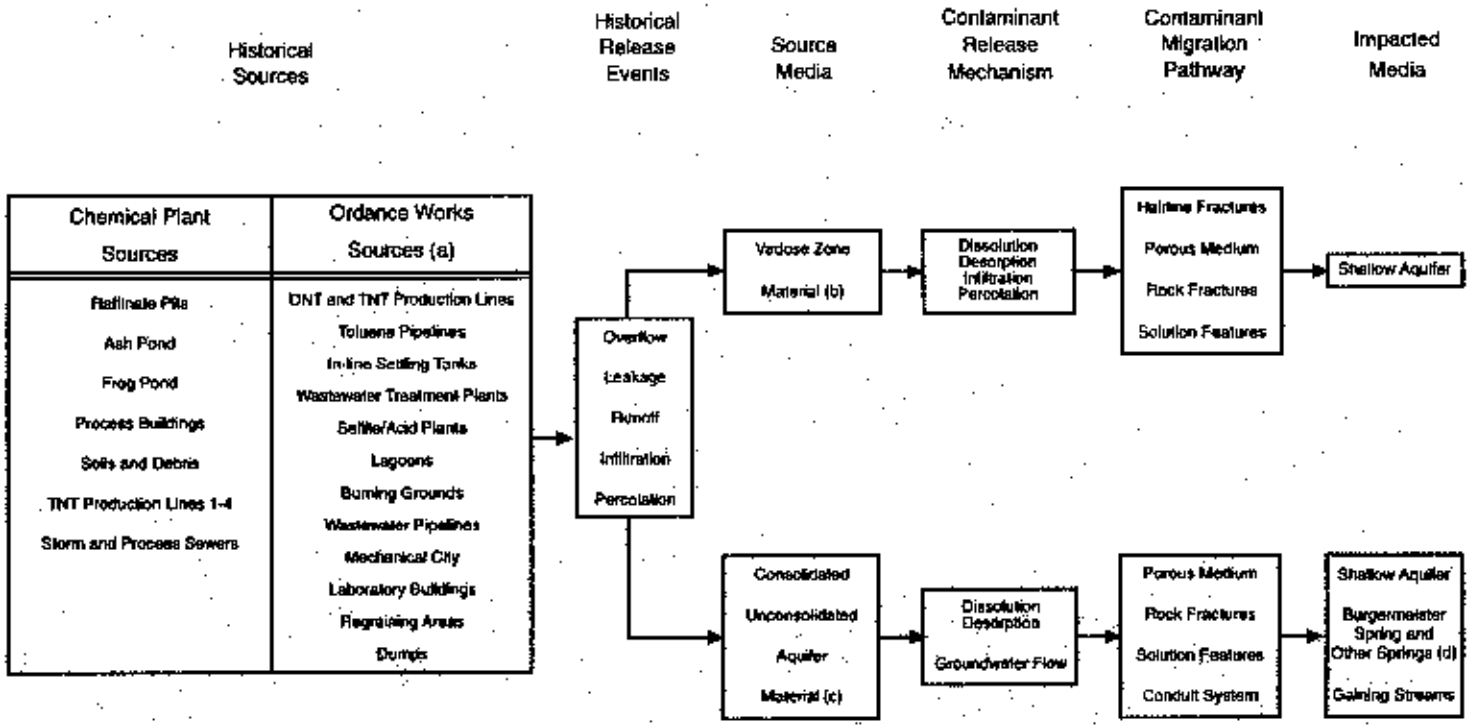
Figure 5.1 illustrates the fate and transport conceptual model that identifies historical and current source areas, release and transport mechanisms, migration pathways, and environmental media at the chemical plant area and the ordnance works area.

Contaminant migration to groundwater in the chemical plant area and the ordnance works area can be attributed to:

- Migration of contaminants from surface or near-surface sources through the overburden to the shallow aquifer,
- Seepage from surface water impoundments,
- Surface water runoff carrying contaminants from the historic surface source areas that entered the shallow groundwater system through losing stream segments, and
- Mobilization of contaminants within the groundwater system.

5.2 CONTAMINANT PERSISTENCE AND ATTENUATION

Uranium, metals (lithium and molybdenum), inorganic anions, nitroaromatic compounds, and volatile organic compounds (TCE) are the COPC for the GWOUs at the chemical plant area and the ordnance works area. Except for nitroaromatic and volatile organic compounds, these constituents also occur naturally. The fate and migration of these substances through the groundwater system depend in part on their mobility and persistence. The following sections briefly discuss the mobility and persistence of each contaminant on the basis of theoretical considerations,



NOTES

(a) Other minor sources are laboratory building, storage bunkers, and dumps.

(b) Includes adsorbed contaminants and pore water in the vadose zone.

(c) Includes the adsorbed contaminants within the shallow unconfined aquifer.

(d) Includes sediments.

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FIGURE 5.1 Fate and Transport Model for the Groundwater Operable Unit

the results of laboratory experiments to identify geochemical controls of the migration of contaminants (Schumacher and Stollenwerk 1991; Schumacher 1993), and the evaluation of groundwater quality data. These factors provide the basis for the information on the nature and distribution of contamination reported for the shallow aquifer.

5.2.1 Uranium

Dissolved uranium has three valence states: +4, +5, and +6. In the presence of reduced iron or sulfur, U(6+) is removed from solution by reduction to U(4+) and precipitation of U(4+) minerals such as uraninite (UO_2), which is relatively insoluble (Fetter 1993). Uraninite was not identified in the soils and pit sludges in the chemical plant area. U(6+) has a tendency to form soluble complexes with a wide variety of inorganic anions, including carbonate, hydroxide, fluoride, phosphate, and sulfate (Fetter 1993). Most of the uranium within the sludges was present as U(6+) and in minerals such as carnotite or associated with phosphate minerals such as apatite (Schumacher 1993). Schumacher and Stollenwerk (1991) concluded that reduction to U(4+) and precipitation of U(4+) minerals probably do not occur within the raffinate pit sludges, and, as a result, uranium presumably exists mainly in the dissolved phase in infiltrating waters.

The results of geochemical modeling and laboratory experiments (Schumacher 1993) indicate significant adsorption of uranium within the overburden (Ferrelview Formation and clay till) beneath the raffinate pits. Adsorption of uranium was found to be dependent on the pH of the groundwater; adsorption generally decreased with an increase in pH.

The adsorption experiments (Schumacher 1993) indicate that uranium can be effectively removed from raffinate pit seepage during infiltration through the overburden. Although uranium concentrations are elevated (four to five times) above background in wells adjacent to the raffinate pits, they are much lower than uranium concentrations in the raffinate pits. This decrease has been attributed to saturation of available adsorption sites, the formation of weakly sorbed uranium carbonate complexes, the existence of preferential flow paths through the overburden, or a combination of these possibilities (Schumacher and Stollenwerk 1991). Once in the groundwater, equilibrium-speciation calculations indicate that U(6+), in the form of uranium carbonate complexes, is very stable and mobile.

5.2.2 Metals

Metals have fairly limited mobility in soil and groundwater because of their tendency to undergo cation exchange or sorbtion to the surfaces of negatively charged clay particles. A distribution coefficient (K_d) is a measure of the partitioning of solutes between liquid and solid phases in a porous medium. The K_d depends on the solute species, the nature of the porous medium,

and other conditions of the system such as pH and temperature. A compound having a large K_d is strongly adsorbed by aquifer materials and, consequently, moves slower than the groundwater velocity.

Metals speciation, the form in which a molecule or ion is present in solution, is controlled by redox conditions. Speciation values indicating oxidation state and stable complex for the metals at the chemical plant area and the ordnance works area are presented in Table D.1 of Appendix D. The speciation, and thus the mobility of metals, can be changed significantly by relatively small quantities of iron and manganese oxides that often form amorphous coatings on the aquifer matrix. In some media, these hydrous-oxides help increase the adsorption capacity more than either clay particles or organic matter. Hydrous-oxides are thought to increase the adsorption of molybdenum and uranium in the overburden soils at the chemical plant area (Schumacher 1993).

Lithium is commonly present in trace amounts with aluminosilicate and hydroxide minerals and manganese oxides in soil; water-soluble lithium is correspondingly low. Lithium readily forms the stable monovalent ion, and although many lithium salts can be soluble in water, they are generally less soluble than the corresponding salts of other alkali metals such as sodium or potassium. Lithium does not substitute in carbonate rocks, and the carbonate is insoluble in water. Although transport would be expected to be similar to that for the other alkali metals as a result of the valence state, exchangeable lithium is usually found in much lower concentrations than sodium or potassium. Site-specific data were used to determine a K_d of between 0.6 and 1.5 mL/g for a solution in equilibrium with the clay till at neutral pH and values between 1.4 and 1.8 mL/g for the Ferrelview Formation at neutral pH (Schumacher and Stollenwerk 1991). As part of the baseline assessment for the chemical plant area, a K_d of 9 mL/g was used on the basis of the calculated values and the results of a screening level leaching calculation using data for soil and groundwater near the site (DOE 1992a). Lithium is, therefore, expected to be fairly mobile at the chemical plant area.

The presence and concentrations of lithium in Burgermeister Spring are consistent with the low calculated distribution coefficients (<2 mL/g at neutral pH) on the basis of laboratory sorption experiments (Schumacher 1993). Calculated distribution coefficient values for sorption of the site-related contaminants are given in Table D.1 of Appendix D. Site-specific distribution coefficients at various pH values for the Ferrelview Formation and the clay till are given in Table D.2 of Appendix D.

Molybdenum commonly occurs as the oxide in uranium ore, as molybdate in solution, and can exist over a range of oxidation states. The molybdenate ion can complex with calcium, and adding lime to soil to increase the pH can increase molybdenum solubility. Adsorption of molybdate by iron and aluminum oxides decreases as soil pH increases above 4. Hydrous iron oxides are the major influence on molybdenum adsorption in soil and in combination with organic matter may provide additional absorption in acid soil. Molybdenum is expected to be mobile in the neutral to

alkaline pH conditions found in groundwater in the area, although the mobility will be partially restricted by the presence of iron oxides.

5.2.3 Anions

Nitrate is a highly soluble anion that is mobile in the subsurface because it is repelled by negatively charged clay particles. Nitrate may be removed from groundwater by plant uptake to a limited extent, but this process is generally considered insignificant. The most significant removal process for nitrate is denitrification, the biological or chemical reduction of nitrate to gaseous nitrogen compounds such as nitrous oxide and nitrogen gas. Environmental conditions favorable to denitrification include high organic carbon content, high pH, and a restricted oxygen supply. Nitrate reducing organisms are inhibited by the presence of dissolved oxygen; therefore, the potential for nitrate accumulation is greater under aerobic conditions. If nitrate concentrations exceed the available carbon supply, nitrate accumulations could occur. Samples of groundwater from shallow monitoring wells completed in the weathered Burlington-Keokuk Limestone contain measurable quantities of dissolved oxygen (>1 mg/L), which is indicative of a moderately oxidizing environment (Schumacher 1993). Therefore, denitrification generally will be inhibited within the weathered limestone, and nitrate will persist.

The raffinate pits constitute the greatest source of nitrate contamination to the shallow aquifer. Nitrate concentrations exceed the EPA MCL of 10 mg/L in 22 wells at the chemical plant area and in 7 wells on the eastern part of the training area. These seven wells are completed in the weathered unit of the Burlington-Keokuk Limestone. Two wells completed in the unweathered unit at the chemical plant area had concentrations greater than 10 mg/L (Figures 4.5 and 4.6). The highest nitrate concentrations were found in wells near the raffinate pits and Ash Pond. Concentrations of nitrate in groundwater decrease outside these areas (except for nitrates at Burgermeister Spring) and are found infrequently at low levels.

Nitrate concentrations from monitoring well samples within the training area are generally low. Wells just northeast and west of the chemical plant boundary (MWS-21, MW-4001, MW-4003, MW-4006, MW-4011, MW-4012, MW-4013, MW-4014, and MW-4016) show elevated nitrate concentrations above the MCL. The elevated concentrations in these wells can probably be attributed to the raffinate pits, Ash Pond, and the production lines.

Sulfate (SO_4^{-2}) and chloride (Cl^-) are the most common forms of sulfur and chlorine present in groundwater systems. The chemical behavior of sulfur is strongly related to the redox properties of the groundwater environment. In the moderately oxidizing weathered bedrock, sulfur will be present as sulfate. The primary removal mechanism for sulfate in groundwater is reduction to sulfide and the subsequent formation of hydrogen sulfide (H_2S) or the precipitation of sulfide minerals such as pyrite (FeS). Increased concentrations of sulfate have been detected in monitoring

wells downgradient of the former sellite plants and near the raffinate pits. Sulfate reduction is favored in anaerobic environments generally having a high organic carbon content. Anaerobic conditions have not been found within the shallow aquifer at the chemical plant area or the training area, but may exist in isolated areas within deeper parts of the unweathered rock near discharge areas along Dardenne Creek. Therefore, sulfate is expected to persist in the aquifer.

Because chloride does not enter into any significant microbiologic reactions or geochemical reactions (e.g., ion exchange, precipitation-dissolution), its migration in the environment will be attenuated only slightly, if at all. Thus, its behavior is conservative; that is, it will migrate at about the same velocity as the groundwater.

5.2.4 Nitroaromatic Compounds

More than 30 nitroaromatic compounds have been identified in wastewater from TNT manufacturing at ordnance works sites (Spanggord and Suta 1982). The major compounds identified were 2,4-DNT, 2,6-DNT, and 1,3,5-TNB. Munitions compounds produced at the ordnance works included 2,4,6-trinitrotoluene (2,4,6-TNT), 2,4-dinitrotoluene (2,4-DNT), and 2,6-dinitrotoluene (2,6-DNT). The predominant DNT isomer produced during the dinitration process was 2,4-DNT. The compound 2,4-DNT also composes about 2% by weight of crude TNT. During nitration, a small amount of TNT is oxidized to trinitrobenzoic acid, which appears in the finished product and waste streams as 1,3,5-trinitrobenzene (1,3,5-TNB) (Davis 1943).

Two important factors affecting the persistence and environmental fate of most nitroaromatic compounds are the presence of the benzene ring and the presence of the nitro-(NO_2^-) group. The benzene ring imparts a certain amount of stability to the compounds and, in addition, the electronegativity of the nitro-(NO_2^-) group makes nitroaromatics reactive and susceptible to reduction (McGrath 1995). Selected physical and chemical properties of several nitroaromatic compounds are summarized in Table D.2 of Appendix D.

Photolysis is one of the major processes affecting the transformation of nitroaromatic compounds in waste streams and surface water bodies exposed to sunlight (Spanggord et al. 1980; Rosenblatt et al. 1989). Photolysis modifies the composition of the nitroaromatic waste material present in lagoons, surface water ponds, or spilled material at the soil surface. Photolysis of nitroaromatic compounds such as TNT and DNT involves the absorbance of light energy and the reduction to nitrobenzenes (such as TNB) and other compounds (McGrath 1995). Photolysis can occur relatively rapidly; half-lives are measured in hours to days (Table D.3).

Biotransformation is another process affecting the transportation of nitroaromatic compounds beneath the ground surface. The biochemistry of TNT is complicated by the fact that it contains toluene. Toluene is an organic compound that generally serves as an electron donor, along

with the nitroaromatic compounds with the relatively oxidized nitro-(NO_2^-) groups that generally function as electron acceptors. In effect, TNT may act as both an electron donor and electron acceptor, while also being a carbon and nitrogen source. These various properties make TNT susceptible to a wide variety of transformations.

The microbial degradation of TNT and other nitroaromatic compounds has been reported in the literature. Studies have focused on degradation by artificially selected microbial communities (Parrish 1977; Carpenter et al. 1978; Kaplan and Kaplan 1982; Boopathy and Kupla 1992; Boopathy et al. 1993; Funk et al. 1993). Field investigations by the USGS at the ordnance works area have demonstrated that microorganisms indigenous to the soils and, more importantly, to the shallow aquifer have the ability to transform and degrade TNT, 2,4-DNT, and 2,6-DNT (Jones 1984; Missouri Department of Conservation 1991; DOE 1992a; MK-Environmental Services 1992a; Chapelle and Bradley 1993; Ecological Specialists 1996). Laboratory microcosm experiments conducted on core samples from saturated residuum and bedrock and uniformly radiolabeled (carbon-14) TNT and DNT showed that a variety of TNT and DNT degradation products were formed.

TNT mineralization (complete degradation to carbon dioxide [CO_2]) studies using two different types of Weldon Spring topsoils showed approximately 11% and 6.5% TNT conversions to CO_2. Similar TNT mineralization studies using shallow aquifer material showed a TNT to CO_2 conversion of approximately 1% (Bradley et al. 1994). In DNT mineralization experiments using shallow aquifer material, approximately 28% and 8% of the 2,4-DNT and 2,6-DNT, respectively, were transformed to CO_2 (Bradley et al. 1997).

The USGS also performed experiments using Weldon Spring topsoil to study the effects of moisture content, TNT concentration, oxygen condition, and supplemental carbon on the mineralization of TNT (Bradley and Chapelle 1995). Those studies concluded that the mineralization of TNT was inhibited by the addition of carbon substrate and by elevated TNT soil concentrations. Also, experiments using different soil-moisture levels (oversaturation to moisture levels representative of summer dry periods) showed that soil drying significantly inhibited TNT mineralization under both aerobic and anaerobic conditions. In addition, the experiments performed to study the effects of oxygen condition on TNT mineralization showed the highest mineralization rates using air head spaces in the incubation tubes, with lower rates for head spaces with oxygen amended air, and the lowest rates for helium (no oxygen) head spaces.

USGS laboratory experiments also indicated that 2,4-DNT and 2,4,6-TNT are more readily metabolized in the shallow aquifer than 2,6-DNT. More than 95% of 2,4-DNT and 2,4,6-TNT was metabolized within 68 days in microcosms using material from the shallow aquifer, compared with 55% to 80% for 2,6-DNT. In all cases, the decrease in TNT or DNT was coupled with the appearance of 4-amino-2,6-dinitrotoluene (4-Am) and 2-amino-4,6-dinitrotoluene (2-Am) or amino

nitrotoluenes (Bradley et al. 1994). Transformation of TNT to 4-Am and 2-Am appears to be the initial step in the degradation of TNT.

Mass balance experiments using radiolabeled DNT indicated that a significant mass of 2,4-DNT was transformed into highly polar intermediates hypothesized to be acid-derivatives of nitroaromatic compounds (Figure 5.2). Similar studies were not performed with TNT; however, chemical analysis of lysimeter samples from the unsaturated zone detected polar acid intermediates. The presence of these acid derivatives is important because these compounds generally are readily metabolized by a variety of microorganisms (Cartwright and Cain 1959; Nadiau and Spain 1995).

Processes other than transformation can significantly affect the fate and transport of nitroaromatics, including reversible and irreversible reactions of nitroaromatics with the soil. These processes, along with photolysis and biodegradation, are expected to be important attenuation mechanisms for nitroaromatics in the soil and groundwater.

The reversible reactions include nitroaromatic adsorption and desorption to soil. Experiments by USGS indicate that TNT and DNT adsorb to the glacial drift in moderate quantities, with distribution coefficients ranging from 0.53 to 3.5 mL/g (Table D.3). Distribution coefficients from additional USGS studies for the aquifer materials were less than 1 mL/g (Table D.3).

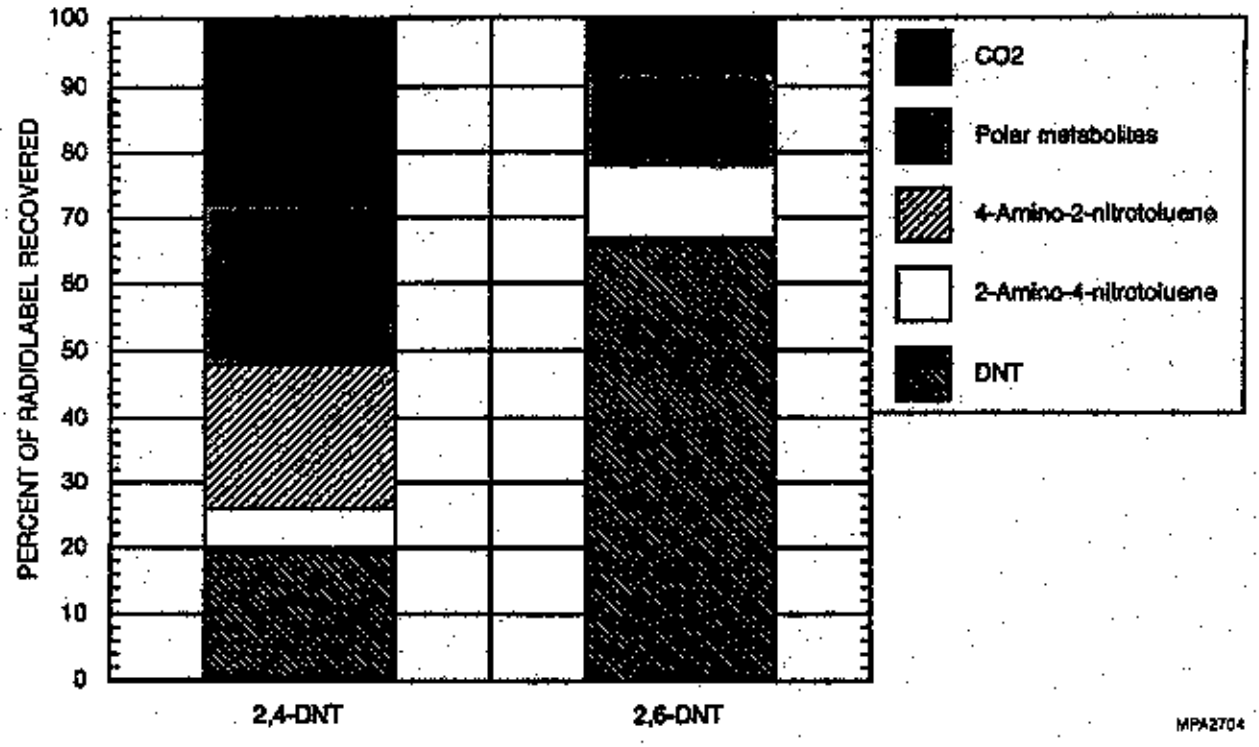

FIGURE 5.2 Microbial Transformation Productions of 2,4-DNT and 2,6-DNT in Residuum

A phenomenon that potentially affects the prediction of the adsorption and desorption of nitroaromatics to soil is the time that the nitroaromatic has resided in the soil and/or aquifer. For example, Grant et al. (1995) have found significant differences in the recoveries of nitroaromatics in field-contaminated soils as compared with soils freshly spiked with nitroaromatics. In addition, they found significant differences between the stability of the nitroaromatics in field and freshly spiked samples. Since lab samples are normally prepared under relatively short time frames compared with the residence times of nitroaromatics in the soil and groundwater at Weldon Spring, use of the lab sorption and biodegradation results in predicting nitroaromatic behavior at Weldon Spring needs to take into account the potential differences between lab and field behavior.

In addition to reversible reactions, irreversible nitroaromatic-soil reactions can potentially affect nitroaromatic fate and transport. Price et al. (1995) discuss the apparent irreversible binding of TNT degradation products, 2-Amino and 4-Amino, to the soil. This process is potentially an important attenuation mechanism in determining the amount of nitroaromatics migrating to groundwater.

5.2.5 Volatile Organic Compounds

Recent sampling of groundwater in the chemical plant area indicates the presence of volatile organic compounds (TCE and 1,2-DCE). In general, detection of TCE has been limited to the area south and southeast of Raffinate Pits 3 and 4. The maximum concentrations of TCE observed (Section 4) exceed the EPA guideline value of 0.005 mg/L; the maximum concentrations for 1,2-DCE are below the EPA guideline of 0.07 mg/L for cis-1,2-DCE, and 0.1 mg/L for trans-1,2-DCE.

As implied by their designation (volatile organic compounds), TCE and 1,2-DCE readily volatilize from aquatic systems. In surface water, the half-life for TCE is about 3.5 hours (Thomas 1981). On the other hand, degradation by photolysis (Callahan et al. 1979) or hydrolysis (Dilling et al. 1975) is expected to be negligible.

Once in the groundwater system, TCE and 1,2-DCE would not be readily adsorbed onto soil or rock particles. Using the reported partition coefficients with respect to the organic fraction (K_{oc}) for TCE and trans-1,2-DCE of about 65 mL/g (Montgomery and Welkom 1991), the distribution coefficient, K_d, for the volatile organic compounds in a soil having an organic content of about 0.05% (consistent with site values measured by the USGS for depths greater than 0.3 m [1 ft]) (Schumacher et al. 1996) would be 0.3 mL/g. Because the distribution coefficient is small, adsorption would not be a significant process.

Under anoxic (anaerobic) conditions, reductive dehalogenation of TCE forms cis- and trans-1,2-DCE (Montgomery and Welkom 1991). These compounds further biodegrade to vinyl chloride.

Because conditions at the chemical plant area are mostly aerobic, these biodegradation processes are unlikely to occur, and the volatile organics would not significantly biodegrade.

Because TCE is fairly soluble in water (1,100 mg/L) (Montgomery and Welkom 1991) and is more dense (specific gravity of approximately 1.46), it would leach from the soil into the groundwater, dissolve until it reaches an equilibrium value, and tend to sink in the aquifer. When TCE exceeds its solubility limit, it forms globules that sink to the bottom of the aquifer and form a pool of dense, nonaqueous phase liquid (DNAPL). This DNAPL pool would then slowly dissolve into the passing groundwater and provide a continuous source of contamination for a potentially long period (Mackay and Cherry 1989).

5.3 CONTAMINANT MIGRATION

Several routes of migration have been identified that transport contaminants to the shallow aquifer and springs. Shallow aquifers in weathered limestone are vulnerable to contamination by percolation through the unsaturated overburden and bedrock and by surface runoff through losing stream segments. In the Weldon Spring area, the shallow aquifer is recharged by surface water from leaking surface impoundments, losing stream segments, and infiltration through overburden. The presence of contaminants in the aquifer results from contaminant loading from historic sources by infiltration through the overburden and contaminants that entered the groundwater through losing streams.

Elevated concentrations of nitrate, metals, uranium, and nitroaromatics have been detected in soils at the training area, the chemical plant area, and the ordnance works area (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1989b). Nitrate, uranium, lithium, and molybdenum are the only constituents that persist with depth in soils, a condition that indicates that specific processes reduce substantial contaminant loading to the shallow aquifer via infiltration (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1989a). Although nitroaromatic compounds do not persist in soil samples with depth, significant concentrations of nitroaromatic compounds have been detected by the USGS in pore water within the unsaturated zone beneath contaminated surficial soils. The presence of significant concentrations of nitroaromatic compounds in pore water samples suggests that infiltration from contaminated surficial soils is a significant source of nitroaromatic compounds to the groundwater.

Contaminant migration can also be tracked by analyzing the presence of tritium in groundwater (Schumacher 1990; Schumacher et al. 1993). Groundwater samples from the weathered and unweathered units of the Burlington-Keokuk Limestone were analyzed for tritium. The occurrence of tritium in groundwater arises from both natural and man-made sources. Tritium is produced naturally in the earth's atmosphere by the interaction of cosmic-ray–produced neutrons with nitrogen in a manner similar to carbon-14 production (Freeze and Cherry 1979). Large

quantities of man-made tritium were introduced to the hydrological system as a result of atmospheric testing of thermonuclear devices. Groundwater that was recharged prior to 1953 is expected to have tritium concentrations below 5.7 pCi/L. Because groundwater contains tritium at concentration levels above 5.7 pCi/L, it is evident that the water, or at least a large fraction of the water, entered the aquifer sometime after 1953.

Contaminant fate and transport are further discussed by presenting the physical controls and migration processes that occur within the vadose zone, the shallow aquifer system, and from surface and subsurface runoff.

5.3.1 Migration within the Vadose Zone

5.3.1.1 Physical Controls

The movement of recharge water physically controls contaminant migration in the vadose zone. The primary mechanism of recharge for the underlying shallow aquifer at the chemical plant area and the training area is infiltration of precipitation through the overburden material. Substantial recharge also enters the unsaturated zone through losing stream segments. Most of this recharge is quickly lost, however, by rapid discharge to springs. In the vicinity of the raffinate pits, recharge from surface water impoundments may also be significant. The overburden below these features contains hairline fractures and macropores that act as preferential flow paths for the seepage and downward movement of water to the shallow aquifer.

Seepage from surface water impoundments at the chemical plant area also results in perched water above the Ferrelview Formation and mounding effects on the water table. The perched water indicates a zone of higher hydraulic conductivity over a zone of lower conductivity within the unsaturated zone. The mounded water table is a result of higher aquifer recharge at seepage points. The occurrence of contamination near the groundwater divide at the chemical plant area suggests seepage as the only possible source. Hydrologic factors contributing to the development of perched or mounded water in the overburden include the generally low vertical hydraulic conductivity, high soil moisture retention characteristics (MK-Environmental Services 1993), and the driving force for flow (hydraulic head) provided by impounded surface water.

At the ordnance works area, the primary physical controls on contaminant migration are infiltration of precipitation through the overburden, recharge from losing stream segments, and the hydrogeological and geochemical properties of the shallow aquifer.

5.3.1.2 Migration Process

The migration pathways from potential source areas at the chemical plant area and the training area include infiltration through the overburden, which may require decades, and preferential flow through macropores. Macropores are large aperture pore spaces such as fractures and root holes in surficial soils and glacial drift. The probable migration route from the raffinate pits is downward seepage through unconsolidated surficial materials (Kleeschulte and Imes 1994). The widespread occurrence of tritium in groundwater beneath the low-permeability till portion of the overburden at the chemical plant area and the training area suggests that these fractures allow recharge and potential contaminants of concern to enter the aquifer quickly. Preferential flow through macropores is suspected on the basis of TCE migration from the raffinate pits and incomplete retardation of uranium and molybdenum in the overburden beneath the raffinate pits (Schumacher 1993). The overburden thickness beneath Raffinate Pits 3 and 4 is estimated to range from 3 to 7.6 m (10 to 25 ft); the minimum thickness occurs beneath Raffinate Pit 4 (MK-Engineering Company and Jacobs Engineering Group, Inc. 1992a).

Preferential flow through macropores may also account for the nitrate and nitroaromatic contamination observed beneath other surface impoundments on the chemical plant and ordnance works properties, particularly in areas where the overburden is thin, such as beneath Ash Pond, Burning Ground 1, and Lagoon 6 (Figure 3.2). The Ash Pond area has relatively high levels of contamination and is near a subsurface preferential flow path that is in hydraulic communication with Burgermeister Spring. Infiltration from Lagoon 6 is probably a source of nitroaromatics detected in Spring 5602 (IT Corporation 1992a; Schumacher et al. 1996), and Burning Ground 1 is the likely source of nitroaromatics detected in Spring 5201 (IT Corporation 1993a).

At the training area, water quality data obtained from lysimeters installed beneath a former wastewater settling tank indicate that nitroaromatic compounds, especially TNT and TNB, are migrating through the overburden (Schumacher et al. 1996). The lysimeters are located at various depths in the unsaturated zone (0.6 m, 1.5 m, and 3.0 m [2 ft, 5 ft, and 10 ft]) between highly contaminated surficial soils (more than 100,000 mg/kg TNT) and the water table (about 4 m [12 ft] deep). In general, concentrations of nitroaromatic compounds in the deep lysimeter (completed in the residuum) were larger than concentrations detected in most monitoring well samples from the ordnance works area. Concentrations of nitroaromatic compounds in monitoring well MWS-24 downgradient of the lysimeters were greater than those in upgradient wells MWV-22 and MWS-22. This condition indicates that surficial soils are a source for groundwater contamination.

Data from the lysimeter clusters indicate substantial degradation of TNT and TNB, because these compounds migrate downward through the unsaturated zone. Large concentrations (up to several milligrams per liter) of the microbial transformation products 2-Am and 4-Am were detected in samples from the shallow unsaturated zone. Moderately large concentrations of 3,5-dinitroaniline

(3,5-DNA) were also detected, which suggests microbial degradation of TNB (Schumacher et al. 1996).

Data from the lysimeters indicate that the flux of nitroaromatic compounds through the unsaturated zone is seasonal and depends on the availability of moisture within the soil. Nitroaromatic concentrations generally increase in the fall and winter and peak in the spring. Infiltration increases during this period because of the sustained decreased evapotranspiration in the fall and winter months (Schumacher et al. 1992). The lysimeter data, combined with the presence of detectable tritium concentrations in the shallow aquifer at the training area, indicate that soils constitute a potential source of nitroaromatic compounds in groundwater.

5.3.2 Migration of Contaminants within the Shallow Aquifer

5.3.2.1 Physical Controls

Because of the topographic influence on the potentiometric surface, the east-west groundwater divide that transects the chemical plant area and the training area is coincident with the surface water divide that separates the Missouri and Mississippi river drainages (Figure 3.18). Seasonal water-level fluctuations are generally less than 1 m (4 ft), and the locations of the divide and the groundwater flow pattern are nearly constant throughout the year (Kleeschulte and Imes 1994). Exceptions have been observed in several ordnance works and chemical plant monitoring wells that respond dramatically to precipitation events and that have had historical water-level fluctuations exceeding 3 m (10 ft). The locations of these wells coincide with the general locations of preferential flow paths identified by the Missouri Department of Natural Resources (1991).

Typically, the shallow aquifer becomes less permeable with depth because of the decrease in rock weathering and fracture intensity of the Burlington-Keokuk Limestone. The greatest variability in hydraulic conductivity typically occurs in the upper 6 m (20 ft) of the weathered limestone. The highest values were observed at saturated areas of the residuum/bedrock interface. The locations of highest hydraulic conductivity generally correspond to linear depressions in the bedrock topography that are speculated to be conduits consisting of highly weathered limestone.

At the training area, nitroaromatics have migrated into the groundwater despite the presence of fairly thick, impermeable overburden on the site. Fractures in the clay or root holes may act as preferred pathways leading to the underlying bedrock. The limestone bedrock underlying the site is close to the surface in the natural drainageways of the site. The migration of COPC into the shallow bedrock aquifer has been enhanced by this relationship. Fractures and secondary porosity due to solution features, such as those that formed the springs, also allow for relatively easy lateral transport (IT Corporation 1993a).

Analysis of rock core from angle borings indicates that fracturing in the shallow bedrock aquifer is predominantly horizontal and typically occurs along bedding planes. Fracture densities are significantly higher in the weathered bedrock unit than in the unweathered unit (DOE 1996). Dissolution features are also present in the weathered unit and are generally oriented parallel to bedding planes.

Loss of circulation and core were common during drilling in the northern part of the chemical plant area. The aquifer is highly anisotropic where preferential flow occurs along horizontal features; the horizontal hydraulic conductivity is much greater than the vertical hydraulic conductivity. In the weathered limestone, high hydraulic conductivity estimates and high nitrate concentrations relative to concentrations in the unweathered unit indicate that the shallow aquifer is stratified, with most of the recharge water moving laterally within the weathered limestone. Deep percolation through the unweathered limestone is low. The presence of tritium and larger calcium/magnesium ratios in water samples from shallow uncontaminated monitoring wells can be explained by the shorter residence time of water in the weathered upper part of the shallow aquifer (Schumacher 1993).

In the chemical plant area, the horizontal migration of groundwater contaminants in the shallow aquifer appears to be controlled by preferential flow pathways linked to paleochannels in the weathered Burlington-Keokuk Limestone, as discussed in Chapter 3. Dye tracer tests indicate that the preferential flow system in the chemical plant area north of the groundwater divide is convergent to Burgermeister Spring. Dye tracer studies at the chemical plant area and the ordnance works have identified several subsurface conduit flow systems (Chapter 3). These tests indicate that the limestone conduit system has storage capacity as illustrated by the persistence of the tracer in Burgermeister Spring several months after injection. These tests also indicate that intermittently active conduits are present. The dispersion of the tracer and the varying peaks in tracer concentration in relation to precipitation events suggest that the tracer resides in portions of the system. Hydraulic connection was also demonstrated between losing stream segments and downstream gaining segments and springs in drainages south of the chemical plant area and the training area.

5.3.2.2 Migration Processes

Solute migration within the shallow aquifer is affected by the processes of advection, dispersion, sorption, irreversible binding, and degradation. The rate of solute migration by advection is a function of the concentration gradient and the volumetric flow rate. Dispersion of the solute front occurs as a result of mechanical mixing, nonuniform flow velocities, and molecular diffusion in response to chemical gradients (Freeze and Cherry 1979).

Adsorption occurs along the flow path as dissolved material interacts with the porous medium and is removed from solution. Degradation removes material from solution by changing its

physical or chemical properties. General patterns in the distribution of COPC are consistent with operations at the ordnance works area, site hydrology, and microbial processes in the aquifer.

Overall, nitroaromatic compounds were detected less frequently and in smaller average concentrations in downgradient wells on the Busch Conservation Area to the north than in wells at the chemical plant area and the training area (Figures 5.3 and 5.4). Although TNT and 2,4-DNT were the predominant nitroaromatic compounds produced at the ordnance works area, 2-Am and 4-Am are frequently detected in the groundwater and spring samples (Figure 5.3) and represent a substantial quantity of the total concentration of nitroaromatics detected in the shallow aquifer (Figure 5.4).

The greater persistence of 2,6-DNT compared with that of 2,4-DNT in the laboratory results is consistent with higher relative concentrations of 2,6-DNT in the shallow aquifer. 2,6-DNT is generally detected at a slightly higher frequency (Figure 5.3) and has larger average concentrations compared with 2,4-DNT (Figure 5.4).

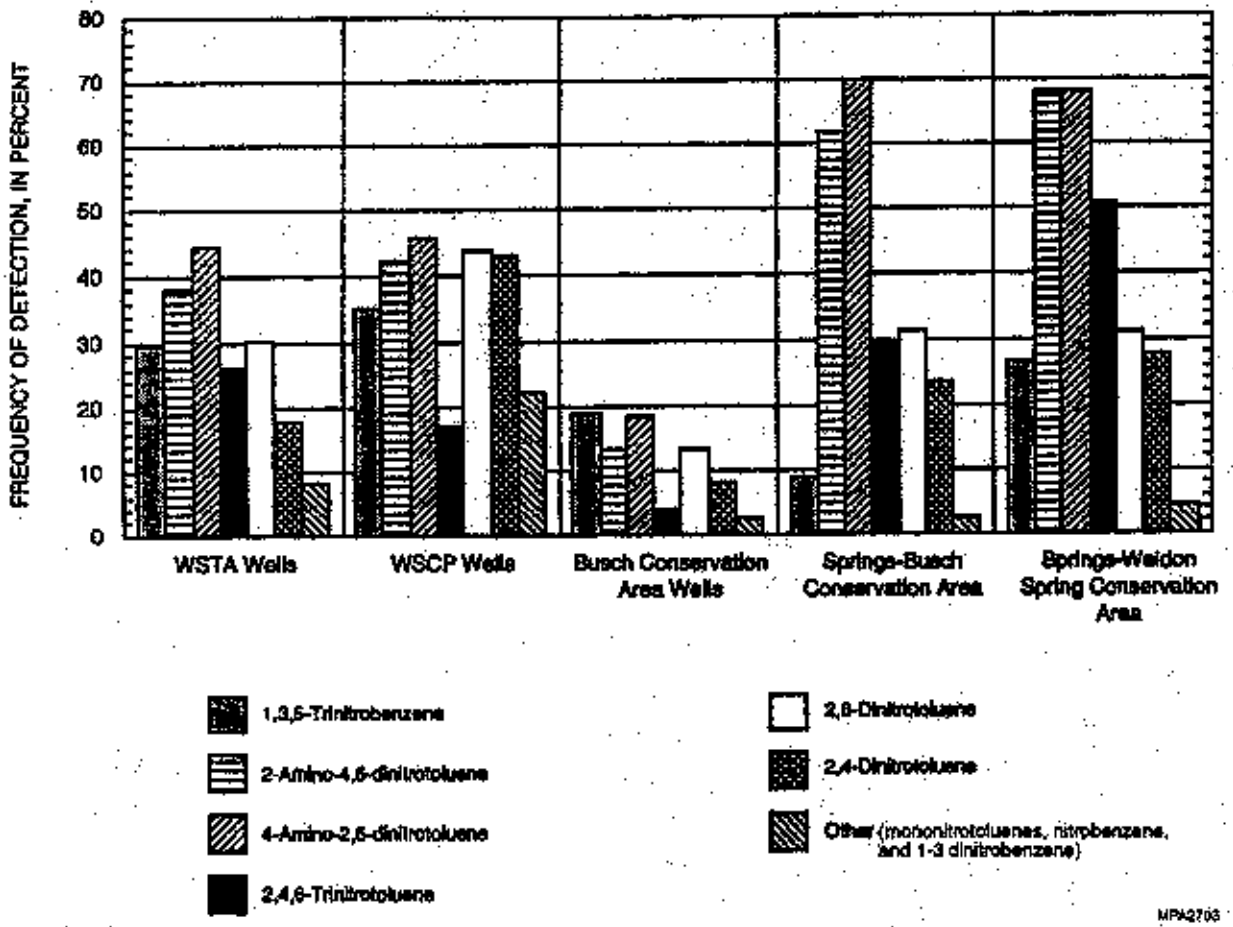

FIGURE 5.3 Frequency of Detection of Selected Nitroaromatic Compounds in Groundwater Samples from the Ordnance Works Area

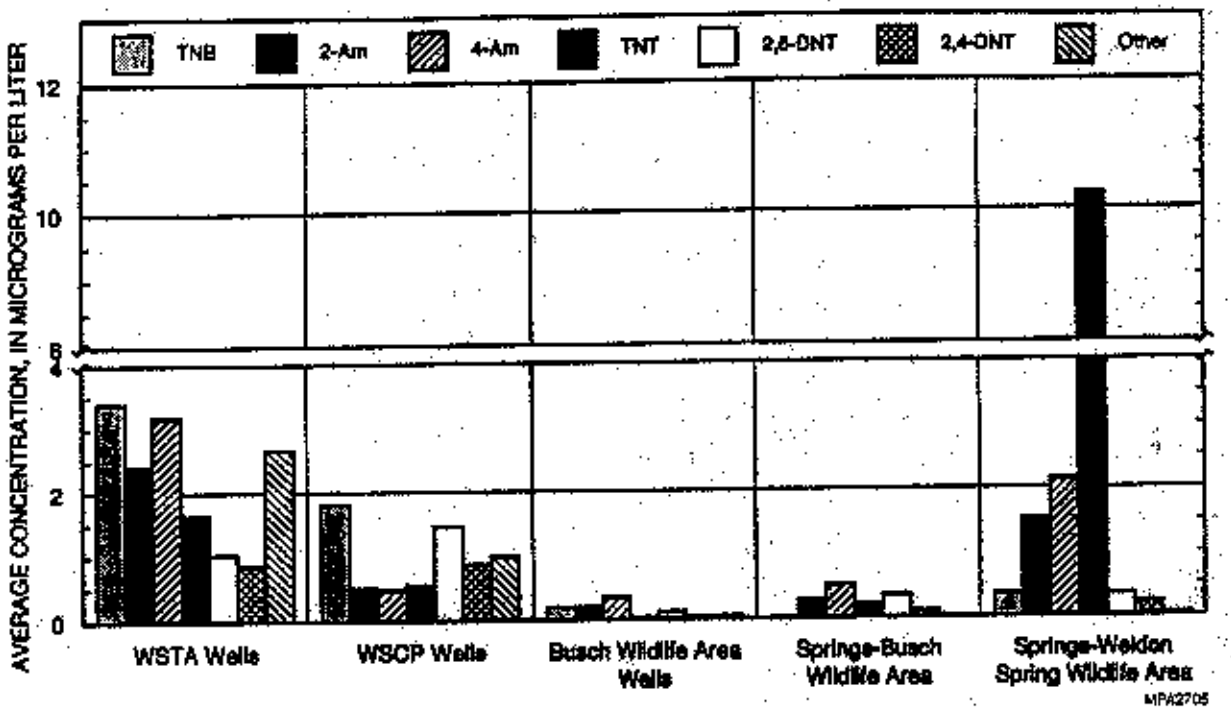

FIGURE 5.4 Average Concentrations of Selected Nitroaromatic Compounds in Groundwater Samples from the Ordnance Works Area

The distribution of nitrotoluenes is also consistent with site hydrology and microbial processes in the aquifer. Small concentrations (less than 1 µg/L) of nitrotoluenes are widely scattered across the ordnance works; however, nitrotoluenes are generally absent in samples from springs and surface water (Schumacher et al. 1996). Average concentrations of nitrotoluenes larger than a few micrograms per liter were found only in samples from monitoring wells MW-3023, MWS-12, and MWS-17. Concentrations of the DNT degradation product 2-nitrotoluene in samples from MWS-12 and MWS-17 are highly correlated to concentrations of 2,4-DNT and 2,6-DNT and have correlation coefficients of linear regression of 0.72 and 0.87 at a 99% significance level. Only two samples from well MW-3023 were analyzed for nitrotoluenes, thus precluding the use of regression analysis. The strong relationship between 2-nitrotoluene and DNT and the transient appearance of nitrotoluene as a microbial transformation product of DNT in microcosm experiments suggest that DNT is being transformed to nitrotoluene in the aquifer. Nitrotoluenes are generally metabolized rapidly, which may explain why appreciable concentrations were detected in only a few wells.

Contamination originating at either the chemical plant area or the training area can migrate toward the Twin Island Lakes area to the north of the ordnance works area by a combination of diffuse flow in a direction consistent with the existing hydraulic gradient and losing stream segments

that carried red water in the past. Because streams in the immediate vicinity of Twin Island Lakes are weak losers, the dominant flow path would be diffuse flow through the shallow groundwater aquifer.

5.3.3 Migration of Contaminants by Surface and Subsurface Runoff

5.3.3.1 Physical Controls

The chemical plant area and the ordnance works area are located on the east-west drainage divide between the Missouri and Mississippi watersheds. Surface water runoff in the western part of the ordnance works area and south of the divide flows to the Little Femme Osage Creek and its tributaries, which ultimately discharge into the Missouri River. Surface water runoff in the eastern part of the ordnance works area and south of the drainage divide also discharges to the Missouri River. However, surface drainage to the north of the divide converges at Dardenne Creek and its tributaries. Schote Creek, the largest of the tributaries, drains a major portion of the chemical plant area and the training area. Dardenne Creek flows easterly to the Mississippi River.

Most of the tributaries in these areas have losing reaches and springs and, therefore, surface water and shallow groundwater interactions are significant within the chemical plant areas and the ordnance works area. Surface water entering the shallow groundwater system along losing reaches is a potential pathway for groundwater contamination. At the training and chemical plant areas, some shallow groundwater north of the divide flows to the north, crosses drainage boundaries, and emerges in other drainages. This groundwater eventually discharges to tributaries of the Mississippi River. South of the divide, groundwater typically remains within drainage basins and discharges to both perennial and wet weather springs located in the same drainage and flows to tributaries of the Missouri River. This discharge includes water that enters the drainage basin from overland flow and precipitation and is lost in losing stream reaches to the shallow aquifer.

In the northeastern portion of the training area and the northwestern portion of the chemical plant area, a subsurface conduit system transports water rapidly to Burgermeister Spring and an associated wet weather spring. Historical data indicate relatively low flow rates under baseflow conditions (~2 L/s [~0.07 ft^3/s]) and much higher rates during and following precipitation events. A total combined discharge exceeding 113 L/s (4 ft^3/s) was measured for these springs.

5.3.3.2 Migration Processes

Historical documentation of contaminants entering losing streams and affecting groundwater, as evidenced by red water contamination emerging in vicinity springs, was

documented by the USGS during operation of the ordnance works (Fishel and Williams 1944). In addition, groundwater contamination from leakage of lagoons was also noted. In general, contaminants entering the groundwater system through losing stream reaches will likely move in the shallow, more active flow system that is dominated by conduit flow and will discharge rapidly to springs.

Surface drainages receiving part of their flow from the chemical plant area and the training area are the Southeast Drainage (5300), Schote Creek (6200), and the 6300 drainage via interconnection with Schote Creek through the conduit flow system (Figures 3.9 and 3.10). Water-level, dye-trace, and water-quality data indicate groundwater contamination by interception of surface runoff in the Southeast Drainage and the Burgermeister Spring conduit system. Elevated concentrations of sodium and chloride in the discharge at Burgermeister Spring indicate the contribution of surface runoff from a highway department facility on the east tributary of Schote Creek through a losing stream reach upstream from Lake 35. Dye injected into a losing stream segment of Schote Creek north of the chemical plant area emerged at Burgermeister Spring (approximately 1,981 m [6,500 ft] away) two to three days later (Missouri Department of Natural Resources 1991).

The ability of streams to maintain flow and transport sediment is significant in determining the potential for surface water to act as a source of contamination. The flow-duration curve for Schote Creek has a steep slope, indicating that this stream derives much of its flow from direct runoff, as does the hydrograph for Burgermeister Spring. Recharge to the shallow groundwater aquifer in the immediate vicinity of losing stream segments is primarily derived from the losing stream. Contamination in the stream can, therefore, directly contaminate the groundwater. Once lost from a surface stream, water can enter the existing conduit system and be transported rapidly to emergent springs. Residual contamination in the conduit system can be mobilized by dissolution, desorption, and sediment transport during precipitation events.

Comparison of mass flux patterns for uranium and nitrate at Burgermeister Spring reveals potentially different trends in the transport mechanisms for these contaminants (Figure 5.5). The mass flux of nitrate is about constant or slightly decreased with increasing discharge, whereas the mass flux of uranium increases with increasing discharge. The direct relationship for uranium suggests that the major sources of uranium are recharge by surface runoff lost to the subsurface (Johnson et al. 1989) and mobilization from storage in the conduit. Raffinate pit seepage is suspected as a source of low uranium levels during baseflow. The lower nitrate flux at high discharge is a result of groundwater dilution by surface water.

The historical tendency for uranium concentrations in Burgermeister Spring discharge to decrease during low-flow periods appears to be related to the absence of flow in the losing segment of Schote Creek downstream from Ash Pond (Schumacher 1993). In contrast, values of specific conductance, anions, nitrate, and lithium increase during low-flow conditions, which indicates a base

flow source (raffinate pits) for these constituents (Figure 5.5). To date, no volatile organic compounds have been detected at the springs. A plot of uranium concentration versus time (Figure 5.6) shows an upward trend prior to 1989 and then suggests a decrease in uranium concentration from 1990 to 1995 since completion of the Ash Pond diversion in 1989.

Dye tracer studies performed at the chemical plant area indicate that the limestone has storage capacity because of the temporary entrapment in dead-end conduits, which results in a rate-limited storage-release mechanism. The higher uranium values observed at Burgermeister Spring during high flow may be partially attributable to this storage in the conduit system. The low-permeability limestone beneath the preferential pathways provides contaminant storage and supplies the baseflow discharge at Burgermeister Spring. Raffinate pit seepage has been shown to contribute uranium measured at low concentrations during baseflow (Schumacher 1993).

In areas such as in the vicinity of USGS-3, the concentration of nitroaromatic compounds (TNB) is high, whereas the concentration of tritium is low. Losing stream segments containing red water in the early 1940s acted as a source for groundwater contamination. It is possible that nitroaromatic concentrations in runoff entering losing streams were large enough that molecular diffusion into the surrounding rock matrix or precipitation of crystalline material within the deeper unsaturated zone or the shallow aquifer occurred. The reversal of this process would occur much more slowly and would act as a source for nitroaromatic contamination for many years. The present absence of tritium at these locations indicates that either the geometry of the losing stream segments has changed since the 1940s or that tritium has not had sufficient time to be transported by diffuse flow to the vicinity of the wells.

In the vicinity of the training area and Burning Ground 1 (5200 drainage), an area that on average has a relatively high nitroaromatic concentration in runoff water, it is unlikely that losing stream segments would contribute significantly to nitroaromatic groundwater contamination for the following reasons: the concentrations of nitroaromatic compounds in stormwater runoff are small (generally less than a few µg/L) (Schumacher et al. 1996); groundwater concentrations, on average, are larger than those measured in surface water runoff; and groundwater sampling indicates a detectable quantity of nitrotoluene that is generally absent in surface water runoff. Comparison of filtered and unfiltered samples indicates that the nitroaromatic compounds detected are being transported primarily in the dissolved phase (particle sizes less than 0.45 µm).

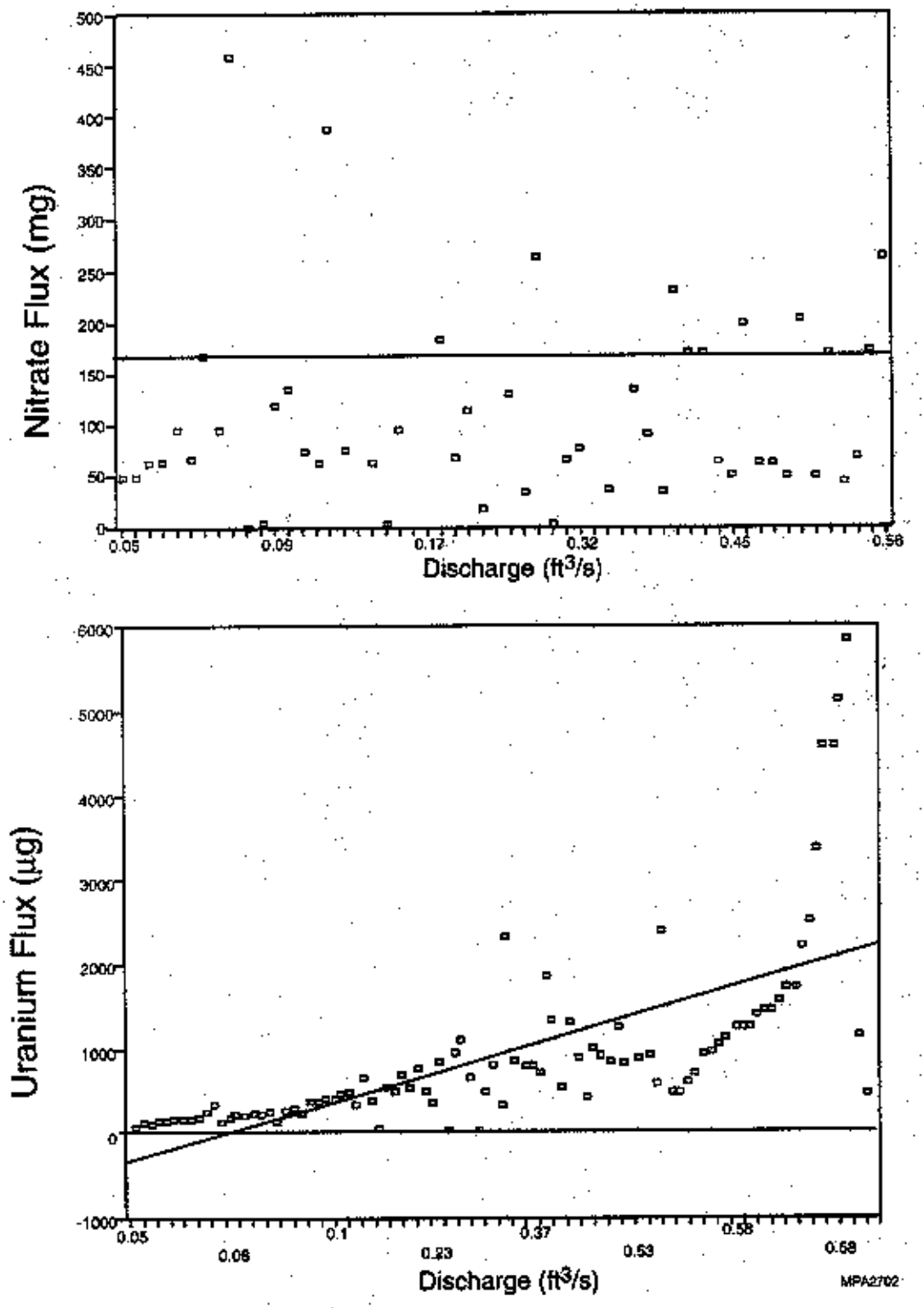

FIGURE 5.5 Contaminant Flux versus Discharge of Burgermeister Spring 1987 to 1995

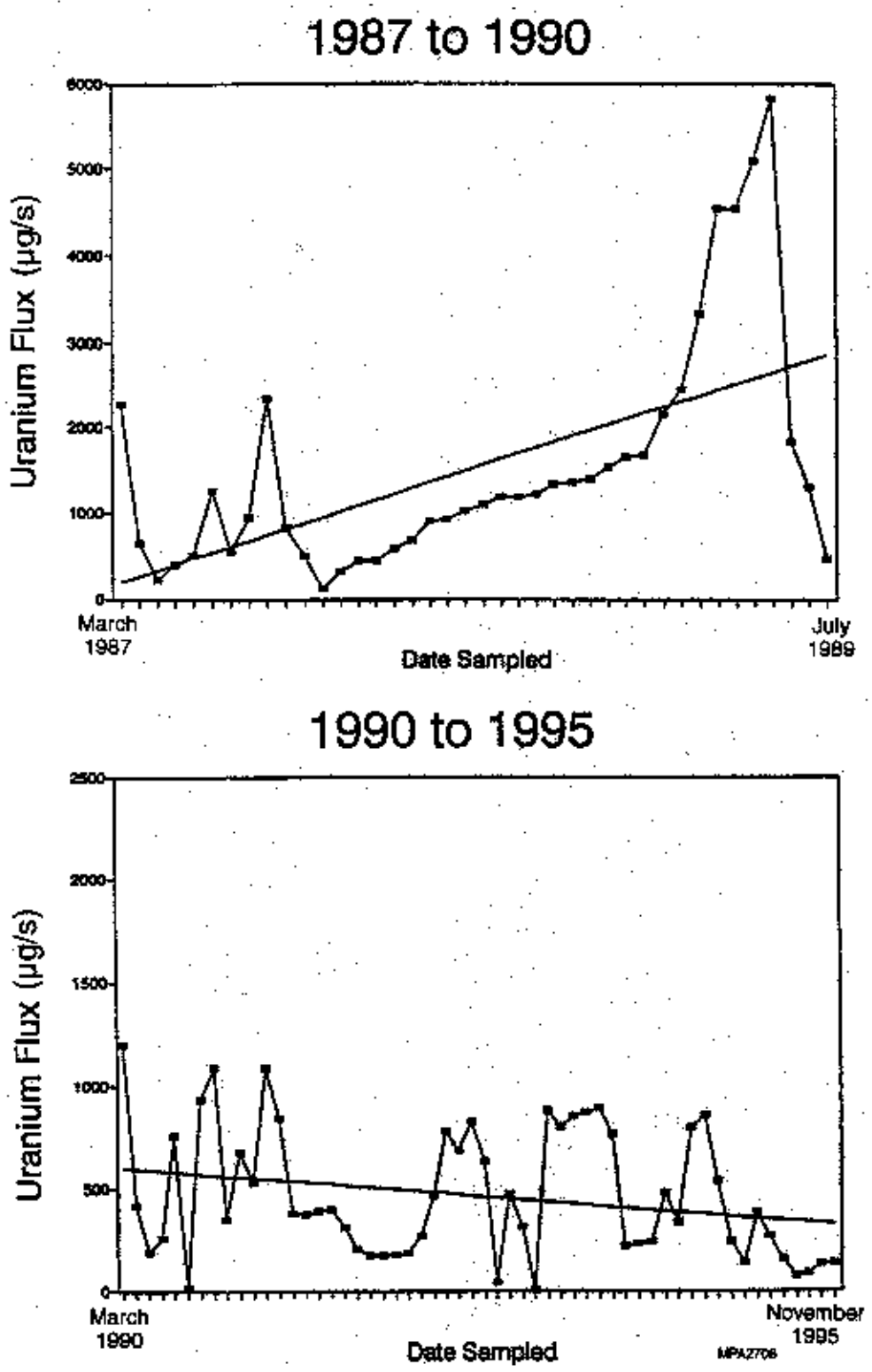

FIGURE 5.6 Uranium Flux versus Date Sampled, Burgermeister Spring

6 SUMMARY OF THE BASELINE RISK ASSESSMENT

A combined assessment addressing both human health and ecological impacts was performed as part of this RI. A separate report has been prepared to present details of the risk assessment (DOE and DA 1997); this section summarizes that assessment. The human health component of the baseline risk assessment included an evaluation of the radiological and chemical risks from contamination in the shallow aquifer system that are common to both the chemical plant area and ordnance works area. Springwater data were also used to calculate potential human health impacts at the springs. The ecological risk assessment focused on Burgermeister Spring because the aquatic habitats associated with this spring are more permanent than the habitats at other springs in the area and, thus, may be used by a greater variety and number of biota than habitats at other springs.

6.1 HUMAN HEALTH ASSESSMENT

Site-related COPC were identified from the list of contaminants presented in Table 2.4. For groundwater, the COPC are lithium, molybdenum, uranium, nitrate, chloride, sulfate, nitroaromatic compounds, TCE, and 1,2-DCE.

Under current land use, the most likely receptor was assumed to be a recreational visitor who might be exposed to contaminated discharge water at one of the springs. No current access and use of the groundwater was assumed on the basis of current land use information. Foreseeable future land use is expected to be similar to current land use. Exposure of Army reservists that visit the training area for drills was not evaluated separately because there are no active springs within the boundaries of the training area. Also, calculations presented for the recreational visitor are representative of those for Army reservists because the exposure parameters (e.g., duration and frequency) would be similar.

Calculations for a residential scenario were also included to provide upper-bound information regarding human health risk from groundwater. Maximum concentrations in groundwater for COPC from the 1995 joint DOE/DA sampling rounds were used as exposure point concentrations. This approach was taken because the 1995 joint data were consistent with the data obtained since 1987 and are, therefore, representative of the nature and extent of contamination. The use of more recent data also provides risk estimates that are representative of current conditions at the site. In addition, a well-by-well calculation was performed because results of the RI have shown contaminant concentrations to be heterogeneous.

Both a hazard index and carcinogenic risk were calculated by using the UCL or maximum value for each COPC in springwater for each of the 15 springs sampled in 1995 to evaluate potential

exposure of the recreational visitor. Similar calculations were performed for each well to determine potential exposure of a future resident. Pathways evaluated for the recreational scenario were ingestion and dermal contact. The primary pathway of concern for groundwater is ingestion; however, the dermal pathway was also assessed. In addition, the inhalation pathway was evaluated for TCE. Standard exposure parameters recommended by the EPA were used in the calculations. Current contaminant concentrations were also assumed for future scenarios. This approach is considered conservative since contaminant concentrations are expected to decrease with time as a result of source removal activities currently in progress at both the chemical plant area and the ordnance works area.

Neither carcinogenic risk nor systemic toxicity is indicated for the recreational visitor incidentally ingesting and dermally exposed to springwater in the area covered by the GWOUs. The radiological risk estimates range from 4×10^{-9} to 2×10^{-6}. These values are low and well within the target risk range of 1×10^{-6} to 1×10^{-4} recommended by the EPA (EPA 1990). The chemical risk estimates are similarly low, ranging from 2×10^{-10} to 3×10^{-7}. The EPA has provided a quantitative measure for adverse health effects other than cancer; a hazard index greater than 1 indicates potential adverse health effects. The hazard indexes estimated for the recreational visitor at the springs range from less than 0.001 to 0.2.

The well-by-well calculations of radiological and chemical carcinogenic risks to determine potential exposure of a hypothetical future resident indicate that the majority of the 155 wells evaluated do not contain contaminants at levels that contribute to a risk higher than 10^{-4}. Excluding contributions from TCE, chemical risk estimates for only 4 of the 155 wells are higher than 10^{-4} (e.g., MWV-09, MWS-12, MW-2030, MWS-17). The chemical risk estimates for the 155 wells range from 1×10^{-7} to 2×10^{-4}. The primary contributors to the risks are 2,4-dinitrotoluene and 2,6-dinitrotoluene. The radiological risk estimates for all wells are within the target risk range. The range of estimates for radiological risks from uranium is 7×10^{-8} to 7×10^{-5}.

Concentrations of TCE were detected in nine wells at or in the vicinity of the chemical plant area. The total carcinogenic risks at these wells, incorporating risk from TCE, are as follows: 2×10^{-5} (MW-3024), 4×10^{-4} (MW-2037), 1×10^{-3} (MW-2038), 1×10^{-5} (MW-3025), 1×10^{-6} (MW-4001), 2×10^{-7} (MW-2032), 3×10^{-4} (MWS-21), 9×10^{-7} (MW-3027), and 6×10^{-7} (MW-2013).

The hazard indexes for the 155 wells evaluated range from less than 0.01 to 40. Forty-three of 155 hazard indexes are greater than 1. Twenty-seven of the estimates that are greater than 1 are attributable primarily to nitroaromatic compounds; 15 estimates are attributable to nitrates, and 1 to uranium. Elevated nitroaromatic compounds have been identified for wells in various locations at the two areas. Elevated nitrates occur mostly in chemical plant area wells.

6.2 ECOLOGICAL ASSESSMENT

The ecological risk assessment evaluated risks to ecological resources by using data on springs in the chemical plant area and the ordnance works area. Although direct exposure to groundwater is unlikely for aquatic and terrestrial biota, fish and wildlife may be exposed at locations where the groundwater discharges to surface water habitats, namely springs. Risks to aquatic biota were evaluated by using biotic surveys and media toxicity and by comparing media concentrations to ecological benchmark ("safe") media concentrations. Risks to terrestrial biota were evaluated by melding contaminant uptake via ingestion of water and comparing the predicted doses to species-specific benchmark doses. Maximum concentrations of the potential site-related contaminants were used for all benchmark comparisons and uptake modeling. The data used for the ecological risk assessment included the same data on springs used in the human health risk assessment, as well as sediment data collected specifically for the ecological risk assessment at the Burgermeister Spring and selected downstream locations. Burgermeister Spring was selected as the exposure area for all uptake modeling scenarios, biotic surveys, and toxicity testing because the spring and downstream habitats represent the largest and most permanent spring-related aquatic habitat in the area.

Surveys of macroinvertebrates, fish, and amphibians inhabiting the Burgermeister Spring drainage found no evidence of adverse effects to these aquatic biota. The spring was determined to contain generally good aquatic habitat comparable to the habitat evaluated at a reference spring location, and the species present are typical of those found in similar habitats throughout the Midwest. Although the fish community was limited in diversity and the macroinvertebrate community was categorized as slightly impaired, the communities are likely affected by the physical nature of the spring and its drainage rather than by contaminant levels. Flow in the uppermost portion of Burgermeister Spring is maintained by groundwater discharge at the spring. Under low flow conditions, as commonly occur in the summer, the spring becomes intermittent, and portions of the habitat become dry. Surveys found the amphibian community to be similar in species composition to the community identified at the reference spring and to typical communities in similar habitats in the Midwest.

The results of toxicity testing indicate the potential for some toxicity to fish and invertebrates from surface water and sediment in Burgermeister Spring proper. Surface water and sediment toxicity were also measured at some locations downstream of the spring, but no clear toxicity gradient is evident extending downstream from the spring. The presence of apparently unaffected macroinvertebrate, fish, and amphibian communities in the drainage at locations where media toxicity was detected suggests that local populations are tolerant of (or have adapted to) the contaminant levels present in surface water and sediment in the Burgermeister Spring drainage.

Modeling of contaminant uptake by the white-tailed deer and the American robin drinking from Burgermeister Spring (but using maximum contaminant concentrations reported from all

springs) predicted very low levels of contaminant uptake by these species. Risk estimation based on the modeled contaminant doses indicates no risk to terrestrial biota drinking from the spring. Risk estimates for aquatic biota on the basis of media concentrations indicate that surface water concentrations of arsenic, cadmium, copper, lead, manganese, 1,3,5-trinitrobenzene, 2,4,6-trinitrotoluene, and sediment concentrations of arsenic, lead, and silver may pose low to moderate risks to aquatic biota in the drainage.

Although the risk estimates for iron and mercury indicated extreme risks to aquatic biota, the risk estimates were derived on the basis of maximum reported concentrations that may represent outliers. Risk estimates derived without using these maximum values indicated low or no risks for mercury and iron, respectively. Even though some risks to aquatic biota are indicated, the aquatic community in Burgermeister Spring is typical of similar habitats elsewhere in the Midwest and does not appear to be adversely affected by contaminant concentrations at this time. Few of the remaining springs in the area provide suitable habitat and, at best, naturally support only very limited aquatic communities.

These evaluations indicate that current contaminant levels in surface water in area springs pose little or no risk to terrestrial biota of the chemical plant and ordnance works areas. Risk calculations for aquatic biota indicate that concentrations of some contaminants in surface water and sediment from springs may pose low risks to aquatic biota. However, most of the risk estimates only slightly exceeded the target risk range. In addition, most springs do not naturally provide permanent habitat to support aquatic biota, and, thus, the potential risks are not expected to be ecologically significant. Although some toxicity has been indicated for surface water and sediment from Burgermeister Spring, the results of the biotic surveys show no evidence that the aquatic biota are being adversely affected by present contaminant levels. Thus, the ecological significance of the toxicity is small, and aquatic ecological resources of the area should not be expected to be adversely affected.

7 QUALITY ASSURANCE

Remedial investigation activities for the GWOUs were conducted in accordance with the respective quality assurance program plans (QAPPs) developed for each site. The QAPP used for GWOU activities at the ordnance works area is entitled the *Chemical Data Acquisition Plan, Weldon Spring Ordnance Works Remedial Design, Weldon Spring, Missouri* (IT Corporation 1994a). For the chemical plant area, the QAPP is entitled *Environmental Quality Assurance Project Plan* (EQAPjP) (MK-Ferguson and Jacobs Engineering Group, Inc. 1993a). These documents provide guidelines to ensure that all environmental activities conducted for the groundwater remedial investigation were performed in a manner resulting in the collection of quality data.

Extensive quality control (QC) measures and quality assurance (QA) evaluations were performed on data collected for the groundwater operable unit. This section summarizes these measures. Table 7.1 defines the types of QC samples that were collected, frequency of collection, and the purpose for sample collection.

7.1 ANALYTICAL REVIEW

The data quality objectives developed for the GWOUs provide for the collection of the right type, quality, and quantity of data to support remedial decisions. This process ensures that the samples collected were analyzed at appropriate detection limits and by adequate methods to support the risk assessment. All laboratories (including those used for the 1995 sampling) are required to conform to approved analytical methods and QA/QC procedures.

All data quality requirements for the GWOUs were met as required in the Sampling Plan (DOE 1995a), with the following exceptions: two chain-of-custody incidents, a sample filter problem, and analytical problems resulting from the grout used during well installation. These exceptions are discussed in Sections 7.1.1.1 to 7.1.1.3. Reasons for the rejection of certain data are discussed in Sections 7.1.1.4 and 7.1.1.5. Section 7.1.1.6 discusses other data quality uncertainties.

7.1.1 Field Filters

Beginning with the fifth sampling round in April 1992 for training area and ordnance works wells and all chemical plant area samples from 1987 to 1995, filters manufactured by QED Groundwater Specialists were used for filtering groundwater prior to metals analysis. IT Corporation reported in the July 1992 Groundwater Monitoring Report (IT Corporation 1992c) that antimony appeared in the dissolved metals results. This was inconsistent with past sampling results, and IT Corporation suspected that antimony was being leached from the filter paper. In a subsequent

TABLE 7.1 Summary of Quality Control Samples

Quality Control Sample Type	Frequency[a]	Purpose
Matrix spikes	1 per 20 (5%) samples or 1 per 14 days	Monitors the effect of matrix interferences on the detection of an analyte.
External QA sample	1 per 10 samples	Compares the primary laboratory with the secondary laboratory and provides an additional check on the performance of the primary laboratory.
Field duplicate	1 per month	Monitors field conditions that may affect the reproducibility of samples collected from a given location.
Equipment blank (nondedicated equipment only)	1 per 20 (5%) samples	Monitors the effectiveness of decontamination procedures used on nondedicated sampling equipment.
Deionized water blank	1 per month	Monitors the purity of distilled water used for field blanks and decontamination of sampling equipment.
Trip blank	1 per month	Monitors VOCs that may be introduced during sampling, transportation, or handling at the laboratory.

[a] As stipulated in Weldon Spring Site Remedial Action Project Environmental Safety and Health Procedure 4.1.4s, Rev. 3.

November 1992 report, a sample of the filter paper was analyzed, and antimony was indeed found to be present (IT Corporation 1993b). In addition, it was reported by the manufacturer of the filters that up to 50 µg/L of antimony can be leached from the filter papers (Kaminski 1995). According to EPA guidance, if filtered samples showed detected antimony at a concentration of less than 250 µg/L (5 × 50 µg/L), the data point would be rejected. Because no samples exceeded this concentration, all filtered samples that had detections for antimony were rejected and not used. A large number of filtered samples were affected by this situation, and, therefore, only antimony data from unfiltered samples were used for the RI and BRA.

7.1.2 Chain-of-Custody

Chain-of-custody was maintained on all sample collection and shipment activities with the exception of one request for eight samples. In the cases where chain-of-custody was not maintained, the data were rejected.

One shipping incident was also reported during the August sampling event; two coolers were inadvertently shipped to the wrong laboratory. One cooler of nitroaromatic samples was shipped to the analytical laboratory that performed metals analysis, while the other cooler went to the nitroaromatics lab. The chain-of-custody was maintained on the coolers, and the shipments were reshipped to the appropriate laboratories.

7.1.3 Well Installation

Monitoring Well 4024 was installed in early July 1995, and on July 5, 1995, the well was sampled. The total uranium value for the first sample for this well was much higher than expected on the basis of values reported for nearby wells. After observing this, an informal study was performed on the bentonite grout used in well construction. In this study, 500 g of dry bentonite supplied by the well subcontractor was analyzed by gamma spectroscopy and found to have 2.84 pCi/g of uranium-238. This grout comes from natural sources, which means that about half of the total uranium activity in the grout comes from uranium-238 and about half comes from uranium-234. Therefore, the activity of the total uranium in the bentonite should be roughly two times the activity of uranium-238. In an effort to determine if leaching occurs, about 500 g of the bentonite was placed in a 1-L nalgene container. Approximately 150 mL of tap water was added to the container, which resulted in saturation of the bentonite. The tap water, as well as the following aliquots, were analyzed by KPA. The uranium activity level in the tap water was below the detection limit at 0.0032 pCi/L. Aliquots of the water sitting above the grout were collected after one day, two days, and seven days. The analysis results after one, two, and seven days were 1.65 pCi/L, 2.49 pCi/L, and 38.9 pCi/L of total uranium, respectively. These results demonstrate that some of the uranium from the bentonite may have leached into the water in the wells. Furthermore, the values of total uranium for subsequent samples in this well dropped considerably. The value for the sample taken on August 11, 1995, was 16.6 pCi/L. The values for the samples taken in May and September 1996 were 8.67 and 4.07 pCi/L, respectively. This analysis will help to assess previous and future elevated uranium concentrations reported in existing and newly developed wells at the chemical plant area and the ordnance works area.

7.1.4 Data from Early Sampling Rounds

Because of discrepancies in analytical methods and QA procedures that occurred during the first and third rounds of DA sampling in March and October 1989 and May and June 1991, data from the ordnance works area and training area sampling Rounds 1 and 3 were not used for the RI and BRA. The data were excluded because of QA/QC problems, such as missed holding times, poor matrix spike (MS) recoveries, and poor laboratory chemical spike (LCS) recoveries.

Nitroaromatics data generated from samples taken at the ordnance works and the training area in November 1992 (Round 7) were rejected because of sporadic blank contamination. Metals data were acceptable. Nitroaromatic data were retaken in December 1992 (Round 7A) and were found to be acceptable.

In Round 15, November 1994, nitroaromatic data from Well USGS2A were rejected because the holding time was exceeded.

7.1.5 Other Data Quality Uncertainties

Issues that could affect data used in the RI and BRA include changes in sampling techniques and analytical methodologies and modified laboratory procedures, for example:

- *Changes in Sampling Techniques.* In May 1994, wells at the training and ordnance works areas were switched from bailers to bladder pumps. This sampling methodology is known to affect analytical results. The actual magnitude of this effect is uncertain.

- *Changes in Analytical Methodology.* Theoretically, all valid analytical methods should arrive at the same result for the same sample. In practice, however, because each method requires slightly different analytical expertise, changes in analytical methods can produce different analytical results from the same sample. This, however, appears to be a minor problem for the groundwater data since split samples taken and analyzed by subcontracted laboratories have generally agreed with QA laboratory split samples by the DA. This is true even though the QA laboratory of the DA has been using Method 8330 (a high-performance chromatograph/ chromatography [HPLC] method), the USGS has been using a variation of Method 8330, and other subcontractor laboratories were using other versions of a gas chromatograph (GC) method. Before Method 8330 was used, the Weldon Spring Ordnance Works wells were analyzed by a U.S. Army Toxic and Hazardous Materials Agency HPLC method for Rounds 1 and 2 for training area wells and by EPA Method 609 for Round 1 for other ordnance works wells. Method 8330 was used for all ordnance works wells in Rounds 3 to 12, and variations of the Army Environmental Hygiene Agency GC/electron capture detector (ECD) method were used for all subsequent rounds. Results from all of these methods have been generally comparable. Therefore, the changes in methodology over the years are not considered a significant factor in data quality.

7.2 DATA VALIDATION

The DOE and DA QA program for environmental data includes validation or assessment of quality sufficiency of the analytical data that are used to make remedial decisions under CERCLA. Data validation is defined as the review of analytical data documentation used to qualify the quality and usability of data. Factors considered in this determination include sample integrity, laboratory performance, and compliance with procedural QC criteria and data quality requirements. Data validation also provides an assessment of the accuracy, precision, and completeness of the reported analytical data.

Accuracy is defined as how close an analyzed value is to the true value. It is usually associated with LCS recoveries and MS recoveries. A value of 100% is the best accuracy. Precision is defined as how close two analyzed values match each other. Precision is normally expressed as the relative percent difference (RPD). An RPD of 0% is the best precision. The data acceptance criterion is defined as the ratio of accepted data points to the validated data points (accepted plus rejected) in a data set. The EPA uses an acceptance limit of 85% for its Contract Laboratory Program work with individual laboratories. The Weldon Spring Site Remedial Action Project uses this value as well.

Validation was conducted on at least 10% of the chemical plant data collected before 1995, as required by standard operating procedures. For the ordnance works data, quality sufficiency evaluations were conducted for 100% of the groundwater data collected before the joint sampling quarters. The objectives of the DA quality sufficiency evaluations are similar to those of DOE's validation activities performed at the Weldon Spring Site Remedial Action Project. All data collected from the 1995 joint sampling events from both areas were validated or evaluated. Similar evaluation and validation procedures and frequencies were applied to data collected from springs.

7.3 DATA REVIEW AND USE

In the preparation of the RI report, data from the 1995 joint sampling quarters were compared with previously collected data for the sample location. Data were reported as nondetected (but with the detection limit identified), as detected values, or as uncensored data. Uncensored values were defined as data reported at a concentration measured at less then the required detection limit of the analytical methods or instrumentation. For the chemical plant groundwater data, 1.37% of the data were reported as uncensored; for the ordnance works groundwater data, 1.83% of the data were uncensored; the percent of uncensored data in the sediments database was 0.93%; the percentage of uncensored data in the springs database was 0.54%. In all statistical summaries provided in this RI report, one-half the detection limit was used for calculating averages in nondetect data. The EPA recommends the use of this value for statistical manipulation of data when the percentage of nondetects in the data set is small and uncensored data are not available (EPA 1989a).

Data for the GWOUs were also evaluated with a statistical method whereby data for the same location for each parameter are reviewed to examine potential outliers within the data set. The summary is based on trimmed data sets and Gaussian statistics. The data are ranked relative to the tolerance intervals, which are defined by the trimmed mean (μ) ± 3 standard deviations (σ). Although some data sets may not follow a Gaussian (normal) distribution, this approach provides a conservative means for identifying extreme values (potential outliers) and is simple to use. This value also approximates the 98th percentile of the data set for the location and the parameter. For the RI, these data were included in summary tables but were not used in statistical summary or average calculations. Table 7.2 lists the data points that were identified as outliers as a result of calculation of the mean from historic data, existing conditions at the sites, and potential contaminant source areas.

TABLE 7.2 Data Points Identified as Outlier Values for the Groundwater Operable Units

Parameter	Location	Outlier Value	Next Value in Data Set
Manganese	MWS-111	27,000 µg/L (Round 8)	904 µg/L
Aluminum	MWD-106	2,000 µg/L (Round 7)	29 µg/L
Iron	MWD-106	1,400 µg/L (Round 7)	76.8 µg/L
Iron	MWD-109	4,100 µg/L (Round 4)	270 µg/L

8 SUMMARY AND CONCLUSIONS

An RI was conducted to evaluate the nature and extent of potential contamination in the shallow aquifer system at the DOE chemical plant area and the DA ordnance works area. The remedial investigation evaluated geological, groundwater, and spring data collected from 1987 to 1995, including data from a 1995 joint sampling effort conducted at the chemical plant area and the ordnance works area. These data were used to characterize the hydrogeology of the chemical plant area and the ordnance works area and to describe the nature and extent of contamination in the groundwater system of the area. These data were also used to prepare a BRA that evaluates the potential effects of exposure to contaminated groundwater and springwater to human health and the environment.

8.1 HYDROGEOLOGY

The focus of the groundwater remedial investigation was the shallow aquifer system, which consists of the first encountered groundwater at the chemical plant area and the ordnance works area. The shallow aquifer system includes the saturated overburden, the Burlington-Keokuk Limestone, and the Fern Glen Formation. In general, the flow in this aquifer can be characterized as Darcian diffuse flow through the saturated overburden and limestone bedrock matrix, with superimposed conduit flow through the larger joints and solution features in the limestone bedrock. Interaction between the surface water and groundwater occurs through losing and gaining stream segments in the ordnance works area and through groundwater discharge to springs. Losing stream segments allow surface water runoff to enter into the subsurface and act as localized recharge to the shallow groundwater system. Gaining stream segments and springs reflect discharge of the aquifer to the surface water system. This type of groundwater flow is typical of carbonate aquifer systems.

The Burlington-Keokuk Limestone can be divided into weathered and unweathered hydrostratigraphic units on the basis of stratigraphic characteristics, degree of weathering, and fracture density. This division is pertinent to the ability of groundwater to move through the bedrock. The hydraulic conductivity of the Burlington-Keokuk Limestone decreases with depth, and the greatest variation in hydraulic conductivity occurs in the upper 3 to 6 m (10 to 20 ft) of the weathered unit. The Fern Glen Formation is included in the lower hydrostratigraphic unit because of its similarity to the unweathered Burlington-Keokuk unit, thick bedding, fine-grained texture, and its position directly below the unweathered unit.

Recharge to the shallow aquifer occurs as infiltration of precipitation and impounded surface water through the overburden materials. The hydraulic conductivity of the overburden units is low due to the predominance of clay in the till and residuum units, which contain permeable zones and hairline fractures that allow infiltration by gravity drainage. Recharge also occurs as surface

water runoff entering the aquifer system through numerous losing stream segments; however, the residence time of this water in the system is short. Discharge of the shallow aquifer occurs at springs and seeps in the area. The larger flow rates from these springs are due, in part, to precipitation events.

Paleochannels or paleovalleys (preglacial drainages) have been identified in the top of the bedrock surface in the northern portion of the chemical plant area and the training area. These paleochannels, which in some cases coincide with troughs in the shallow groundwater surface, are more transmissive than other areas. Higher hydraulic conductivities are associated with the paleochannels in these areas, primarily at the residuum/bedrock contact. These higher conductivity values are likely due to increased weathering along the contact, which results in high fracture intensity and gravel content. These paleochannels allow for a greater horizontal movement of groundwater.

Tracer tests indicate that the paleochannel or paleovalley areas are connected to a subsurface conduit system in the northern portion of the chemical plant area and the training area. The conduit system allows for rapid movement of groundwater through the bedrock; travel times are on the order of several feet per minute. The conduit system is complex and consists of branching and converging conduit flow routes. Tracer tests indicate a relationship between precipitation events and groundwater discharge in the conduit system.

Vertical gradients between the overburden and Burlington-Keokuk Limestone and within the Burlington-Keokuk Limestone indicate recharge (downward movement) conditions. Upward gradients between and within these units in the northern portion of the training area likely represent localized discharge of the shallower groundwater to stream segments in this area. Vertical gradients between the Burlington-Keokuk Limestone and the Fern Glen Formation indicate upward gradients, generally in the northern portion of the ordnance works area, and reflect the discharge of the shallow aquifer to Dardenne Creek.

8.2 NATURE AND EXTENT OF POTENTIAL SITE-RELATED CONTAMINATION

The site-related contaminants of potential concern include uranium, nitroaromatic compounds, nitrate, sulfate, chloride, lithium, molybdenum, TCE, and 1,2-DCE. Contamination in the groundwater is generally confined to the shallow, weathered portion of the Burlington-Keokuk, which discharges to springs in the ordnance works area.

Historical sources of groundwater contamination at the chemical plant and ordnance works areas include surface water impoundments, buildings, TNT and DNT production lines, wastewater pipelines, soils and debris from the ordnance production and uranium processing activities, and waste disposal areas, including burning grounds and dumps. Contaminant sources of the

groundwater also include sorbed contaminants in the overburden material and contaminated sediment within the shallow aquifer system.

The current sources of uranium in the groundwater and springs are the absorbed uranium and contaminated sediment in the shallow aquifer system (including the conduits) and the adsorbed material in the vadose zone. Uranium-contaminated groundwater is detected north of the raffinate pits, near Frog Pond, south of the chemical plant area, and on the eastern part of the training area near the raffinate pits. Previous sludge and surface water analyses indicate that the raffinate pits probably are the primary historical source of uranium groundwater contamination (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992a). Uranium entered the shallow aquifer from the pits via infiltration through fractures in the overburden. Geochemical investigations previously conducted by the USGS indicate that uranium and other metals readily sorb to overburden materials, thus limiting their transport to the underlying shallow groundwater system (Schumacher et al. 1993). The results of these investigations suggest that the uranium infiltrating from the pits has reduced mobility because of precipitation and adsorption to materials in the saturated overburden, which supports the limited extent of uranium contamination detected in the groundwater.

In contrast, the historical data on concentrations of uranium in the nearby surface water (i.e., Burgermeister Spring) suggest that during storm events, surface water runoff increased and transported uranium from contaminated soils in the areas of Ash Pond and Frog Pond. The uranium was probably transported in both the dissolved and particulate forms. In the drainages downstream from Ash Pond and Frog Pond, surface water is lost to the subsurface. In the subsurface, a portion of the dissolved uranium was probably transferred to solid phases by chemical precipitation and adsorption, while the remainder of the uranium was transported through conduits and discharged to Burgermeister Spring. In addition to carrying the dissolved uranium, surface runoff also transported sediment contaminated with uranium to the subsurface.

The results of the in situ groundwater sampling in the Southeast Drainage reveal concentrations of uranium to be relatively elevated (as high as 164 pCi/L). To provide better delineation of the extent of uranium contamination in this area, DOE has installed a monitoring well in the Southeast Drainage area. Data collection began in May 1997. Uranium was not detected in the initial round of sampling. Analyses for other site contaminants indicated low levels and nondetections. Further data collected for this well will be summarized in the annual site monitoring report and/or the FS, as appropriate.

Higher concentrations of lithium and molybdenum were detected in the shallow aquifer near the raffinate pits. As is the case for uranium, the raffinate pits constitute the historical source of these two metals. Adsorption and precipitation play a role in attenuating metal concentrations in the saturated overburden. However, lithium, because of its fairly low estimated distribution coefficient, is one of the more mobile metals (DOE 1992a). Lithium potentially seeps from the raffinate pits into the shallow aquifer and is transported by diffuse flow until it enters the conduit

system and discharges to springs. Molybdenum behaves in a similar manner except that its mobility is inhibited by a larger distribution coefficient (DOE 1992a).

The contamination of groundwater with nitrate and sulfate is detected near the raffinate pits and Ash Pond area, which are the historic sources of these contaminants. Nitrate and sulfate probably infiltrate from the raffinate pits and Ash Pond into the shallow groundwater, enter the conduit system, and are discharged to springs. Unlike metals, nitrate and sulfate are highly mobile in the shallow groundwater system. In addition, conditions for denitrification, a naturally occurring process that converts nitrate to nitrogen, are not present at the chemical plant area, thus allowing nitrate to persist in the groundwater. Similarly, sulfate-reducing conditions have not been identified within the shallow aquifer, thus sulfate is also persistent in the groundwater.

Groundwater contamination with nitroaromatic compounds occurs sporadically at low levels across the groundwater system. Presence of nitroaromatic compounds in the groundwater is suspected to be a result of leakage from former TNT process lines, discharge from wastewater lines, and leaching of TNT-contaminated soils. The nitroaromatic compounds and their degradation products infiltrate into the shallow groundwater system and are discharged to springs by diffuse and discrete flow mechanisms. Nitroaromatics have low persistence and relatively low solubilities, but their mobilities are high as a result of low distribution coefficients. Biotransformation in the overburden material and shallow aquifer is the primary process affecting their distribution in the groundwater system. Microorganisms have been shown to transform and degrade TNT and DNT (Schumacher et al. 1993). The groundwater characterization results suggest that biotransformation is affecting nitroaromatic contamination in groundwater at the chemical plant area and the ordnance works area. In general, TNT and DNT concentrations decrease with distance from the historic source areas, while concentrations of degradation products increase. The decrease in TNT and DNT has been shown to be correlated at the ordnance works area with the increase in 2-amino-4,6-dinitrotoluene and 4-amino-2,6-dinitrotoluene (Schumacher et al. 1993).

Recent groundwater contamination with TCE and 1,2-DCE is localized primarily in the vicinity of Raffinate Pits 3 and 4. Contamination extends to the southwestern boundary within the training area and is contained in the weathered portion of the aquifer. Volatiles have not been detected in the springs. Possible sources of contamination include waste drums that were recently removed from Pit 4 and contaminated soils and sludges in Raffinate Pits 3 and 4. Further sampling of possible remaining sources is planned using a soil gas technology and soil sampling. Any contamination found will be scheduled for removal as part of the raffinate pit remediation.

Carcinogenic (radiological and chemical) risk and systemic toxicity are not indicated for current or future recreational visitors from incidental ingestion and dermal exposure to springwater. Potential chemical carcinogenic risks above the acceptable risk range of 1×10^{-6} to 1×10^{-4} for a hypothetical future resident are indicated for only a few wells. Risks are due primarily to nitroaromatic compounds and TCE. No radiological carcinogenic risks above a risk level of 1×10^{-4}

are indicated for any of the wells. Systemic toxicity is indicated for about 25% of the wells evaluated, due primarily to the presence of nitroaromatic compounds in well water from various locations at the chemical plant area and the ordnance works area, and the presence of nitrates mostly in chemical plant area wells.

Little evidence exists to indicate that aquatic biota are being adversely affected by contaminants in groundwater that is discharging to area springs. Some surface water and sediment toxicity were identified for Burgermeister Spring, and calculations based on maximum contaminant concentrations reported from all area springs indicate a potential for low or moderate risks to aquatic biota. However, the ecological significance of the observed toxicity and estimated risks is very minor. Biotic surveys at Burgermeister Spring identified the presence of an aquatic community typical of similar habitats in the Midwest. That community exhibited no indications of being affected by contaminants. Furthermore, most springs in the area do not provide permanent habitat capable of supporting more than a very limited aquatic biota. No risks were identified for terrestrial biota drinking from area springs; risk levels were two or more orders of magnitude below the target risk level. On the basis of these results, there is no evidence that ecological resources are being adversely affected by groundwater contamination discharging to springs in the area, and current levels of groundwater contamination pose little or no risk to aquatic or terrestrial biota.

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APPENDIX A:

ECOLOGICAL EVALUATIONS OF THE BURGERMEISTER SPRING DRAINAGE

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ECOLOGICAL EVALUATIONS OF THE BURGERMEISTER SPRING DRAINAGE

A.1 STUDY AREA

The U.S. Department of Energy (DOE) and the U.S. Department of the Army (DA) are conducting cleanup activities at two properties — the chemical plant area and the ordnance works area (the latter includes the training area) — located adjacent to one another in St. Charles County, Missouri. The chemical plant area and the ordnance works area are located about 48 km (30 mi) west of St. Louis and 22 km (14 mi) southwest of the city of St. Charles (Figure A.1). The ordnance works area was a former explosives production facility that manufactured trinitrotoluene (TNT) and dinitrotoluene (DNT) and covered 7,000 ha (17,232 acres). The 88-ha (217-acre) chemical plant area is located within the boundaries of the ordnance works area. This area is chemically and radioactively contaminated as a result of uranium processing activities conducted during the 1950s and 1960s, as well as explosives work conducted during the 1940s (DOE 1995).

The ordnance works area and the chemical plant area are located within the Ozark Border physiographic province. Land in the area varies from rolling hills to sloped forests to floodplains. This province possesses a variety of habitats that support a diverse flora and fauna (Missouri Department of Conservation 1991). The chemical plant area and portions of the ordnance works area are characterized by grasslands, old field habitat, and sparse to moderate woodland growth, primarily along creeks and drainages. Much of the chemical plant area is now cleared as a result of remedial actions.

About 60% of the ordnance works area is forested and includes upland, slope, riparian, and wetland forests. Open field, pasture, and cultivated farmland habitats also occur in the upland areas. The upland forests consist of oak and oak-hickory forests dominated by northern red oak, white oak, and shagbark hickory; understory species include flowering dogwood and redbud. Coniferous species that occur in upland and slope areas include eastern red cedar and short-leaved pine. The riparian and wetland forests are dominated by silver maple, American elm, eastern sycamore, and eastern cottonwood. Upland forest trees include oaks and shagbark hickory. Slopes of streams typically include oak and hickory, as well as species common to mesic sites, such as sugar maple, American elm, and black walnut. Floodplains, creek bottoms, and banks of lakes support willow, cottonwood, silver maple, elm, hackberry, and boxelder. Other prominent habitat types of the ordnance works area include old fields and pastures. Typical plants of old fields include grasses, goldenrod, asters, mustards, and ragweed (IT Corporation 1993).

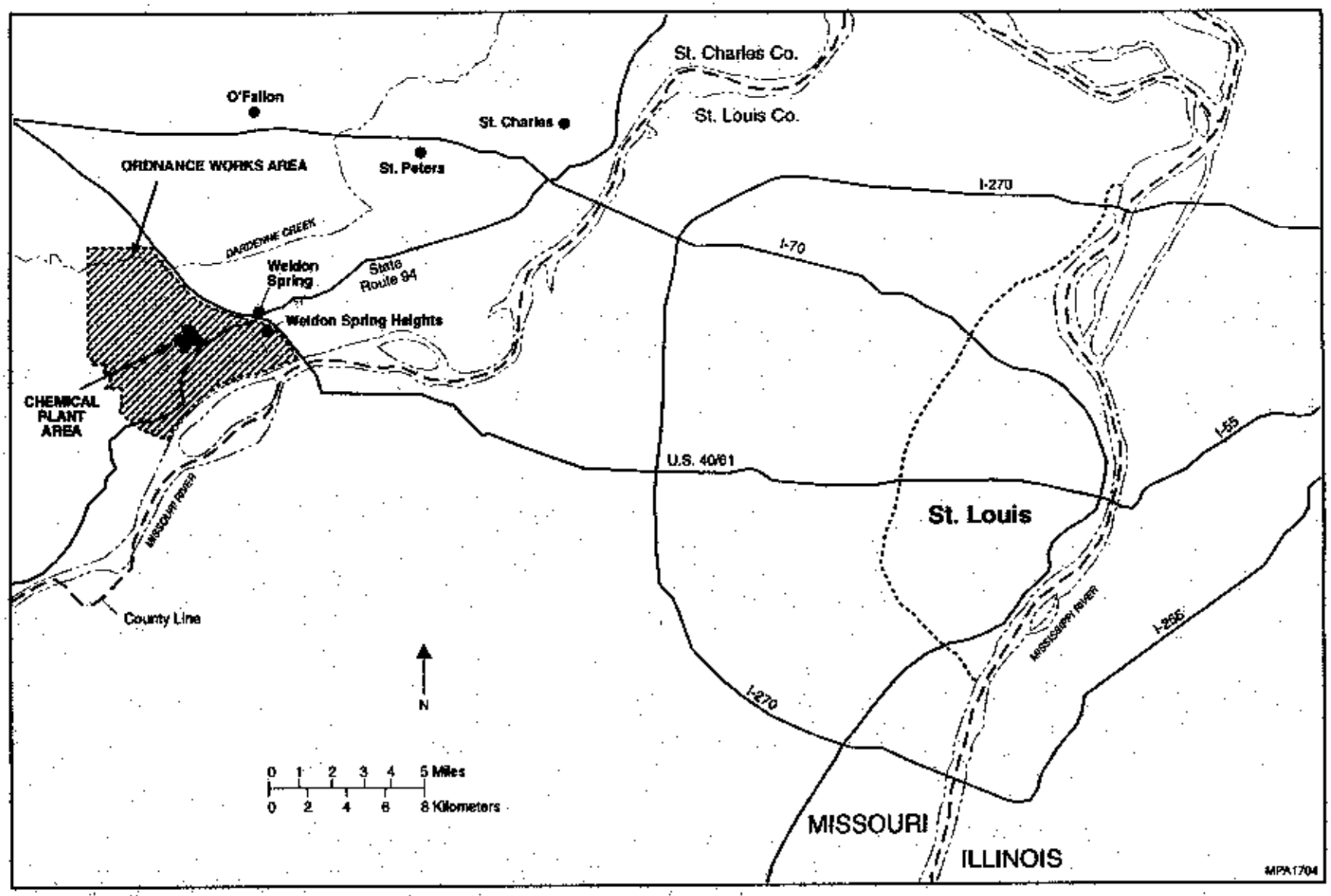

FIGURE A.1 Locations of the Chemical Plant Area and the Ordnance Works Area

The original Weldon Spring Ordnance Works has been divided into several contiguous areas with different ownership (Figure 1.2). These areas now include the chemical plant area and the quarry, the Weldon Spring Training Area, the August A. Busch Memorial Conservation Area, the Weldon Spring Conservation Area, the Francis Howell High School and Francis Howell Administration Annex, the community of Weldon Spring Heights, the University of Missouri Research Park, the St. Charles County well field, and the maintenance facility of the Missouri Highway Department (DOE 1995). The Busch Conservation Complex, which consists of the August A. Busch Memorial Conservation Area (2,828 ha [6,987 acres] of grassland and forest) and the Weldon Spring Conservation Area (2,977 ha [7,356 acres] of primarily forest land), is actively managed for wildlife by the Missouri Department of Conservation (DOE 1995).

The Busch Conservation Complex contains a wide variety of terrestrial and aquatic habitats and supports a diverse biota. More than 277 species of birds, 29 species of mammals, 47 species of reptiles, 25 species of amphibians, and 100 species of fish have been reported in St. Charles County; many of which occur at the Busch Conservation Complex (Missouri Department of Conservation 1989, 1991; Dickneite 1988). A detailed description of the vegetation, fish and wildlife, and habitats of the Busch Conservation Complex is presented in the baseline assessment of the chemical plant area (DOE 1992).

Burgermeister Spring has been routinely monitored by both the DA and DOE because it appears to be a major groundwater discharge area for drainage from the eastern and central portions of the training area and the northern portion of the chemical plant area (DOE 1995). Concentrations of some contaminants in Burgermeister Spring are as high or higher than concentrations from most other springs in the area. In addition, Burgermeister Spring and downstream areas provide more permanent habitat for aquatic biota than most of the other springs in the area and thus likely support a more diverse and abundant aquatic biota than the other springs. Therefore, maximum environmental impacts could be associated with contaminants in the Burgermeister Spring system.

A.2 BURGERMEISTER SPRING — AFFECTED ENVIRONMENT

A.2.1 Habitat Description

At Burgermeister Spring, groundwater discharges into a square concrete enclosure about 1.5 m (4.9 ft) on each side and about 0.5 m (1.6 ft) high. The floor of the enclosure is clean sand and gravel, through which groundwater discharge is evident. Springwater within the enclosure flows through a crack in the concrete wall into a small natural stream channel (DOE 1995). This drainage occurs within a small corridor of riparian forest surrounded by agricultural fields and some upland forest areas. Soils along Burgermeister Spring are characterized as Dockery silt loam, a poorly drained soil located on nearly level lands (MK-Environmental Services 1992). Portions of the

Burgermeister Spring drainage have been identified as palustrine emergent wetlands (U.S. Fish and Wildlife Service 1989). However, no wetland surveys have been conducted as part of the remediation investigation to confirm whether these areas meet the criteria for jurisdictional wetlands (i.e., hydrological conditions, wetland soils, and predominance of wetland plant species). The Burgermeister Spring drainage is located within the 100-year floodplain of Dardenne Creek (Federal Insurance Administration 1978). This drainage in turn flows into a main reach of an unnamed tributary of Dardenne Creek about 1.0 km (0.6 mi) downstream of the spring. This stream flows into Lake 34 and eventually discharges into Dardenne Creek (Figure 1.2). Because riffle areas below the weir were not flowing from late August to November of 1995, isolated pool areas were created within the length of the drainage to Lake 34 (Ecological Specialists, Inc. 1996a).

Four sites were sampled from the Burgermeister Spring drainage (Figure A.2). The sites were located along an approximately 300-m (984-ft) reach of stream between the spring (Site 6301) and its receiving stream that drains toward Lake 34. Location 1 encompassed the area from the spring to the weir, which is located about 30 m (98 ft) downstream of the spring. This area is primarily shallow riffle, but is pooled by the weir. The small pool created by the weir is about 2 m (7 ft) by 3 m (9 ft) and about 0.3 m (1 ft) deep with a sand/silt bottom (DOE 1995). Stream width averages 1.5 m (5 ft); water depths average 5 cm (2 in.) in riffles, 10 cm (4 in.) in runs, and 30 cm (12 in.) in the pooled area near the weir. Substrates at Location 1 consisted of gravel (50%), cobble (10%), sand (25%), and silt (15%) (Ecological Specialists, Inc. 1996b).

Location 2 extended from the weir 15 m (49 ft) downstream to the confluence with a larger stream. Stream width averages 1.0 m (3.3 ft); water depths average 5 cm (2 in.) in riffles, 10 cm (4 in.) in runs, and 15 cm (6 in.) in the pooled area in the middle of the location. The substrate throughout Location 2 consisted of gravel (60%), cobble (30%), and sand (10%) (Ecological Specialists, Inc. 1996b).

Location 3 was in the larger stream, starting at the downstream end of Location 2 and extending 30 m (98 ft) downstream from Location 2. Habitat within Location 3 consists of two small pools and a shallow riffle/run. Stream width averages 2.5 m (8.0 ft); water depths average 5 cm (2 in.) in riffles, 15 cm (6 in.) in runs, and 30 cm (12 in.) in the pooled areas. The substrate throughout Location 3 consisted of gravel (50%), cobble (10%), sand (25%), and silt (15%) (Ecological Specialists, Inc. 1996b).

Location 4 started 100 m (305 ft) downstream from Location 3 and was 30 m (98 ft) long. This site consists of one small pool and one larger pool connected by a shallow riffle/run. Stream width averages 2.0 m (6.5 ft); water depths average 5 cm (2 in.) in riffles, 30 cm (12 in.) in runs, and 75 cm (30 in.) in the pooled areas. The substrate throughout Location 4 consisted of boulders (5%), gravel (40%), cobble (50%), and sand (5%) (Ecological Specialists, Inc. 1996b).

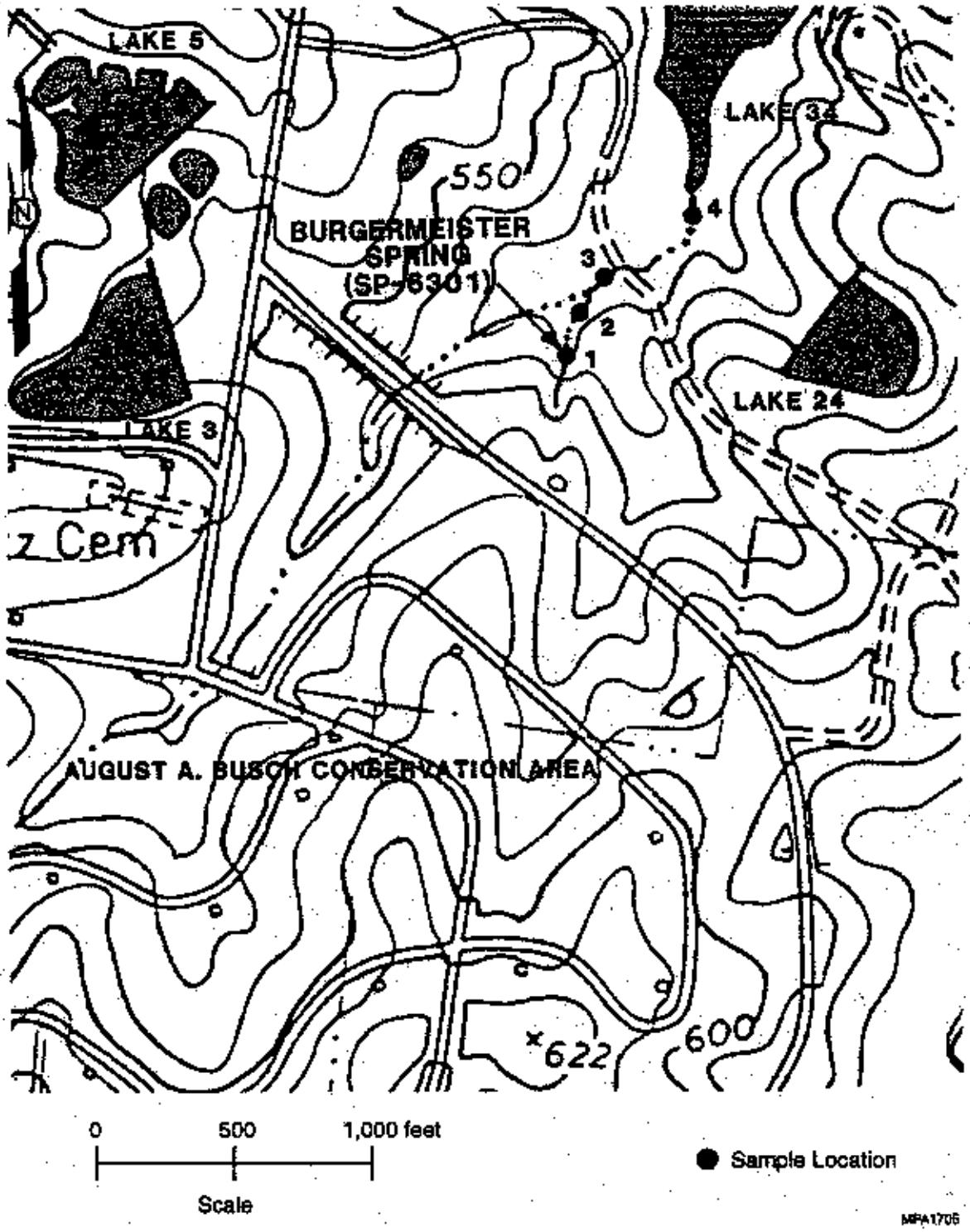

FIGURE A.2 Sampling Locations from the Burgermeister Spring Drainage

Flow throughout the drainage averages <0.008 m^3/s (<0.3 ft^3/s). However, Burgermeister Spring discharge responds rapidly to precipitation. Although normally clear running, the drainage becomes turbid during storms. Daily mean groundwater discharge values have ranged from a low of 0.001 m^3/s (0.05 ft^3/s) in September to a maximum of 0.025 m^3/s (0.89 ft^3/s) in May. Sediment odor is normal and deposits of oils are absent. The bottoms of stones are not blackened by microbes common in low oxygen environments; dissolved oxygen concentrations have averaged 9.2 to 9.3 mg/L. Water temperatures during the spring of 1996 averaged 13.6 to 14.3°C (56.5–57.7°F). Yearly water temperatures range from 11.4 to 28.4°C (52.5–83.1°F). The pH averaged from 6.7 to 7.0, while conductivity averages 344 to 391 µS/s. The high water mark estimated at the top of the bank is about 0.5 m (20 in.), except at Location 4, where it is 1.0 m (3.3 ft) (Ecological Specialists, Inc. 1996b). Water clarity is rated as clear, and the stream type is rated cold on the basis of its temperature and subsurface source (Ecological Specialists, Inc. 1996a).

A.2.2 Biota

Burgermeister Spring is located in the former ordnance works area north of the chemical plant in an area of upland forest with relatively dense understory. Tree species present in this area include red oak, persimmon, Kentucky coffee tree, and cottonwood. Vegetation along the bank of the drainage has greater than 80% coverage and consists predominantly of shrubs and small deciduous trees. The dominant tree species found along the Burgermeister Spring drainage include northern red oak and eastern cottonwood; understory species consist of American elm and persimmon. Ground cover immediately around the spring is dominated by periwinkle, whereas the shrubby understory is predominantly honeysuckle (DOE 1995).

The Burgermeister Spring drainage is of sufficient size and habitat diversity to support a variety of aquatic species. Water quality is adequate to support pollution-intolerant fish and invertebrates (Ecological Specialists, Inc. 1996a). However, the weir located about 75 m (246 ft) downstream of the spring outflow area creates a man-made barrier for fish habitation of the upper portion of the drainage. Surveys of aquatic macroinvertebrates and fish in Burgermeister Spring drainage were conducted to identify biota most at risk of exposure to contaminants and to identify any realized adverse ecological effects.

Macroinvertebrates were collected from Burgermeister Spring drainage following the U.S. Environmental Protection Agency's (EPA's) Rapid Bioassessment Protocol (RBP) Method III Protocol (EPA 1989). A fairly diverse assemblage of macroinvertebrates was collected from the drainage (Table A.1). The most abundant macroinvertebrates collected were amphipods (*Gammarus* sp.), isopods, and chironomids (*Microspectra* sp.).

TABLE A.1 Macroinvertebrates Collected from the Burgermeister Spring Drainage

Turbellaria (flatworms)	Insecta
Tricladida	Plecoptera (stoneflies)
Planariidae	Nemouridae
Dugesia sp.	Trichoptera (caddisflies)
Oligochaeta (worms)	Trichoptera pupae
Plesiopora	Glossosomatidae
Naididae	*Glossosoma sp.*
Dero digitata	Lepidostomatidae
Tubificidae	*Lepidostoma sp.*
Limnodrilus hoffmeisteri	Brachycentridae
Tubifex tubifex	Polycentropodidae
Immature tubificids	Coleoptera (beetles)
	Noteridae
Hirudinea (leeches)	Dytiscidae
	Diptera (flies)
Crustacea	Ceratopogonidae
Amphipoda (scuds)	Chironomidae
Gammaridae	*Orthocladius sp.*
Gammarus sp.	*Eukiefferiella sp.*
Isopoda (sow bugs)	*Paratendipes sp.*
Asellidae	*Polypedilum sp.*
Caecidotea sp.	*Polypedilum illinoense*
Lirceus sp.	*Microspectra*
	Muscidae
Mollusca	Tipulidae
Gastropoda (snails)	
Physidae	
Pelecypoda (clams)	
Sphaeriidae	
Sphaerium sp.	

Fish surveys were conducted in the Burgermeister Spring drainage in 1991, 1994, and 1995 by seining and electrofishing. Eight species and one hybrid were collected (Table A.2). Most of the individuals collected were juveniles of species that inhabit Lake 34 (e.g., sunfish, largemouth bass, and black crappie). The orangethroat darter and brook silverside are creek species. No fish were collected in the upper reach of the drainage because of the barrier created by the weir. A debris dam located just downstream of the weir also acted as a partial barrier and likely limited the occurrence of fish between the debris dam and weir. Another fish reported from the drainage below the weir is the redfin shiner; other fish species in the larger stream that flows into Lake 34 are white crappie, carp, and black bullhead (DOE 1995). Other species known to occur in Lake 34 (e.g., channel catfish

TABLE A.2 Fish Species Collected from the Burgermeister Spring Drainage

Common Name	Scientific Name
Brook silverside	*Labidesthes sicculus*
Bluegill	*Lepomis macrochirus*
Longear sunfish	*Lepomis megalotis*
Green sunfish	*Lepomis cyanellus*
Orangespotted sunfish	*Lepomis humilis*
Longear x green sunfish hybrid	*Lepomis megalotis x cyanellus*
Largemouth bass	*Micropterus salmoides*
Black crappie	*Pomoxis nigromaculatus*
Orangethroat darter	*Etheostoma spectabile*

and flathead catfish) may use the Burgermeister Spring drainage as a spawning area, although it is unlikely that they would enter the spring and its immediate downstream reach (i.e., Locations 1 and 2).

Amphibian and reptile surveys were conducted in the Burgermeister Spring drainage during March and April and September and October, 1995; auditory and transect surveys and bucket traps were used. Six amphibian and one reptile species were identified (Table A.3). All species encountered were common species ubiquitous to the Midwest.

Table A.4 lists the rare, threatened, and endangered species that have been known to occur in St. Charles County. The list includes four state endangered species, 12 state rare species, and two state watch list species. Two of these species (sturgeon and sicklefin chubs) are also federal candidate species (species being considered for inclusion as threatened or endangered on the federal listing), while the bald eagle is a federal threatened species.

The chub species are not expected to occur in the Burgermeister Spring drainage because they are known to prefer large river habitat such as the Missouri River (Pflieger 1975). A night roost for overwintering bald eagles is located at Howell Island Wildlife Area in the Missouri River southeast of the site. This roost site has been declared critical habitat by the State of Missouri. A critical habitat is a specific area of the state that is occupied by a threatened or endangered species and is essential to the conservation of the species. Areas identified as critical habitat are granted special management considerations for protection. However, the Howell Island Wildlife Area is not classified as a federally designated critical habitat. No state or federal critical habitat has been identified at Burgermeister Spring or in the Busch Conservation Complex.

TABLE A.3 Reptiles and Amphibians Collected from the Burgermeister Spring Drainage

Common Name	Scientific Name
Reptiles	
Northern water snake	*Nerodia sipedon sipedon*
Amphibians	
Eastern American toad	*Bufo americanus americanus*
Blanchard's cricket frog	*Acris crepitans*
Spring peeper	*Pseudacris crucifer*
Green frog	*Rana clamitans*
Southern leopard frog	*Rana spenocephala*
Eastern gray treefrog	*Hyla versicolor*
Central newt	*Notophthalmus viridescens louisianensis*

Four of the state-listed species are known to occur in the Weldon Spring area: Cooper's hawk, pied-billed grebe, Blanding's turtle, and wood frog. The Cooper's hawk nests in pine plantations in the Weldon Spring Conservation Area. It was not sighted during surveys conducted at Burgermeister Spring in 1992 (MK-Ferguson and Jacobs Engineering Group, Inc. 1993). The pied-billed grebe is commonly found during spring and fall at the Busch Conservation Area, but it primarily uses the open waters of the lakes. The Blanding's turtle inhabits marshes, bogs, lakes, and small streams. Although it has been reported from the Busch Conservation Area, it has not been reported from Lake 34 or at the Burgermeister Spring drainage. The wood frog is generally associated with wooded hillsides, and it usually breeds in small, fishless woodland ponds and pools. It has been reported from the Weldon Spring Conservation Area but not from the Burgermeister Spring drainage during amphibian surveys.

The king rail and the common moorhen are listed as state endangered and rare species, respectively. They are reported as occurring casually in the Busch Conservation Area, but not every year. The long-tailed weasel, a state rare species, occurs in the Weldon Spring Conservation Area and could potentially use the terrestrial habitats in the vicinity of Burgermeister Spring (DOE 1995). The remaining species listed in Table A.4 are not expected to be found at the Busch Conservation Area or to use the Burgermeister Spring drainage.

A.3 ENVIRONMENTAL EVALUATION

As previously mentioned, groundwater from portions of the chemical plant area and the DA training area discharges into Burgermeister Spring. As a result, surface water and sediments in the

TABLE A.4 Rare, Threatened, and Endangered Animals Reported from St. Charles County

Species		Status	
Common Name	Scientific Name	Federal[a]	State[b]
Fish			
Brown bullhead	*Ameiurus nebulosus*	-	R
Highfin carpsucker	*Carpiodes velifer*	-	R
Blue sucker	*Cycleptus elongatus*	-	WL
Mooneye	*Hiodon tergisus*	-	R
Alligator gar	*Atractosteus spatula*	-	R
Sturgeon chub	*Macrhybopsis gelida*	C	R
Sicklefin chub	*Macrhybopsis meeki*	C	R
River darter	*Percina shumardi*	-	WL
Amphibians and Reptiles			
Wood frog	*Rana sylvatica*	-	R
Western fox snake	*Elaphe vulpina vulpina*	-	E
Blanding's turtle	*Emydoidea blandingi*	-	E
Birds			
Bald eagle	*Haliaeetus leucocephalus*	T	E
Cooper's hawk	*Accipiter cooperii*	-	R
Common moorhen	*Gallinula chloropus*	-	R
Pied-billed grebe	*Podilymbus podiceps*	-	R
King rail	*Rallus elegans*	-	E
Barn owl	*Tyto alba*	-	R
Mammals			
Long-tailed weasel	*Mustela frenata*	-	R

[a] A hyphen indicates that no federal status has been established; C = candidate; T = threatened.

[b] E = endangered; R = rare; WL = watch list.

Burgermeister Spring drainage can contain site-related contaminants at levels that may affect ecological receptors that inhabit or utilize the drainage. The EPA has developed the Rapid Bioassessment Protocol (RBP) Method (EPA 1989) that provides guidance regarding information needed to establish a relationship between environmental contaminants and observed ecological effects. This information includes (1) characterization of the nature, extent, and magnitude of contamination; (2) ecological surveys to identify biota potentially at risk of exposure and to establish whether adverse ecological effects have occurred; and (3) toxicity tests to identify potential ecological impacts and to establish a link between the toxicity of the hazardous waste or contaminants and any realized adverse ecological effects. These data were obtained to determine whether measurable contaminant levels occur in Burgermeister Spring drainage and whether the contaminants pose an unacceptable risk to ecological resources in the area.

A.3.1 Rapid Bioassessment Protocol

The EPA's RBP Method (EPA 1989) was conducted at four locations in the Burgermeister Spring drainage (Figure A.2). The habitat assessment portion of the RBP evaluated physical conditions of the spring (Section 2.1), as well as its potential to support a biological community. The habitat assessment of the Burgermeister Spring drainage revealed a generally undisturbed, silt free, variable streambed habitat. Low flow, low pool to riffle ratios, and presence of channel obstructions (e.g., wood debris and weirs) are important factors that limit overall habitat quality (Ecological Specialists, Inc. 1996a). Deeper pools located in areas downstream of the spring provide better habitat than the shallow water levels near the mouth of the spring. No local watershed erosion or non-point-source pollution was evident. However, the lowermost sampling location (Location 4) near Lake 34 did show some evidence of channel alteration, scouring, and less embeddedness compared with the other sampling locations.

Various biotic matrices were calculated as part of the RBP macroinvertebrate assessment. The macroinvertebrate community was found to be slightly impaired in May 1995; in November 1995, it was classified as not impaired (Environmental Science and Engineering, Inc. 1995).

Fish surveys (May and November 1995) were used to assess community structure and impairment of the Burgermeister Spring drainage in accordance with the RBP Method V (EPA 1989). The results of those surveys showed a community integrity rating of fair to poor. The low community integrity rating is the result of low flow and physical habitat constraints for many fish species, rather than water quality conditions.

A.3.2 Tissue Analysis

The potential contaminants of ecological concern in Burgermeister Spring include arsenic, chromium, lead, mercury, selenium, silver, uranium, nitrate, and nitroaromatics (DOE 1995); macroinvertebrates and fishes were collected and prepared for whole body tissue analysis for these contaminants. Amphipods and chironomids constituted the dominant taxa used for the macroinvertebrate tissue samples; various sunfish species were used for the fish samples. The concentrations of uranium and metals in macroinvertebrates and fish collected from the Burgermeister Spring drainage are presented in Table A.5. No nitroaromatics were detected in fish samples. Macroinvertebrates were not sampled for nitroaromatics, and neither macroinvertebrates nor fish were sampled for nitrates because of low sample mass. Uranium concentrations in macroinvertebrates ranged from 0.048 pCi/g to 294 pCi/g; concentrations in fish ranged from 0.045 pCi/g to 0.073 pCi/g.

Mercury and silver were not detected in macroinvertebrate tissue samples; arsenic, chromium, and selenium were detected infrequently. Lead was detected more frequently in macroinvertebrates but at low levels ranging from 1.1 to 2.7 µg/g. Silver and selenium were not detected in fish samples, while arsenic was detected infrequently. Chromium, lead, and mercury were detected in fish samples but at low concentrations.

A.3.3 Toxicity Testing

Toxicity testing data were generated from surface water and sediment samples collected from the four sampling locations in the Burgermeister Spring drainage. The toxicity tests were performed with four test organisms: cladocera (*Daphnia magna*), amphipod (*Hyallela azteca*), fathead minnow (*Pimephales promelas*), and African clawed frog (*Xenopus laevis*). Acute and chronic tests were performed, as needed. Abbreviated acute toxicity tests were performed first. If the results indicated significant mortality at the 5% level, then additional samples were collected and submitted for acute serial dilution (definitive) tests. If mortality was not found to be significant at the 5% level, then samples were recollected and chronic toxicity tests were performed. Table A.6 gives the results of the toxicity tests.

While a few positive responses were reported from toxicity testing among species, media, and location, toxicity was not consistently found for any location in the Burgermeister Spring drainage.

A.4 CONCLUSIONS

Results of surveys for macroinvertebrates, fish, and herpetofauna at the Burgermeister Spring drainage indicated no evidence of adverse effects to these biota resulting from site-related

TABLE A.5 Contaminant Tissue Concentrations and Estimated Bioconcentration Factors for Macroinvertebrate and Fish Tissue Samples Collected from Burgermeister Spring

Contaminant	Detects/Total	Mean Tissue Concentration (µg/g, except as noted)	Bioconcentration Factor[a]
Macroinvertebrate Tissue			
Arsenic	1/4	3.89	0.23
Chromium	1/4	3.61	0.14
Lead	3/4	2.18	0.06
Mercury	0/4	ND[b]	NA[c]
Selenium	1/4	3.98	11.05
Silver	0/4	ND	NA
Uranium	16/16	31.1 pCi/g	13.2
Fish Tissue			
Arsenic	1/4	0.04	20.0
Chromium	4/4	0.62	103.3
Lead	3/4	0.03	30
Mercury	4/4	0.11	1,100[d]
Selenium	0/4	ND	NA
Silver	0/4	ND	NA
Uranium	4/4	0.049 pCi/g	0.98

[a] Bioconcentration factor calculated as the mean tissue concentration divided by the mean sediment concentration (for macroinvertebrates) or the mean surface water concentration (for fish). Mean sediment and surface water concentrations were calculated by using only data collected concurrently with fish samples from Burgermeister Spring.

[b] ND = not detected.

[c] NA = not applicable.

[d] Mercury was not detected in surface water samples collected concurrently with fish samples from Burgermeister Spring. Bioconcentration factor estimated using 1/2 the detection limit.

TABLE A.6 Results of Acute and Chronic Toxicity Testing from the Burgermeister Spring Drainage

Organism, Toxicity Test	Toxicity at Sampling Location			
	Location 1	Location 2	Location 3	Location 4
Surface Water				
Daphnia, 96-hour acute survival	-[a]	-	-	-
Hyallela, 96-hour acute survival	-	-	-	-
Pimephales, 96-hour acute survival	37.5%[b]	37.5%	-	-
Xenopus, 96-hour acute survival	-	-	-	-
Daphnia, 7-day chronic	-	-	-	-
Hyallela, 7-day chronic	-	-	-	-
Pimephales, 7-day chronic	NC[c]	NC	-	-
Xenopus, 7-day chronic	-	-	70%	-
Sediment				
Daphnia, 96-hour acute survival	-	-	-	-
Hyallela, 96-hour acute survival	-	-	-	-
Pimephales, 96-hour acute survival	-	75%	-	-
Xenopus, 96-hour acute survival	-	-	-	-
Daphnia, 7-day chronic	-	-	-	-
Hyallela, 7-day chronic	82%	-	-	-
Pimephales, 7-day chronic	-	-	-	50%
Xenopus, 7-day chronic	-	73%	-	-

[a] A hyphen indicates no significant media toxicity ($p > 0.05$).

[b] Values are percent survival for significant media toxicity ($p \leq 0.05$).

[c] NC = chronic toxicity testing not conducted because media toxicity at this sampling location indicated by the results of the corresponding acute toxicity test.

contaminants. The drainage was determined to have generally good aquatic habitat, and the species present are typical of those found in comparable habitats throughout the Midwest. Although the fish community was limited in diversity and the macroinvertebrate community was categorized as slightly impaired, the communities are likely affected by the physical nature of the drainage system rather than by contaminant levels. In particular, the aquatic community is strongly influenced by low flow in late summer and fall. The habitat found at the spring is adequate to support a variety of aquatic fauna, but is limited by the availability of permanent surface water.

The results of toxicity testing indicate the potential for some toxicity to biota from water and sediments in Burgermeister Spring and its drainage, although no clear toxicity gradient is evident extending downstream from the spring. The presence of apparently unaffected macro-

invertebrates, fish, and amphibians in the drainage suggests that local biota are tolerant of (or have adapted to) the contaminant levels present in surface waters and sediments in the Burgermeister Spring drainage.

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APPENDIX B:

HYDROGEOLOGIC INVESTIGATIONS

APPENDIX B:

HYDROGEOLOGIC INVESTIGATIONS

B.1 BACKGROUND INFORMATION ON GEOLOGY AND HYDROGEOLOGY OF THE WELDON SPRING AREA

Numerous investigations have been performed at the chemical plant area, the training area, and the ordnance works area to characterize the overburden materials and bedrock units and to quantify the hydraulic properties of these materials. As part of these investigations, monitoring wells were installed in the chemical plant area and the ordnance works area to provide geologic and hydrologic characterization data. Tables B.1 and B.2 list the groundwater monitoring wells and give the construction summaries for these two respective areas. The information in this section is provided to support the discussion in Chapter 3.

B.1.1 Overburden

The thickness of unconsolidated material or overburden ranges from 0 to 21 m (0 to 70 ft) in the vicinity of the chemical plant area and the ordnance works area (Mugel 1997). The seven principal overburden units include (1) fill/topsoil, (2) Peoria Loess, (3) Roxana Silt, (4) Ferrelview Formation, (5) clay till, (6) basal till, and (7) residuum. Table B.3 gives the physical characteristics of each of these overburden units.

B.1.1.1 Unsaturated Overburden

Laboratory testing for determination of in situ moisture content, porosity, and saturated hydraulic conductivity of the overburden materials has been performed in support of the design of the disposal cell at the chemical plant area. The results of these tests can generally be applied to the same units in both the training area and ordnance works area sites. A summary of these properties is provided in Table B.4.

Each of these hydraulic parameters plays a part in recharge to the shallow aquifer. The results of the in situ moisture testing indicate that with the exception of the residuum, the upper overburden units are generally near moisture saturation (MK-Environmental Services 1993). This finding is consistent with the low permeability and small particle size of the overburden units. These near-saturation moisture contents are likely the result of infiltration from precipitation, capillary rise from groundwater, and low hydraulic conductivities. The moisture content of the residuum is below

TABLE B.1 Monitoring Well Network Construction Summary — Chemical Plant Area

Well ID					Burlington-Keokuk Limestone		
Present	Old	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Depth to Top of Weathered (ft)	Depth to Top of Unweathered (ft)	Units Monitored[a]
MW-2001	GMW-1	Active	611.8	31.6–64.0	26.5	53.3	W/UW
MW-2002	GMW-2/2A	Active	623.8	31.7–64.0	28.5	NA[b]	W
MW-2003	GMW-3	Active	637.1	41.5–64.0	38.8	NA	W
MW-2004	GMW-4	Abandoned	642.8	54.3–77.0	37.0	70.0	W/UW
MW-2005	GMW-5	Active	635.7	50.0–81.0	44.8	NA	W
MW-2006	GMW-6	Active	634.2	27.0–71.0	22.6	58.1	W/UW
MW-2007	GMW-7	Active	651.9	62.3–99.0	59.0	89.0	W/UW
MW-2008	GMW-8	Abandoned	622.7	34.0–63.0	31.5	51.3	W/UW
MW-2009	GMW-9	Abandoned	636.3	27.2–58.6	20.5	NA	W
MW-2010	GMW-10	Active	642.9	37.2–64.0	32.8	NA	W
MW-2011	GMW-11	Active	653.2	36.6–79.0	32.0	71.3	W/UW
MW-2012	GMW-12	Active	634.8	29.3–69.5	25.5	51.0	W/UW
MW-2013	GMW-13	Active	645.4	31.3–75.0	27.5	60.0	W/UW
MW-2014	GMW-14	Active	647.6	37.0–64.0	33.0	NA	W
MW-2015	GMW-15	Active	657.7	47.3–86.0	45.5	70.4	W/UW
MW-2016	B-3	Active	635.7	62.7–150.5	54.0	64.5	W/UW
MW-2017	GMW-17	Active	657.9	30.0–69.0	23.5	61.8	W/UW
MW-2018	GMW-18	Active	661.7	37.4–69.0	32.5	NA	W
MW-2019	-[c]	Active	661.5	103.0–116.4	NA	81.0	UW
MW-2020	B-4	Retrofitted	655.1	36.5–19.6	23.7	47.5	W/UW
MW-2021	-	Active	624.6	96.3–111.0	NA	81.5	UW
MW-2022	-	Active	636.1	112.0–128.0	NA	100.5	UW

TABLE B.1 (Cont.)

Well ID					Burlington-Keokuk Limestone		
Present	Old	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Depth to Top of Weathered (ft)	Depth to Top of Unweathered (ft)	Units Monitored[a]
MW-2023	-	Active	635.8	68.5–91.5	NA	NA	UW[d]
MW-2024	-	Active	634.9	135.0–149.6	ND	NA	UW[d]
MW-2025	-	Abandoned	622.2	94.0–108.6	ND	70.5	UW
MW-2026	-	Active	634.8	105.5–118.0	ND	81.0	UW
MW-2027	-	Active	646.3	107.0–122.0	ND	80.2	UW
MW-2028	-	Active	657.8	116.0–131.5	ND	91.6	UW
MW-2029	-	Abandoned	643.1	89.0–101.3	ND	NA	UW[c]
MW-2030	-	Active	652.9	30.5–59.0	29.5	NA	W
MW-2031	-	Abandoned	660.6	55.0–67.5	58.0	NA	OB/W
MW-2032	-	Active	635.8	48.0–58.6	53.2	NA	OB/W
MW-2033	-	Active	644.8	23.1–46.3	23.2	NA	OB/W
MW-2034	-	Active	658.2	34.5–60.0	34.5	NA	W
MW-2035	-	Active	667.0	62.8–77.5	35.0	73.1	W/UW
MW-2036	-	Active	655.9	52.5–8.0	46.0	64.6	W/UW
MW-2037	-	Active	656.7	45.5–63.5	40.0	NA	W
MW-2038	-	Active	665.0	55.0–71.5	52.5	NA	UD
MW-2039	-	Active	663.4	53.3–69.0	44.5	NA	UD
MW-2040	-	Active	662.4	54.5–74.0	44.5	NA	UD
MW-2041	-	Active	661.6	61.5–82.0	43.0	NA	UD
MW-2042	-	Active	662.7	56.0–77.5	43.5	NA	UD
MW-2043	-	Active	662.6	56.5–75.0	45.0	NA	UD
MW-2044	-	Retrofitted	655.1	37.1–64.1	23.7	47.5	W/UW
MW-3001	-	Abandoned	664.3	52.8–78.0	53.5	85.0	OB/W

TABLE B.1 (Cont.)

Well ID					Burlington-Keokuk Limestone		
Present	Old	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Depth to Top of Weathered (ft)	Depth to Top of Unweathered (ft)	Units Monitored[a]
MW-3002	-	Abandoned	664.7	134.0–150.0	53.5	80.8	UW
MW-3003	-	Active	645.5	75.7–90.0	NA	NA	W/UW[f]
MW-3004	B-14	Abandoned	653.5	13.7–21.8	NA	NA	OB
MW-3005	B-15A/OW-3503	Inactive	663.4	24.3–37.0	NA	NA	OB
MW-3006	-	Active	645.9	120.0–135.5	NA	98.0	U
MW-3007	-	Inactive	645.6	39.0–99.1	25.0	78.0	W/UW
MW-3008	B-19A	Retrofitted	645.2	39.0–101.0	28.0	71.0	W/UW
MW-3009	B-21	Retrofitted	644.3	45.0–99.4	35.0	55.6	W/UW
MW-3010	B-23	Abandoned	665.0	52.5–90.7	38.0	75.8	W/UW
MW-3011	B-24	Abandoned	649.2	20.0–23.5	23.5	NA	OB
MW-3012	W-1	Abandoned	Unknown	???–33.0[g]	ND	NA	OB
MW-3013	W-2	Inactive	641.5	???–22.0	ND	NA	OB
MW-3014	W-3	Abandoned	Unknown	???–25.0	ND	NA	OB
MW-3015	W-4	Abandoned	640.1	???–20.0	ND	NA	OB
MW-3016	W-5	Inactive	664.0	???–51.0	ND	NA	OB
MW-3017	W-7	Abandoned	649.8	???–35.0	ND	NA	OB
MW-3018	B-2	Inactive	631.0	18.8–29.6	29.6	NA	OB
MW-3019	NA	Active	660.1	70.0–84.3	35.0	78.3	W/UW
MW-3022	NA	Inactive	656.9	35.2–51.0	45.5	NA	OB/W
MW-3023	-	Active	645.9	22.0–48.0	22.0	NA	W/UW
MW-3024	-	Active	645.2	75.3–101.0	28.0	71.0	UW
MW-3025	-	Active	645.2	31.5–53.0	ND	NA	W[h]
MW-3026	-	Active	644.3	74.3–99.4	35.0	55.6	UW[i]

TABLE B.1 (Cont.)

Well ID					Burlington-Keokuk Limestone		
Present	Old	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Depth to Top of Weathered (ft)	Depth to Top of Unweathered (ft)	Units Monitored[a]
MW-3027	-	Active	644.2	35.0–57.0	ND	ND	W/UW[i]
MW-4001	GMW-16	Active	621.1	25.0–41.0	14.0	34.0	W/UW
MW-4002	-	Active	632.7	41.0–84.7	26.0	70.5	W/UW
MW-4003	-	Active	669.4	52.0–106.2	23.0	NA	W
MW-4004	-	Active	651.7	63.0–75.0	37.5	63.0	UW
MW-4005	-	Active	656.4	63.9–78.8	44.2	NA	W
MW-4006	B-16	Active	621.7	20.5–28.5	NA	NA	W[j]
MW-4007	-	Active	621.5	77.0–99.0	NA	50.0	UW
MW-4008	-	Active	635.5	70.0–83.0	32.4	57.4	UW
MW-4009	-	Active	624.2	64.0–76.8	19.0	54.6	UW
MW-4010	-	Active	629.1	64.6–77.1	15.7	70.8	W/UW
MW-4011	-	Active	626.9	64.1–77.7	30.0	58.7	UW
MW-4012	-	Active	615.5	62.7–80.2	33.0	60.7	UW
MW-4013	-	Active	606.7	37.5–60.0	35.1	51.7	W/UW
MW-4014	-	Active	607.3	43.0–65.5	42.0	54.2	W/UW
MW-4015	-	Active	617.8	40.0–63.2	13.0	56.5	W/UW
MW-4016	-	Active	642.8	71.6–85.3	30.0	74.2	W/UW
MW-4017	-	Abandoned	649.3	62.3–85.1	40.0	78.0	W/UW
MW-4018	-	Active	647.7	61.5–79.5	44.0	73.0	WUW
MW-4019	GMW-19	Active	645.3	40.0–61.0	21.9	53.3	W/UW
MW-4020	-	Active	657.7	65.0–81.3	36.0	67.5	W/UW
MW-4021	-	Active	649.9	49.0–71.0	26.5	68.0	W/UW
MW-4022	-	Active	666.3	67.0–90.9	35.0	60.2	UW

TABLE B.1 (Cont.)

Well ID					Burlington-Keokuk Limestone		
Present	Old	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Depth to Top of Weathered (ft)	Depth to Top of Unweathered (ft)	Units Monitored[a]
MW-4023	-	Active	646.6	30.5–54.0	28.9	59.0	W
MW-4024	-	Active	655.2	45.0–59.0	24.3	NA	W
MW-4025	-	Active	645.3	37.8–53.7	27.5	NA	W

[a] OB = overburdened; UD = undifferentiated; rock not cored, no samples or log; UW = unweathered; W = weathered.

[b] NA = data not available.

[c] A hyphen indicates no prior identification system.

[d] No log; unit open to well based on stratigraphy in MW-2016.

[e] No log; unit open to well based on stratigraphy in MW-2004.

[f] No log; units open to well based on stratigraphy in MW-3007.

[g] ??? = questionable data.

[h] No log; unit open to well based on stratigraphy in MW-3024 (retrofit of MW-3008).

[i] No log; units open to well based on stratigraphy in MW-3026.

[j] No core; unit open to well based on MW-4001 and MW-4007.

Source: Mugel (1997).

TABLE B.2 Monitoring Well Network Construction Summary — Ordnance Works Area

Well ID	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Burlington-Keokuk Limestone: Depth to Top of Weathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Unweathered (ft)	Depth to Top of Fern Glen (ft)	Units Monitored[a]
MWV-01	Active	595.8	7.3–15.0	15.0	NA[b]	NA	OB
MWS-01	Active	595.9	26.0–43.0	15.2	38.0	NA	W/UW
MWV-02	Active	603.1	8.8–16.8	17.0	NA	NA	OB
MWS-02	Active	603.9	37.8–55.8	15.5	NA	NA	W/UW[c]
MWD-02	Active	604.1	107.5–125.0	17.1	53.3	133.5	UW
MWS-03	Active	633.7	46.0–63.0	41.0	48.7	NA	W/UW
MWS-04	Active	622.5	20.6–39.6	11.0	NA	NA	W
MWS-05	Active	599.1	43.8–67.0	35.0	NA	NA	UW/FG[d]
MWD-05	Active	599.1	98.0–116.1	37.0	41.4	49.4	FG/CH[e]
MWS-06	Active	619.8	40.0–60.0	21.8	NA	NA	UW[f]
MWD-06	Active	619.9	112.1–129.5	21.9	37.5	NA	UW
MWS-07	Active	639.4	44.0–63.0	43.5	NA	NA	W
MWV-08	Active	688.8	9.8–23.8	23.8	NA	NA	OB
MWS-08	Active	688.9	27.5–42.5	26.5	NA	NA	W
MWV-09	Active	634.5	10.4–25.4	25.4	NA	NA	OB
MWS-09	Active	634.2	31.6–46.6	25.0	NA	NA	W
MWD-09	Active	634.6	121.4–146.0	25.8	53.0	NA	UW
MWS-10	Active	652.5	27.0–43.0	23.1	54.0	NA	W
MWS-11	Active	674.8	40.7–57.0	30.5	NA	NA	W
MWS-12	Active	655.0	31.0–48.0	22.1	NA	NA	W

TABLE B.2 (Cont.)

Well ID	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Burlington-Keokuk Limestone: Depth to Top of Weathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Unweathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Fern Glen (ft)	Units Monitored[a]
MWV-13	Active	690.3	27.0–41.5	41.5	NA	NA	OB
MWS-13	Active	690.2	48.1–71.1	40.5	NA	NA	W
MWS-14	Active	702.8	24.9–41.8	7.0	NA	NA	W
MWS-15	Active	654.7	31.5–48.0	26.0	NA	NA	W
MWD-15	Active	654.3	117.0–133.5	26.0	NA	138.5	W
MWV-16	Active	649.5	25.0–39.0	39.7	NA	NA	OB
MWS-16	Active	649.7	27.0–66.0	38.5	NA	NA	W
MWV-17	Active	658.5	4.0–17.0	17.0	NA	NA	OB
MWS-17	Active	657.7	32.0–49.5	19.0	33.5	NA	W/UW
MWV-18	Active	599.6	6.0–19.0	19.6	NA	NA	OB
MWS-18	Active	600.2	54.9–75.0	NA	NA	NA	CH/BCH/SS[g]
MWD-18	Active	599.8	113–129.5	NP[h]	NP	20.0	KM[i]
MWS-19A	Abandoned	646.8	NA	36.5	NA	NA	NA
MWS-19	Active	646.8	46.0–61.5	37.0	NA	NA	W
MWS-20	Active	667.2	45.0–61.0	36.1	55.0	NA	W/UW
MWS-21	Active	641.0	36.5–50.9	36.3	NA	NA	W
MWV-22	Active	661.9	25.0–37.6	37.6	NA	NA	OB
MWS-22	Active	661.9	41.0–53.9	37.8	NA	NA	W
MWS-23	Active	707.0	56.7–70.0	54.5	NA	NA	W
MWD-23	Active	707.9	113–125.5	38.3	100.2	NA	UW
MWV-24	Abandoned	655.0	NA	36.5	NA	NA	OB
MWS-24	Active	654.6	42.0–57.4	39.2	NA	NA	W
MWV-24R	Active	640.0	26.7–41.0	41.0	NA	NA	OB
MWS-25	Active	681.0	47.0–59.6	36.2	NA	NA	W

TABLE B.2 (Cont.)

Well ID	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Burlington-Keokuk Limestone: Depth to Top of Weathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Unweathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Fern Glen (ft)	Units Monitored[a]
MWD-25	Active	681.0	102.5–114.5	36.5	103.0	NA	W/UW
MWS-26	Active	672.4	41.5–54.5	40.6	NA	NA	W
MWD-26	Retrofitted	607.2	121.5–134.0	46.0	79.0	NA	UW
MWS-101	Active	489.5	50.0–85.0	NP	NP	NP	KM[j]
MWS-102	Active	479.2	57.5–90.0	NP	NP	NP	DC
MWS-103	Active	527.7	28.0–65.0	NP	NP	NP	SS/KM
MWS-104	Active	564.7	22.9–56.0	15.5	43.8	NA	W/UW
MWS-105	Active	573.7	30.2–69.2	28.7	NA	NA	UW[k]
MWD-105	Active	573.7	115.3–152.3	NA	28.9	130.4	UW/FG
MWS-106	Active	530.7	25.0–48.0	NA	NA	NA	UW[l]
MWD-106	Active	531.0	114.7–148.2	NA	23.5	132.8	UW/FG
MWS-107	Active	607.2	52.0–85.5	49.0	78.5	NA	W/UW
MWD-107	Active	607.2	121.5–134.0	46.0	79.0	NA	UW
MWS-108	Active	604.4	52.0–85.0	NP	50.3	NA	UW
MWS-109	Active	550.3	41.2–75.5	22.0	NA	NA	UW[m]
MWD-109	Active	550.4	105.1–139.3	NP	21.8	124.9	UW/FG
MWS-110	Active	604.8	55.0–89.5	15.5	79.0	NA	W/UW
MWS-111	Active	620.8	42.0–75.2	35.5	NA	NA	W
MWS-112	Active	572.6	23.7–38.7	18.0	28.5	NA	W/UW
MWD-112	Active	572.6	94.2–106.8	18.0	ND	NA	UW
USGS-1	Active	589.0	57–107	38.0	48.0	NA	UW
USGS-2	Abandoned	554	at 50	50	NA	NA	UD B-K[h]
USGS-2A	Active	559	26–107	50	NA	NA	OB/UD B-K

TABLE B.2 (Cont.)

Well ID	Well Status	Ground Elevation (ft)	Monitor Interval (ft)	Burlington-Keokuk Limestone: Depth to Top of Weathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Unweathered (ft)	Burlington-Keokuk Limestone: Depth to Top of Fern Glen (ft)	Units Monitored[a]
USGS-3	Active	585	66–80	66	NA	NA	UD B-K
USGS-4	Active	601	30–107	30	NA	NA	UD B-K
USGS-5	Active	580	23–87	23	NA	NA	UD B-K
USGS-6	Active	590	70–107	56	70	NA	UW
USGS-7	Retrofitted	570	32–107	32	NA	NA	UD B-K
USGS-8	Active	625	60–107	60	NA	NA	UD B-K
USGS-9	Active	590	24–90	24	NA	NA	UD B-K

[a] BCH = Bachelor Formation; CH = Chouteau Group; DC = Decorah Group; FG = Fern Glen Formation; KM = Kimmswick Limestone; OB = overburden; SS = Sulphur Springs Group; UD = undifferentiated; UW = unweathered Burlington-Keokuk Limestone; W = weathered Burlington-Keokuk Limestone.
[b] NA = no data available.
[c] Units open to well based on MWD-02 stratigraphy.
[d] Units open to well based on MWD-05 stratigraphy.
[e] Depth to top of Chouteau Group - 116 ft; depth to top of Bachelor Formation - 138.6 ft; depth to top of Sulphur Springs Group-140.8 ft.
[f] Unit open to well based on MWD-06 stratigraphy.
[g] Units open based on MWD-18 stratigraphy.
[h] NP = not present.
[i] Depth to top of Chouteau Group - 48.7 ft; depth to top of Bachelor Formation - 70 ft; depth to top of Sulphur Springs Group - 71.1 ft; depth to top of Kimmswick Limestone - 91.0 ft.
[j] Depth to top of Kimmswick Limestone - 44 ft.
[k] Units open to well based on MWD-25 stratigraphy.
[l] Units open to well based on MWD-26 stratigraphy.
[m] Units open to well based on MWD-109 stratigraphy.

Sources: IT Corporation (1993); Mugel (1997).

TABLE B.3 Physical Characteristics of the Overburden Units

Unit	Lithology	Description	Physical Characteristics
Topsoil/Fill	Clayey silt to silty clay	The topsoil portion of this unit is generally black and organically rich and ranges from 0 to 3.5 ft in thickness. The fill portion of this unit is believed to have been obtained from on-site sources. Thickness: 0 to 30 ft Color: Varies	LL: 47.5[a] PI: 29.7[b] Mechanical Analysis[c] % Gravel: 0.3 % Sand: 8.3 % Fines: 91.3 Classification: CL[d]
Peoria Loess[e]	Silty clay	This unit was derived from Missouri River outwash and deposited during the second loess depositional period of the Wisconsin Age. The Peoria Loess is a homogeneous fine-grained unit. This unit is generally moist and ranges from soft near the surface to very stiff at the base of the unit. Iron oxide and manganese oxide staining have been observed in this unit. Thickness: 0 to 5 ft Color: Reddish brown to dark gray	LL: 48 PI: 25 Mechanical Analysis[c,f] % Gravel: 0 % Sand: 3.2 % Fines: 96.9 Hydrometer Analysis[g] % Sand: 4.3 % Silt: 60.1 % Clay: 35.5 Classification: CL
Roxana Loess[e]	Silty clay	This unit was deposited during the first loess depositional period of the Wisconsin Age. This unit is a dense, stiff to very stiff, blocky structured, dry silty clay. Iron oxide and manganese oxide staining in hairline fractures are common throughout the unit but tend to be concentrated near the bottom. This unit is present over most of the training area except in the southwestern portion. Thickness: 0 to 6 ft Color: Light gray and yellowing brown	LL: 40 PI: 20 Mechanical Analysis[c] - See above Hydrometer Analysis[g] % Sand: 4.9 % Silt: 64.3 % Clay: 30.8 Classification: CL

TABLE B.3 (Cont.)

Unit	Lithology	Description	Physical Characteristics
Ferrelview Formation	Clay and some silty clay	This unit is speculated to be a mid-Pleistocene glacial till plain sediment. The unit is very stiff and plastic. Iron oxide nodules and manganese oxide fracture coatings are common. Fractures are frequently conchoidal and in many cases slickensided due to consolidation and compaction after deposition. This unit is present over most of the chemical plant area, the training area, and the northern portion of the ordnance works area. Thickness: 0 to 22 ft Color: gray and dark yellowish-orange (mottled)	LL: 52.2 PI: 32.8 Mechanical Analysis[c] % Gravel: 0.3 % Sand: 5.1 % Fines: 94.6 Hydrometer Analysis[g] % Sand: 8.4 % Silt: 44.0 % Clay: 47.6 Classification: CL-CH[h]
Clay Till[i]	Sandy silty clay to clayey silt with minor gravel clay	This Pleistocene glacial till unit is the most areally extensive unit. This unit is massive, very stiff, and contains some sand and rounded pebbles, cobbles, and boulders of chert and igneous and metamorphic rock. Pyrolusite fracture coatings and iron oxide nodules are abundant. Outwash subunit Thickness: 0 to 30 ft Color: yellowish-brown	LL: 48.8 PI: 32.9 Mechanical Analysis[a] % Gravel: 0.9 % Sand: 23.2 % Fines: 75.9 Hydrometer Analysis[e,j] % Sand: 22.6 % Silt: 34.1 % Clay: 43.3 Classification: CL-CH
Basal Till[e]	Sandy, clayey, silty gravely, or gravelly silt	This unit is the lower member of the Pleistocene glacial till sediments and underlies the clay till unit. At the chemical plant area, it has been found mainly on the western and north-central areas of the site. Deposition appears to be influenced by the bedrock topography since the unit is generally thin or absent in areas of higher bedrock elevations. This unit has been tentatively identified in several monitoring wells on the training area. This unit is a clayey, silty gravel or gravelly silt. The gravel fraction is usually angular chert, which is bound in the silty matrix. Thickness: 0 to 11 ft Color: yellowish-brown	LL: 40.0 PI: 23.7 Mechanical Analysis[c] % Sand: 12.1 % Silt: 21.8 % Clay: 66.1 Hydrometer Analysis[d,f] - See above Classification: CL

TABLE B.3 (Cont.)

Unit	Lithology	Description	Physical Characteristics
Residuum	Gravelly clay and clayey gravel	This unit is the residual erosional material derived from the physical and chemical weathering of the underlying and possibly overlying limestone. This unit is highly heterogeneous with a wide range of particle sizes (clay, gravel, boulder, cobble). Relict chert beds were noted. Thickness: 0 to 34 ft Color: reddish-brown	LL: 63.7 PI: 44.3 Mechanical Analysis[g] % Sand: 37.9 % Silt: 19.3 % Clay: 42.8 Hydrometer Analysis[d] % Sand: 21.6 % Silt: 25.2 % Clay: 53.2 Classification: CL/GC

[a] LL = liquid limit.

[b] PI = plasticity index.

[c] Source: MK-Environmental Services (1991).

[d] CL = low plastic clay.

[e] This unit is not differentiated in discussions regarding the chemical plant area.

[f] Results of mechanical analysis for loess unit; the Roxana Silt and Peoria Loess are not differentiated.

[g] Source: Rueff (1992).

[h] CH = high plastic clay.

[i] This unit is not differentiated in discussions regarding the ordnance works area.

[j] Results of hydrometer analysis for till unit; the Clay Till and Basal Till are not differentiated.

TABLE B.4 Hydraulic Properties of the Overburden Units in the Vadose Zone as Determined from Laboratory Testing[a]

Overburden Unit	In situ Moisture Content (%)	Porosity (%)	Average Hydraulic Conductivity (cm/s)
Loess	NA[b]	NA	6.2×10^{-6}
Ferrelview Formation	90	40.3	8.9×10^{-8}
Clay Till	93	37.8	2.6×10^{-8}
Basal Till	91	36.2	3.8×10^{-8}
Residuum	65	44.2	5.0×10^{-8}

[a] Overburden samples were obtained from the chemical plant area.

[b] NA = data not available.

Sources: MK-Environmental Services (1991); MK-Ferguson Company and Jacobs Engineering Group, Inc. (1992); MK-Environmental Services (1993).

saturation because of the variability of composition (clay, gravel, and relict chert beds) of the residuum, which allows water to be released more readily. The moisture contents of the Ferrelview Formation and till units would suggest that the release of water is slow, which would result in steady recharge to the shallow aquifer.

Because of the fine textures of the materials in these units, the total porosity is relatively high, ranging from 36 to 44% (MK-Environmental Services 1993). Effective porosity, or those void spaces in the soils that are interconnected, controls the hydraulic properties of each unit. On the basis of a bromide ion tracer test performed on six soils samples, the observed effective porosities ranged from 5 to 11.7%. These values are consistent with soil moisture characteristic curve data from previous testing.

The soil moisture characteristic curves describe the relationship between the suction head and the moisture content for a soil and are used to develop a relationship between the unsaturated hydraulic conductivity and the moisture content as determined from the suction head. In general, the soil-water retention curves for the Ferrelview Formation and clay till units are very steep, which indicates a relatively minor moisture content decrease with increasing suction head. Also, the residual moisture content (Θ_r) is not significantly different from the moisture content at saturation (Θ_s), in most cases. The results of these tests indicated an effective porosity of 4.6% for the Ferrelview Formation and 5.3% for the clay till unit. These values agree with the lower range of effective porosity determined from previous tests. Table B.5 gives a statistical summary of soil-

moisture curve fitting parameters. A narrow range between the saturated and residual moisture contents was determined for each unit and indicates the magnitude of the effective porosity. It can be assumed that the residual moisture content cannot be drained and, therefore, represents the dead pore space. The difference between the saturated and residual moisture contents is approximately the minimum value of the effective porosity.

Two-stage borehole tests (Boutwell tests) were conducted to determine saturated hydraulic conductivity of the overburden units (Ferrelview Formation and clay till) and to provide additional values for hydraulic properties of the soils underlying the disposal cell (MK-Environmental Services 1993). Hydraulic conductivity results of the in situ testing were 1.2×10^{-9} cm/s (3.9×10^{-11} ft/day) for the Ferrelview Formation and 3.25×10^{-9} cm/s (1.1×10^{-10} ft/day) for the clay till. Boutwell tests provide estimates of saturated hydraulic conductivity from the material in the immediate vicinity of the borehole. The saturated hydraulic conductivity values estimated from the tests appear to be representative of the matrix material.

For comparison, laboratory tests (flexible wall permeameter and submerged pressure outflow cell tests) were conducted on soil samples obtained from the same locations and depths tested in the field. The laboratory results were similar to those obtained from field testing. Average values obtained from triaxial permeability tests were 8.94×10^{-9} cm/s (2.9×10^{-10} ft/s) for the Ferrelview Formation, 6.46×10^{-8} cm/s (2.1×10^{-9} ft/s) for the clay till, 2.45×10^{-7} cm/s (8.0×10^{-9} ft/s) for the basal till, and 2.58×10^{-7} cm/s (8.5×10^{-9} ft/s) for the residuum (MK-Environmental Services 1994). Because of the variable composition of the residuum, a range of values for this unit is possible and likely a function of secondary porosity (gravel, relic chert beds, etc.) within the unit as indicated from the slug tests results in Table B.6.

TABLE B.5 Soil-Moisture Characteristics of Overburden at the Chemical Plant Area[a]

	Average Moisture Content (%)		
Overburden Unit	Residual	Saturated	Average Effective Porosity (%)
Ferrelview Formation	36.9	41.5	4.6
Clay Till	31.7	37.0	5.3

[a] Samples were obtained from the chemical plant area.

Source: MK-Environmental Services (1993).

TABLE B.6 Summary of Single Well Hydraulic Conductivity Testing Results in the Overburden Units

Well ID	Hydraulic Conductivity (cm/s)	Unit
Chemical Plant Area		
MW-3004	1.4×10^{-8}	Clay Till
MW-3005	9.4×10^{-9}	Ferrelview/Clay Till
MW-3011	1.2×10^{-8}	Clay Till/Basal Till
Ordnance Works Area		
MWV-09	1.05×10^{-7}	Till/Residuum
MWV-16	2.60×10^{-7}	Residuum
MWV-22[a]	$\mathbf{2.37 \times 10^{-5}}$	Residuum
MWV-24R	$\mathbf{1.26 \times 10^{-5}}$	Residuum

[a] New data to support this RI are shown in **bold**.

Sources: IT Corporation (1992); Allan (1987).

B.1.1.2 Saturated Overburden

Saturated overburden materials occur in localized areas of the chemical plant area and the ordnance works area. In the northern and western parts of the chemical plant area, the residuum unit of the overburden is saturated in bedrock lows associated with paleochannels. In localized areas in the vicinity of Raffinate Pits 1, 3, and 4, the clay till unit is saturated where perched water occurs from seepage of the raffinate pits. In the northern portion of the ordnance works, the residuum and till units are likely saturated where the potentiometric surface extends into these units (Mugel 1997).

Eight monitoring wells were installed in the overburden adjacent to the raffinate pits (Figure B.1). A comparison between the water levels measured in each of these wells with the water-table surface and water levels measured in the weathered Burlington-Keokuk indicated that perched water exists. In the vicinity of the raffinate pits, the elevation of the water table ranges from about 181 to 187 m (594 to 614 ft) on the basis of wells open to the Burlington-Keokuk (see Section B.3.6). The static water levels in monitoring wells MW-3004, MW-3005, MW-3011, MW-3013, and MW-3015 have been consistently much higher than the elevation of the water-table surface (Table B.7). On the basis of the static water levels measured in MW-3016, MW-3017, and MW-3018 these wells monitor the shallow aquifer (Figure B.2, Table B.7).

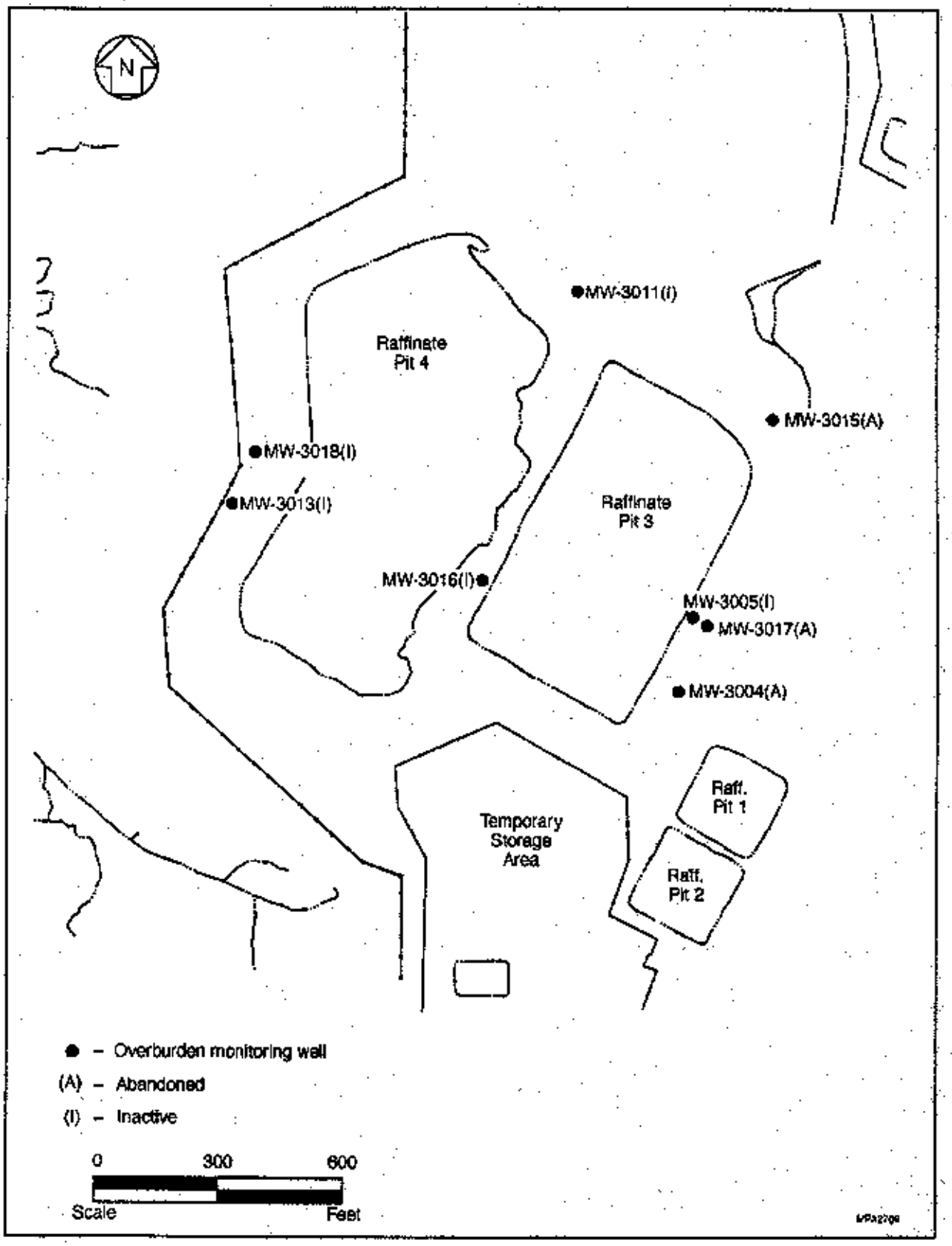


FIGURE B.1 Overburden Monitoring Locations — Chemical Plant Area

TABLE B.7 Overburden Monitoring Well Construction and Water-Level Data at the Chemical Plant Area

Well ID	Ground Elevation (ft)	Monitor Interval (ft)	Total Depth (ft)	Depth to Bedrock (ft)	Range Groundwater Elevation (ft) Maximum (ft)	Range Groundwater Elevation (ft) Minimum (ft)	Monitor Location
MW-3004	653.5	13.7–21.8	21.8	ND[a]	641.08	633.86	Perched
MW-3005	663.4	24.3–37.0	37.0	ND	651.14	634.03	Perched
MW-3011	649.2	20.0–23.5	23.5	23.5	630.41	626.68	Perched
MW-3013	641.5	NA[b]–22.0	22.0	ND	634.63	634.09	Perched
MW-3015	640.1	NA–20.0	20.0	ND	627.36	627.28	Perched
MW-3016	664	NA–51.0	51.0	ND	618.11	617.28	Shallow aquifer
MW-3017	649.8	NA–35.0	35.0	ND	618.58	618.31	Shallow aquifer
MW-3018	631	18.8–29.6	29.6	29.6	611.1	609.15	Shallow aquifer

[a] ND = not detected.

[b] NA = data not available.

At the ordnance works area, 10 monitoring wells open to the overburden (vadose) unit. A comparison between the water levels measured in each of these wells with the water-table surface and water levels measured in the nearby wells open to the shallow aquifer indicate that perched water exists. The static water levels in MWV-08, MWV-17, and MWV-18 are either dry or are consistently higher than the water-table elevation or, in many cases, these wells are dry (Table B.8). It appears that these three wells monitor perched water, and the other overburden wells monitor the shallow aquifer.

A geophysical survey was performed (Bechtel National, Inc. 1984) in the raffinate pit area in an effort to delineate the saturated overburden area. The results were inconclusive but have provided information on possible areas of saturation that are generally supported by static water-level data from overburden monitoring wells. On the basis of the results of geophysical surveys, it was inferred that unsaturated overburden occurs beneath Raffinate Pit 4 and portions of Raffinate Pit 3 and generally outside these pits, especially along the western half of Raffinate Pit 4. Possible areas of saturation were outlined by seismic methods beneath the center of Raffinate Pit 3. Thin, shallow layers were also outlined on the east side of Raffinate Pit 3 (between Raffinate Pit 3 and Raffinate Pits 1 and 2), on the south side of Raffinate Pit 3, and on the northern side of Raffinate Pit 1. Additional areas of possible saturation were identified at the northeastern corner of Raffinate Pit 3 and in the area south of Raffinate Pit 3, which is now the Temporary Storage Area, although the results were inconclusive. Table B.6 summarizes the results of the single well hydraulic conductivity testing in the overburden units.

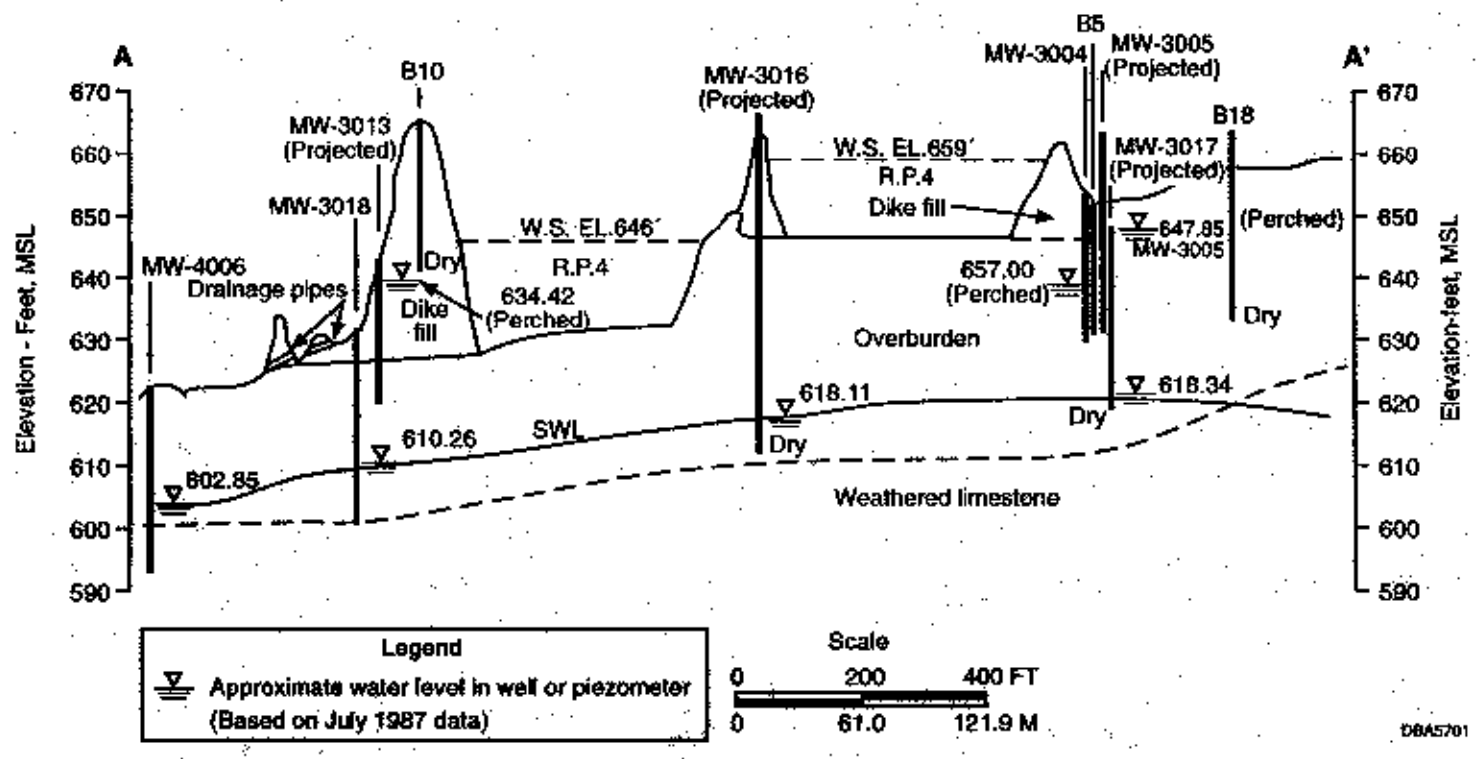


FIGURE B.2 Cross Section through Raffinate Pits 3 and 4

TABLE B.8 Overburden Monitoring Well Construction and Water-Level Data at the Ordnance Works Area

Well ID	Ground Elevation (ft)	Monitor Interval (ft)	Total Depth (ft)	Depth to Bedrock (ft)	Range Groundwater Elevation (ft) Maximum (ft)	Range Groundwater Elevation (ft) Minimum (ft)	Monitor Location
MWV-01	595.84	7.3–15.0	15.0	15.0	586.94	Dry	Shallow aquifer
MWV-02	603.07	8.8–16.8	17.0	17.0	589.41	Dry	Shallow aquifer
MWV-08	688.80	9.8–23.8	23.8	23.8	666.25	Dry	Perched
MWV-09	634.49	10.4–25.4	25.4	25.4	619.94	616.75	Shallow aquifer
MWV-13	690.18	27.0–41.5	41.5	41.5	655.42	648.94	Shallow aquifer
MWV-16	649.48	25.0–39.0	39.7	39.7	639.84	625.46	Shallow aquifer
MWV-17	658.53	4.0–17.0	17.0	17.0	645.83	Dry	Perched
MWV-18	599.61	6.0–19.0	19.6	19.6	581.21	Dry	Perched
MWV-22	661.9	25.0–37.6	37.6	37.6	649.25	645.38	Shallow aquifer
MWV-24R	640	26.7–41.0	41.0	41.0	623.06	621.04	Shallow aquifer

B.1.2 Bedrock

The following sections discuss the properties and flow dynamics of the shallow bedrock aquifer on the basis of data obtained from previous investigations and the remedial investigations for these GWOUs. The bedrock geology of the shallow aquifer system consists of Burlington-Keokuk Limestone and the Fern Glen Formation. These units are composed of Osagean Mississippian limestones and dolomites. Emphasis has been placed on the Burlington- Keokuk Limestone, the uppermost rock unit over the majority of the chemical plant area and the ordnance works area. The underlying Fern Glen Formation is discussed, where necessary, to elaborate on the interaction of this formation with the Burlington-Keokuk Limestone.

Subsurface investigations have defined two units, weathered and unweathered, within the Burlington-Keokuk Limestone on the basis of lithology and the degree of weathering and fracturing. A third subunit that is strongly weathered has been identified in some borings and is not continuous across the chemical plant area and the ordnance works area. The contact between the weathered and unweathered units is not distinct, but rather gradual, since the degree of weathering gradually decreases with depth.

The weathered unit is an argillaceous, silty limestone that contains up to 60% chert. The unit is micritic to finely crystalline, thinly bedded, fossiliferous, closely fractured, and slightly to severely weathered with abundant iron and manganese oxide staining in the rock matrix and along fractures. Fracture spacing ranges from 3 to 30 cm (0.1 to 1 ft). Angled borings indicate that

horizontal bedding plane fractures occur more frequently than vertical fractures by approximately 20 to 1. Horizontal fractures typically occur along shaley interbeds, bedding planes, and chert interbeds (DOE 1995b). The weathered unit is moderately to highly fractured with 73% of the rock quality designation (RQD) values in the poor to very poor category (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992).

On the basis of data gathered during geologic investigations at both sites, the weathered Burlington-Keokuk Limestone at the chemical plant area ranges in thickness from 3 to 17 m (10 to 55 ft) (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992) and ranges from 0 to 19.5 m (0 to 64 ft) at the ordnance works area; however, at one well location (MWS-111), this unit is 34-m (113-ft) thick (Mugel 1997). Solution features are quite common in this unit and range from pinpoint vugs to cavities up to 1.6 m (5 ft) (Bechtel National, Inc. 1987). Smaller cavities are commonly lined with calcite and drusy to euhedral quartz. The larger cavities appear to be filled with clay or mixtures of silty clay and chert gravel. Solution features in this unit are typically oriented parallel to bedding planes (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992).

The strongly weathered subunit has been identified where weathering features are particularly abundant or intense (Mugel 1997). Poor RQDs and core recovery, which may be indicative of clay-filled voids, are typical of this subunit. A distinguishing characteristic of the strongly weathered unit is a vuggy, weakly cemented chert breccia that sometimes contains limestone. Core recovery from this breccia is typically poor. This unit usually occurs in the upper portions of the weathered unit but has been observed within lower sections of weathered Burlington-Keokuk Limestone at the chemical plant.

Beneath the weathered unit is the unweathered unit of the Burlington-Keokuk Limestone. The unit is finely to coarsely crystalline, thin to massively bedded, locally argillaceous, fossiliferous, and slightly weathered to fresh with 20 to 40% chert, although zones or more intense weathering may occur (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992). Fresh pyrite is present on some of the fracture surfaces, although this portion of the unit lacks significant fracturing and iron staining. An estimated 79% of the RQD values for this unit are in the fair to excellent category (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1992). Large solution features are uncommon in this unit on the basis of logging of rock core obtained from the chemical plant area and the ordnance works area.

The unweathered unit makes up the remaining thickness of the Burlington-Keokuk Limestone, which overlies the Fern Glen Formation. On the basis of coring activities at both the chemical plant area and the ordnance works area, the unweathered portion of this formation ranges from 0 to greater than 34 m (0 to greater than 113 ft) (Mugel 1997).

The Fern Glen Formation is generally a finely crystalline dolomite and less commonly limestone with nodular and interbedded chert. Parts of the Fern Glen Formation are characterized

by pinpoint porosity, some quartz- or calcite-lined or filled vugs (geodes) (Whitfield et al. 1989). The base of this unit typically becomes coarser and exhibits a lesser chert content. This unit ranges in thickness from 8.8 to 20.3 m (28.7 to 66.6 ft) on the basis of geologic information from the training area (Mugel 1997).

B.2 SUMMARY OF FIELD INVESTIGATIONS

Field investigations performed in support of this remedial investigation consisted of soil and rock core logging, monitoring well installation, packer testing, slug testing, and subsurface dye tracer testing. A summary of each of these activities and the methodology used is provided in the following sections.

B.2.1 Soil and Rock Core Logging

The soil and rock portions of the six new monitoring wells and three angled borings were logged to provide additional information on the overburden and bedrock units encountered at the chemical plant area and the ordnance works area. These materials were logged in accordance with the *Sampling Plan* (DOE 1995a), and emphasis during logging was placed on identification of fractures, solution features, and other discontinuities that could affect groundwater movement. These logs are provided in *Hydrogeologic Field Characterization Data for the Chemical Plant Area and Ordnance Works Area Collected in the 1995 Joint Sampling Activities* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1996).

B.2.2 Monitoring Well Installation

Six new groundwater monitoring wells were installed in support of this remedial investigation, and one existing open hole well was retrofitted to monitor a discrete bedrock interval. These wells were installed or retrofitted in accordance with state regulations 10 CSR 23-4 - *Missouri Monitoring Well Construction Code*. Variances for the construction or development were requested and approved by the state. The monitoring well details are provided in MK-Ferguson Company and Jacobs Engineering Group, Inc. (1996).

B.2.3 In Situ Pressure (Packer) Test Methodology

The bedrock portion of the angled borings and the groundwater monitoring wells installed in support of this remedial investigation were pressure tested to determine the hydraulic conductivity of the bedrock. Intervals typically ranging from 3 to 6 m (10 to 20 ft) were tested to determine the

variation of hydraulic conductivity within the bedrock units and to better determine the factors influencing groundwater movement in each unit. The results of these tests and of all the other in situ pressure packer tests are presented in Tables B.9, B.10, and B.11.

The data were analyzed by using a procedure outlined by the U.S. Department of Interior (U.S. Department of the Interior 1977) in the *Sampling Plan* (MK-Ferguson Company and Jacobs Engineering Group 1995). This method is consistent with previous hydraulic conductivity determinations from packer tests. An explanation of the calculations, parameters, and assumptions is provided in Figure B.3. Data sheets are provided in *Hydrogeologic Field Characterization Data for the Chemical Plant Area and Ordnance Works Area Collected in the 1995 Joint Sampling Activities* (MK-Ferguson Company and Jacobs Engineering Group, Inc. 1996).

B.2.4 Single Well Hydraulic Conductivity (Slug) Test Methodology

Existing monitoring wells were tested to determine the variation in hydraulic conductivity within the Burlington-Keokuk across the chemical plant area and the ordnance works area. These data were obtained to determine the heterogeneity and anisotropy of this limestone unit and to identify possible preferential flow zones.

Slug testing was performed in accordance with Environmental Safety and Health Procedure 4.3.2s., *Single Well Hydraulic Conductivity Testing*, or ASTM D-4044, *Test Method for Instantaneous Change in Head for Determining Hydraulic Head Properties of Aquifers*, as outlined in the *Sampling Plan* (MK-Ferguson Company and Jacobs Engineering Group 1995). Both rising and falling head tests were performed on each well. Standard pressure transducers and data loggers were used to obtain water-level measurements as recommended in ASTM D-4050, *Test Method for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems.*

TABLE B.9 Summary of Packer Test Results from the Overburden/Bedrock Interface

Well ID	Location	Hydraulic Conductivity (cm/s)	Well ID	Location	Hydraulic Conductivity (cm/s)
G8	East-central portion of the chemical plant area	4.7×10^{-3}	G16	Southwest portion of the chemical plant area	1.5×10^{-4}
G9	East-central portion of the chemical plant area	9.2×10^{-2}	G19	Northwest portion of the chemical plant area	6.3×10^{-2}

Source: MK-Ferguson Company and Jacobs Engineering Group, Inc. (1992).

TABLE B.10 Summary of Packer Test Results at the Chemical Plant Area

Location	Interval[a] (ft)	Unit	Depth to Rock (ft)	K (cm/s)[b]
MW-2001	29.0–35.0	Weathered	26.5	$< 9.5 \times 10^{-7}$
MW-2002	39.2–45.2	Weathered	28.5	2.1×10^{-4}
MW-2002	53.8–59.8	Weathered		$< 6.8 \times 10^{-7}$
MW-2003	30.0–36.0	Weathered	38.8	3.4×10^{-4}
MW-2003	44.0–50.0	Weathered		$< 8.0 \times 10^{-7}$
MW-2004	38.0–44.0	Weathered	37	$< 9.3 \times 10^{-7}$
MW-2004	52.0–58.0	Weathered		$< 9.3 \times 10^{-7}$
MW-2004	53.6–72.0	Weathered		$< 3.9 \times 10^{-7}$
MW-2006	32.8–38.7	Weathered	22.6	2.6×10^{-6}
MW-2006	41.8–47.7	Weathered		8.9×10^{-5}
MW-2007	62.0–68.0	Weathered	59	8.2×10^{-7}
MW-2008	35.0–41.0	Weathered	31.5	3.7×10^{-5}
MW-2008	47.9–53.9	Weathered/ unweathered		3.9×10^{-5}
MW-2009	22.0–28.0	Weathered	20.5	3.6×10^{-3}
MW-2010	43.3–49.3	Weathered	32.8	2.1×10^{-3}
MW-2012	52.0–58.0	Unweathered	25	1.7×10^{-5}
MW-2013	40.0–46.0	Weathered	27.5	5.9×10^{-6}
MW-2013	62.0–68.0	Unweathered		5.2×10^{-6}
MW-2014	43.0–49.0	Weathered	33	2.8×10^{-4}
MW-2015	50.3–56.2	Weathered	45.5	9.1×10^{-3}
MW-2015	62.3–68.7	Weathered		5.2×10^{-5}
MW-2017	25.7–31.7	Weathered	23.6	4.7×10^{-3}
MW-2018	30.0–36.0	Residuum/ Weathered	32.5	6.8×10^{-6}
MW-2018	42.0–48.0	Weathered		8.9×10^{-5}
MW-4024	27.0–37.6	**Weathered[c]**	**24.3**	$\mathbf{2.61 \times 10^{-3}}$
MW-4024	**37.0–49.0**	**Weathered**		$\mathbf{1.25 \times 10^{-3}}$
MW-4024	**48.5–59.0**	**Weathered**		$\mathbf{5.73 \times 10^{-5}}$
MW-4025	**32.0–43.7**	**Weathered**	**27.5**	$\mathbf{4.17 \times 10^{-4}}$
MW-4025	**43.0–53.7**	**Weathered**		$\mathbf{6.88 \times 10^{-5}}$
G1	54.0–64.7	Weathered	39.7	1.0×10^{-3}
G1	69.6–90.6	Weathered/ unweathered		2.8×10^{-4}

TABLE B.10 (Cont.)

Location	Interval[a] (ft)	Unit	Depth to Rock (ft)	K (cm/s)[b]
G2A	64.7–75.4	Weathered/ unweathered		3.5×10^{-4}
G2A	75.2–85.9	Unweathered	44.8	1.2×10^{-4}
G3	56.0–66.7	Weathered	54.6	1.4×10^{-3}
G4	58.8–69.5	Weathered	53	1.1×10^{-3}
G5	45.3–51.3	Weathered	40	$< 6.4 \times 10^{-7}$
G5	50.0–56.0	Weathered		1.3×10^{-6}
G7	0–5.9	Weathered	26.0	2.2×10^{-3}
G9	66.0–76.0	Unweathered	37.5	3.6×10^{-6}
G13	30.1–36.0	Weathered	28.5	5.0×10^{-3}
G14	64.0–76.4	Unweathered	37.5	$< 3.5 \times 10^{-7}$
G15	53.0–59.3	Weathered	41.0	2.4×10^{-4}
G16	45.5–50.8	Weathered	34.0	6.1×10^{-3}
G18	41.6–47.6	Weathered	30.0	8.5×10^{-3}
G19	41.5–49.5	Weathered	41.5	8.0×10^{-3}
G19	51.0–570	Weathered/ unweathered	41.5	$< 7.8 \times 10^{-7}$
G20	40.0–46.0	Weathered	32.5	1.9×10^{-3}
G20	43.0–49.0	Weathered	NA	6.9×10^{-4}
G21	38.7–54.7	Weathered	34.2	2.1×10^{-6}
AH-2001	34.5–43.3	Weathered	30.7	9.3×10^{-4}
AH-2001	43.1–52.0	Weathered	NA	6.1×10^{-4}
AH-2001	51.3–60.2	Weathered	NA	Not determined[d]
AH-2001	59.9-77.5	Weathered/ unweathered	NA	$< 1.16 \times 10^{-5}$
AH-2001	77.4-94.8	Unweathered	NA	$< 3.6 \times 10^{-7}$
AH-2001	94.7-112.1	Unweathered	NA	8.4×10^{-6}
AH-2001	110.4-131.3	Unweathered	NA	$< 6.60 \times 10^{-8}$
AH-2002	46.4-54.9	Weathered	42.2	8.7×10^{-4}
AH-2002	53.7-63.6	Weathered	NA	1.7×10^{-4}
AH-2002	63.2-72.2	Weathered	NA	4.0×10^{-7}
AH-2002	72.0-89.5	Weathered/ unweathered	NA	$< 8.4 \times 10^{-6}$
AH-2002	89.4-106.9	Unweathered	NA	$< 1.9 \times 10^{-6}$
AH-2002	106.7-124.2	Unweathered	NA	1.0×10^{-6}
AH-2002	124.0-142.9	Unweathered	NA	2.1×10^{-5}

TABLE B.10 (Cont.)

Location	Interval[a] (ft)	Unit	Depth to Rock (ft)	K (cm/s)[b]
AH-2003	**40.9-50.0**	**Residuum/ Weathered**	**46.5**	**6.74×10^{-4}**
AH-2003	**50.1-58.6**	**Weathered**	**NA**	**7.67×10^{-6}**
AH-2003	**58.0-67.3**	**Weathered**	**NA**	**1.43×10^{-5}**
AH-2003	**66.7-75.9**	**Weathered/ unweathered**	**NA**	**3.8×10^{-4}**
AH-2004	**29.9-38.1**	**Weathered**	**26.8**	**5.69×10^{-4}**
AH-2004	**46.7-53.7**	**Weathered**	**NA**	**Not determined**
AH-2005	**37.2-46.7**	**Weathered**	**24.7**	**Not determined**
AH-2005	**45.9-55.0**	**Weathered**	**NA**	**Not determined**
AH-2005	**54.5-62.6**	**Weathered**	**NA**	**8.61×10^{-6}**

[a] Interval measured as depth below ground surface.

[b] Convert cm/s to ft/s by dividing by 30.48.

[c] NA = data not available.

[d] The formation did not take measurable quantities of water during the test period. Hydraulic conductivity cannot be estimated for this interval; it is, however, expected to be lower than the lowest estimate given in this table.

[e] New data to support this RI are shown in **bold**.

Sources: Bechtel National, Inc. (1987); MK-Ferguson Company and Jacobs Engineering Group, Inc. (1992).

Hydraulic conductivity values obtained from these tests were determined by the Bouwer and Rice (1976) method. Data sheets are provided in MK-Ferguson Company and Jacobs Engineering Group (1996). Tables B.12 and B.13 give the single well hydraulic conductivity (slug) test results for all the wells tested.

B.2.5 Dye Tracer Tests

Dye tracer tests were performed in conjunction with the angled boring drilling at the chemical plant area to obtain information on conduit flow connecting the chemical plant with Burgermeister Spring. These tests were performed with the assistance of the Missouri Department of Natural Resources - Division of Geology and Land Survey. All testing was performed in accordance with state regulations in Section 256.621 of the *Water Well Drillers Act* and as outlined in the *Sampling Plan* (MK-Ferguson Company and Jacobs Engineering Group 1995). Copies of the

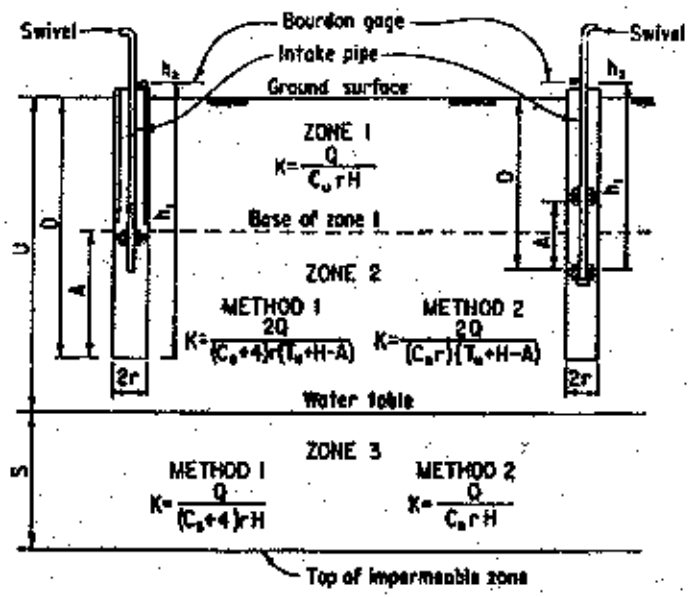
TABLE B.11 Summary of Packer Test Results at the Ordnance Works Area[a]

Location	Interval (ft)[b]	Unit	Depth to Rock (ft)	K (cm/s)[c]
MWD-23	38.3–52.9	Weathered	38.3	1.65×10^{-6}
MWD-23	60–70	Weathered		1.10×10^{-4}
MWD-23	70–85	Weathered		3.27×10^{-4}
MWD-23	85–125	Weathered/ unweathered		8.52×10^{-6}
MWD-23	105–125	Unweathered		6.92×10^{-6}
MWD-25	18–28	Residuum	36.5	4.11×10^{-5}
MWD-25	44.5–54.5	Weathered		6.75×10^{-4}
MWD-25	54.5–64.5	Weathered		1.12×10^{-6}
MWD-25	64.5–74.5	Weathered		9.87×10^{-6}
MWD-25	74.5–84.5	Weathered		3.12×10^{-6}
MWD-25	84.5–94.5	Weathered		1.77×10^{-6}
MWD-25	94.5–114.5	Weathered/ unweathered		1.11×10^{-5}
MWS-26	39.0–44.5	Residuum/ weathered	40.6	6.20×10^{-4}
MWS-26	44.5–55	Weathered		$< 1 \times 10^{-7}$
MWS-26	55–65	Weathered		$< 1.46 \times 10^{-6}$
MWD-107	44–54	Residuum/ weathered	46.0	7.28×10^{-4}
MWD-107	54–64	Weathered		$< 1 \times 10^{-7}$
MWD-107	64–74	Weathered		$< 1 \times 10^{-7}$
MWD-107	74–84	Weathered/ unweathered		$< 3.32 \times 10^{-6}$
MWD-107	84–94	Unweathered		1.65×10^{-6}
MWD-107	94–114	Unweathered		3.77×10^{-6}
MWD-107	114–134	Unweathered		7.95×10^{-6}
MWS-112	28.5–38.5	Unweathered	18.0	2.99×10^{-6}
MWS-112	38.5–48.5	Unweathered		5.77×10^{-6}
MWS-112	48.5–58.5	Unweathered		2.19×10^{-6}

[a] All new data were obtained to support this RI.

[b] The test interval was measured as the depth below the ground surface.

[c] Convert cm/s to ft/s by dividing by 30.48.



K = coefficient of permeability, feet per second under a unit gradient

Q = steady flow into well, ft^3/s

$H = h_1 + h_2 - L$ = effective head, ft

h_1 (above water table) = distance between Bourdon gage and bottom of hole for method 1 or distance between gage and upper surface of lower packer for method 2, ft

h_2 (below water table) = distance between gage and water table, ft

h_2 = applied pressure of gage, 1 lb/in^2 = 2.307 ft of water

L = head loss in pipe due to friction, ft; ignore head loss for Q<4 gal/min in $1\frac{1}{4}$-inch pipe; use length of pipe between gage and top of test section for computations

$X = \frac{H}{T_w}(100)$ = percent of unsaturated stratum

A = length of test section, ft

r = radius of test hole, ft

C_u = conductivity coefficient for unsaturated materials with partially penetrating cylindrical test wells

C_s = conductivity coefficient for semi-spherical flow in saturated materials through partially penetrating cylindrical test wells

U = thickness of unsaturated material, ft

S = thickness of saturated material, ft

$T_w = U - D + H$ = distance from water surface in well to water table, ft

D = distance from ground surface to bottom of test section, ft

o = surface area of test section, ft^2; area of wall plus area of bottom for method 1; area of well for method 2

Limitations:

$Q/o \leq 0.10$, $S \geq 5A$, $A \geq 10r$; thickness of each packer must be $\geq 10r$ in method 2

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FIGURE B.3 Permeability Test Setup for Saturated and Unsaturated Bedrock

TABLE B.12 Summary of Single Well Hydraulic Conductivity Slug Test Results at the Chemical Plant Area

Well ID	Stratigraphic Unit	Hydraulic Conductivity (cm/s)[a]	Well ID	Stratigraphic Unit	Hydraulic Conductivity (cm/s)[a]
MW-2001	Weathered/unweathered[b]	3×10^{-5}	MW-2044	Weathered/unweathered	1×10^{-3}
MW-2002	Weathered/unweathered	7.52×10^{-5}	MW-3003	Weathered/unweathered	5.79×10^{-6}
MW-2003	Weathered	3×10^{-5}	MW-3006	Unweathered	2.66×10^{-4}
MW-2005	Weathered	2.08×10^{-5}	MW-3019	Weathered/unweathered	5.44×10^{-5}
MW-2006	Weathered/unweathered	6.83×10^{-5}	MW-3023	Weathered	2×10^{-5}
MW-2007	Weathered/unweathered	6×10^{-5}	MW-3024	Unweathered	3×10^{-3}
MW-2008	Weathered/unweathered	6.90×10^{-6}	MW-3025	Weathered	Not Determined
MW-2010	Weathered	9×10^{-3}	MW-3026	Unweathered	Not Determined
MW-2011	Weathered/unweathered	4×10^{-3}	MW-3027	Weathered	9×10^{-4}
MW-2012	Weathered/unweathered	1 × 10-3	MW-4001	Weathered/unweathered	4.98×10^{-5}
MW-2013	Weathered/unweathered	4.75×10^{-5}	MW-4002	Weathered/unweathered	1×10^{-3}
MW-2014	Weathered	6×10^{-3}	MW-4003	Weathered	6×10^{-5}
MW-2015	Weathered/unweathered	1.16×10^{-4}	MW-4004	Unweathered	6.37×10^{-6}
MW-2017	Weathered/unweathered	7×10^{-4}	MW-4005	Weathered	4.17×10^{-6}
MW-2018	Weathered	6.60×10^{-5}	MW-4007	Unweathered	5×10^{-6}
MW-2019	Unweathered	1.97×10^{-5}	MW-4008	Unweathered	1.03×10^{-5}
MW-2021	Unweathered	2.43×10^{-5}	MW-4009	Unweathered	6.71×10^{-6}
MW-2022	Unweathered	4.05×10^{-5}	MW-4010	Weathered/unweathered	4.98×10^{-6}
MW-2023	Unweathered	9.14×10^{-6}	MW-4011	Unweathered	1.74×10^{-6}
MW-2024	Unweathered	3.94×10^{-5}	MW-4012	Unweathered	4.51×10^{-6}
MW-2025	Unweathered	3.94×10^{-5}	MW-4013	Weathered/unweathered	5.67×10^{-5}
MW-2026	Unweathered	3.36×10^{-5}	MW-4014	Weathered/unweathered	1.02×10^{-3}
MW-2027	Unweathered	1.39×10^{-5}	MW-4015	Weathered/unweathered	2.89×10^{-5}

TABLE B.12 (Cont.)

Well ID	Stratigraphic Unit	Hydraulic Conductivity (cm/s)[a]	Well ID	Stratigraphic Unit	Hydraulic Conductivity (cm/s)
MW-2028	Unweathered	1.74×10^{-5}	MW-4016	Weathered/unweathered	4.05×10^{-5}
MW-2029	Unweathered	1.74×10^{-6}	MW-4017	Weathered/unweathered	3.01×10^{-5}
MW-2032	**Weathered**	$\mathbf{4 \times 10^{-2}}$	MW-4018	Weathered/unweathered	3.01×10^{-5}
MW-2034	**Weathered**	$\mathbf{3 \times 10^{-6}}$	MW-4020	Weathered/unweathered	2.31×10^{-5}
MW-2035	**Weathered/unweathered**	$\mathbf{2 \times 10^{-5}}$	MW-4021	Weathered/unweathered	3.94×10^{-5}
MW-2036	**Weathered/unweathered**	$\mathbf{1 \times 10^{-4}}$	MW-4022	Unweathered	2.31×10^{-5}
MW-2037	**Weathered**	$\mathbf{2 \times 10^{-2}}$	MW-4023	Weathered	7.75×10^{-5}
MW-2038	**Weathered**	$\mathbf{3 \times 10^{-4}}$	GT58P (MW-2030)	Weathered	4.51×10^{-3}
MW-2039	**Weathered**	$\mathbf{1 \times 10^{-5}}$	GT66P (MW-2033)	Weathered	6.36×10^{-5}
MW-2040	**Weathered**	$\mathbf{2 \times 10^{-5}}$	PW-1	Weathered	1.6×10^{-5}
MW-2041	**Weathered**	$\mathbf{5 \times 10^{-4}}$	PW-2	Weathered	2.4×10^{-5}
MW-2042	**Weathered**	$\mathbf{4 \times 10^{-3}}$	PW-3	Weathered	2.1×10^{-5}
MW-2043	**Weathered**	$\mathbf{4 \times 10^{-4}}$	NA[b]	NA	NA

[a] Convert cm/s to ft/s by dividing by 30.48.

[b] New data to support this RI are shown in **bold**.

[c] NA = data not available.

[d] The formation did not take measurable quantities of water during the test period. Hydraulic conductivity cannot be estimated for this interval, but it is expected to be below the lowest estimate given in this table.

Source: MK-Ferguson Company and Jacobs Engineering Group, Inc. (1992).

TABLE B.13 Summary of Single Well Hydraulic Conductivity Slug Test Results at the Ordnance Works Area

Well ID	Stratigraphic Unit	Hydraulic Conductivity (cm/s)[a]	Well ID	Stratigraphic Unit	Hydraulic Conductivity (cm/s)[a]
MWS-01	Weathered/unweathered	1.94×10^{-7}	MWD-D18	Kimmswick	4.95×10^{-6}
MWS-02	Weathered/unweathered	1.31×10^{-7}	MWS-19	Weathered	2.42×10^{-7}
MWD-02	Unweathered	9.13×10^{-7}	MWS-20	Weathered/unweathered	2.84×10^{-7}
MWS-03	Weathered/unweathered	7.36×10^{-8}	**MWS-21[b]**	**Weathered**	$\mathbf{3.61 \times 10^{-6}}$
MWS-04	Weathered	1.58×10^{-5}	**MWS-22**	**Weathered**	$\mathbf{1.58 \times 10^{-4}}$
MWS-05	Unweathered/Fern Glen	6.97×10^{-7}	**MWS-24**	**Weathered**	$\mathbf{7.44 \times 10^{-6}}$
MWD-05	Fern Glen/Chouteau	2.51×10^{-8}	MWS-101	Kimmswick	5.44×10^{-7}
MWS-06	Unweathered	1.94×10^{-7}	MWS-102	Decorah	1.01×10^{-8}
MWD-06	Unweathered	8.97×10^{-7}	MWS-103	Sulphur Springs/ Kimmswick	2.12×10^{-8}
MWS-07	Weathered	7.01×10^{-6}	MWS-104	Weathered/unweathered	8.22×10^{-8}
MWS-09	Weathered	3.46×10^{-7}	MWS-105	Unweathered	7.39×10^{-8}
MWD-09	Unweathered	1.93×10^{-6}	MWD-105	Unweathered/Fern Glen	5.91×10^{-7}
MWS-10	Weathered	9.32×10^{-7}	MWS-106	Unweathered	4.68×10^{-8}
MWS-11	Weathered	2.80×10^{-5}	MWD-106	Unweathered/Fern Glen	7.26×10^{-5}
MWS-12	Weathered	1.43×10^{-6}	MWS-107	Weathered/unweathered	2.24×10^{-7}
MWS-13	Weathered	5.15×10^{-7}	MWS-108	Unweathered	1.82×10^{-7}
MWS-15	Weathered	1.10×10^{-6}	MWS-109	Unweathered	1.12×10^{-7}
MWD-15	Weathered	4.19×10^{-7}	MWD-109	Unweathered/Fern Glen	2.18×10^{-7}
MWS-16	Weathered	2.35×10^{-7}	MWS-110	Weathered/unweathered	4.28×10^{-7}
MWS-17	Weathered/unweathered	1.46×10^{-7}	MWS-111	Weathered	8.66×10^{-7}

[a] Convert cm/s to ft/s by dividing by 30.48.

[b] New data to support this RI are shown in **bold**.

Source: IT Corporation (1993).

registration forms and data sheets are provided in MK-Ferguson Company and Jacobs Engineering Group (1996).

B.2.6 Groundwater Elevation Measurements

As part of the joint sampling effort, water-level elevations were measured from all active chemical plant area and ordnance works area monitoring wells in April and July 1995 to provide a regional representation of the water table surface. Table B.14 summarizes the static water-level measurements for these two months.

Table B.15 summarizes the elevation fluctuations at each monitoring well on the basis of the water-level data collected from 1987 through July 1995.

TABLE B.14 Summary of Water-Level Measurements — April and July 1995

Well ID	Top of Casing Elevation (ft)	April 1995 Depth to Water (ft)	April 1995 Groundwater Elevation (ft)	July 1995 Depth to Water (ft)	July 1995 Groundwater Elevation (ft)
Chemical Plant Area					
MW-2001	613.44	22.70	590.74	24.78	588.66
MW-2002	625.75	31.65	594.10	31.91	593.84
MW-2003	638.78	35.66	603.12	40.86	597.92
MW-2005	637.38	49.62	587.76	49.58	587.80
MW-2006	635.92	33.45	602.47	38.17	597.75
MW-2007	653.60	59.44	594.16	60.85	592.75
MW-2010	644.67	44.06	600.61	43.97	600.70
MW-2011	655.28	54.18	600.10	54.45	600.83
MW-2012	636.61	29.21	607.40	28.78	607.83
MW-2013	647.13	41.11	606.02	40.83	606.30
MW-2014	649.37	44.96	604.41	44.81	604.56
MW-2015	659.99	56.08	603.91	55.98	604.01
MW-2017	659.84	54.15	605.69	53.80	606.04
MW-2018	663.50	47.77	615.73	47.39	616.11
MW-2019	663.24	70.28	592.96	69.96	593.28
MW-2021	626.19	36.24	589.95	36.36	589.83
MW-2022	637.24	50.45	586.79	51.47	585.77
MW-2023	637.29	54.60	582.69	54.34	582.95
MW-2024	636.70	67.33	569.37	67.29	569.41
MW-2026	637.22	45.22	592.00	45.63	591.59
MW-2027	646.83	53.84	592.99	54.27	592.56
MW-2028	659.74	64.10	595.64	64.08	595.66
MW-2030	654.63	53.70	600.93	53.66	600.97
MW-2032	635.81	54.27	581.54	54.31	581.50
MW-2033	647.50	41.41	606.09	40.82	606.68
MW-2034	660.83	54.19	606.64	53.71	607.12
MW-2035	668.40	53.86	614.54	53.57	614.83
MW-2036	658.01	44.38	613.63	44.07	613.94
MW-2037	659.08	45.07	614.01	44.86	614.22
MW-2038	667.19	53.86	613.33	53.68	613.51
MW-2039	665.25	51.52	613.73	51.24	614.01
MW-2040	662.39	49.50	612.89	49.15	613.24

TABLE B.14 (Cont.)

Well ID	Top of Casing Elevation (ft)	April 1995 Depth to Water (ft)	April 1995 Groundwater Elevation (ft)	July 1995 Depth to Water (ft)	July 1995 Groundwater Elevation (ft)
MW-2041	661.59	48.31	613.28	48.05	613.54
MW-2042	662.68	48.51	614.17	48.17	614.51
MW-2043	662.30	48.59	613.71	48.20	614.10
MW-2044	657.11	43.04	614.07	43.10	614.01
Raffinate Pits					
MW-3003	646.96	46.94	600.02	46.92	600.04
MW-3006	647.13	53.05	594.08	53.42	593.71
MW-3019	662.03	54.56	607.47	53.98	608.05
MW-3023	648.07	45.27	602.80	45.23	602.84
MW-3024	647.90	35.45	612.45	34.47	612.43
MW-3025	648.58	37.57	611.01	37.21	611.37
MW-3026	647.07	36.68	610.39	36.25	610.82
MW-3027	647.41	33.99	613.42	33.89	613.52
Off-Site Wells					
MW-4001	622.83	18.82	604.01	19.34	603.49
MW-4002	635.20	53.85	581.35	66.36	568.84
MW-4003	671.52	56.85	614.67	56.26	615.26
MW-4004	653.19	40.22	612.97	40.09	613.10
MW-4005	657.25	46.76	610.49	46.42	610.83
MW-4006	622.95	18.73	604.22	19.10	603.85
MW-4007	624.13	26.63	597.50	27.25	596.88
MW-4008	637.47	39.38	598.09	39.33	598.14
MW-4009	625.89	30.53	595.36	30.91	594.98
MW-4010	630.70	40.06	590.64	41.18	589.52
MW-4011	628.16	36.05	592.11	37.29	590.87
MW-4012	617.38	49.88	567.50	46.12	571.26
MW-4013	608.73	48.21	560.52	48.24	560.49
MW-4014	609.30	47.75	561.55	47.85	561.45
MW-4015	619.58	37.10	582.48	37.81	581.77
MW-4016	643.91	54.36	589.55	54.04	589.87
MW-4018	649.93	51.37	598.56	51.27	598.66

TABLE B.14 (Cont.)

Well ID	Top of Casing Elevation (ft)	April 1995 Depth to Water (ft)	April 1995 Groundwater Elevation (ft)	July 1995 Depth to Water (ft)	July 1995 Groundwater Elevation (ft)
MW-4019	647.34	34.26	613.08	33.85	613.49
MW-4020	659.17	53.16	505.01	52.78	606.39
MW-4022	667.98	70.57	597.41	69.82	598.16
MW-4023	648.53	32.85	615.68	32.81	615.72
MW-4024	657.84	Not installed	NA[a]	51.06	606.48
MW-4025	648.46	Not installed	NA	42.63	605.83
Training Area					
MWS-01	597.83	14.06	583.77	16.30	581.53
MWV-01	597.84	13.15	584.69	Dry	NA
MWD-02	605.88	19.62	586.26	21.90	583.98
MWS-02	605.25	19.69	585.56	22.62	582.63
MWV-02	604357	17.35	587.22	17.56	587.01
MWS-03	635.39	39.50	595.89	39.46	595.93
MWS-04	624.09	20.49	603.60	21.28	602.81
MWD-05	600.68	19.87	580.81	20.10	580.58
MWS-05	600.60	34.98	565.62	35.71	564.89
MWD-06	621.56	17.99	603.57	17.45	604.11
MWS-06	621.32	18.11	603.21	17.54	603.78
MWS-07	641.49	42.66	598.83	41.97	599.52
MWS-08	690.15	34.24	655.91	35.08	655.07
MWV-08	690.36	24.58	665.78	24.49	665.87
MWD-09	636.08	17.19	618.89	17.12	618.96
MWS-09	635.37	15.53	619.84	16.03	619.34
MWV-09	635.79	17.51	618.28	18.20	617.59
MWS-10	654.19	22.93	631.26	23.52	630.67
MWS-11	676.35	26.79	649.56	26.45	649.90
MWS-12	657.11	20.47	636.64	20.46	636.65
MWS-13	692.39	38.93	653.46	38.72	653.67
MWV-13	692.18	38.61	653.57	38.63	653.55
MWS-14	705.07	37.10	667.97	38.76	666.31
MWD-15	655.76	29.00	626.76	28.98	626.78

TABLE B.14 (Cont.)

Well ID	Top of Casing Elevation (ft)	April 1995 Depth to Water (ft)	April 1995 Groundwater Elevation (ft)	July 1995 Depth to Water (ft)	July 1995 Groundwater Elevation (ft)
MWS-15	656.72	28.25	628.47	28.61	628.11
MWS-16	651.78	17.93	633.85	17.31	634.47
MWV-16	651.24	17.02	634.22	16.76	634.48
MWS-17	660.28	20.29	639.99	22.23	638.05
MWV-17	659.60	15.40	644.20	17.22	642.38
MWD-18	601.55	20.24	581.31	22.95	578.60
MWS-18	601.43	66.84	534.59	66.87	534.56
MWV-18	601.91	20.32	581.59	Dry	NA
MWS-19	648.66	20.46	528.20	22.96	625.70
MWS-20	668.48	35.41	633.07	34.59	633.89
MWS-21	642.28	28.12	614.16	27.91	614.37
MWS-22	664.14	15.26	648.88	15.31	648.83
MWV-22	663.82	14.87	648.95	14.81	649.01
MWD-23	710.80	Not installed	NA	57.94	652.86
MWS-23	710.32	54.48	655.84	56.40	653.92
MWS-24	657.23	22.52	634.71	22.50	634.73
MWV-24R	642.19	21.25	620.94	21.81	620.38
MWD-25	683.84	Not installed	NA	59.32	624.52
MWS-25	683.46	Not installed	NA	51.51	631.95
MWS-26	675.19	Not installed	NA	Dry	NA
Ordnance Works Area					
MWS-101	491.55	Access flooded	NA	11.28	480.27
MWS-102	481.13	17.66	463.47	15.11	466.02
MWS-103	529.67	14.25	515.42	24.65	505.02
MWS-104	566.85	9.55	557.30	10.81	556.04
MWD-105	575.48	19.98	555.50	19.83	555.65
MWS-105	575.45	19.49	555.96	20.49	554.96
MWD-106	532.03	0	532.03[b]	0	532.03
MWS-106	532.93	1.44	531.49	3.42	529.51
MWD-107	609.96	Not installed	NA	25.62	584.34
MWS-107	608.99	25.30	583.69	23.82	585.17
MWS-108	606.56	19.62	586.94	19.81	586.75

TABLE B.14 (Cont.)

Well ID	Top of Casing Elevation (ft)	April 1995 Depth to Water (ft)	April 1995 Groundwater Elevation (ft)	July 1995 Depth to Water (ft)	July 1995 Groundwater Elevation (ft)
MWD-109	552.17	7.46	544.71	7.47	544.70
MWS-109	552.31	7.14	545.17	7.84	544.47
MWS-110	607.03	59.61	547.42	59.93	547.10
MWS-111	622.90	1.42	621.48	3.12	619.78
MWD-112	571.00	19.64	551.36	17.38	553.62
MWS-112	575.45	28.35	547.10	28.62	546.83
USGS-1	591.00	46.64	544.36	46.00	545.00
USGS-2A	560.00	7.61	552.39	8.83	551.17
USGS-3	586.00	22.40	564.10	22.33	564.17
USGS-4	602.00	12.71	589.29	13.06	588.94
USGS-5	581.00	41.56	539.44	41.39	539.61
USGS-6	591.00	56.55	534.45	56.84	534.16
USGS-8	626.00	53.65	572.35	53.93	572.07
USGS-9	591.00	15.07	575.93	16.90	574.10

[a] NA = data not available.

[b] The groundwater elevation in MWD-106 is given as the top of casing elevation because groundwater flows from this well.

TABLE B.15 Summary of Maximum and Minimum Static Water-Level Fluctuations of the Shallow Aquifer — the Chemical Plant Area and the Ordnance Works Area

Well ID	Groundwater Elevation Maximum (ft)	Groundwater Elevation Minimum (ft)	Groundwater Fluctuation (ft)
Chemical Plant Area			
MW-2001	590.74	587.64	3.10
MW-2002	595.41	591.49	3.92
MW-2003	603.12	597.12	6.00
MW-2005	588.27	587.19	1.08
MW-2006	602.74	598.94	3.80
MW-2007	594.16	592.30	1.86
MW-2010	601.57	599.60	1.97
MW-2011	601.10	600.48	0.62
MW-2012	610.20	603.37	6.83
MW-2013	608.66	602.29	6.37
MW-2014	605.15	602.97	2.18
MW-2015	604.94	601.36	3.58
MW-2017	607.41	604.10	3.31
MW-2018	616.84	613.30	3.54
MW-2030	613.15	612.54	0.61
MW-2032	583.28	583.09	0.19
MW-2033	608.68	605.26	3.42
MW-2034	607.68	604.92	2.76
MW-2035	616.84	614.54	2.30
MW-2036	614.06	613.45	0.61
MW-2037	614.48	613.59	0.89
MW-2038	613.64	613.00	0.64
MW-2039	614.27	613.55	0.72
MW-2040	613.30	612.71	0.59
MW-2041	614.39	613.12	1.27
MW-2042	619.08	613.70	5.38
MW-2043	614.48	613.59	0.89
MW-2044	614.21	614.00	0.21
Raffinate Pits			
MW-3001	613.92	610.00	3.92
MW-3019	608.35	603.35	5.00

TABLE B.15 (Cont.)

Well ID	Groundwater Elevation Maximum (ft)	Groundwater Elevation Minimum (ft)	Groundwater Fluctuation (ft)
MW-3023	602.91	593.86	9.05
MW-3025	611.40	610.93	0.47
MW-3027	613.96	612.72	1.24
Off-Site Wells			
MW-4002	588.43	568.68	19.75
MW-4003	616.35	608.96	7.39
MW-4005	612.78	607.45	5.33
MW-4006	607.44	600.85	6.59
MW-4010	592.10	588.17	3.93
MW-4013	563.25	560.34	2.91
MW-4014	561.89	561.31	0.58
MW-4015	583.40	579.93	3.47
MW-4016	589.91	588.52	1.39
MW-4017	597.21	592.66	4.55
MW-4018	599.37	596.18	3.19
MW-4019	614.07	609.14	4.93
MW-4020	608.17	603.78	4.39
MW-4021	610.04	607.26	2.78
MW-4023	618.60	611.27	7.33
Training Area			
MWS-01	584.71	579.96	4.75
MWS-02	588.05	581.85	6.20
MWS-03	596.39	594.01	2.38
MWS-04	604.33	602.05	2.28
MWS-05	567.44	565.06	2.38
MWS-07	601.01	596.35	4.66
MWS-08	656.82	652.30	4.52
MWS-09	621.29	617.93	3.36
MWS-10	631.91	626.28	5.63
MWS-11	650.84	646.11	4.73
MWS-12	637.59	634.99	2.60
MWS-13	655.11	649.58	5.53

TABLE B.15 (Cont.)

Well ID	Groundwater Elevation Maximum (ft)	Groundwater Elevation Minimum (ft)	Groundwater Fluctuation (ft)
MWS-14	668.51	666.17	2.34
MWS-15	630.66	621.59	8.47
MWS-16	638.44	624.75	13.69
MWS-17	641.51	635.15	6.36
MWS-19	630.72	621.40	9.32
MWS-20	635.34	629.26	6.08
MWS-21	614.81	613.56	1.25
MWS-22	649.98	645.37	4.61
MWS-23	655.84	649.45	6.39
MWS-24	635.31	632.73	2.58
Ordnance Works Area			
MWS-104	560.14	552.52	7.62
MWS-105	560.41	552.52	7.89
MWS-107	587.06	580.98	6.08
MWS-110	555.15	545.65	9.50
MWS-111	622.90	613.24	9.66
USGS-1	547.60	542.19	5.41
USGS-2A	556.24	547.54	8.70
USGS-3	564.65	563.06	1.59
USGS-4	591.40	573.95	17.45
USGS-5	540.93	534.38	6.55
USGS-6	536.30	532.60	3.70
USGS-7	545.20	544.35	0.85
USGS-8	572.77	570.85	1.92
USGS-9	577.45	572.08	5.37

Sources: Field sheets and IT Corporation (1995).

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APPENDIX C:

RESULTS OF THE 1995 JOINT GROUNDWATER SAMPLING FOR WELLS AND SPRINGS

APPENDIX C:

RESULTS OF THE 1995 JOINT GROUNDWATER SAMPLING FOR WELLS AND SPRINGS

Appendix C presents the data from the May and August 1995 joint sampling of groundwater and springs. All nondetected values are expressed as less than (<) the analytical detection limit. The values shown in parentheses are categorized as "uncensored" data, that is, data that are below the detection limit but reported as a measured value. "NA" indicates that sampling was not scheduled, whereas "NS" indicates that the location was not sampled as scheduled because of sampling problems such as low-flow or dry conditions.

TABLE C.1 Nitroaromatic Results from Joint Sampling, May 1995

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MW-2001	0.054	<0.09	<0.03	0.12	0.056	13	24	<0.03	<0.03	<0.03	<0.04
MW-2002	<0.03	<0.09	<0.03	0.055	0.36	0.64	0.80	<0.03	<0.03	<0.03	<0.04
MW-2003	<0.03	<0.09	<0.03	0.15	0.45	0.18	0.46	0.18	<0.03	<0.03	<0.04
MW-2005	0.035	<0.09	<0.03	0.057	0.090	0.12	0.12	<0.03	<0.03	<0.03	<0.04
MW-2006	6.1	<0.09	<0.03	0.14	1.3	1.9	1.6	<0.03	<0.03	<0.03	<0.04
MW-2007	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	0.083	<0.03	<0.03	<0.04
MW-2010	0.14	<0.09	0.28	0.094	0.50	0.82	0.82	0.20	<0.03	<0.03	<0.04
MW-2011	0.27	<0.09	<0.03	0.20	1.6	1.5	0.81	<0.06	<0.03	<0.03	<0.04
MW-2012	1.4	<0.09	0.46	0.079	0.44	0.31	0.37	0.16	<0.03	<0.03	<0.04
MW-2013	4.8	<0.09	0.52	0.30	3.5	1.4	1.5	0.22	0.049	<0.03	<0.04
MW-2014	3.0	(0.86)	0.039	0.16	0.56	0.55	0.78	<0.03	<0.03	<0.03	<0.04
MW-2015	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2017	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2018	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2019	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2021	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2022	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2023	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2024	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.016	<0.03	<0.03	<0.04
MW-2026	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2027	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2028	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.45	<0.03	<0.03	<0.04
MW-2030	8.3	<0.18	29	0.25	11	3.9	4.3	0.24	0.039	<0.03	<0.04
MW-2032	4.9	<0.03	6.7	<1.5	2.9	2.6	2.0	0.47	0.080	<0.03	<0.04
MW-2033	3.8	<0.09	1.2	0.44	3.7	2.7	2.7	<0.03	0.032	0.071	<0.04
MW-2034	<0.03	<0.03	<0.03	<1.5	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2035	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2036	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.17	<0.03	<0.03	<0.04
MW-2037	0.19	<0.09	<0.03	0.56	0.13	0.11	0.10	<0.24	<0.06	<0.03	<0.04
MW-2038	0.24	<0.09	<0.03	1.7	0.32	0.40	0.46	<0.03	<0.06	<0.06	0.062

TABLE C.1 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MW-2039	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2040	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2041	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2042	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2043	<0.03	<0.09	<0.03	0.073	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-2044	<0.03	<0.09	<0.03	<0.03	<0.01	0.022	0.033	0.50	<0.03	<0.03	<0.04
MW-3003	<0.03	<0.03	<0.03	(0.048)	0.085	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MW-3006	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-3019	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	54	<0.03	<0.03	<0.04
MW-3023	<0.03	<0.09	<0.06	5.0	5.0	0.17	0.32	0.29	4.3	0.70	<0.04
MW-3024	<0.03	<0.09	<0.03	0.12	0.44	0.032	0.057	0.18	0.041	<0.03	<0.04
MW-3025	<0.03	<0.09	<0.03	0.063	0.22	<0.02	0.020	<0.03	<0.03	<0.03	<0.04
MW-3026	0.068	<0.09	<0.03	0.072	0.040	0.30	0.37	<0.03	<0.03	<0.03	<0.04
MW-3027	0.074	<0.09	<0.03	0.058	0.040	0.19	0.18	0.83	<0.03	<0.03	<0.04
MW-4001	35	<0.09	1.8	0.42	3.1	16	22	<0.03	<0.06	<0.03	<0.04
MW-4002	0.062	<0.09	1.8	0.14	0.29	1.4	2.3	<0.03	<0.03	<0.03	<0.04
MW-4003	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.03	<0.03	<0.03	<0.03	<0.04
MW-4004	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4005	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	0.69	<0.03	<0.03	<0.04
MW-4006	19	<0.09	<0.03	0.16	3.1	1.8	2.5	<0.03	0.032	<0.03	<0.04
MW-4007	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.03
MW-4008	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4009	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4010	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4012	<0.03	<0.09	<0.03	<0.03	0.062	0.77	1.8	<0.03	<0.03	<0.03	<0.04
MW-4013	27	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4014	0.11	<0.09	0.039	0.059	0.66	1.7	1.3	<0.03	<0.03	<0.03	<0.04
MW-4015	1.8	<0.09	<0.03	(0.026)	0.087	0.28	0.52	0.11	<0.03	<0.03	<0.04
MW-4016	<0.03	<0.09	<0.03	0.14	1.1	3.0	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4018	<0.03	<0.09	<0.03	<0.03	<0.01	<0.03	<0.02	<0.03	<0.03	<0.03	<0.04

TABLE C.1 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MW-4019	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4020	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MW-4021	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4022	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MW-4023	0.088	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MW-4024[a]	<0.03	<0.09	<0.03	0.065	0.023	0.038	0.050	<0.03	<0.03	<0.03	<0.04
MW-4025	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MWD-2	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-5	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-6	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-9	0.065	<0.09	<0.03	0.042	0.16	0.095	0.50	<0.15	<0.03	<0.03	<0.04
MWD-15	<0.03	<0.1	<0.03	<0.03	0.64	0.71	1.7	<0.03	<0.03	<0.03	<0.04
MWD-18	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-23	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-25	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-105	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-106	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MWD-107	0.047	<0.09	<0.03	(0.020)	0.090	0.040	0.51	<0.08	<0.03	<0.03	<0.04
MWD-109	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWD-112	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-1	<0.03	<0.09	<0.03	<0.03	0.64	<0.02	0.044	<0.03	<0.03	<0.03	<0.04
MWS-2	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-3	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	0.21	<0.03	<0.03	<0.04
MWS-4	9.2	<0.09	0.88	0.082	1.2	7.6	8.3	<0.03	<0.03	<0.03	<0.04
MWS-5	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-6	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.07	<0.03	<0.03	<0.04
MWS-7	18	<0.09	2.6	0.048	1.2	5.6	11	<0.03	<0.03	<0.03	<0.04
MWS-8	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-9	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	0.10	<0.03	<0.03	<0.04
MWS-10	0.30	<0.09	<0.03	0.069	1.9	5.1	15	<0.06	<0.03	<0.03	<0.04

TABLE C.1 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MWS-11	0.037	<0.09	0.037	0.035	0.46	0.39	1.8	35	<0.03	<0.03	<0.04
MWS-12	1.9	0.17	0.18	4.2	7.3	0.92	2.1	<0.03	2.4	8.8	<0.04
MWS-13	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-14	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.09	<0.03	<0.03	<0.04
MWS-15	1.8	<0.09	5.9	0.076	1.0	11	19	0.16	<0.03	<0.03	<0.04
MWS-16	6.9	<0.09	2.4	0.092	1.2	4.7	8.4	8.8	<0.03	<0.03	<0.04
MWS-17	0.070	<0.09	0.15	0.61	13	3.3	4.4	<0.03	0.29	0.58	<0.04
MWS-18	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-19	0.051	<0.09	<0.03	0.080	0.14	0.20	0.30	<0.03	<0.03	<0.03	<0.04
MWS-20	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	0.057	0.15	<0.03	<0.03	<0.04
MWS-21	<0.03	<0.09	<0.09	0.85	0.16	0.20	0.51	<0.06	<0.03	<0.03	<0.04
MWS-22	<0.03	<0.09	<0.03	(0.025)	0.13	0.061	0.16	<0.03	<0.03	<0.03	<0.04
MWS-23	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-25	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MWS-26	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-101	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.06	<0.03	<0.03	<0.04
MWS-102	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-103	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-104	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-105	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-106	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-107	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-108	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-109	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-110	0.19	<0.09	<0.03	<0.03	0.053	0.18	0.36	<0.03	<0.03	<0.03	<0.04
MWS-111	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWS-112	<0.03	<0.09	<0.03	0.056	0.018	0.056	0.14	<0.06	<0.03	<0.03	<0.04
TIL3	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
USG1	0.044	0.12	<0.03	0.051	0.021	0.057	0.20	<0.03	<0.03	<0.03	<0.04
USG2	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04

TABLE C.1 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
USG3	0.058	<0.09	<0.03	<0.03	0.19	0.023	0.25	1.0	<0.03	<0.03	<0.04
USG4	1.3	<0.09	<0.03	1.5	2.1	1.5	1.8	<0.06	0.11	<0.03	<0.04
USG5	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.12	<0.03	<0.03	<0.04
USG6	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
USG8	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	0.16	<0.03	<0.03	<0.04
USG9	<0.03	<0.09	<0.03	0.091	0.015	2.6	3.7	<0.03	<0.03	<0.03	<0.04
MWV-1	0.038	<0.09	11	0.11	1.0	3.8	6.8	<0.03	<0.03	<0.03	<0.04
MWV-2	<0.03	<0.09	0.11	0.059	0.048	0.50	1.0	<0.03	<0.03	<0.03	<0.04
MWV-9	13	0.32	28	15	2.9	35	26	<0.03	0.098	0.16	<0.04
MWV-13	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.02	<0.03	<0.03	<0.03	<0.04
MWV-16	0.29	<0.09	0.25	<0.03	0.043	0.32	0.41	0.14	<0.03	<0.03	<0.04
MWV-17	<0.03	<0.09	<0.03	<0.03	<0.01	<0.02	<0.03	<0.03	<0.03	<0.03	<0.04
MWV-22	<0.03	<0.09	<0.03	<0.03	0.13	0.050	0.18	<0.03	<0.03	<0.03	<0.04
MWV-24	2.0	<0.09	0.67	0.062	1.2	0.47	1.0	0.14	<0.03	<0.03	<0.04

[a] Sample taken in July 1995.

[b]

TABLE C.2 Anion and Radiological Results from Groundwater Locations Sampled in May 1995[a]

Well No.	Nitrate (mg/L)	Uranium (pCi/L)
MW-2001	43	1.8
MW-2002	100	1.4
MW-2003	280	1.8
MW-2005	66	0.73
MW-2006	4.7	(0.48)
MW-2007	2.9	1.0
MW-2010	1.4	1.2
MW-2011	4.5	0.30
MW-2012	0.53	0.96
MW-2013	0.99	3.9
MW-2014	1.8	0.94
MW-2015	<0.1	1.9
MW-2017	0.81	15
MW-2018	0.61	1.5
MW-2019	<0.1	3.0
MW-2021	<0.1	0.86
MW-2022	<0.1	1.2
MW-2023	<0.1	2.8
MW-2024	<0.1	(0.11)
MW-2026	<0.1	0.81
MW-2027	<0.1	0.99
MW-2028	<0.1	1.3
MW-2030	1.3	11
MW-2032	56	4.5
MW-2033	1.1	0.84
MW-2034	4.8	2.7
MW-2035	0.42	0.39
MW-2036	2.9	0.72
MW-2037	34	1.2
MW-2038	900	1.4
MW-2039	52	3.1
MW-2040	230	3.0
MW-2041	300	3.3
MW-2042	5.6	2.6
MW-2043	5.8	1.8
MW-2044	1.2	2.3

TABLE C.2 (Cont.)

Well No.	Nitrate (mg/L)	Uranium (pCi/L)
MW-3003	300	16.0
MW-3006	<0.1	0.29
MW-3019	1.2	2.1
MW-3023	210	6.8
MW-3024	370	3.0
MW-3025	250	2.8
MW-3026	220	4.2
MW-3027	62	1.3
MW-4001	24	0.41
MW-4002	5.2	0.60
MW-4003	0.65	1.1
MW-4004	1.1	2.1
MW-4005	1.6	1.6
MW-4006	14	0.21
MW-4007	<0.1	1.78
MW-4008	<0.1	0.82
MW-4009	0.14	1.7
MW-4010	<0.1	3.1
MW-4011	160	3.0
MW-4012	<0.1	2.7
MW-4013	75	1.2
MW-4014	5.8	0.22
MW-4015	4.0	0.32
MW-4016	<0.1	3.2
MW-4018	2.7	0.64
MW-4019	0.26	1.4
MW-4020	<0.1	9.7
MW-4021	<0.1	3.1
MW-4022	0.39	4.5
MW-4023	2.6	1.6
MW-4024[b]	0.46	60.0
MW-4025	1.1	1.0
MWD-2	<0.1	2.5
MWD-5	0.13	0.57
MWD-6	<0.1	0.58
MWD-9	0.80	0.93
MWD-15	4.0	0.49
MWD-18	<0.1	0.78

TABLE C.2 (Cont.)

Well No.	Nitrate (mg/L)	Uranium (pCi/L)
MWD-23	<0.1	5.0
MWD-25	0.38	1.6
MWD-105	<0.1	0.32
MWD-106	<0.1	<0.16
MWD-107	<0.1	1.9
MWD-109	<0.1	0.56
MWD-112	<0.1	0.77
MWS-1	2.2	1.3
MWS-2	0.10	2.0
MWS-3	<0.1	3.3
MWS-4	8.9	0.64
MWS-5	<0.1	0.99
MWS-6	<0.1	2.0
MWS-7	2.2	0.72
MWS-8	1.5	1.1
MWS-9	<0.1	1.2
MWS-10	8.6	<0.17
MWS-11	7.9	1.7
MWS-12	2.9	(0.700)
MWS-13	1.2	0.54
MWS-14	0.18	2.7
MWS-15	0.90	0.56
MWS-16	7.7	0.65
MWS-17	1.6	0.80
MWS-18	0.30	1.5
MWS-19	0.13	1.3
MWS-20	5.5	0.56
MWS-21	520	3.0
MWS-22	3.0	1.2
MWS-23	0.20	0.94
MWS-25	0.15	0.92
MWS-26	0.52	3.9
MWS-101	<0.1	0.53
MWS-102	<0.1	2.6
MWS-103	<0.1	0.76
MWS-104	<0.1	1.3
MWS-105	<0.1	(0.16)
MWS-106	<0.1	1.2

TABLE C.2 (Cont.)

Well No.	Nitrate (mg/L)	Uranium (pCi/L)
MWS-107	1.0	1.7
MWS-108	<0.1	<0.14
MWS-109	<0.1	1.01
MWS-110	0.80	0.49
MWS-111	0.24	0.41
MWS-112	0.13	2.7
TIL3	<0.1	(0.07)
USGS1	0.77	1.05
USGS2	<0.1	(0.001)
USGS3	0.88	1.4
USGS4	1.3	0.24
USGS5	<0.1	4.9
USGS6	0.55	1.7
USGS8	3.2	0.62
USGS9	3.2	0.34
MWV-1	0.68	0.92
MWV-2	0.33	3.04
MWV-9	<0.1	0.72
MWV-13	1.5	1.4
MWV-16	1.1	0.59
MWV-17	0.18	<0.20
MWV-22	3.3	0.88
MWV-24	0.21	0.60

[a] Chloride, fluoride, and sulfate were not scheduled for sampling in May 1995.

[b] Sample taken in July 1995.

TABLE C.3 Metals Data (filtered and unfiltered) from May 1995 Joint Sampling

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-2001	<14.0	<1.0	<2.0	282	<1.0	4.4	<2.0	40.0	4.0	2.6
MW-2001-F[a]	<14.0	<1.0	<2.0	279	<1.0	4.5	<2.0	<15.0	1.9	2.5
MW-2002	90.2	1.7	<2.0	113	<1.0	5.9	<2.0	114	3.0	269
MW-2002-F	<14.0	1.4	<2.0	111	<1.0	3.5	<2.0	28	<1.0	251
MW-2003	1,040	<1.0	<2.0	303	<1.0	5.7	<2.0	862	4.7	428
MW-2003-F	<14.0	2.0	<2.0	266	<1.0	4.3	<2.0	68	<1.0	497
MW-2005	19	<1.0	<2.0	165	<1.0	1.6	3.0	65	6.1	81
MW-2005-F	<14.0	1.7	<2.0	166	<1.0	3.3	<2.0	55.0	2.5	83
MW-2006	22	<1.0	<2.0	338	<1.0	10.8	<2.0	143	7.3	8.8
MW-2006-F	<14.0	<1.0	<2.0	322	<1.0	<1.0	<2.0	115	<1.0	9.1
MW-2007	<14.0	<1.0	<2.0	148	<1.0	3.1	2.2	<15.0	11.7	3.4
MW-2007-F	<14.0	<1.0	<2.0	147	<1.0	2.4	2.5	<15.0	<1.0	3.5
MW-2010	22	<1.0	<2.0	242	<1.0	37.0	<2.0	188	2.5	17.0
MW-2010-F	24	2.0	<2.0	236	<1.0	23	<2.0	126	<1.0	13
MW-2011	35	<1.0	<2.0	137	<1.0	4.3	2.6	39	1.0	6.4
MW-2011-F	37	<1.0	<2.0	137	<1.0	1.7	<2.0	<15.0	<1.0	5.8
MW-2012	<14.0	<1.0	<2.0	113	<1.0	1.4	<2.0	54	<1.0	<2.0
MW-2012-F	16	<1.0	<2.0	113	<1.0	1.0	<2.0	43	<1.0	<2.0
MW-2013	<14.0	<1.0	<2.0	111	<1.0	2.3	<2.0	21	1.0	4.5
MW-2013-F	<14.0	<1.0	<2.0	107	<1.0	2.1	3.0	<15.0	<1.0	4.2
MW-2014	170	<1.0	<2.0	257	<1.0	3.8	8.4	726	2.9	4.6
MW-2014-F	<14.0	2.2	<2.0	248	<1.0	1.5	<2.0	32	<1.0	7.6
MW-2015	<14.0	<1.0	<2.0	68	<1.0	7.5	2.2	29	1.7	15
MW-2015-F	<14.0	<1.0	<2.0	68	<1.0	9.8	<2.0	35	1.4	15
MW-2017	40.9	<1.0	<2.0	320	<1.0	5.6	10.8	812	2.6	108
MW-2017-F	<14.0	2.7	<2.0	36	<1.0	8.9	3.3	59	<1.0	69

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-2018	<14.0	<1.0	<2.0	404	<1.0	<1.0	3.4	<15.0	1.7	17
MW-2018-F	<14.0	<1.0	<2.0	415	<1.0	<1.0	<2.0	<30.0	<1.0	16
MW-2019	<14.0	<1.0	<2.0	142	<1.0	2.3	2.7	<15.0	<1.0	18
MW-2019-F	<14.0	<1.0	<2.0	140	<1.0	1.9	2.3	<30.0	<1.0	19
MW-2021	452	<1.0	<2.0	225	<1.0	21	<2.0	255	<1.0	3.8
MW-2021-F	14	<1.0	<2.0	218	<1.0	18	<2.0	49	<1.0	3.3
MW-2022	883	<1.0	<2.0	181	<1.0	<1.0	<2.0	<15.0	1.0	3.4
MW-2022-F	<14.0	2.1	<2.0	178	<1.0	1.7	<2.0	18	<1.0	3.6
MW-2023	100	1.1	<2.0	97	<1.0	5.7	6.5	204	16	3.2
MW-2023-F	49	<1.0	<2.0	93	<1.0	2.9	2.1	34	1.1	3.3
MW-2024	23	<1.0	<2.0	83.0	<1.0	3.8	2.4	157	5.1	3.9
MW-2024-F	22	<1.0	<2.0	82	<1.0	3.9	2.1	40	<1.0	3.8
MW-2026	232	<1.0	<2.0	225	<1.0	5.8	2.2	119	2.0	2.9
MW-2026-F	23	<1.0	<2.0	216	<1.0	2.4	<2.0	<15.0	<1.0	2.8
MW-2027	<14.0	<1.0	<2.0	271	<1.0	2.0	<2.0	216	<1.0	4.1
MW-2027-F	21	<1.0	<2.0	269	<1.0	2.8	<2.0	23	<1.0	4.2
MW-2028	123	<1.0	<2.0	110	<1.0	24	3.3	320	3.3	19
MW-2028-F	<14.0	1.5	<2.0	107	<1.0	11.0	<2.0	57	<1.0	17
MW-2030	8840	<1.0	<2.0	285	<1.0	12.0	85	10400	13	6.4
MW-2030-F	26	<1.0	<2.0	132	<1.0	3.8	4.8	42	<1.0	2.4
MW-2032	425	<1.0	<2.0	322	<1.0	5.6	11	850	2.5	14
MW-2032-F	27	6.8	<2.0	298	<1.0	4.6	5.0	136	<1.0	13
MW-2033	1270	<1.0	<2.0	126	<1.0	7.5	16	2770	12	3.5
MW-2033-F	<14.0	<1.0	<2.0	107	<1.0	2.6	4.2	54	<1.0	3.0
MW-2034	201	<1.0	<2.0	27	<1.0	6.3	16	573	12	30.0
MW-2034-F	18	2.6	<2.0	19	<1.0	5.2	5.8	71	<1.0	28

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-2035	15	<1.0	<2.0	89.0	<1.0	3.8	3.0	90	<1.0	<2.0
MW-2035-F	19	<1.0	<2.0	89.4	<1.0	3.7	2.8	<15.0	<1.0	2.1
MW-2036	143	<1.0	<2.0	274	<1.0	2.4	<2.0	<15.0	<1.0	6.7
MW-2036-F	<14.0	<1.0	<2.0	280	<1.0	1.7	<2.0	<15.0	<1.0	7.0
MW-2037	<14.0	<1.0	<2.0	82	<1.0	<1.0	<2.0	<15.0	<1.0	411
MW-2037-F	<14.0	1.2	<2.0	83	<1.0	1.4	<2.0	<15.0	<1.0	415
MW-2038	100	<1.0	<2.0	193	<1.0	2.5	<2.0	135	<1.0	516
MW-2038-F	14	<1.0	<2.0	200	<1.0	2.6	<2.0	59	<1.0	523
MW-2039	386	<1.0	<2.0	221	<1.0	11	4.1	588	1.5	22
MW-2039-F	<14.0	1.8	<2.0	203	<1.0	5.8	<2.0	36	<1.0	21
MW-2040	1,100	<1.0	<2.0	784	<1.0	12	4.9	1,410	1.1	33.0
MW-2040-F	<14.0	<1.0	<2.0	766	<1.0	5.3	3.3	47	<1.0	32
MW-2041	15	<1.0	<2.0	206	<1.0	1.4	3.1	71	<1.0	25
MW-2041-F	<14.0	1.7	<2.0	200	<1.0	1.3	<2.0	24	<1.0	26
MW-2042	42	<1.0	<2.0	498	<1.0	3.8	2.3	139	<1.0	20
MW-2042-F	<14.0	<1.0	<2.0	504	<1.0	3.4	<2.0	43	<1.0	21
MW-2043	52	<1.0	<2.0	291	<1.0	3.8	4.4	141	<1.0	17.0
MW-2043-F	<14.0	2.1	<2.0	293	<1.0	3.5	3.9	20	<1.0	17
MW-2044	65	<1.0	<2.0	48	<1.0	2.5	2.2	55	1.1	29
MW-2044-F	28	3.8	<2.0	47	<1.0	2.8	2.1	18	<1.0	29
MW-3003	36.0	<1.0	<2.0	164	<1.0	4.6	3.6	136	2.8	498
MW-3003-F	21.0	<1.0	<2.0	164	<1.0	3.8	3.2	78	1.3	500
MW-3006	25	<1.0	<2.0	157	<1.0	3.6	<2.0	329	<1.0	12
MW-3006-F	25	<1.0	3.0	158	<1.0	3.8	<2.0	336	<1.0	13
MW-3019	19	<1.0	<2.0	342	<1.0	7.5	<2.0	42	2.6	15
MW-3019-F	19	<1.0	<2.0	346	<1.0	5.0	<2.0	19	<1.0	11

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-3023	4,090	<1.0	2.8	69	<1.0	16.0	25	6,800	16	601
MW-3023-F	17.0	<1.0	<2.0	42	<1.0	3.7	7.5	79	<1.0	611
MW-3024	<14.0	<1.0	<2.0	170	<1.0	1.7	3.3	33	<1.0	202
MW-3024-F	<14.0	1.5	<2.0	165	<1.0	2.1	3.2	<15.0	<1.0	213
MW-3025	148	<1.0	<2.0	654	<1.0	2.4	3.5	1,070	1.2	109
MW-3025-F	<14.0	<1.0	<2.0	610	<1.0	2.7	3.0	30	<1.0	135
MW-3026	2,520	<1.0	<2.0	1,660	<1.0	2.1	9.4	1,230	8.2	34
MW-3026-F	<14.0	1.6	<2.0	1,360	<1.0	1.6	<2.0	105	<1.0	34
MW-3027	825	<1.0	<2.0	900	<1.0	2.9	7.6	1,120	2.3	18.0
MW-3027-F	<14.0	<1.0	<2.0	832	<1.0	1.4	<2.0	69.0	<1.0	17
MW-4001	28	<1.0	<2.0	83	<1.0	1.9	<2.0	70	1.6	7.7
MW-4001-F	<14.0	<1.0	<2.0	80	<1.0	1.8	<2.0	<15.0	<1.0	6.7
MW-4002	128	<1.0	<2.0	109	<1.0	1.6	3.4	643	3.2	2.4
MW-4002-F	32.0	<1.0	<2.0	92	<1.0	1.6	2.1	26	<1.0	<2.0
MW-4003	<14.0	<1.0	<2.0	162	<1.0	2.3	3.3	42	<1.0	3.0
MW-4003-F	<14.0	1.9	<2.0	163	<1.0	1.7	<2.0	<15.0	<1.0	3.1
MW-4004	118	<1.0	<2.0	86	<1.0	3.6	<2.0	632	2.3	4.0
MW-4004-F	<14.0	<1.0	<2.0	81	<1.0	3.6	<2.0	<15.0	<1.0	4.2
MW-4005	<14.0	1.0	<2.0	93	<1.0	13	2.4	123	31	6.7
MW-4005-F	<14.0	2.4	<2.0	92	<1.0	12.0	<2.0	24	15	6.8
MW-4006	135	<1.0	<2.0	180	<1.0	1.5	<2.0	102	1.8	<2.0
MW-4006-F	<14.0	1.3	2.5	173	<1.0	1.6	<2.0	<15.0	<1.0	<2.0
MW-4007	163	<1.0	2.2	76	<1.0	9.8	3.0	125	4.8	6.0
MW-4007-F	<14.0	2.1	<2.0	75.0	<1.0	9.5	<2.0	<15.0	<1.0	5.9
MW-4008	25	<1.0	<2.0	109	<1.0	5.7	<2.0	95	15	2.6
MW-4008-F	<14.0	<1.0	<2.0	106	<1.0	3.7	<2.0	<15.0	<1.0	2.3

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-4009	19	2.1	<2.0	31	<1.0	27	<2.0	18	4.3	90
MW-4009-F	36	2.9	<2.0	31	<1.0	25	<2.0	<15.0	<1.0	87.0
MW-4010	18	1.3	<2.0	83.0	<1.0	2.7	6.6	75	35	4.9
MW-4010-F	<14.0	1.2	<2.0	78	<1.0	4.7	39.0	<15.0	14	4.7
MW-4011	20	<1.0	<2.0	334	<1.0	13	2.1	<15.0	5.8	65.0
MW-4011-F	28	5.0	<2.0	318	<1.0	16	2.3	<15.0	1.4	66
MW-4012	46	<1.0	3.7	20	<1.0	99	2.6	199	3.3	84
MW-4012-F	<14.0	2.5	5.4	18.0	<1.0	94	<2.0	21	<1.0	81
MW-4013	<14.0	<1.0	6.3	152	<1.0	3.5	<2.0	63	<1.0	68.0
MW-4013-F	16	1.6	5.4	158	<1.0	3.8	<2.0	80	<1.0	72
MW-4014	50.0	2.1	4.1	122	<1.0	4.8	<2.0	437	1.5	2.8
MW-4014-F	<14.0	1.3	5.4	125	<1.0	4.9	<2.0	72	<1.0	2.9
MW-4015	40.0	<1.0	<2.0	235	<1.0	2.7	<2.0	325	<1.0	<2.0
MW-4015-F	20	1.3	<2.0	218	<1.0	1.5	<2.0	64	<1.0	<2.0
MW-4016	15	<1.0	<2.0	246	<1.0	3.8	<2.0	154	1.3	3.7
MW-4016-F	<14.0	<1.0	<2.0	244	<1.0	4.2	<2.0	68	<1.0	3.7
MW-4018	<14.0	<1.0	3.6	214	<1.0	5.2	<2.0	35	10	4.1
MW-4018-F	<14.0	1.4	3.7	216	<1.0	4.4	<2.0	32	<1.0	3.3
MW-4019	322	<1.0	<2.0	189	<1.0	6.1	5.4	411	46	10.0
MW-4019-F	231	<1.0	5.3	178	<1.0	7.1	3.7	452	23	9.8
MW-4020	<14.0	<1.0	3.8	72	<1.0	13	<2.0	89	3.6	22
MW-4020-F	<14.0	<1.0	4.0	71.0	<1.0	13	<2.0	93	1.4	21
MW-4021	<14.0	<1.0	<2.0	35	<1.0	5.8	<2.0	70	3.4	23
MW-4021-F	20	2.9	<2.0	36.0	<1.0	4.5	<2.0	53	1.7	20
MW-4022	33,200	<1.0	18	635	1.9	180	67	56,800	206	28
MW-4022-F	29	1.2	4.1	85	<1.0	9.2	<2.0	71	<1.0	7.0

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-4023	<14.0	<1.0	<2.0	90	<1.0	3.0	2.4	79	1.1	14
MW-4023-F	<14.0	1.4	<2.0	92	<1.0	2.0	<2.0	29	<1.0	15
MW-4024[b]	26,800.0	<25.0	<4.0	143.0	<3.0	122.0	33.7	14,800.0	7.0	81.8
MW-4024-F[b]	40.4	<25.0	<4.0	21.2	<3.0	7.6	<2.0	7.6	<5.0	24.8
MW-4025	2,370	2.3	6.1	183	<1.0	35	15	4,480	6.9	12
MW-4025-F	<14.0	<1.0	4.7	127	<1.0	3.9	3.4	33	<1.0	9.2
MWD-2	62,400	1.4	12	674	<1.0	25	28.0	33,200	82	30
MWD-2-F	569	3.4	3.1	108	<1.0	3.1	<2.0	272	<1.0	4.7
MWD-5	234	<1.0	<2.0	103	<1.0	3.5	2.0	194	<1.0	20
MWD-5-F	<14.0	2.6	<2.0	100	<1.0	3.4	<2.0	<15.0	<1.0	20
MWD-6	<14.0	<1.0	<2.0	175	<1.0	1.7	<2.0	<15.0	<1.0	3.5
MWD-6-F	<14.0	<1.0	<2.0	181	<1.0	2.4	<2.0	<15.0	<1.0	3.6
MWD-9	20	<1.0	<2.0	145	<1.0	1.1	<2.0	<15.0	<1.0	5.4
MWD-9-F	<14.0	<1.0	<2.0	142	<1.0	2.0	<2.0	25	<1.0	5.5
MWD-15	496	<1.0	<2.0	118	<1.0	1.7	<2.0	171	<1.0	<2.0
MWD-15-F	<14.0	<1.0	<2.0	118	<1.0	2.2	<2.0	20	<1.0	<2.0
MWD-18	46	<1.0	<2.0	129	<1.0	1.7	<2.0	179	<1.0	6.7
MWD-18-F	<14.0	<1.0	<2.0	131	<1.0	1.7	<2.0	<15.0	<1.0	7.3
MWD-23	903	<1.0	3.3	167	<1.0	4.3	7.4	612	2.1	4.3
MWD-23-F	74	2.1	<2.0	155	<1.0	2.0	2.4	90	<1.0	3.8
MWD-25	21	<1.0	2.9	121	<1.0	4.4	<2.0	181	<1.0	2.4
MWD-25-F	27	<1.0	2.2	122	<1.0	3.6	<2.0	104	<1.0	2.3
MWD-105	23	<1.0	<2.0	107	<1.0	2.4	<2.0	<15.0	<1.0	3.7
MWD-105-F	<14.0	<1.0	<2.0	110	<1.0	1.8	<2.0	<15.0	<1.0	3.8
MWD-106	<14.0	<1.0	<2.0	133	<1.0	2.1	2.3	157	<1.0	3.6
MWD-106-F	<14.0	<1.0	<2.0	134	<1.0	2.1	<2.0	77	<1.0	3.6
MWD-107	963	<1.0	7.3	174	<1.0	2.5	9.2	494	2.5	5.4
MWD-107-F	36	<1.0	4.4	153	<1.0	2.8	<2.0	33	<1.0	5.0

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-D109	<14.0	<1.0	<2.0	150	<1.0	1.3	<2.0	22	<1.0	3.9
MWD-109-F	<14.0	<1.0	<2.0	146	<1.0	<1.0	<2.0	<15.0	<1.0	3.3
MWD-112	<14.0	<1.0	4.9	86	<1.0	5.7	<2.0	245	<1.0	2.7
MWD-112-F	14.0	<1.0	5.6	85	<1.0	5.8	<2.0	270	<1.0	2.7
MWS-1	<14.0	<1.0	<2.0	98	<1.0	2.9	<2.0	41	<1.0	<2.0
MWS-1-F	<14.0	<1.0	<2.0	98	<1.0	2.2	<2.0	<15.0	<1.0	<2.0
MWS-2	<14.0	<1.0	<2.0	101	<1.0	6.1	<2.0	22	<1.0	3.6
MWS-2-F	<14.0	<1.0	<2.0	99	<1.0	4.4	<2.0	<15.0	<1.0	3.8
MWS-3	58	<1.0	<2.0	90	<1.0	9.4	2.4	43	<1.0	5.1
MWS-3-F	<14.0	<1.0	<2.0	93	<1.0	9.3	<2.0	<15.0	<1.0	4.8
MWS-4	557	<1.0	<2.0	166	<1.0	2.0	7.2	521	2.1	4.0
MWS-4-F	69	<1.0	<2.0	158	<1.0	1.7	<2.0	48	<1.0	3.6
MWS-5	62	<1.0	<2.0	107	<1.0	3.2	<2.0	74	<1.0	3.0
MWS-5-F	<14.0	<1.0	<2.0	107	<1.0	5.3	2.3	182	<1.0	2.9
MWS-6	<14.0	<1.0	<2.0	160	<1.0	1.7	<2.0	18	<1.0	3.5
MWS-6-F	<14.0	<1.0	<2.0	161	<1.0	1.6	<2.0	<15.0	<1.0	3.6
MWS-7	<14.0	<1.0	<2.0	138	<1.0	1.2	<2.0	16	<1.0	<2.0
MWS-7-F	<14.0	<1.0	<2.0	136	<1.0	1.2	<2.0	<15.0	<1.0	<2.0
MWS-8	550	<1.0	<2.0	229	<1.0	7.6	9.8	792	3.0	22.6
MWS-8-F	<14.0	1.8	<2.0	221	<1.0	3.4	<2.0	26	<1.0	22.0
MWS-9	<14.0	<1.0	<2.0	134	<1.0	2.5	<2.0	<15.0	<1.0	6.5
MWS-9-F	<14.0	<1.0	<2.0	136	<1.0	2.5	<2.0	25	<1.0	6.7
MWS-10	<14.0	<1.0	<2.0	215	<1.0	2.7	<2.0	25.0	<1.0	4.5
MWS-10-F	<14.0	<1.0	<2.0	214	<1.0	3.2	<2.0	<15.0	<1.0	4.4
MWS-11	89	(0.55)	<2.0	122	(0.12)	<1.8	(1.20)	<80	(0.04)	2.4
MWS-11-F	<14.0	2.0	<2.0	125	(0.09)	<1.4	(1.02)	(8.3)	<1.0	2.2

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MWS-12	601	<1.0	<2.0	77	<1.0	3.9	<2.0	33	<1.0	3.1
MWS-12-F	<14.0	<1.0	<2.0	73	<1.0	2.9	<2.0	25	<1.0	2.5
MW-13	(5.00)	(0.49)	<2.0	26	(0.54)	<1.6	3.4	<47	<1.0	6.8
MWS-13-F	(5.1)	2.6	<2.0	25	(0.53)	<1.8	3.4	<33	<1.0	6.7
MWS-14	179	<1.0	<2.0	604	<1.0	3.9	7.2	798	2.4	25
MWS-14-F	<14.0	1.4	2.4	573	<1.0	1.9	2.1	37	<1.0	24.0
MWS-15	<14.0	<1.0	<2.0	80	<1.0	1.1	<2.0	30.0	<1.0	<2.0
MWS-15-F	<14.0	1.1	<2.0	79	<1.0	2.1	<2.0	38	<1.0	<2.0
MWS-16	<14.0	<1.0	<2.0	139	<1.0	<1.0	<2.0	21	<1.0	<2.0
MWS-16-F	<14.0	<1.0	<2.0	134	<1.0	1.2	<2.0	17	<1.0	<2.0
MWS-17	81.0	(0.23)	<2.0	79	<1.0	<2.0	(1.3)	127	(0.03)	(2.0)
MWS-17-F	<14.0	(0.43)	(2.0)	78	(0.11)	<1.5	(1.2)	27	(0.09)	2.0
MWS-18	326	1.7	2.4	67	<1.0	5.9	3.3	772	2.9	9.4
MWS-18-F	37	3.2	<2.0	58	<1.0	2.4	2.3	<15.0	<1.0	9.6
MWS-19	1,140	<1.0	<2.0	116	<1.0	3.4	2.9	669	2.7	<2.0
MWS-19-F	<14.0	2.2	<2.0	109	<1.0	2.4	<2.0	27	<1.0	<2.0
MWS-20	(3.9)	(0.005)	<2.0	78	(0.06)	7.9	(1.4)	<63.0	(0.01)	(1.4)
MWS-20-F	(2.4)	<1.0	2.2	78	(0.06)	<7.1	(1.5)	<27	(0.03)	(1.3)
MWS-21	723	<1.0	<2.0	372	<1.0	2.2	5.5	1220	3.8	356
MWS-21-F	<14.0	<1.0	<2.0	357	<1.0	1.7	24	62	<1.0	348
MWS-22	50	<1.0	<2.0	147	(0.08)	<2.4	(1.1)	<111	(0.13)	2.9
MWS-22-F	<14.0	(0.68)	(0.07)	153	(0.11)	(0.91)	(0.69)	<15.0	<1.0	2.9
MWS-23	15,900	<1.0	7.8	215	<1.0	19	33	21,200	15	10
MWS-23-F	<14.0	1.2	<2.0	89	<1.0	1.8	2.3	16	<1.0	<2.0
MWS-25	559	<1.0	5.2	81	<1.0	1.8	2.6	552	<1.0	<2.0
MWS-25-F	<14.0	<1.0	3.6	77	<1.0	<1.0	2.5	52	<1.0	<2.0

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MWS-26	16,400	(0.28)	<7.2	158	(0.74)	23	25	31,500	19	15
MWS-26-F	282	(0.24)	(0.63)	37	(0.08)	<1.8	6.4	514	1.3	5.8
MWS-101	<14.0	<1.0	11	449	<1.0	<1.0	<2.0	5,650	<1.0	<2.0
MWS-101-F	888	<1.0	11	463	<1.0	4.9	7.3	6,300	1.9	<2.0
MWS-102	8,190	<1.0	12	255	<1.0	5.0	13.0	7,670	14	7.4
MWS-102-F	56	<1.0	14	216	<1.0	1.0	5.3	2,850	<1.0	3.1
MWS-103	3,620	<1.0	56	210	<1.0	4.6	19.0	15,800	11	4.2
MWS-103-F	<14.0	4.7	6.0	150	<1.0	<1.0	<2.0	77.0	<1.0	<2.0
MWS-104	593	<1.0	<2.0	183	<1.0	1.5	<2.0	220	<1.0	<2.0
MWS-104-F	33	<1.0	<2.0	183	<1.0	1.6	<2.0	<15.0	<1.0	<2.0
MWS-105	<14.0	<1.0	<2.0	137	<1.0	2.3	<2.0	<15.0	<1.0	<2.0
MWS-105-F	<14.0	<1.0	2.3	136	<1.0	2.3	<2.0	<15.0	<1.0	<2.0
MWS-106	1,070	<1.0	<2.0	223	<1.0	2.4	10	859	6.0	2.3
MWS-106-F	<14.0	<1.0	<2.0	203	<1.0	2.4	<2.0	54.0	<1.0	<2.0
MWS-107	599	<1.0	<2.0	142	<1.0	4.1	7.7	713	1.7	4.3
MWS-107-F	<14.0	<1.0	2.1	126	<1.0	3.0	<2.0	175	<1.0	4.8
MWS-108	<14.0	1.0	5.6	137	<1.0	3.1	2.0	39	<1.0	4.0
MWS-108-F	<14.0	<1.0	<2.0	126	<1.0	2.5	<2.0	148	<1.0	4.7
MWS-109	109	<1.0	<2.0	223	<1.0	1.0	<2.0	242	<1.0	2.2
MWS-109-F	<14.0	1.3	<2.0	222	<1.0	1.6	<2.0	<15.0	<1.0	2.3
MWS-110	431	<1.0	<2.0	175	<1.0	2.3	<2.0	516	<1.0	2.8
MWS-110-F	<14.0	<1.0	<2.0	167	<1.0	1.4	<2.0	<15.0	<1.0	2.5
MWS-111	<14.0	<1.0	<2.0	377	<1.0	2.9	<2.0	20	<1.0	<2.0
MWS-111-F	<14.0	<1.0	<2.0	374	<1.0	2.8	<2.0	<15.0	<1.0	<2.0
MWS-112	356	1.3	5.4	58	<1.0	3.7	15	283	1.6	17.0
MWS-112-F	209	2.5	4.5	52	<1.0	2.3	13	193	1.2	21

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
TIL3	166	<1.0	<2.0	194	<1.0	2.6	19	12,600	85	3.3
TIL3-F	21	<1.0	<2.0	191	<1.0	2.1	<2.0	2,340	<1.0	3.3
USG1	<14.0	1.5	<2.0	205	<1.0	1.4	<2.0	<15.0	<1.0	3.8
USG1-F	18	<1.0	<2.0	209	<1.0	2.9	<2.0	<15.0	<1.0	4.0
USG2	58	5.6	<2.0	253	<1.0	2.5	<2.0	229	<1.0	<2.0
USG2-F	<14.0	<1.0	<2.0	252	<1.0	1.8	<2.0	51	<1.0	<2.0
USG3	<14.0	<1.0	<2.0	216	<1.0	2.4	<2.0	<15.0	<1.0	3.7
USG3-F	14.0	<1.0	<2.0	204	<1.0	6.1	<2.0	18	<1.0	3.8
USG4	<14.0	<1.0	<2.0	101	<1.0	2.4	<2.0	<15.0	<1.0	3.9
USG4-F	<14.0	<1.0	<2.0	102	<1.0	2.9	<2.0	25	<1.0	3.5
USG5	<14.0	<1.0	<2.0	178	<1.0	1.5	<2.0	<15.0	<1.0	3.5
USG5-F	<14.0	<1.0	<2.0	177	<1.0	1.0	<2.0	<15.0	<1.0	3.4
USG6	<14.0	<1.0	<2.0	224	<1.0	1.6	<2.0	44	<1.0	<2.0
USG6-F	<14.0	<1.0	<2.0	224	<1.0	<1.0	<2.0	<15.0	<1.0	<2.0
USG8	34	<1.0	<2.0	122	<1.0	2.3	<2.0	883	2.8	10
USG8-F	<14.0	<1.0	<2.0	145	<1.0	1.0	<2.0	<15.0	<1.0	3.9
USG9	<14.0	<1.0	<2.0	92	<1.0	2.3	<2.0	<15.0	<1.0	3.0
USG9-F	<14.0	<1.0	<2.0	88.0	<1.0	2.7	<2.0	<15.0	<1.0	2.9
MSV-1	1,330	<1.0	<2.0	62.0	<1.0	2.6	3.5	1,020	<1.0	<2.0
MSV-1-F	132	1.4	<2.0	53.0	<1.0	<1.0	2.1	122	<1.0	<2.0
MSV-2	1,380	<1.0	<2.0	63	<1.0	3.7	8.6	1,350	1.6	2.4
MSV-2-F	571	<1.0	<2.0	54	<1.0	1.1	2.4	382	<1.0	2.0
MSV-9	<14.0	<1.0	<2.0	104	<1.0	1.8	2.8	92	<1.0	7.0
MSV-9-F	<14.0	<1.0	<2.0	84	<1.0	1.0	<2.0	16	<1.0	5.8
MSV-13	96	<1.0	(0.40)	37	(0.07)	<5.4	2.3	259	(0.41)	3.2
MSV-13-F	<14.0	1.5	<2.0	26	(0.15)	<2.6	2.5	<15.0	<1.0	3.1

TABLE C.3 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MSV-16	362	<1.0	3.8	75	<1.0	4.3	7.9	515	1.7	<2.0
MSV-16-F	26	<1.0	4.5	67	<1.0	1.9	<2.0	35	<1.0	<2.0
MSV-17	25	<1.0	(0.26)	94	(0.09)	<1.3	(0.90)	<33	(0.07)	(0.26)
MSV-17-F	<14.0	2.9	<2.0	91	(0.06)	<1.1	(1.6)	<20.0	(0.55)	(0.25)
MSV-22	25	<1.0	<2.0	158	(0.10)	<1.7	(1.1)	<50	<1.0	2.3
MSV-22-F	(0.25)	(0.30)	<2.0	156	(0.04)	<1.2	(0.48)	(0.91)	<1.0	2.3
MSV-24	<14.0	<1.0	<2.0	100	<1.0	<1.0	<2.0	178	<1.0	8.2
MSV-24-F	<14.0	<1.0	<2.0	98.8	<1.0	1.0	<2.0	33	<1.0	7.9

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-2001-F	<1.0	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MW-2002	2.6	<0.2	111	6.7	4.2	<1.0	<1.0
MW-2002-F	<1.0	<0.2	12	5.5	3.9	<1.0	<1.0
MW-2003	32	<0.2	2.2	8.1	8.8	5.5	<1.0
MW-2003-F	2.5	<0.2	2.1	7.1	8.3	<1.0	<1.0
MW-2005	<1.0	<0.2	1.4	2.1	<3.0	<1.0	<1.0
MW-2005-F	<1.0	<0.2	1.1	2.3	<3.0	<1.0	<1.0
MW-2006	24	<0.2	2.4	65	<3.0	<1.0	<1.0
MW-2006-F	22	<0.2	1.4	62	<3.0	<1.0	<1.0
MW-2007	15	<0.2	4.2	2.5	<3.0	<1.0	<1.0
MW-2007-F	4.0	<0.2	4.4	1.9	<3.0	<1.0	<1.0
MW-2010	74	<0.2	11	72	<3.0	<1.0	<1.0
MW-2010-F	61	<0.2	9.7	62.0	<3.0	<1.0	<1.0
MW-2011	<1.0	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MW-2011-F	<1.0	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MW-2012	<1.0	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MW-2012-F	<1.0	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MW-2013	<1.0	<0.2	<1.0	3.4	<3.0	<1.0	<1.0
MW-2013-F	<1.0	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MW-2014	20	<0.2	<1.0	4.3	<3.0	<1.0	<1.0
MW-2014-F	1.1	<0.2	1.0	2.1	<3.0	<1.0	<1.0
MW-2015	<1.0	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MW-2015-F	<1.0	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MW-2017	19	<0.2	2.0	6.6	<3.0	<1.0	<1.0
MW-2017-F	1.0	<0.2	19	9.9	4.5	<1.0	<1.0
MW-2018	2.6	<0.2	4.5	2.1	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-2018-F	<1.0	<0.2	2.7	1.1	<3.0	<1.0	<1.0
MW-2019	51	<0.2	27	3.8	<3.0	<1.0	<1.0
MW-2019-F	48	<0.2	27	3.7	<3.0	<1.0	<1.0
MW-2021	38	<0.2	7.6	11.0	<3.0	<1.0	<1.0
MW-2021-F	33.0	<0.2	6.8	9.5	<3.0	<1.0	<1.0
MW-2022	102	<0.2	2.3	3.6	<3.0	<1.0	<1.0
MW-2022-F	100	<0.2	3.0	3.5	<3.0	<1.0	<1.0
MW-2023	34	<0.2	6.6	6.1	<3.0	<1.0	<1.0
MW-2023-F	6.0	<0.2	6.5	3.4	<3.0	<1.0	<1.0
MW-2024	77	<0.2	2.0	3.6	<3.0	<1.0	<1.0
MW-2024-F	69	<0.2	1.1	3.3	<3.0	<1.0	<1.0
MW-2026	142	<0.2	8.2	25	<3.0	<1.0	<1.0
MW-2026-F	118	<0.2	7.2	18	<3.0	<1.0	<1.0
MW-2027	432	<0.2	3.2	2.1	<3.0	<1.0	<1.0
MW-2027-F	431	<0.2	3.4	2.5	<3.0	<1.0	<1.0
MW-2028	226	<0.2	4.7	7.8	<3.0	<1.0	<1.0
MW-2028-F	197	<0.2	4.9	5.7	<3.0	<1.0	<1.0
MW-2030	310	0.20	<1.0	15	<3.0	<1.0	<1.0
MW-2030-F	4.3	<0.2	<1.0	4.3	<3.0	<1.0	<1.0
MW-2032	20	<0.2	1.8	6.7	4.1	<1.0	<1.0
MW-2032-F	1.5	<0.2	<1.0	4.2	3.3	<1.0	<1.0
MW-2033	148	<0.2	<1.0	9.4	<3.0	<1.0	<1.0
MW-2033-F	2.5	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MW-2034	12	<0.2	<1.0	19	4.0	<1.0	<1.0
MW-2034-F	1.2	<0.2	<1.0	15.0	3.3	<1.0	<1.0
MW-2035	9.4	<0.2	3.4	1.9	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-2035-F	<1.0	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
MW-2036	<1.0	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
MW-2036-F	<1.0	<0.2	<1.0	1.7	<3.0	<1.0	<1.0
MW-2037	66.0	3.5	<1.0	9.9	<3.0	<1.0	<1.0
MW-2037-F	68	1.4	<1.0	9.9	4.1	<1.0	<1.0
MW-2038	26	4.5	1.4	18	9.3	<1.0	<1.0
MW-2038-F	22	3.8	<1.0	18.0	11	<1.0	<1.0
MW-2039	49	<0.2	4.3	7.5	5.7	<1.0	<1.0
MW-2039-F	<1.0	<0.2	3.0	4.5	5.8	<1.0	<1.0
MW-2040	67	<0.2	5.0	8.9	<3.0	<1.0	<1.0
MW-2040-F	4.4	<0.2	5.2	6.1	3.6	<1.0	<1.0
MW-2041	27	<0.2	<1.0	5.2	12	<1.0	<1.0
MW-2041-F	22	<0.2	<1.0	5.0	11	<1.0	<1.0
MW-2042	4.8	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MW-2042-F	<1.0	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MW-2043	9.9	<0.2	1.5	2.9	3.1	<1.0	<1.0
MW-2043-F	1.3	<0.2	1.4	2.4	<3.0	<1.0	<1.0
MW-2044	2.3	<0.2	1.8	3.3	<3.0	<1.0	<1.0
MW-2044-F	1.7	<0.2	1.4	3.3	<3.0	<1.0	<1.0
MW-3003	25	<0.2	5.7	11	6.9	<1.0	<1.0
MW-3003-F	23	<0.2	5.7	11	6.7	<1.0	<1.0
MW-3006	111	<0.2	7.0	4.8	<3.0	<1.0	<1.0
MW-3006-F	127	<0.2	8.1	4.7	<3.0	<1.0	<1.0
MW-3019	127	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MW-3019-F	129	<0.2	<1.0	1.8	<3.0	<1.0	<1.0
MW-3023	102	<0.2	252	19	8.1	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-3023-F	7.2	<0.2	257	8.1	6.3	<1.0	<1.0
MW-3024	<1.0	1.5	<1.0	8.3	10	<1.0	<1.0
MW-3024-F	<1.0	0.94	<1.0	8.6	12	<1.0	<1.0
MW-3025	31	0.43	<1.0	14	8.0	<1.0	<1.0
MW-3025-F	18	0.42	<1.0	12	7.7	<1.0	<1.0
MW-3026	69	<0.2	2.1	14	<3.0	<1.0	<1.0
MW-3026-F	1.1	<0.2	2.0	11.0	<3.0	<1.0	<1.0
MW-3027	25.0	0.46	<1.0	6.7	<3.0	<1.0	<1.0
MW-3027-F	2.4	0.29	<1.0	2.0	<3.0	<1.0	<1.0
MW-4001	4.1	<0.2	1.8	2.7	<3.0	<1.0	<1.0
MW-4001-F	1.6	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MW-4002	22	<0.2	<1.0	2.8	<3.0	<1.0	<1.0
MW-4002-F	1.7	<0.2	1.2	1.8	<3.0	<1.0	<1.0
MW-4003	<1.0	<0.2	<1.0	1.1	<3.0	<1.0	<1.0
MW-4003-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MW-4004	75	<0.2	4.7	2.8	<3.0	<1.0	<1.0
MW-4004-F	<1.0	<0.2	5.9	<1.0	3.4	<1.0	<1.0
MW-4005	5.3	<0.2	5.0	6.1	<3.0	<1.0	<1.0
MW-4005-F	<1.0	<0.2	5.3	4.8	<3.0	<1.0	<1.0
MW-4006	26.0	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
MW-4006-F	<1.0	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
MW-4007	43	<0.2	5.8	5.0	<3.0	<1.0	<1.0
MW-4007-F	1.2	<0.2	5.9	2.3	<3.0	<1.0	<1.0
MW-4008	32	<0.2	<1.0	3.8	<3.0	<1.0	<1.0
MW-4008-F	8.1	<0.2	<1.0	1.7	<3.0	<1.0	<1.0
MW-4009	3.7	<0.2	8.3	1.3	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-4009-F	<1.0	<0.2	9.1	1.0	<3.0	<1.0	<1.0
MW-4010	9.3	<0.2	3.1	4.5	<3.0	<1.0	<1.0
MW-4010-F	5.2	<0.2	2.8	3.1	<3.0	<1.0	<1.0
MW-4011	27	<0.2	1.2	8.3	4.2	<1.0	<1.0
MW-4011-F	<1.0	<0.2	2.2	7.4	3.9	<1.0	<1.0
MW-4012	16	<0.2	37.0	2.2	<3.0	<1.0	<1.0
MW-4012-F	<1.0	<0.2	37	<1.0	<3.0	<1.0	<1.0
MW-4013	<1.0	<0.2	<1.0	3.3	<3.0	<1.0	<1.0
MW-4013-F	<1.0	<0.2	<1.0	3.5	<3.0	<1.0	<1.0
MW-4014	24	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
MW-4014-F	16	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MW-4015	14	<0.2	<1.0	2.1	<3.0	1.8	<1.0
MW-4015-F	<1.0	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MW-4016	84	<0.2	9.6	3.3	<3.0	<1.0	<1.0
MW-4016-F	41	<0.2	10	2.0	<3.0	<1.0	<1.0
MW-4018	<1.0	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MW-4018-F	<1.0	<0.2	<1.0	2.6	<3.0	<1.0	<1.0
MW-4019	33	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MW-4019-F	47	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MW-4020	35	<0.2	1.3	16	<3.0	<1.0	<1.0
MW-4020-F	21	<0.2	1.1	16	<3.0	<1.0	<1.0
MW-4021	50	<0.2	<1.0	8.9	<3.0	<1.0	<1.0
MW-4021-F	32	<0.2	1.7	7.6	<3.0	<1.0	<1.0
MW-4022	2140	<0.2	6.3	246	<3.0	19.1	<1.0
MW-4022-F	286	<0.2	4.0	12	<3.0	<1.0	<1.0
MW-4023	<1.0	<0.2	<1.0	2.6	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-4023-F	<1.0	<0.2	<1.0	1.7	<3.0	<1.0	<1.0
MW-4024[b]	388.0	<0.8	11.1	166.0	<4.0	14.4	<2.0
MW-4024-F[b]	105.0	<0.8	<5.0	49.8	<4.0	3.2	<2.0
MW-4025	177	<0.2	4.2	32	<3.0	1.8	<1.0
MW-4025-F	9.6	<0.2	<1.0	3.8	<3.0	<1.0	<1.0
MWD-2	2130	<0.2	8.0	27	<3.0	<1.0	1.1
MWD-2-F	100	<0.2	11	1.5	<3.0	<1.0	<1.0
MWD-5	19	<0.2	1.3	2.0	<3.0	<1.0	<1.0
MWD-5-F	1.4	<0.2	1.1	1.4	<3.0	<1.0	<1.0
MWD-6	73	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MWD-6-F	73	<0.2	<1.0	2.8	<3.0	<1.0	<1.0
MWD-9	<1.0	<0.2	<1.0	1.2	<3.0	<1.0	<1.0
MWD-9-F	<1.0	<0.2	<1.0	1.2	<3.0	<1.0	<1.0
MWD-15	11.0	<0.2	<1.0	1.1	<3.0	<1.0	<1.0
MWD-15-F	9.7	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MWD-18	6.1	<0.2	<1.0	1.8	<3.0	<1.0	<1.0
MWD-18-F	2.8	<0.2	<1.0	1.1	<3.0	<1.0	<1.0
MWD-23	357	<0.2	24	94	<3.0	<1.0	<1.0
MWD-23-F	340	<0.2	25	90	<3.0	<1.0	<1.0
MWD-25	22	<0.2	<1.0	4.2	<3.0	<1.0	<1.0
MWD-25-F	18	<0.2	<1.0	3.7	<3.0	<1.0	<1.0
MWD-105	6.8	<0.2	<1.0	1.5	<3.0	<1.0	<1.0
MWD-105-F	6.2	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MWD-106	5.5	<0.2	<1.0	1.2	<3.0	<1.0	<1.0
MWD-106-F	5.3	<0.2	<1.0	1.1	<3.0	<1.0	<1.0
MWD-107	36	<0.2	2.1	28	<3.0	<1.0	<1.0
MWD-107-F	25	<0.2	2.3	27	<3.0	<1.0	<1.0
MWD-109	9.5	<0.2	2.4	2.8	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWD-109-F	6.3	<0.2	<1.0	2.2	<3.0	<1.0	<1.0
MWD-112	19.0	<0.2	2.2	11.0	<3.0	<1.0	<1.0
MWD-112-F	20.2	<0.2	2.9	11	<3.0	<1.0	<1.0
MWS-1	2.3	<0.2	<1.0	1.5	<3.0	<1.0	<1.0
MWS-1-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-2	1.9	<0.2	4.2	2.1	<3.0	<1.0	<1.0
MWS-2-F	<1.0	<0.2	3.8	2.0	<3.0	<1.0	<1.0
MWS-3	2.4	<0.2	3.4	2.8	<3.0	<1.0	<1.0
MWS-3-F	<1.0	<0.2	4.1	2.9	<3.0	<1.0	<1.0
MWS-4	22	<0.2	<1.0	4.9	<3.0	<1.0	<1.0
MWS-4-F	<1.0	<0.2	<1.0	2.6	<3.0	<1.0	<1.0
MWS-5	9.2	<0.2	<1.0	3.4	<3.0	<1.0	<1.0
MWS-5-F	4.0	<0.2	<1.0	5.7	<3.0	<1.0	<1.0
MWS-6	1.8	<0.2	<1.0	4.0	<3.0	<1.0	<1.0
MWS-6-F	1.6	<0.2	<1.0	4.3	<3.0	<1.0	<1.0
MWS-7	<1.0	<0.2	<1.0	1.6	<3.0	<1.0	<1.0
MWS-7-F	<1.0	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MWS-8	38	<0.2	<1.0	12	<3.0	<1.0	<1.0
MWS-8-F	1.0	<0.2	<1.0	4.5	<3.0	<1.0	<1.0
MWS-9	4.2	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MWS-9-F	5.3	<0.2	<1.0	2.9	<3.0	<1.0	<1.0
MWS-10	<1.0	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MWS-10-F	<1.0	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MWS-11	7.1	<0.2	<1.3	2.4	(1.3)	(0.03)	(0.180)
MWS-11-F	(0.980)	<0.2	(0.880)	2.3	(0.53)	<1.0	<1.0
MWS-12	6.9	<0.2	<1.0	2.4	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWS-12-F	5.5	<0.2	<1.0	1.7	<3.0	<1.0	<1.0
MWS-13	12	<0.2	(0.53)	6.5	(0.27)	(0.005)	<1.0
MWS-13-F	10	<0.2	(0.39)	7.9	<3.0	(0.010)	<1.0
MWS-14	26	<0.2	1.6	7.9	<3.0	<1.0	<1.0
MWS-14-F	<1.0	<0.2	1.1	3.7	<3.0	<1.0	<1.0
MWS-15	2.0	<0.2	<1.0	15	<3.0	<1.0	<1.0
MWS-15-F	<1.0	<0.2	<1.0	23	<3.0	<1.0	<1.0
MWS-16	<1.0	<0.2	<1.0	2.8	<3.0	<1.0	<1.0
MWS-16-F	<1.0	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MWS-17	4.7	<0.2	<1.1	2.2	(1.8)	(0.005)	<1.0
MWS-17-F	(0.60)	<0.2	(0.80)	2.0	(1.30)	<1.0	(0.18)
MWS-18	81	<0.2	7.1	8.6	<3.0	<1.0	<1.0
MWS-18-F	1.5	<0.2	6.7	5.0	<3.0	<1.0	<1.0
MWS-19	42	<0.2	<1.0	5.0	<3.0	<1.0	<1.0
MWS-19-F	32	<0.2	<1.0	3.7	<3.0	<1.0	<1.0
MWS-20	1.4	<0.2	<1.0	1.8	(0.33)	<1.0	<1.0
MWS-20-F	(0.09)	<0.2	(0.49)	1.7	(0.36)	(0.007)	<1.0
MWS-21	149	0.35	4.9	101	6.5	<1.0	<1.0
MWS-21-F	100	<0.2	4.6	95	7.3	<1.0	<1.0
MWS-22	3.6	<0.2	(0.13)	3.2	<3.0	(0.043)	<1.0
MWS-22-F	1.8	<0.2	(0.39)	2.7	(0.88)	(0.033)	(0.083)
MWS-23	739	<0.2	<1.0	38	<3.0	<1.0	<1.0
MWS-23-F	74	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MWS-25	27	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MWS-25-F	4.7	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
MWS-26	1040	<0.2	2.0	54	<3.0	(0.031)	(0.17)

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWS-26-F	44	<0.2	<2.2	3.0	(0.045)	<1.0	<1.0
MWS-101	842	<0.2	<1.0	1.6	<3.0	<1.0	<1.0
MWS-101-F	852	<0.2	<1.0	5.1	<3.0	<1.0	<1.0
MWS-102	560	<0.2	1.9	8.9	<3.0	<1.0	<1.0
MWS-102-F	508	<0.2	3.5	4.2	<3.0	<1.0	<1.0
MWS-103	356	<0.2	<1.0	13	<3.0	<1.0	<1.0
MWS-103-F	33	<0.2	<1.0	3.3	<3.0	<1.0	<1.0
MWS-104	7.8	<0.2	2.9	3.9	<3.0	<1.0	<1.0
MWS-104-F	2.5	<0.2	3.5	3.0	<3.0	<1.0	<1.0
MWS-105	19	<0.2	1.6	3.7	<3.0	<1.0	<1.0
MWS-105-F	18	<0.2	2.0	3.3	<3.0	<1.0	<1.0
MWS-106	119	<0.2	1.1	6.2	<3.0	<1.0	<1.0
MWS-106-F	93	<0.2	1.9	1.6	<3.0	<1.0	<1.0
MWS-107	28	<0.2	<1.0	3.5	<3.0	<1.0	<1.0
MWS-107-F	32	<0.2	<1.0	1.5	<3.0	<1.0	<1.0
MWS-108	4.0	<0.2	1.9	1.4	<3.0	<1.0	<1.0
MWS-108-F	30	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MWS-109	111	<0.2	1.2	4.4	<3.0	<1.0	<1.0
MWS-109-F	70	<0.2	1.8	3.6	<3.0	<1.0	<1.0
MWS-110	13	<0.2	<1.0	3.3	<3.0	<1.0	<1.0
MWS-110-F	1.3	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-111	4.9	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-111-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-112	60	<0.2	35	39	<3.0	<1.0	<1.0
MWS-112-F	61	<0.2	46	55	<3.0	<1.0	<1.0
TIL3	40	<0.2	1.6	2.6	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
TIL3-F	33	<0.2	1.8	1.7	<3.0	<1.0	<1.0
USG1	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
USG1-F	<1.0	<0.2	1.3	1.4	<3.0	<1.0	<1.0
USG2	5.1	<0.2	1.8	2.9	<3.0	<1.0	<1.0
USG2-F	4.4	<0.2	1.9	4.5	<3.0	<1.0	<1.0
USG3	<1.0	<0.2	<1.0	1.5	<3.0	<1.0	<1.0
USG3-F	<1.0	<0.2	2.4	1.8	<3.0	<1.0	<1.0
USG4	<1.0	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
USG4-F	<1.0	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
USG5	77	<0.2	5.4	49	<3.0	<1.0	<1.0
USG5-F	64	<0.2	4.9	49	<3.0	<1.0	<1.0
USG6	14	<0.2	1.8	2.3	<3.0	<1.0	<1.0
USG6-F	<1.0	<0.2	4.0	1.8	<3.0	<1.0	<1.0
USG8	14	<0.2	1.6	8.4	<3.0	<1.0	<1.0
USG8-F	6.8	<0.2	2.5	2.3	<3.0	<1.0	<1.0
USG9	<1.0	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
USG9-F	<1.0	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MWV-1	10	<0.2	<1.0	2.9	<3.0	<1.0	<1.0
MWV-1-F	2.4	<0.2	<1.0	1.4	<3.0	<1.0	<1.0
MWV-2	12.0	<0.2	1.6	3.7	<3.0	<1.0	<1.0
MWV-2-F	3.9	<0.2	1.4	2.4	<3.0	<1.0	<1.0
MWV-9	23	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MWV-9-F	6.7	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
MWV-13	16	<0.2	<1.6	3.5	(0.39)	<1.0	<1.0
MWV-13-F	(0.42)	<0.2	(0.80)	2.4	(0.14)	<1.0	<1.0
MWV-16	34	<0.2	<1.0	4.2	<3.0	<1.0	<1.0

TABLE C.3 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWV-16-F	1.4	<0.2	<1.0	2.2	<3.0	<1.0	<1.0
MWV-17	43	<0.2	<1.0	(0.94)	<3.0	<1.0	<1.0
MWV-17-F	1.2	<0.2	<1.0	(0.64)	<3.0	<1.0	<1.0
MWV-22	6.7	<0.2	(0.49)	51	<3.0	<1.0	<1.0
MWV-22-F	2.4	<0.2	(0.34)	55	<3.0	<1.0	<1.0
MWV-24	38.0	<0.2	1.1	4.3	<3.0	<1.0	<1.0
MWV-24-F	19	<0.2	1.2	4.0	<3.0	<1.0	<1.0

[a] F = filtered data.

[b] Sample taken in July 1995.

TABLE C.4 Nitroaromatic Results from Joint Sampling, August 1995

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MW-2001	0.052	<0.090	<0.030	0.13	0.054	13	24	<0.030	<0.030	<0.030	<0.040
MW-2002	<0.030	<0.090	<0.030	0.070	0.41	0.83	0.93	<0.030	<0.030	<0.030	<0.040
MW-2003	<0.030	<0.090	<0.030	0.13	0.40	0.14	0.32	<0.120	<0.060	<0.030	<0.040
MW-2005	<0.060	<0.090	<0.030	0.061	0.084	0.099	0.095	<0.030	<0.030	<0.030	<0.040
MW-2006	<0.030	<0.090	<0.030	<0.030	(0.009)	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2007	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2010	0.15	<0.090	0.34	0.088	0.75	0.72	0.81	<0.060	<0.030	<0.030	<0.040
MW-2011	0.40	<0.090	<0.030	0.18	1.4	2.0	0.98	0.22	<0.030	<0.030	<0.040
MW-2012	1.2	<0.090	0.45	0.099	0.65	0.27	0.28	<0.060	<0.030	0.28	<0.040
MW-2013	6.2	<0.090	0.85	0.36	4.4	2.4	2.2	0.26	0.058	<0.030	<0.040
MW-2014	1.9	<0.090	0.044	0.15	0.41	0.41	0.63	0.14	<0.030	<0.030	<0.040
MW-2015	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2017	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2018	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.060	<0.030	<0.030	<0.040
MW-2019	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.070	<0.030	<0.030	<0.040
MW-2021	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2022	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2023	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2024	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2026	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2027	<0.030	<0.090	<0.030	NS[a]	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2028	<0.030	<0.090	<0.030	NS[a]	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2030	7.2	<0.090	19	0.16	7.7	5.5	4.4	<0.210	0.060	<0.030	<0.040
MW-2032	2.3	<0.180	6.2	0.14	4.4	3.6	2.8	0.21	0.043	<0.030	<0.040
MW-2033	4.5	<0.090	1.1	0.55	4.9	3.6	3.3	0.65	0.047	0.090	<0.040
MW-2034	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2035	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.030
MW-2036	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.030

TABLE C.4 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MW-2037	0.16	<0.090	<0.030	0.42	0.097	0.086	0.11	<0.140	<0.030	<0.030	<0.060
MW-2038	0.21	<0.090	<0.030	1.6	0.30						<0.040
MW-2039	7.3	<0.090	<0.030	0.12	1.7	2.0	1.6	0.63	<0.030	<0.030	0.054
MW-2040	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2041	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2042	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2043	<0.030	<0.090	<0.030	0.087	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-2044	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-3003	<0.030	<0.090	<0.030	0.17	0.37	<0.020	0.034	<0.030	0.14	0.15	<0.040
MW-3006	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	1.6	<0.030	<0.030	<0.040
MW-3019	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-3023	<0.030	<0.090	<0.030	4.9	4.4	0.12	0.28	45	3.3	0.50	<0.040
MW-3024	<0.030	<0.090	<0.030	0.13	0.45	0.031	0.047	0.30	<0.110	<0.060	<0.040
MW-3025	<0.030	<0.090	<0.030	0.094	0.26	<0.020	0.030	0.20	<0.030	<0.030	<0.040
MW-3026	0.14	<0.090	<0.030	0.063	0.046	0.20	0.25	<0.030	<0.030	<0.030	<0.040
MW-3027	0.051	<0.090	<0.030	0.052	0.026	0.13	0.13	<0.030	<0.030	<0.030	<0.040
MW-4001	39	<0.090	1.6	1.3	3.0	14	20	0.7	<0.060	<0.030	<0.060
MW-4002	<0.030	<0.090	<0.030	<0.030	(0.0071)	0.026	0.059	<0.030	<0.030	<0.030	<0.040
MW-4003	<0.030	<0.090	<0.030	<0.030	<0.010	(0.016)	0.028	<0.030	<0.030	<0.030	<0.040
MW-4004	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4005	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4006	10	<0.090	<0.030	0.11	2.4	1.5	2.1	0.32	<0.030	<0.030	<0.040
MW-4007	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	(0.017)	<0.030	<0.030	<0.030	<0.040
MW-4008	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4009	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4010	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4011	<0.030	<0.090	<0.030	<0.030	0.065	0.75	1.7	<0.030	<0.030	<0.030	<0.040
MW-4012	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4013	24	<0.090	0.046	0.077	0.74	1.7	2.0	<0.030	<0.030	<0.030	<0.040
MW-4014	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040

TABLE C.4 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MW-4015	1.5	<0.090	<0.030	0.19	0.84	3.2	4.1	<0.030	<0.030	<0.030	<0.040
MW-4016	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4018	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4019	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4020	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4021	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4022	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.130	<0.030	<0.030	<0.040
MW-4023	0.082	<0.090	<0.030	0.067	0.021	0.034	0.041	<0.030	<0.030	<0.030	<0.040
MW-4024	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MW-4025	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-2	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-5	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-6	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-9	0.055	<0.090	<0.030	0.036	0.13	0.071	0.42	<0.060	<0.030	<0.030	<0.040
MWD-15	<0.030	<0.090	<0.030	<0.030	0.076	0.66	1.4	<0.030	<0.030	<0.030	<0.040
MWD-18	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-23	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-25	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-105	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-106	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-107	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-109	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWD-112	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-1	<0.030	<0.090	<0.030	<0.030	0.43	<0.020	0.028	<0.030	<0.030	<0.030	<0.040
MWS-2	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-3	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-4	11	<0.090	1.2	0.10	0.96	6.3	6.9	<0.29	<0.030	<0.030	<0.040
MWS-5	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-6	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-7	11	<0.090	1.0	0.049	0.49	4.1	8.4	<0.080	<0.030	<0.030	<0.040

TABLE C.4 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
MWS-8	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-9	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-10	0.21	<0.090	(0.028)	0.082	2.0	6.3	16	<0.090	<0.030	<0.030	<0.040
MWS-11	<0.060	<0.090	0.046	0.055	0.54	0.48	2.3	<0.070	<0.030	<0.030	<0.040
MWS-12	0.49	0.27	0.14	8.8	15	1.1	2.5	100	7.7	30	<0.040
MWS-13	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-14	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-15	1.1	<0.090	5.6	0.081	1.0	11	20	<0.060	<0.030	<0.030	<0.040
MWS-16	10	<0.090	2.9	0.074	0.99	3.9	6.0	0.14	<0.030	<0.030	<0.040
MWS-17	<0.030	<0.090	<0.030	1.1	1.8	3.9	4.6	7.2	0.31	0.93	<0.040
MWS-18	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-19	0.042	<0.090	<0.030	0.079	0.10	0.27	0.39	<0.040	<0.030	<0.030	<0.040
MWS-20	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	0.040	<0.030	<0.030	<0.030	<0.040
MWS-21	<0.030	<0.090	<0.060	0.94	0.17	0.23	0.41	<0.090	<0.060	<0.030	<0.040
MWS-22	<0.030	<0.090	<0.030	<0.060	0.12	0.073	0.19	<0.060	<0.030	<0.030	<0.040
MWS-23	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-25	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-26	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-101	<0.030	<0.090	<0.030	<0.040	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-102	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-103	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-104	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-105	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-106	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-107	0.065	<0.090	<0.030	0.059	0.16	0.059	0.65	<0.030	<0.030	<0.030	<0.040
MWS-108	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-109	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-110	0.072	<0.090	<0.030	<0.030	0.054	0.17	0.37	<0.030	<0.030	<0.030	<0.040
MWS-111	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWS-112	<0.030	<0.090	<0.030	(0.027)	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	0.062

TABLE C.4 (Cont.)

Well No.	1,3,5-TNB (µg/L)	1,3-DNB (µg/L)	2,4,6-TNT (µg/L)	2,4-DNT (µg/L)	2,6-DNT (µg/L)	2-Amino (µg/L)	4-Amino (µg/L)	2-Nitrotoluene (µg/L)	3-Nitrotoluene (µg/L)	4-Nitrotoluene (µg/L)	Nitrobenzene (µg/L)
TIL3	<0.030	<0.090	<0.030	<0.060	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
USG1	0.063	0.14	<0.030	0.046	0.022	0.057	0.17	<0.030	<0.030	<0.030	<0.040
USG2	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
USG3	0.10	<0.090	<0.030	(0.022)	0.15	0.025	0.19	<0.030	<0.030	<0.030	<0.040
USG4	1.8	<0.090	<0.030	0.19	1.7	2.0	2.2	0.57	0.049	<0.030	<0.040
USG5	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
USG6	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
USG8	<0.030	<0.090	<0.030		<0.010	<0.020	<0.020	<0.030	<0.070	<0.030	<0.040
USG9	<0.030	<0.090	<0.030	0.092	(0.0080)	2.0	2.7	<0.030	<0.030	<0.030	<0.040
MWV-1	<0.030	<0.090	0.035	0.067	0.40	1.7	3.3	0.13	<0.030	<0.030	<0.040
MWV-2	<0.030	<0.090	<0.030	<0.030	0.018	0.17	0.54	<0.030	<0.030	<0.030	<0.040
MWV-9	14	0.40	30	20	2.9	31	24	NS[a]	0.13	0.22	<0.040
MWV-13	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWV-16	0.33	<0.090	0.27	<0.030	0.069	0.040	0.57	<0.030	<0.030	<0.030	<0.040
MWV-17	<0.030	<0.090	<0.030	<0.030	<0.010	<0.020	<0.020	<0.030	<0.030	<0.030	<0.040
MWV-22	<0.030	<0.090	<0.030	<0.030	0.14	0.057	0.21	<0.060	<0.030	<0.030	<0.040
MWV-24	3.1	<0.090	1.1	0.13	1.4	0.42	0.74	0.36	<0.030	0.063	<0.040

[a] NS = no sample.

TABLE C.5 Anion and Radiological Results for Groundwater Samples from August 1995

Well No.	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Uranium (pCi/L)
MW-2001	5.9	(0.066)	49	12	(0.65)
MW-2002	6.6	(0.055)	130	120	(0.48)
MW-2003	9.0	<0.1	310	100	1.06
MW-2005	3.5	<0.1	60	29	(0.45)
MW-2006	3.7	<0.1	4.9	(9.2)	(0.310)
MW-2007	1.2	0.12	<0.1	15	0.95
MW-2010	47	0.10	1.1	41	1.11
MW-2011	4.2	0.11	4.8	13	(0.27)
MW-2012	48	<0.1	0.37	58	(0.33)
MW-2013	5.3	<0.1	1.0	27	0.66
MW-2014	26	<0.1	1.7	38	(0.48)
MW-2015	1.07	0.11	0.53	132	1.5
MW-2017	15	0.14	5.5	1120	12.0
MW-2018	7.9	0.23	0.67	11	1.5
MW-2019	1.0	0.26	<0.1	22	2.2
MW-2021	1.10	0.110	(0.005)	13.0	0.87
MW-2022	1.2	0.12	<0.1	14	1.03
MW-2023	1.1	0.18	<0.1	14	2.5
MW-2024	1.7	0.18	<0.1	29	(0.11)
MW-2026	1.4	0.18	<0.1	13	0.63
MW-2027	1.1	0.21	<0.1	(5.3)	0.81
MW-2028	1.3	0.12	<0.1	125	0.73
MW-2030	24	<0.1	1.3	50.0	13
MW-2032	17	(0.09)	29	54	4.20
MW-2033	5.4	<0.1	1.1	42	2.3
MW-2034	26	0.19	<0.1	320	3.0
MW-2035	<1.0	0.30	0.41	<10.0	(0.36)
MW-2036	<1.0	0.24	3.2	<10.0	0.77
MW-2037	32	0.10	290	130	0.93
MW-2038	<1.0	<0.1	780	110	1.1
MW-2039	49	0.27	36	33	2.80
MW-2040	3.0	0.17	197	(9.9)	1.7
MW-2041	5.7	0.18	260	35	2.3
MW-2042	8.80	0.26	4.8	24	2.2

TABLE C.5 (Cont.)

Well No.	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Uranium (pCi/L)
MW-2043	3.30	0.23	5.17	15.1	1.5
MW-2044	19	0.24	1.3	130	1.6
MW-3003	12	0.14	440	135	12.2
MW-3006	1.2	0.16	<1.0	22	0.700
MW-3019	<1.0	0.28	<0.1	<10.0	1.7
MW-3023	9.6	0.17	49	250	7.9
MW-3024	12	0.15	350	81	2.9
MW-3025	11	0.15	520	55	2.7
MW-3026	6.3	<0.1	200	14	3.07
MW-3027	2.4	0.23	57	<10.0	0.98
MW-4001	3.1	<0.1	40	65	(0.25)
MW-4002	(0.99)	0.11	0.80	14	0.56
MW-4003	4.8	0.22	0.63	27	1.1
MW-4004	3.3	0.28	0.88	19	1.7
MW-4005	5.7	0.28	1.6	19	1.50
MW-4006	1.6	0.13	11	24	(0.26)
MW-4007	2.3	0.23	<0.1	62	1.4
MW-4008	<1.0	0.26	<0.1	14	0.64
MW-4009	<1.0	0.23	0.11	13	1.2
MW-4010	1.1	0.17	<0.1	23	2.8
MW-4011	11	(0.07)	170	83	3.1
MW-4012	1.8	0.34	<0.1	36	5.00
MW-4013	7.6	<0.1	94	56	<0.67
MW-4014	1.7	0.21	0.25	25	<0.67
MW-4015	8.1	(0.083)	4.2	27	(0.25)
MW-4016	(0.81)	0.17	(0.04)	13.9	2.5
MW-4018	20	<0.1	2.6	<10.0	0.51
MW-4019	<1.0	0.31	0.23	<10.0	1.7
MW-4020	15	0.19	<0.1	150	0.85
MW-4021	1.2	0.11	<0.1	260	1.8
MW-4022	2.6	0.22	0.26	23	5.2
MW-4023	12	0.19	2.3	93	0.47
MW-4024	7.5	0.16	1.4	680	16.6
MW-4025	8.7	0.13	0.86	26	0.98
MWD-2	1.1	0.20	<0.1	16	1.1
MWD-5	1.9	1.2	0.12	26	(0.26)
MWD-6	<1.0	0.16	<0.1	20	0.49

TABLE C.5 (Cont.)

Well No.	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Uranium (pCi/L)
MWD-9	1.2	0.16	<0.1	12	0.54
MWD-15	1.4	0.12	4.3	<10.0	(0.34)
MWD-18	1.8	0.63	<0.1	15	(0.08)
MWD-23	3.1	0.26	<0.1	20	3.6
MWD-25	11	0.18	0.33	45	1.8
MWD-105	1.7	0.59	<0.1	29	(0.28)
MWD-106	1.8	0.99	<0.1	16	<0.67
MWD-107	3.1	0.16	<0.1	25	2.03
MWD-109	1.1	0.19	<0.1	14	(0.51)
MWD-112	1.3	0.34	<0.1	19	(0.40)
MWS-1	2.3	<0.1	2.5	<10.0	0.68
MWS-2	1.0	0.18	<0.1	15	1.4
MWS-3	1.3	0.26	<0.1	23	3.0
MWS-4	2.2	<0.1	7.9	35	10
MWS-5	<1.0	0.20	<0.1	19	0.83
MWS-6	1.0	0.17	<0.1	19	2.8
MWS-7	1.9	0.14	2.3	39	0.71
MWS-8	3.9	0.14	1.9	33	0.98
MWS-9	(0.96)	0.24	<0.1	12	1.00
MWS-10	2.1	0.16	7.2	64	(0.13)
MWS-11	3.2	0.21	8.8	43	1.4
MWS-12	1.9	0.16	2.8	<10.0	1.0
MWS-13	6.6	<0.1	1.2	600	(0.5)
MWS-14	11	0.17	0.14	24	1.50
MWS-15	1.8	<0.1	0.91	33	0.45
MWS-16	9.0	<0.1	6.6	23	0.55
MWS-17	4.3	<0.1	3.1	45	1.2
MWS-18	2.9	0.88	0.33	100	1.2
MWS-19	1.4	<0.1	0.15	20	0.64
MWS-20	2.4	0.11	5.6	17	0.69
MWS-21	26	0.18	420	95	2.9
MWS-22	4.3	0.22	3.0	18	0.72
MWS-23	<1.0	<0.1	<0.1	<10.0	(0.44)
MWS-25	6.8	0.17	0.60	37	1.6
MWS-26	ns	ns	ns	ns	ns
MWS-101	9.1	0.11	<0.1	(8.4)	(0.07)
MWS-102	4.2	0.21	<0.1	15	<4.2
MWS-103	3.2	(0.09)	<0.1	49	<0.84

TABLE C.5 (Cont.)

Well No.	Chloride (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Uranium (pCi/L)
MWS-104	<1.0	0.13	<0.1	11	1.30
MWS-105	1.3	0.25	<0.1	11	(0.12)
MWS-106	1.6	0.47	<0.1	11	(0.42)
MWS-107	3.9	0.14	1.6	16	1.81
MWS-108	1.1	0.25	<0.1	14	<0.57
MWS-109	1.0	0.14	<0.1	12	0.73
MWS-110	1.6	0.14	0.68	20	(0.62)
MWS-111	1.2	0.17	0.25	(0.42)	(0.75)
MWS-112	3.1	0.29	<0.1	20	1.1
TIL3	2.3	1.5	<0.1	11	(0.11)
USG1	3.7	0.19	0.79	15	0.85
USG2	1.2	0.25	<0.1	10	<0.67
USG3	2.2	0.23	0.85	17	1.1
USG4	2.8	(0.09)	1.5	25	(0.54)
USG5	1.2	0.14	0.23	(8.1)	<0.84
USG6	1.8	0.50	0.51	15	3.9
USG8	2.9	0.10	3.0	13	(0.41)
USG9	5.1	<0.1	3.2	19	(0.13)
MWV-1	<1.0	0.14	1.5	14	4.1
MWV-2	1.8	0.13	2.7	25	3.4
MWV-9	2.3	0.19	0.79	56	0.43
MWV-13	6.6	0.11	1.1	360	1.2
MWV-16	3.0	0.19	0.82	25	1.2
MWV-17	<1.0	<0.1	2.1	15	(0.06)
MWV-22	4.0	0.23	3.4	14	0.74
MWV-24	1.1	0.26	0.35	31	1.5

TABLE C.6 Metals Results (filtered and unfiltered) for August 1995 Joint Sampling

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-2001	<480	<1.0	<2.0	272	<1.0	<2.3	<35	<89.0	<3.3	<3.0
MW-2001-F[a]	<473	<1.0	<2.0	279	<1.0	<3.4	<35	<92	<3.0	<3.0
MW-2002	<469	<1.0	<2.0	123	<1.0	<2.2	<34	<105	<3.1	256
MW-2002-F	<573	1.5	<2.0	119	<1.0	<2.4	<37	<101	<2.5	243
MW-2003	<1,040	<1.0	<2.0	259	<1.0	<1.6	<35.0	774	<3.2	378
MW-2003-F	<484	<1.0	<2.0	253	<1.0	<1.40	<34	<114	<1.6	405
MW-2005	<14.0	<1.0	<2.0	166	<1.0	3.7	<2.0	118	7.3	97
MW-2005-F	<14.0	1.2	<2.0	169	<1.0	3.0	2.6	86	3.0	101
MW-2006	41	1.1	2.8	292	<1.0	12	3.3	179	4.4	16
MW-2006-F	39	3.4	3.5	272	<1.0	7.1	<2.0	103	1.1	17
MW-2007	<14.0	<1.0	<2.0	157	<1.0	3.6	<2.0	88	10.6	4.0
MW-2007-F	<14.0	2.5	<2.0	150	<1.0	1.9	<2.0	49	<1.0	3.9
MW-2010	38	<1.0	<2.0	262	<1.0	22	2.1	323	2.3	6.7
MW-2010-F	51	6.0	8.0	245	<1.0	10	2.2	183	<1.0	7.4
MW-2011	<28	<1.0	5.3	136	<1.0	<2.7	<2.0	41	<1.0	4.5
MW-2011-F	<19	<1.0	4.8	140	<1.0	<5.4	<2.0	140	<1.0	4.3
MW-2012	50	1.9	2.3	110	<1.0	<1.0	2.6	250	1.7	1.8
MW-2012-F	23	<1.0	<2.0	114	<1.0	<1.0	<2.0	94	<1.0	1.9
MW-2013	(26)	<1.0	<2.0	110	<1.0	<1.0	2.7	<32.0	1.8	6.1
MW-2013-F	(16)	3.1	<2.0	112	<1.0	<1.0	2.2	<32.0	1.1	6.0
MW-2014	<14.0	<1.0	<2.0	270	<1.0	1.6	<2.0	293	<1.0	20
MW-2014-F	<14.0	2.2	<2.0	260	<1.0	2.0	<2.0	262	<1.0	40
MW-2015	<19	<1.0	4.6	66	<1.0	<5.7	<2.0	42	1.4	13
MW-2015-F	<14	<1.6	6.3	67	<1.0	<5.8	<2.0	34.0	<1.0	13
MW-2017	813	<2.0	<3.0	65	<1.0	4.0	<2.0	566	<7.70	86
MW-2017-F	<98	6.5	3.3	38.0	<1.0	1.8	<2.0	<34.0	<4.20	170

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-2018	17.0	<1.0	<2.0	439	<1.0	1.5	<2.0	54	1.7	20.0
MW-2018-F	<14.0	3.6	<2.0	438	<1.0	1.0	<2.0	102	1.4	20
MW-2019	<14.0	<1.0	<2.0	168	<1.0	2.9	3.1	160	<1.0	21.0
MW-2019-F	32	2.9	<2.0	167	<1.0	2.1	<2.0	128	<1.0	21
MW-2021	<768	<1.0	<2.0	224	<1.0	15	<35	<278	<2.1	(0.90)
MW-2021-F	<471	1.3	<2.0	214	<1.0	16	<34	<80	<1.4	(0.30)
MW-2022	28	<1.0	<2.0	183	<1.0	2.7	2.2	124	1.1	3.7
MW-2022-F	<14.0	1.6	<2.0	184	<1.0	2.8	4.2	91	<1.0	3.7
MW-2023	74	1.7	<2.0	100	<1.0	4.8	8.0	261	6.7	3.6
MW-2023-F	<14.0	3.1	<2.0	89	<1.0	2.3	<2.0	49	<1.0	3.0
MW-2024	27	<1.0	<2.0	86	<1.0	1.6	<2.0	241	<1.0	5.3
MW-2024-F	<14.0	2.1	<2.0	83	<1.0	2.1	<2.0	251	<1.0	5.2
MW-2026	232	<1.0	7.4	214	<1.0	11.0	4.3	315	5.0	2.7
MW-2026-F	76.0	1.7	9.2	202	<1.0	3.3	<2.0	86	<1.0	2.7
MW-2027	(20)	<1.0	<2.0	264	<1.0	1.6	<2.0	198	<1.0	3.7
MW-2027-F	(23)	1.6	<2.0	274	<1.0	1.5	<2.0	211	<1.0	3.9
MW-2028	<30	<1.0	6.9	122	<1.0	<3.7	2.9	605	<1.0	15
MW-2028-F	<23	<2.3	<2.0	116	<1.0	<2.6	<2.0	87	<1.0	15
MW-2030	1,960	<1.0	<2.0	228	<1.0	<5.0	32	2,840	7.2	3.4
MW-2030-F	<19	<1.0	<2.0	192	<1.0	<1.7	3.5	149	<1.0	2.5
MW-2032	2,190	<1.0	3.1	343	<1.0	6.5	16	3,160	9.7	14
MW-2032-F	74	1.6	<2.0	314	<1.0	2.9	6.8	82	1.5	13
MW-2033	881	<1.0	<2.0	128	<1.0	3.8	13	1,450	7.1	3.7
MW-2033-F	(20)	2.6	<2.0	110	<1.0	<1.0	2.8	<32.0	<1.0	3.3
MW-2034	<168	<2.0	<3.0	27.0	<1.0	1.2	<2.0	44.0	<5.90	32
MW-2034-F	<85	2.4	<3.0	26	<1.0	<1.0	<2.00	<34.0	<2.50	32

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-2035	21.0	<1.0	<2.0	88	<1.0	<1.0	2.0	120	1.1	2.7
MW-2035-F	27	2.2	<2.0	87	<1.0	1.0	<2.0	122	1.3	2.7
MW-2036	<14.0	<1.0	<2.0	284	<1.0	<1.0	<2.0	<32.0	<1.0	6.8
MW-2036-F	43	1.0	<2.0	279	<1.0	1.3	34	152	<1.0	6.7
MW-2037	19	<1.0	<2.0	79	<1.0	<1.0	<2.0	130	1.5	395
MW-2037-F	17	1.3	<2.0	75	<1.0	<1.0	<2.0	56.0	<1.0	380
MW-2038	299	<1.0	<2.0	178	<1.0	1.7	3.6	472	<1.0	496
MW-2038-F	19	<1.0	<2.0	172	<1.0	<1.0	2.4	100	<1.0	449
MW-2039	1,320	<1.0	6.2	214	<1.0	10	6.4	1,490	3.0	22
MW-2039-F	50	2.7	<2.0	212	<1.0	6.1	3.1	33	<1.0	21
MW-2040	1,310	<1.0	<2.0	562	<1.0	25	52	4,930	12.0	23
MW-2040-F	<14.0	<1.0	<2.0	606	<1.0	14	11	89	<1.0	24
MW-2041	125	<1.0	<2.0	223	<1.0	2.4	<2.0	231	1.1	24
MW-2041-F	(17)	2.0	<2.0	228	<1.0	4.3	<2.0	44	<1.0	23
MW-2042	261	<1.0	<2.0	472	<1.0	<3.8	3.7	328	<1.0	18.0
MW-2042-F	<14.0	2.1	<2.0	446	<1.0	<2.4	<2.0	53	<1.0	16
MW-2043	171	<1.0	<2.0	254	<1.0	<4.6	5.2	238	<1.0	13
MW-2043-F	<14.0	<1.0	<2.0	253	<1.0	<5.3	4.9	38	<1.0	14
MW-2044	517	<1.0	<2.0	46	<1.0	3.8	6.8	315	4.9	28
MW-2044-F	(23)	3.1	2.5	43	<1.0	4.5	<2.0	61	<1.0	28
MW-3003	42	1.1	<2.0	180	<1.0	2.2	<2.0	87	1.9	648
MW-3003-F	54	3.2	<2.0	175	<1.0	2.1	<2.0	47	<1.0	676
MW-3006	(25)	<1.0	<2.0	149	<1.0	2.4	<2.0	299	<1.0	12
MW-3006-F	(17)	2.1	<2.0	148	<1.0	1.8	<2.0	300	<1.0	12.0
MW-3019	<14.0	1.8	<2.0	342	<1.0	1.5	<2.0	54	2.2	11.0
MW-3019-F	<14.0	<1.0	2.1	333	<1.0	1.8	2.1	159	<1.0	12.0

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-3023	1,680	<1.0	<2.0	48	<1.0	6.8	7.5	2,430	4.0	644
MW-3023-F	(16)	2.1	<2.0	35	<1.0	1.2	<2.0	<32.0	<1.0	603
MW-3024	<14.0	<1.0	<2.0	164	<1.0	2.0	2.0	160	<1.0	201
MW-3024-F	<14.0	2.5	<2.0	162	<1.0	1.6	<2.0	144	<1.0	212
MW-3025	897	1.6	<2.0	490	<1.0	3.7	3.8	2,490	2.4	159
MW-3025-F	<14.0	1.5	<2.0	470	<1.0	2.7	<2.0	130	<1.0	151
MW-3026	8,650	<1.0	<2.0	2,600	<1.0	2.7	20	3,580	25	35
MW-3026-F	19	4.1	<2.0	1,310	<1.0	1.2	2.1	73	<1.0	31
MW-3027	924	<1.0	<2.0	772	<1.0	2.7	2.3	1,880	2.1	16
MW-3027-F	26	2.9	<2.0	766	<1.0	<1.0	<2.0	55	<1.0	15.0
MW-4001	34	<1.0	<2.0	76	<1.0	<1.0	<2.0	91	<1.0	6.5
MW-4001-F	<14.0	2.4	<2.0	75	<1.0	<1.0	<2.0	59	<1.0	7.6
MW-4002	1,210	(0.86)	<2.0	129	(0.13)	<8.0	8.2	2,240	6.1	3.9
MW-4002-F	<20	1.8	<2.0	119	(0.10)	<1.10	6.4	614	(0.68)	1.8
MW-4003	32	<1.0	<2.0	164	<1.0	<1.0	2.0	117	25	2.7
MW-4003-F	20	1.7	<2.0	154	<1.0	<1.0	2.1	<32.0	<1.0	2.7
MW-4004	34	<1.0	<2.0	128	<1.0	<1.0	<2.0	55	6.9	3.6
MW-4004-F	<14.0	1.7	<2.0	124	<1.0	<1.0	<2.0	<32.0	2.7	3.6
MW-4005	40.0	<1.0	<2.0	87	<1.0	4.5	<2.0	<32.0	18	5.1
MW-4005-F	15	1.6	<2.0	90	<1.0	4.8	<2.0	<32.0	12	5.1
MW-4006	753	<1.0	<2.0	173	<1.0	2.3	<2.0	663	2.7	3.0
MW-4006-F	31	1.2	<2.0	176	<1.0	<1.0	<2.0	51	<1.0	2.3
MW-4007	137	<1.0	<2.0	77	<1.0	5.4	2.7	136	3.3	5.5
MW-4007-F	<14.0	4.0	<2.0	76	<1.0	5.3	2.5	34	<1.0	5.9
MW-4008	40	1.5	<2.0	111	<1.0	8.1	5.4	259	71	2.3
MW-4008-F	17	2.7	<2.0	105	<1.0	1.9	<2.0	56	<1.0	2.3

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-4009	<14.0	4.4	<2.0	42	<1.0	21	<2.0	38	3.2	67
MW-4009-F	14	2.1	<2.0	38.0	<1.0	21	<2.0	<32.0	<1.0	67
MW-4010	<20	1.6	(0.12)	83	(0.17)	<2.10	5.4	462	18	5.8
MW-4010-F	<28	2.3	<2.0	85	(0.15)	<2.10	5.1	422	15	5.7
MW-4011	<35	(0.23)	<2.0	298	(0.03)	<2.90	5.9	1,560	2.1	59
MW-4011-F	(13)	2.5	<2.0	303	<1.0	<1.90	5.7	1,530	1.0	58
MW-4012	209	<1.0	<2.0	78.0	1.9	29	<2.0	1,490	6.1	25
MW-4012-F	<14.0	2.7	<2.0	71	<1.0	12	<2.0	81	<1.0	22
MW-4013	<14.0	<1.0	<2.0	178	<1.0	1.2	<2.0	280	1.1	58
MW-4013-F	<14.0	2.3	<2.0	184	<1.0	1.0	<2.0	250	<1.0	67
MW-4014	120	<1.0	<2.0	109	<1.0	1.9	<2.0	887	3.1	3.5
MW-4014-F	<14.0	2.7	<2.0	103	<1.0	1.8	<2.0	107	<1.0	3.1
MW-4015	<57	(0.18)	<2.0	200	(0.10)	<2.40	6.3	907	1.2	1.9
MW-4015-F	<36.0	1.5	(0.73)	198	<1.0	<1.70	3.8	513	(0.67)	1.9
MW-4016	<14.0	<1.0	<2.0	224	<1.0	<5.2	<2.0	163	<1.0	2.7
MW-4016-F	<14.0	1.6	<2.0	221	<1.0	<4.8	<2.0	32	<1.0	2.6
MW-4018	74	<1.0	<2.0	198	<1.0	<1.0	<2.0	34	8.8	3.9
MW-4018-F	61	1.6	<2.0	191	<1.0	<1.0	<2.0	34	1.9	4.6
MW-4019	873	1.7	<2.0	190	<1.0	2.6	5.0	1,510	11.0	9.8
MW-4019-F	19	<1.0	<2.0	180	<1.0	<1.0	<2.0	123	<1.0	8.7
MW-4020	16.0	<1.0	<2.0	69	<1.0	<1.0	<2.0	<32.0	9.1	17
MW-4020-F	34	1.9	<2.0	69	<1.0	2.6	<2.0	65	1.7	18
MW-4021	26	1.1	<2.0	33	<1.0	<1.0	<2.0	51.0	4.7	19
MW-4021-F	34	1.7	<2.0	33	<1.0	<1.0	<2.0	45	<1.0	19
MW-4022	47,600	1.4	12	855	3.0	161	56	57,000	371	34
MW-4022-F	<14.0	4.5	<2.0	152	<1.0	<1.0	<2.0	35	<1.0	7.0

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MW-4023	39.0	<1.0	<2.0	84	<1.0	<1.0	<2.0	<32.0	<1.0	15.0
MW-4023-F	58	1.3	<2.0	84	<1.0	<1.0	<2.0	<32.0	<1.0	15
MW-4024	5,430	<2.0	5.8	88	<1.0	37	15	7,410	16	36
MW-4024-F	<105	2.4	<3.0	34	<1.0	<1.0	<2.0	<34.0	<2.10	31
MW-4025	1,200	<2.0	<3.0	174	<1.0	14	<2.0	2,390	<6.70	9.4
MW-4025-F	<94	<2.0	<3.0	152	<1.0	<1.0	<2.0	<34.0	<2.30	<8.30
MWD-2	2,010	<1.0	<2.0	196	<1.0	2.3	<2.0	1,440	3.7	3.9
MWD-2-F	38	4.2	<2.0	167	<1.0	1.6	<2.0	157	<1.0	2.8
MWD-5	32	1.6	<2.0	99.0	<1.0	<1.0	2.8	33	<1.0	17
MWD-5-F	<14.0	<1.0	<2.0	98	<1.0	<1.0	<2.0	34	<1.0	17.0
MWD-6	15	<1.0	<2.0	155	<1.0	<1.0	<2.0	<32.0	<1.0	4.1
MWD-6-F	55	<1.0	<2.0	156	<1.0	<1.0	6.1	<32.0	<1.0	4.6
MWD-9	<38.0	<1.0	<2.0	129	<1.0	1.2	<2.0	<32.0	<1.0	4.1
MWD-9-F	<38.0	1.5	<2.0	126	<1.0	2.1	<2.0	58	<1.0	4.2
MWD-15	15	<1.0	<2.0	93.0	<1.0	3.7	15	43	<1.0	1.2
MWD-15-F	<14.0	1.7	<2.0	95	<1.0	4.2	2.2	<32.0	<1.0	1.2
MWD-18	19	<1.0	<2.0	127	<1.0	<1.0	3.8	493	<1.0	5.7
MWD-18-F	<14.0	1.3	<2.0	130	<1.0	<1.0	<2.0	127	<1.0	5.9
MWD-23	102	<1.0	4.3	150	<1.0	1.5	2.6	349	<1.0	3.6
MWD-23-F	<29.0	1.1	<2.0	148	<1.0	1.6	<2.0	206	<1.0	3.7
MWD-25	62	<1.0	<2.0	119	<1.0	1.8	2.7	227	<1.0	2.1
MWD-25-F	22	<1.0	<2.0	117	<1.0	1.0	<2.0	83	<1.0	1.4
MWD-105	80	<1.0	3.3	110	<1.0	1.8	2.2	57	<1.0	3.6
MWD-105-F	169	<1.0	4.7	108	<1.0	1.6	<2.0	<32.0	<1.0	3.6
MWD-106	<49.0	<1.0	<2.0	139	<1.0	2.8	216	1,390	<1.0	3.1
MWD-106-F	<49.0	<1.0	<2.0	130	<1.0	3.7	<2.0	70	<1.0	3.0

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MWD-107	<29.0	<1.0	15	143	<1.0	1.7	<2.0	176	<1.0	4.2
MWD-107-F	33.0	<1.0	15	136	<1.0	1.3	<2.0	189	<1.0	4.0
MWD-109	35	<1.0	<2.0	137	<1.0	1.0	<2.0	76	<1.0	3.4
MWD-109-F	16.0	<1.0	<2.0	144	<1.0	1.0	<2.0	<32.0	<1.0	3.5
MWD-112	34	<1.0	<2.0	85	<1.0	1.8	<2.0	248	<1.0	2.2
MWD-112-F	24	<1.0	<2.0	85.0	<1.0	1.8	<2.0	196	<1.0	2.3
MWS-1	26	<1.0	<2.0	116	<1.0	3.4	<2.0	59	<1.0	1.9
MWS-1-F	67	<1.0	<2.0	116	<1.0	3.2	<2.0	71	<1.0	1.8
MWS-2	286	<1.0	<2.0	120	<1.0	5.0	<2.0	361	<1.0	3.4
MWS-2-F	22	1.0	<2.0	116	<1.0	4.9	<2.0	123	<1.0	3.4
MWS-3	49	<1.0	<2.0	98	<1.0	4.6	<2.0	176	<1.0	4.1
MWS-3-F	<14.0	<1.0	<2.0	137	<1.0	2.1	<2.0	79	<1.0	<1.0
MWS-4	915	<1.0	<2.0	149	<1.0	<1.0	3.0	452	2.1	3.9
MWS-4-F	<14.0	<1.0	<2.0	149	<1.0	<1.0	<2.0	<32.0	<1.0	3.5
MWS-5	22	<1.0	<2.0	109	<1.0	<1.0	<2.0	67	<1.0	2.6
MWS-5-F	<14.0	<1.0	<2.0	109	<1.0	<1.0	<2.0	<32.0	<1.0	3.0
MWS-6	<14.0	<1.0	<2.0	150	<1.0	<1.0	<2.0	<32.0	<1.0	4.3
MWS-6-F	33	6.9	<2.0	146	<1.0	<1.0	<2.0	<32.0	<1.0	4.2
MWS-7	49.0	<1.0	<2.0	137	<1.0	2.3	2.1	81	<1.0	<1.0
MWS-7-F	<14.0	<1.0	<2.0	133	<1.0	1.8	<2.0	<32.0	<1.0	<1.0
MWS-8	1,300	2.4	<2.0	223	<1.0	3.3	5.9	607	2.2	22
MWS-8-F	<14.0	1.0	<2.0	216	<1.0	<1.0	<2.0	72	<1.0	19
MWS-9	<38.0	<1.0	<2.0	138	<1.0	4.4	<2.0	37	<1.0	6.6
MWS-9-F	<38.0	<1.0	<2.0	128	<1.0	4.4	<2.0	<32.0	<1.0	6.8
MWS-10	31	<1.0	<2.0	227	<1.0	4.5	<2.0	160	<1.0	3.2
MWS-10-F	<14.0	<1.0	<2.0	222	<1.0	4.4	<2.0	110	<1.0	3.0

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MWS-11	316	<1.0	<2.0	158	<1.0	<1.0	<2.0	283	<1.0	2.0
MWS-11-F	<14.0	<1.0	2.0	150	<1.0	<1.0	<2.0	89	<1.0	1.8
MWS-12	121	<1.0	<2.0	90	<1.0	<1.0	<2.0	231	<1.0	2.5
MWS-12-F	75	<1.0	<2.0	78	<1.0	<1.0	<2.0	138	<1.0	2.5
MWS-13	<14.0	<1.0	<2.0	28	<1.0	<1.0	<2.0	308	<1.0	6.4
MWS-13-F	<14.0	<1.0	<2.0	29	<1.0	<1.0	<2.0	256	<1.0	6.4
MWS-14	220	<1.0	2.2	585	<1.0	<1.0	6.7	495	1.6	22
MWS-14-F	15	<1.0	<2.0	596	<1.0	<1.0	7.2	49	1.0	22
MWS-15	55	<1.0	<2.0	73	<1.0	<1.0	3.0	130	<1.0	1.3
MWS-15-F	<14.0	<1.0	<2.0	73.0	<1.0	<1.0	<2.0	57	<1.0	1.2
MWS-16	<14.0	<1.0	<2.0	114	<1.0	<1.0	3.0	443	<1.0	<1.0
MWS-16-F	<14.0	<1.0	<2.0	117	<1.0	<1.0	<2.0	98.0	<1.0	<1.0
MWS-17	1,250	1.8	<2.0	88	<1.0	1.1	3.0	907	1.7	2.6
MWS-17-F	<14.0	<1.0	<2.0	82	<1.0	1.8	<2.0	86	<1.0	2.2
MWS-18	236	1.1	3.0	60	<1.0	<1.0	2.5	103	1.5	8.2
MWS-18-F	16	1.8	2.9	50	<1.0	<1.0	2.3	56	<1.0	7.9
MWS-19	1,090	<1.0	<2.0	111	<1.0	<1.0	<2.0	571	1.3	1.2
MWS-19-F	23	<1.0	2.0	105	<1.0	<1.0	<2.0	54	<1.0	<1.0
MWS-20	<14.0	<1.0	<2.0	74	<1.0	5.2	<2.0	<32.0	<1.0	1.4
MWS-20-F	19	<1.0	<2.0	74	<1.0	4.2	<2.0	<32.0	<1.0	1.4
MWS-21	329	<1.0	<2.0	212	<1.0	1.2	49	653	<1.0	274
MWS-21-F	<14.0	<1.0	<2.0	213	<1.0	1.1	42	545	<1.0	260
MWS-22	52	<1.0	14	154	<1.0	2.4	3.6	101	<1.0	3.0
MWS-22-F	64	<1.0	2.5	155	<1.0	1.8	2.1	<32.0	<1.0	3.0
MWS-23	15,300	<1.0	8.8	167	<1.0	22	29	17,600	14	10
MWS-23-F	3,860	<1.0	<2.0	89	<1.0	5.6	12	3,170	3.4	3.6

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MWS-25	947	<1.0	2.5	150	<1.0	9.9	14	4,170	4.4	<1.0
MWS-25-F	<14.0	2.5	<2.0	107	<1.0	1.8	2.1	417	<1.0	<1.0
MWS-101	244	<1.0	4.8	426	<1.0	1.2	<2.0	5,600	<1.0	1.1
MWS-101-F	<38.0	<1.0	5.4	425	<1.0	<1.0	<2.0	5,560	<1.0	<1.0
MWS-102	679	<1.0	10	217	<1.0	1.5	10	2,320	2.6	4.9
MWS-102-F	<14.0	<1.0	8.7	198	<1.0	1.1	<2.0	1,590	<1.0	5.3
MWS-103	1,750	<1.0	43	180	<1.0	2.4	11	12,400	8.7	2.0
MWS-103-F	40	<1.0	<2.0	143	<1.0	<1.0	<2.0	152	<1.0	1.0
MWS-104	414	<1.0	<2.0	201	<1.0	<1.0	2.8	254	1.2	1.7
MWS-104-F	<14.0	<1.0	<2.0	195	<1.0	<1.0	<2.0	<32.0	<1.0	1.6
MWS-105	22.0	<1.0	6.0	141	<1.0	2.1	<2.0	72	<1.0	2.0
MWS-105-F	<21	2.6	6.9	141	<1.0	2.1	<2.0	94	<1.0	2.1
MWS-106	939	1.7	<2.0	224	<1.0	2.1	<2.0	629	2.1	1.6
MWS-106-F	<49.0	<1.0	<2.0	214	<1.0	1.6	3.4	63.0	<1.0	1.2
MWS-107	716	<1.0	<2.0	197	<1.0	1.7	5.7	613	2.0	5.0
MWS-107-F	<29.0	<1.0	<2.0	201	<1.0	<1.0	<2.0	<32.0	<1.0	4.3
MWS-108	83	<1.0	9.7	130	<1.0	1.6	3.4	368	<1.0	4.5
MWS-108-F	48	<1.0	3.3	131	<1.0	1.5	2.2	138	<1.0	4.6
MWS-109	69	<1.0	<2.0	214	<1.0	1.5	<2.0	147	<1.0	2.2
MWS-109-F	19	<1.0	<2.0	217	<1.0	1.2	<2.0	<32.0	<1.0	2.3
MWS-110	1,230	<1.0	<2.0	186	<1.0	3.1	7.9	1,530	3.0	3.3
MWS-110-F	<14.0	<1.0	<2.0	171	<1.0	2.2	<2.0	314	<1.0	2.4
MWS-111	110	<1.0	<2.0	420	<1.0	4.0	7.6	983	2.4	2.0
MWS-111-F	<14.0	1.1	<2.0	405	<1.0	1.6	<2.0	41	<1.0	2.0
MWS-112	2,520	1.6	<2.0	148	<1.0	26	63	4,150	11	10
MWS-112-F	16.0	2.0	<2.0	113	<1.0	1.3	<2.0	48	<1.0	13

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
TIL3	207	<1.0	16.0	292	1.6	2.9	33	18,100	184	3.7
TIL3-F	83	1.8	<2.0	293	<1.0	1.5	<2.0	5,640	<1.0	3.6
USG1	62	<1.0	<2.0	202	<1.0	<1.0	<2.0	105	<1.0	3.0
USG1-F	<49.0	<1.0	<2.0	203	<1.0	<1.0	<2.0	34.0	<1.0	3.0
USG2	<49.0	3.1	<2.0	243	<1.0	1.9	<2.0	241	<1.0	<1.0
USG2-F	<49.0	<1.0	<2.0	241	<1.0	1.7	<2.0	80	<1.0	<1.0
USG3	<14.0	<1.0	<2.0	209	<1.0	1.8	<2.0	58	<1.0	4.8
USG3-F	<14.0	1.9	<2.0	217	<1.0	1.6	<2.0	55	<1.0	5.0
USG4	<14.0	<1.0	<2.0	98	<1.0	2.1	<2.0	56	<1.0	3.7
USG4-F	<14.0	<1.0	<2.0	97	<1.0	2.4	<2.0	75	<1.0	3.8
USG5	<14.0	<1.0	<2.0	177	<1.0	1.2	<2.0	54	<1.0	3.0
USG5-F	<14.0	1.0	<2.0	181	<1.0	1.6	<2.0	59.0	<1.0	3.0
USG6	<14.0	<1.0	<2.0	227	<1.0	2.2	<2.0	69	<1.0	1.8
USG6-F	<14.0	<1.0	<2.0	225	<1.0	2.5	<2.0	86	<1.0	1.7
USG8	32.0	1.1	3.6	124	<1.0	2.5	<2.0	344	1.6	1.8
USG8-F	27	2.2	2.6	124	<1.0	2.0	<2.0	105	<1.0	1.7
USG9	<21	<1.0	2.5	88	<1.0	3.0	<2.0	32	<1.0	2.0
USG9-F	<21	<1.0	3.2	90	<1.0	3.1	<2.0	111	<1.0	1.9
MWV-1	332	<1.0	<2.0	105	<1.0	1.2	3.3	335	<1.0	2.3
MWV-1-F	39	2.3	<2.0	102	<1.0	<1.0	2.6	54	<1.0	2.2
MWV-2	449	<1.0	<2.0	115	<1.0	4.6	<2.0	670	1.9	3.0
MWV-2-F	23	4.0	<2.0	106	<1.0	<1.0	2.0	176	<1.0	2.6
MWV-9	<38.0	<1.0	<2.0	109	<1.0	<1.0	<2.0	41	<1.0	6.6
MWV-9-F	<38.0	<1.0	<2.0	91	<1.0	2.5	<2.0	<32.0	<1.0	6.0
MWV-13	133	<1.0	<2.0	39	<1.0	3.3	<2.0	498	<1.0	3.0
MWV-13-F	<14.0	1.9	<2.0	31	<1.0	2.3	<2.0	205	<1.0	3.2

TABLE C.6 (Cont.)

Well No.	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)
MWV-16	93	<1.0	<2.0	90	<1.0	<1.0	2.9	186	<1.0	1.2
MWV-16-F	<14.0	<1.0	<2.0	83	<1.0	<1.0	2.3	169	<1.0	1.1
MWV-17	248	1.7	<2.0	116	1.2	11	7.5	298	19	<1.0
MWV-17-F	36	7.0	<2.0	105	<1.0	6.6	3.8	41	<1.0	<1.0
MWV-22	91.0	<1.0	7.6	148	<1.0	2.2	<2.0	102	<1.0	2.3
MWV-22-F	63.0	<1.0	<2.0	145	<1.0	2.3	<2.0	53	<1.0	2.2
MWV-24	27	<1.0	<2.0	98	<1.0	<1.0	<2.0	277	<1.0	7.4
MWV-24-F	35	1.4	<2.0	98	<1.0	<1.0	<2.0	167	<1.0	7.4

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWD-2001	<2.2	<0.2	<5.9	(0.01)	<3.0	<1.0	<3.6
MWD-2001-F	<2.0	<0.2	<5.4	(0.1)	<3.0	<1.0	<3.4
MWD-2002	<2.8	<0.2	<13	1.6	<3.0	<1.0	<3.2
MWD-2002-F	<2.9	<0.2	<13	1.7	<3.0	<1.0	<3.1
MWD-2003	26.7	<0.2	<6.2	4.5	(1.5)	7.0	<3.2
MWD-2003-F	<3.4	<0.2	<6.2	3.6	3.2	<1.0	<3.2
MWD-2005	1.3	0.48	<1.0	3.6	3.7	<1.0	<1.0
MWD-2005-F	<1.0	<0.2	<1.0	3.1	4.1	<1.0	<1.0
MWD-2006	25	<0.2	1.6	67	<3.0	<1.0	<1.0
MWD-2006-F	26	<0.2	1.2	58	<3.0	<1.0	<1.0
MWD-2007	12	<0.2	<1.0	3.3	<3.0	<1.0	<1.0
MWD-2007-F	4.7	<0.2	<1.0	1.6	<3.0	<1.0	<1.0
MWD-2010	97	<0.2	2.8	85	<3.0	<1.0	<1.0
MWD-2010-F	94	<0.2	2.7	90	<3.0	<1.0	<1.0
MWD-2011	<1.0	<0.2	<1.0	2.4	<3.0	<1.0	<1.0
MWD-2011-F	<1.0	<0.2	<1.0	4.2	<3.0	<1.0	<1.0
MWD-2012	1.8	<0.2	<1.0	1.6	<3.0	<1.0	<1.0
MWD-2012-F	<1.0	<0.2	<1.0	1.5	<3.0	<1.0	<1.0
MWD-2013	<1.0	<0.2	<1.0	3.3	<3.0	<1.0	<1.0
MWD-2013-F	<1.0	<0.2	<1.0	3.5	<3.0	<1.0	<1.0
MWD-2014	1.2	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MWD-2014-F	<1.0	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MWD-2015	<1.0	<0.2	<1.0	2.1	3.5	<1.0	<1.0
MWD-2015-F	<1.0	<0.2	<1.0	1.9	4.0	<1.0	<1.0
MWD-2017	26	<0.2	16	8.9	<5.00	<1.0	<12
MWD-2017-F	<1.0	<0.2	16	4.8	<5.0	<1.0	<12
MWD-2018	2.5	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-2018-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MW-2019	41	<0.2	16	4.0	<3.0	<1.0	<1.0
MW-2019-F	50	<0.2	15	4.2	<3.0	<1.0	<1.0
MW-2021	56	<0.2	<9.7	6.1	<3.0	<1.0	<3.1
MW-2021-F	35	<0.2	<9.7	5.5	<3.0	<1.0	<3.0
MW-2022	124	<0.2	2.1	4.1	<3.0	<1.0	<1.0
MW-2022-F	125	<0.2	2.1	4.0	<3.0	<1.0	<1.0
MW-2023	13	<0.2	6.2	10	<3.0	<1.0	<1.0
MW-2023-F	5.5	<0.2	5.3	2.8	<3.0	<1.0	<1.0
MW-2024	56	<0.2	<1.0	3.0	<3.0	<1.0	<1.0
MW-2024-F	52	<0.2	<1.0	2.8	<3.0	<1.0	<1.0
MW-2026	98	<0.2	5.8	12	<3.0	<1.0	<1.0
MW-2026-F	69	<0.2	5.6	11	<3.0	<1.0	<1.0
MW-2027	376	<0.2	2.9	2.4	<3.0	<1.0	<1.0
MW-2027-F	388	<0.2	3.1	2.2	<3.0	<1.0	<1.0
MW-2028	436	<0.2	1.6	13	<3.0	<1.0	<1.0
MW-2028-F	419	<0.2	1.7	12	<3.0	<1.0	<1.0
MW-2030	123	<0.2	<1.0	9.4	3.5	<1.0	<1.0
MW-2030-F	6.1	<0.2	<1.0	4.3	<3.0	<1.0	<1.0
MW-2032	189	<0.2	<1.0	14	4.8	2.9	<1.0
MW-2032-F	9.1	<0.2	<1.0	6.3	4.6	<1.0	<1.0
MW-2033	86	0.35	<1.0	9.6	<3.0	<1.0	<1.0
MW-2033-F	2.2	<0.2	<1.0	3.4	<3.0	<1.0	<1.0
MW-2034	<1.0	<0.2	<1.0	9.9	<5.00	<1.0	<11.8
MW-2034-F	<1.0	<0.2	<1.0	9.0	<5.0	<1.0	<11.8
MW-2035	<1.0	<0.2	<1.0	2.2	<3.0	<1.0	<1.0
MW-2035-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-2036	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MW-2036-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MW-2037	65	3.6	<1.0	7.4	5.6	<1.0	<1.0
MW-2037-F	58	1.3	<1.0	6.5	3.9	<1.0	<1.0
MW-2038	25	3.5	<1.0	15	12.0	<1.0	<1.0
MW-2038-F	22	2.8	<1.0	13	13	<1.0	<1.0
MW-2039	95	<0.2	4.4	9.6	7.5	<1.0	<1.0
MW-2039-F	1.7	<0.2	3.8	5.4	8.0	<1.0	<1.0
MW-2040	274	<0.2	6.6	32.0	5.5	7.1	<1.0
MW-2040-F	4.2	<0.2	5.9	20	6.1	<1.0	<1.0
MW-2041	36	<0.2	2.2	5.7	12	<1.0	<1.0
MW-2041-F	20	<0.2	1.7	6.4	12	<1.0	<1.0
MW-2042	11	<0.2	<1.0	<6.9	<3.0	<1.0	<1.0
MW-2042-F	<1.0	<0.2	<1.0	<5.7	3.4	<1.0	<1.0
MW-2043	18	<0.2	<1.0	<6.2	4.1	<1.0	<1.0
MW-2043-F	<1.0	<0.2	1.2	<5.6	4.9	<1.0	<1.0
MW-2044	6.5	<0.2	<1.0	5.1	3.7	<1.0	<1.0
MW-2044-F	1.2	<0.2	1.4	3.2	3.5	<1.0	<1.0
MW-3003	23	<0.2	4.9	8.1	8.2	<1.0	<1.0
MW-3003-F	21	<0.2	5.2	7.8	8.0	<1.0	<1.0
MW-3006	120	<0.2	14	4.7	<3.0	<1.0	<1.0
MW-3006-F	120	<0.2	14.0	4.3	<3.0	<1.0	<1.0
MW-3019	153	<0.2	1.0	1.5	<3.0	<1.0	<1.0
MW-3019-F	124	<0.2	1.1	<1.0	<3.0	<1.0	<1.0
MW-3023	40	<0.2	224	7.7	7.3	<1.0	<1.0
MW-3023-F	3.8	<0.2	216	3.8	7.2	<1.0	<1.0
MW-3024	1.0	1.4	<1.0	2.7	13.5	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-3024-F	1.6	0.93	<1.0	10	13	<1.0	<1.0
MW-3025	46	0.53	<1.0	16.0	12	<1.0	<1.0
MW-3025-F	20	0.31	<1.0	15	11	<1.0	<1.0
MW-3026	195	<0.2	<1.0	78	5.5	<1.0	<1.0
MW-3026-F	2.7	<0.2	1.1	9.2	3.4	<1.0	<1.0
MW-3027	44	0.38	<1.0	7.4	<3.0	<1.0	<1.0
MW-3027-F	2.0	0.22	<1.0	2.8	<3.0	<1.0	<1.0
MW-4001	17	<0.2	<1.0	8.5	<3.0	<1.0	<1.0
MW-4001-F	2.0	<0.2	<1.0	6.8	<3.0	<1.0	<1.0
MW-4002	30	<0.2	1.1	8.3	(1.6)	(0.04)	(0.07)
MW-4002-F	3.2	<0.2	1.1	6.7	(1.6)	(0.03)	(0.02)
MW-4003	6.6	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MW-4003-F	<1.0	<0.2	<1.0	1.8	<3.0	<1.0	<1.0
MW-4004	2.6	<0.2	2.3	1.2	<3.0	<1.0	<1.0
MW-4004-F	<1.0	<0.2	2.3	2.1	<3.0	<1.0	<1.0
MW-4005	3.0	<0.2	3.8	4.4	<3.0	<1.0	<1.0
MW-4005-F	<1.0	<0.2	3.7	4.2	<3.0	<1.0	<1.0
MW-4006	97	<0.2	1.1	7.0	3.1	<1.0	<1.0
MW-4006-F	<1.0	<0.2	<1.0	3.9	<3.0	<1.0	<1.0
MW-4007	26	<0.2	5.1	5.9	<3.0	<1.0	<1.0
MW-4007-F	1.4	<0.2	5.5	5.0	<3.0	<1.0	<1.0
MW-4008	135	<0.2	<1.0	10	<3.0	<1.0	<1.0
MW-4008-F	7.8	<0.2	1.0	<1.0	<3.0	<1.0	<1.0
MW-4009	2.8	<0.2	7.0	2.1	<3.0	<1.0	<1.0
MW-4009-F	1.7	<0.2	7.2	1.9	<3.0	<1.0	<1.0
MW-4010	3.2	<0.2	3.7	6.1	(1.5)	(0.03)	<1.0
MW-4010-F	1.4	<0.2	3.7	5.7	(1.1)	(0.005)	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-4011	12	<0.2	3.2	11	5.3	(0.01)	<1.0
MW-4011-F	1.2	<0.2	3.3	11	6.1	<1.0	<1.0
MW-4012	129	<0.2	30	9.6	<3.0	1.4	<1.0
MW-4012-F	5.3	<0.2	31	1.3	<3.0	<1.0	<1.0
MW-4013	2.6	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MW-4013-F	2.4	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MW-4014	66	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MW-4014-F	30	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MW-4015	9.8	<0.2	(0.25)	5.0	(1.9)	(0.16)	<1.0
MW-4015-F	1.5	<0.2	(0.17)	4.4	(1.6)	(0.01)	<1.0
MW-4016	44	<0.2	8.1	<5.1	<3.0	<1.0	<1.0
MW-4016-F	29.0	<0.2	7.8	<4.3	<3.0	<1.0	<1.0
MW-4018	4.6	<0.2	<1.0	4.0	<3.0	<1.0	<1.0
MW-4018-F	<1.0	<0.2	<1.0	3.9	<3.0	<1.0	<1.0
MW-4019	146	<0.2	<1.0	4.7	<3.0	<1.0	<1.0
MW-4019-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MW-4020	48	<0.2	1.4	16	<3.0	<1.0	<1.0
MW-4020-F	27	<0.2	1.6	14	<3.0	<1.0	<1.0
MW-4021	38	<0.2	<1.0	8.6	<3.0	<1.0	<1.0
MW-4021-F	28	<0.2	<1.0	10	<3.0	<1.0	<1.0
MW-4022	4,870	0.21	6.6	293	5.8	22	<1.0
MW-4022-F	329	<0.2	4.3	16	<3.0	<1.0	<1.0
MW-4023	1.5	<0.2	<1.0	2.6	<3.0	<1.0	<1.0
MW-4023-F	<1.0	<0.2	<1.0	2.2	<3.0	<1.0	<1.0
MW-4024	239	<0.2	6.2	67.0	<5.0	1.1	<13
MW-4024-F	122	<0.2	<2.40	17	<5.0	<1.0	<13
MW-4025	118	<0.2	<2.60	15	<5.0	<1.0	<12.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MW-4025-F	<1.0	<0.2	<1.0	<1.0	<5.0	<1.0	<12
MWD-2	205	<0.2	5.3	4.3	<3.0	<1.0	<1.0
MWD-2-F	81	<0.2	5.2	2.3	<3.0	<1.0	<1.0
MWD-5	11	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWD-5-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWD-6	33	<0.2	<1.0	3.7	<3.0	<1.0	<1.0
MWD-6-F	31	<0.2	<1.0	6.3	<3.0	<1.0	<1.0
MWD-9	<1.0	<0.2	<1.0	1.3	<3.0	<1.0	<1.0
MWD-9-F	1.2	<0.2	<1.0	2.8	<3.0	<1.0	<1.0
MWD-15	1.4	<0.2	<1.0	3.2	<3.0	<1.0	<1.0
MWD-15-F	<1.0	<0.2	<1.0	3.3	<3.0	<1.0	<1.0
MWD-18	12	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWD-18-F	8.7	<0.2	<1.0	1.2	<3.0	<1.0	<1.0
MWD-23	358	<0.2	22	58	<3.0	<1.0	<1.0
MWD-23-F	270	<0.2	21	59.0	<3.0	<1.0	<1.0
MWD-25	22	<0.2	1.9	6.7	<3.0	<1.0	1.9
MWD-25-F	16.0	<0.2	1.7	3.7	<3.0	<1.0	2.2
MWD-105	9.9	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
MWD-105-F	1.7	<0.2	<1.0	1.4	<3.0	<1.0	<1.0
MWD-106	8.8	<0.2	<1.0	1.4	<3.0	<1.0	<1.0
MWD-106-F	8.6	<0.2	<1.0	1.4	<3.0	<1.0	<1.0
MWD-107	47	<0.2	4.6	11	<3.0	<1.0	<1.0
MWD-107-F	50.0	<0.2	4.7	11	<3.0	<1.0	<1.0
MWD-109	18	<0.2	1.3	4.8	<3.0	<1.0	<1.0
MWD-109-F	6.4	<0.2	1.3	2.1	<3.0	<1.0	<1.0
MWD-112	16	<0.2	1.6	4.1	<3.0	<1.0	<1.0
MWD-112-F	14	<0.2	1.6	3.3	<3.0	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWS-1	<1.0	<0.2	<1.0	5.2	<3.0	<1.0	<1.0
MWS-1-F	<1.0	<0.2	1.0	4.6	<3.0	<1.0	<1.0
MWS-2	2.5	<0.2	3.2	3.8	<3.0	<1.0	<1.0
MWS-2-F	1.2	<0.2	4.0	3.5	<3.0	<1.0	<1.0
MWS-3	9.2	<0.2	3.3	3.7	<3.0	<1.0	1.1
MWS-3-F	1.2	<0.2	<1.0	2.1	<3.0	<1.0	1.9
MWS-4	21	0.20	<1.0	4.4	<3.0	<1.0	<1.0
MWS-4-F	<1.0	<0.2	<1.0	4.1	<3.0	<1.0	<1.0
MWS-5	6.8	<0.2	<1.0	1.8	<3.0	<1.0	<1.0
MWS-5-F	3.1	<0.2	<1.0	1.7	<3.0	<1.0	<1.0
MWS-6	15	<0.2	<1.0	8.4	<3.0	<1.0	<1.0
MWS-6-F	17	<0.2	<1.0	6.0	<3.0	<1.0	<1.0
MWS-7	1.2	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
MWS-7-F	<1.0	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-8	37	<0.2	<1.0	7.1	<3.0	<1.0	<1.0
MWS-8-F	<1.0	<0.2	<1.0	2.6	<3.0	<1.0	<1.0
MWS-9	3.5	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MWS-9-F	2.5	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MWS-10	<1.0	<0.2	1.7	2.8	<3.0	<1.0	<1.0
MWS-10-F	<1.0	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MWS-11	15	<0.2	<1.0	3.8	<3.0	<1.0	<1.0
MWS-11-F	<1.0	<0.2	<1.0	3.1	<3.0	<1.0	<1.0
MWS-12	38	<0.2	<1.0	2.5	<3.0	<1.0	<1.0
MWS-12-F	38	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MWS-13	22	<0.2	<1.0	5.4	<3.0	<1.0	<1.0
MWS-13-F	20	<0.2	<1.0	4.2	<3.0	<1.0	<1.0
MWS-14	16	<0.2	<1.0	4.4	<3.0	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWS-14-F	1.4	<0.2	<1.0	2.9	<3.0	<1.0	<1.0
MWS-15	4.4	<0.2	<1.0	41	<3.0	<1.0	<1.0
MWS-15-F	<1.0	<0.2	<1.0	56	<3.0	<1.0	<1.0
MWS-16	1.7	<0.2	<1.0	8.6	<3.0	<1.0	<1.0
MWS-16-F	<1.0	<0.2	<1.0	7.1	<3.0	<1.0	<1.0
MWS-17	44	<0.2	<1.0	11	4.2	<1.0	<1.0
MWS-17-F	<1.0	<0.2	<1.0	8.9	3.9	<1.0	<1.0
MWS-18	77	<0.2	7.6	6.7	<3.0	<1.0	<1.0
MWS-18-F	4.9	<0.2	7.2	4.5	<3.0	<1.0	<1.0
MWS-19	39	<0.2	1.0	4.3	<3.0	<1.0	<1.0
MWS-19-F	26	<0.2	<1.0	3.6	<3.0	<1.0	<1.0
MWS-20	<1.0	<0.2	<1.0	1.9	<3.0	<1.0	<1.0
MWS-20-F	<1.0	<0.2	<1.0	2.1	<3.0	<1.0	<1.0
MWS-21	174	<0.2	4.4	86.0	<3.0	<1.0	<1.0
MWS-21-F	167	<0.2	4.4	87	3.9	<1.0	<1.0
MWS-22	2.6	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MWS-22-F	1.5	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MWS-23	554	<0.2	<1.0	35	<3.0	<1.0	<1.0
MWS-23-F	131	<0.2	<1.0	8.7	<3.0	<1.0	<1.0
MWS-25	633	<0.2	1.7	16	<3.0	<1.0	<1.0
MWS-25-F	236	<0.2	1.2	5.1	<3.0	<1.0	<1.0
MWS-101	875	<0.2	<1.0	1.6	<3.0	<1.0	<1.0
MWS-101-F	880	<0.2	<1.0	1.6	<3.0	<1.0	<1.0
MWS-102	610	<0.2	6.7	8.3	<3.0	<1.0	<1.0
MWS-102-F	596	<0.2	6.5	3.3	<3.0	<1.0	<1.0
MWS-103	297	<0.2	<1.0	10	<3.0	<1.0	<1.0
MWS-103-F	33.0	<0.2	<1.0	1.7	<3.0	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
MWS-104	22	<0.2	4.4	2.3	<3.0	<1.0	<1.0
MWS-104-F	15	<0.2	4.2	3.1	<3.0	<1.0	<1.0
MWS-105	13	<0.2	4.4	4.8	<3.0	<1.0	<1.0
MWS-105-F	11	<0.2	4.5	4.8	<3.0	<1.0	<1.0
MWS-106	66	<0.2	2.3	3.3	<3.0	<1.0	<1.0
MWS-106-F	60	<0.2	2.1	1.7	<3.0	<1.0	<1.0
MWS-107	25	<0.2	1.0	3.9	<3.0	<1.0	<1.0
MWS-107-F	2.0	<0.2	<1.0	1.7	<3.0	<1.0	<1.0
MWS-108	39	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-108-F	39	<0.2	<1.0	<1.0	<3.0	<1.0	<1.0
MWS-109	106	<0.2	1.9	4.9	<3.0	<1.0	<1.0
MWS-109-F	76	<0.2	2.3	3.5	<3.0	<1.0	<1.0
MWS-110	48	<0.2	<1.0	18	<3.0	<1.0	<1.0
MWS-110-F	5.5	<0.2	<1.0	2.3	<3.0	<1.0	<1.0
MWS-111	98	<0.2	<1.0	12	<3.0	<1.0	<1.0
MWS-111-F	<1.0	<0.2	<1.0	1.8	<3.0	<1.0	<1.0
MWS-112	190	<0.2	8.8	135	3.9	<1.0	<1.0
MWS-112-F	145	<0.2	11	23	<3.0	<1.0	<1.0
TIL3	47	<0.2	2.5	1.6	<3.0	<1.0	<1.0
TIL3-F	36	<0.2	2.5	<1.0	<3.0	<1.0	<1.0
USG1	1.6	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
USG1-F	<1.0	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
USG2	6.2	<0.2	1.8	3.4	<3.0	<1.0	<1.0
USG2-F	5.0	<0.2	1.7	3.2	<3.0	<1.0	<1.0
USG3	<1.0	<0.2	1.6	2.6	<3.0	<1.0	<1.0
USG3-F	<1.0	<0.2	1.4	2.7	<3.0	<1.0	<1.0
USG4	1.3	<0.2	1.2	8.7	<3.0	<1.0	<1.0

TABLE C.6 (Cont.)

Well No.	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µ/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Thallium (µg/L)
USG4-F	1.1	<0.2	1.3	9.2	<3.0	<1.0	<1.0
USG5	1.6	<0.2	2.0	9.0	<3.0	<1.0	<1.0
USG5-F	<1.0	<0.2	1.9	8.9	<3.0	<1.0	<1.0
USG6	1.4	<0.2	3.2	2.3	<3.0	<1.0	<1.0
USG6-F	<1.0	<0.2	3.1	2.7	<3.0	<1.0	<1.0
USG8	11	<0.2	<1.0	7.2	3.2	<1.0	<1.0
USG8-F	5.9	<0.2	<1.0	4.8	3.1	<1.0	<1.0
USG9	<1.0	<0.2	<1.0	2.2	<3.0	<1.0	<1.0
USG9-F	<1.0	<0.2	<1.0	2.0	<3.0	<1.0	<1.0
MWV-1	8.1	<0.2	<1.0	5.1	<3.0	<1.0	<1.0
MWV-1-F	2.1	<0.2	<1.0	4.7	<3.0	<1.0	<1.0
MWV-2	15	<0.2	<1.0	5.8	<3.0	<1.0	<1.0
MWV-2-F	3.8	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MWV-9	33	<0.2	<1.0	2.2	<3.0	<1.0	<1.0
MWV-9-F	14	<0.2	<1.0	2.7	<3.0	<1.0	<1.0
MWV-13	15	<0.2	<1.0	3.6	<3.0	<1.0	<1.0
MWV-13-F	<1.0	<0.2	<1.0	1.8	<3.0	<1.0	<1.0
MWV-16	10	<0.2	1.3	6.4	<3.0	<1.0	<1.0
MWV-16-F	1.0	<0.2	<1.0	6.3	<3.0	<1.0	<1.0
MWV-17	144	<0.2	<1.0	8.9	<3.0	<1.0	<1.0
MWV-17-F	6.7	<0.2	<1.0	5.1	<3.0	<1.0	<1.0
MWV-22	2.4	<0.2	<1.0	19	<3.0	<1.0	<1.0
MWV-22-F	<1.0	<0.2	<1.0	21	<3.0	<1.0	<1.0
MWV-24	63	<0.2	<1.0	5.4	<3.0	<1.0	<1.0
MWV-24-F	53	<0.2	1.0	5.3	<3.0	<1.0	<1.0

[a] F = filtered sample.

TABLE C.7 Results of 1995 Joint Spring Sampling

	5101		5201		5303		5402		5501		5504	
Parameter	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Ions (mg/L)												
Nitrate	NS[a]	2.5	<0.1	0.17	0.72	2.1	0.42	0.14	0.11	0.41	<0.1	<0.1
Sulfate	NS	48	NS	36	NS	51	NS	23	NS	39	NS	30
Chloride	NS	35	NS	13	NS	21	NS	22	NS	5.4	NS	2.7
Fluoride	NS	0.19	NS	0.14	NS	0.35	NS	0.14	NS	0.13	NS	<0.1
Filtered Metals (µg/L)												
Aluminum	NS	<14	35	<14	<14	<14	<14	<14	25	45	<14	25
Antimony	NS	2.7	<1	2.4	<1	3.2	1.9	1.8	2.6	2.2	<1	1.6
Arsenic	NS	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Barium	NS	153	84	121	90	113	108	180	101	112	93	117
Cadmium	NS	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	NS	<1.2	<1	<1	<1	1.6	<1	2.3	<1	<1	<1	<1
Copper	NS	3.9	2.3	<2	<2	<2	<2	<2	4.1	<2	4.3	6.1
Iron	NS	82	48	64	33	74	24.0	106	60	<32	42	90
Lead	NS	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Lithium	NS	2.5	<2	<1	3.1	8.8	<2	<1	<2	2.2	<2	<1
Manganese	NS	14	<1	3.4	6.9	4.1	1.7	4.7	16	21	1.7	3.9
Mercury	NS	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum	NS	<1	<1	<1	6.7	14	<1	<1	<1	<1	<1	<1
Nickel	NS	4.9	3.2	21	3.3	2.8	1.7	4.5	2.1	2.8	4.6	7.7
Selenium	NS	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Silver	NS	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1.7	<1
Thallium	NS	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

TABLE C.7 (Cont.)

	5101		5201		5303		5402		5501		5504	
Parameter	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Unfiltered Metals (mg/L)												
Aluminum	NS	97	83	<14	153	115	133	80	180	210	33	136
Antimony	NS	<1	<1	<1	<1	<1	1.7	<1	<1	1.2	<1	<1
Arsenic	NS	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Barium	NS	165	85	119	92.0	119	107	183	102	113	103	115
Cadmium	NS	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	NS	<1	<1	2.90	<1	1.2	<1	1.6	1.5	<1	<1	<1
Copper	NS	6.1	2.1	<2	<2.9	<2	<2	<2	<2	<2	<2	<2
Iron	NS	792	130	173	223	1,440	261	859	280	219	96	135
Lead	NS	<1	<1	<1	2.0	1.3	<2	<1	<1	<1	<1	<1
Lithium	NS	2.60	<2	<1	3.1	6.6	<2	<1	<2	2.3	<2	<1
Manganese	NS	55	2.0	5.5	11	44	4.4	13	21	31	1.7	6.1
Mercury	NS	<0.2	<0.2	<0.2	1.1	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum	NS	<1	<1	<1	6.9	10	<1	<1	<1	<1	<1	<1
Nickel	NS	4.7	3.9	5.1	3.8	3.0	1.6	1.8	1.7	2.3	4.1	6.0
Selenium	NS	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
Silver	NS	<1	<1	<1	<2	<1	<2	<1	<1	<1	<1	<1
Thallium	NS	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Radiological (pCi/L)												
Uranium, Total	NS	0.384	0.59	0.87	95	123	0.6	0.95	0.37	0.74	0.39	0.50
Nitroaromatics (mg/L)												
1,3,5-TNB	NS	<0.03	3.6	6.0	0.08	0.41	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
1,3-DNB	NS	<0.09	<0.09	<0.09	<0.09	[b]	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09
2,4,6-TNT	NS	<0.03	40	110	17	120	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
2,4-DNT	NS	<0.03	0.08	0.07	0.05	0.21	<0.03	<0.03	<0.03	0.05	<0.03	<0.03

TABLE C.7 (Cont.)

	5101		5201		5303		5402		5501		5504	
Parameter	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Nitroaromatics (mg/L) (Cont.)												
2,6-DNT	NS	<0.01	0.51	1.8	0.09	0.41	<0.01	<0.01	<0.01	0.08	<0.01	<0.01
2-Amino-4,6-DNT	NS	<0.02	7.4	19	2.6	9.2	<0.02	<0.02	<0.02	0.22	<0.02	<0.02
4-Amino-2,6-DNT	NS	<0.02	8.1	20	3.9	15	<0.02	<0.02	<0.02	0.37	<0.02	<0.02
2-Nitrotoluene	NS	<0.03	<0.03	<0.03	0.003	0.06	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
3-Nitrotoluene	NS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
4-Nitrotoluene	NS	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Nitrobenzene	NS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

TABLE C.7 (Cont.)

	5601		5602		5605		5612		6301	
Parameter	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Ions (mg/L)										
Nitrate	<0.1	<0.1	0.11	0.46	NS	0.14	NS	<0.1	5.1	17
Sulfate	NS	18	NS	14	NS	21	NS	23	NS	43
Chloride	NS	2.1	NS	1.1	NS	2.6	NS	2.2	NS	10
Fluoride	NS	<0.1	NS	<0.1	NS	<0.1	NS	<0.1	NS	0.15
Filtered Metals (µg/L)										
Aluminum	<14	199	28	52	NS	431	NS	51	<14	<14
Antimony	2.0	<1	3.5	<1	NS	<1	NS	13.0	2.1	1.5
Arsenic	<2	<2	<2	<2	NS	<2	NS	<2	3.5	<2
Barium	71	9.8	76	95	NS	116	NS	111	84	121
Cadmium	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Chromium	<1	<1	1.1	<1	NS	<1	NS	<1	<1	1.1
Copper	<2	2.7	<20	<2	NS	2.1	NS	<2	2.2	<2
Iron	19	1,220	829	89	NS	358	NS	86	31.0	53
Lead	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Lithium	<2	<1	<2	<1	NS	<1	NS	<1	5.3	18
Manganese	1.3	261	53	2.4	NS	32	NS	9.6	<1	<1
Mercury	<0.2	<0.2	<0.2	<0.2	NS	<0.2	NS	<0.2	<0.2	<0.2
Molybdenum	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Nickel	1.3	6.8	2.8	5.9	NS	6.6	NS	6.8	1.1	1.7
Selenium	<3	<3	<3	<3	NS	<3	NS	<3	<3	<3
Silver	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Thallium	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1

TABLE C.7 (Cont.)

Parameter	5601 May	5601 Aug.	5602 May	5602 Aug.	5605 May	5605 Aug.	5612 May	5612 Aug.	6301 May	6301 Aug.
Unfiltered Metals (µg/L)										
Aluminum	47	99	301	30	NS	15	NS	49	626	320
Antimony	3.6	<1	<1	9.2	NS	2.7	NS	13.0	<1	<1
Arsenic	2.10	<2	<2	<2	NS	<2	NS	<2	4.3	<2
Barium	72	83	77	67	NS	95	NS	110	89	123
Cadmium	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Chromium	<1	<1	<1	<1	NS	<1	NS	<1	1.5	1.1
Copper	2.5	<2	2.4	2.8	NS	2.1	NS	<2	2.1	<2
Iron	86	139	562	205	NS	57.0	NS	86	428	316
Lead	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Lithium	<2	<1	<2	<1	NS	<1	NS	9.5	6.1	18
Manganese	4.0	5.1	56	242	NS	4.0	NS	<0.2	8.5	4.6
Mercury	<0.2	<0.2	<0.2	<0.2	NS	<0.2	NS	<1.0	<0.2	<0.2
Molybdenum	<1	<1	<1	<1	NS	<1	NS	<1.0	<1.0	<1.0
Nickel	1.5	4.8	2.7	6.6	NS	5.3	NS	<3	<3	2.0
Selenium	<3	<3	<3	<3	NS	<3	NS	<1	<1	<3
Silver	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Thallium	<1	<1	<1	<1	NS	<1	NS	<1	<1	<1
Radiological (pCi/L)										
Uranium, Total	0.45	(0.27)	0.33	(0.14)	NS	0.06	NS	0.52	48	69
Nitroaromatics (µg/L)										
1,3,5-TNB	<0.03	<0.03	0.25	<0.03	NS	0.10	NS	<0.3	<0.03	0.03
1,3-DNB	<0.09	<0.09	<0.09	<0.09	NS	<0.09	NS	<0.09	<0.09	<0.09
2,4,6-TNT	<0.03	<0.03	1.0	<0.03	NS	4.8	NS	0.07	0.09	0.42
2,4-DNT	<0.03	0.04	0.01	0.04	NS	0.15	NS	<0.03	0.05	0.09

TABLE C.7 (Cont.)

	5601		5602		5605		5612		6301	
Parameter	May	Aug.	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Nitroaromatics (µg/L) (Cont.)										
2,6-DNT	0.05	0.04	2.0	0.88	NS	0.27	NS	<0.01	0.15	0.31
2-Amino-4,6-DNT	0.02	0.02	0.01	0.05	NS	1.6	NS	0.46	0.58	0.84
4-Amino-2,6-DNT	0.36	0.37	1.3	1.0	NS	2.8	NS	0.58	1.0	1.5
2-Nitrotoluene	<0.03	<0.03	[c]	<0.06	NS	<0.03	NS	<0.03	<0.03	<0.07
3-Nitrotoluene	<0.03	<0.03	<0.03	<0.03	NS	<0.03	NS	<0.03	<0.03	<0.03
4-Nitrotoluene	<0.03	<0.03	<0.03	<0.03	NS	<0.03	NS	<0.03	<0.03	<0.03
Nitrobenzene	<0.04	<0.04	<0.04	<0.04	NS	<0.04	NS	<0.04	<0.04	<0.04

TABLE C.7 (Cont.)

Parameter	6303		6306		6501		6601	
	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Ions (mg/L)								
Nitrate	2.0	12	<0.1	<0.1	0.49	0.42	0.43	0.76
Sulfate	NS	25	NS	<10	NS	15	NS	14
Chloride	NS	3.3	NS	7.5	NS	2.4	NS	2.1
Fluoride	NS	0.12	NS	0.26	NS	0.12	NS	0.10
Filtered Metals (µg/L)								
Aluminum	<14	<14	<14	<14	534	17	<14	29
Antimony	1.9	5.8	2.4	1.6	<1	1.4	2.4	1.1
Arsenic	<2	<2	2.9	<2	<2	<2	<2	<2
Barium	70	128	308	399	79	90	76	104
Cadmium	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	2.1	1.7	<1	1.5	1.0	<1	<1	<1.0
Copper	<2	<2	<2	<2	<2	<2	<2	<2
Iron	24	66	2,830	1,300	644	<32	28	65
Lead	<1	<1	<1	<1	<1	<1	<1	<1
Lithium	<2	3.5	<2	<1	<2	<1	<2	<1
Manganese	7.4	51	6,240	360	14	4.4	12	42
Mercury	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum	<1	<1	2.5	4.6	<1	<1	<1	<1
Nickel	1.3	2.0	2.8	3.3	2.1	4.4	1.4	5.4
Selenium	<3	<3	<3	<3	<3	<3	<3	<3
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Thallium	<1	<1	<1	<1	<1	<1	<1	<1

TABLE C.7 (Cont.)

Parameter	6303 May	6303 Aug.	6306 May	6306 Aug.	6501 May	6501 Aug.	6601 May	6601 Aug.
Unfiltered Metals (µg/L)								
Aluminum	412	144	93	17	<26	857	229	55
Antimony	3.1	<1	<1	<1	<2	<1	<1	5.3
Arsenic	<2	<2	4.7	15	<4	<2	<2	<2
Barium	77	134	374	450	72	97	80	102
Cadmium	<1	<1	<1	<1	<1	<1	<1	<1
Chromium	2.6	2.2	<1	1.8	<1	<1	<1	<1
Copper	6	<2	<2	<2	<2	2.1	<2	<2
Iron	546	1,040	5,930	727	<55	647	378	147
Lead	<1	<1	<1	<1	<1	<1	<1	<1
Lithium	<2	3.6	<2	<1	<2	<1	<1	<1
Manganese	23.0	52	7,350	8,590	7.9	32	20	45
Mercury	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum	<1.0	<1.0	3.2	4.7	<1.0	<1.0	<1.0	<1.0
Nickel	2.1	2.3	2.8	3.4	2.0	5.2	1.8	4.7
Selenium	<3	<3	<3	<3	<3	<3	<3	<3
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Thallium	<1	<1	<1	<1	<1	<1	<1	<1
Radiological (pCi/L)								
Uranium, Total	0.63	1.3	0.69	0.44	<0.19	(0.21)	0.30	0.38
Nitroaromatics (µg/L)								
1,3,5-TNB	0.06	0.09	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
1,3-DNB	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09
2,4,6-TNT	1.5	0.64	<0.03	<0.03	<0.03	<0.03	<0.03	0.02
2,4-DNT	0.15	0.14	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

TABLE C.7 (Cont.)

Parameter	6303		6306		6501		6601	
	May	Aug.	May	Aug.	May	Aug.	May	Aug.
Nitroaromatics (µg/L) (Cont.)								
2,6-DNT	0.24	0.40	<0.01	<0.01	<0.01	<0.01	(0.007)	0.05
2-Amino-4,6-DNT	1.2	1.2	<0.02	<0.02	<0.02	<0.02	0.08	0.3
4-Amino-2,6-DNT	1.3	2.1	<0.02	<0.02	0.04	<0.02	0.12	0.59
2-Nitrotoluene	<0.03	<0.03	<0.26	<0.03	<0.03	<0.03	<0.03	<0.03
3-Nitrotoluene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
4-Nitrotoluene	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Nitrobenzene	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Note: Data in parentheses are uncensored data; i.e., those data reported below the detection limit.

[a] NS = not sampled.

[b] Indicates rejected datapoint.

[c] Value not quantified by laboratory.

APPENDIX D:

CONTAMINANT FATE AND TRANSPORT TABLES

TABLE D.1 Estimated Distribution Coefficient (K_d) Values for Contaminants in Site Soil[a]

Contaminant	K_d (mL/g)	Source
Radionuclides		
Uranium	330	Schumacher and Stollenwerk (1991)[b]
Metals		
Antimony	150	Sheppard et al. (1984)
Arsenic	10	Baes and Sharp (1983)[c]
Cadmium	27	Baes and Sharp (1983)
Lead	150	Schumacher and Stollenwerk (1991)[d]
Lithium	9	Baes et al. (1984); Schumacher and Stollenwerk (1991)[e]
Manganese	150	Baes and Sharp (1983)
Mercury	100	Nuclear Safety Associates (1980)
Molybdenum	30	Sheppard and Thibault (1990); Baes et al. (1984)[f]
Selenium	110	Sheppard and Thibault (1990)[g]
Silver	120	Sheppard and Thibault (1990)
Inorganic anions		
Nitrate	0.5	Baes et al. (1984)
Nitroaromatic compounds		
DNB	0.22	Verschueren (1983)[h]
2,4-DNT	0.63	Mabey et al. (1982)[i]
2,6-DNT	1.29	Mabey et al. (1982)[i]
NB	0.5	Mabey et al. (1982)[i]
TNB	0.15	Mabey et al. (1982)[i]
TNT	0.28	McKone (1990)[j]

[a] Estimated from literature data in combination with site-specific information, including soil type and pH. Because the range of literature values is highly variable, screening-level leaching calculations were performed for the metals with local soil and groundwater data to provide a limited consistency check for this assessment. Additional site-specific data that will be collected to support the groundwater operable unit will be used to refine these preliminary estimates within the next several years.

[b] Determined from site-specific data for solution in equilibrium with the Ferrelview clay at neutral pH (fixed).

Footnotes continue on next page

TABLE D.1 (Cont.)

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[c] Midrange for pentavalent arsenic in agricultural soil and clay (2 to 18 mL/g), as supported by a screening-level calibration estimate with data for local soil and groundwater.

[d] Determined from site-specific data for solution in equilibrium with the clay till at neutral pH (unadjusted).

[e] Modified from the value of 300 mL/g in Baes et al. (1984) and estimates of 1 to 2 mL/g from Schumacher and Stollenwerk (1991) by a screening-level calibration estimate with data for local soil and groundwater.

[f] Modified from the median values of 125 and 90 mL/g for loam and clay in Sheppard and Thibault (1990), combined with the value of 20 mL/g in Baes et al. (1984) and a screening-level calibration estimate with data for local soil and groundwater.

[g] Modified from the median value of 115 mL/g for clay by a screening-level calibration estimate with data for local soil and groundwater.

[h] Calculated by multiplying the octanol-water partition coefficient (K_{ow}) value given in Verschueren (1983) by a site-specific estimate of 1.4% for the fraction of organic carbon in soil.

[i] Calculated by multiplying the K_{ow} value given in Mabey et al. (1982) by a site-specific estimate of 1.4% for the fraction of organic carbon in soil.

[j] Calculated by multiplying the K_{ow} value given in McKone (1990) by a site-specific estimate of 1.4% for the fraction of organic carbon in soil.

TABLE D.2 Results of Equilibrium-Speciation Calculations on Samples from Selected Contaminated Monitoring Wells at the Weldon Spring Chemical Plant Site and Vicinity Property

Property or Constituent	Monitoring Well				
	GT64-P (6/14/90)	MW-2002 (8/02/89)	MW-2003 (6/06/89)	MW-2005 6/06/89	MW-3003 (5/10/89)
pH	7.0	7.2	6.2	6.9	6.8
Temperature (°C)	16.0	15.0	14.5	14.2	14.0
pE[a]	3.8	3.3	4.3	4.7	4.6
Cadmium (mg/L)	450	260	530	86	320
Magnesium (mg/L)	100	85	190	45	140
Sodium (mg/L)	270	110	240	71	230
Potassium (mg/L)	4.8	2.0	12	1.8	10
Hydrogen carbonate (mg/L)	305	350	300	360	340
Sulfate (mg/L)	130	100	220	7.0	200
Chlorine (mg/L)	18	11	21	2.5	13
Fluorine (mg/L)	0.10	0.10	0.10	0.10	0.20
Silica (mg/L)	12	15	11	9.4	10
Nitrate (mg/L)	1,810	974	3,010	160	1,950
Phosphate (mg/L)	0.09	0.12	0.06	0.12	0.09
Aluminum (μg/L)	<10	<10	<10	<10	<10
Barium (μg/L)	<100	300	300	170	300
Copper (μg/L)	30	30	40	5.0	20
Lithium (μg/L)	1,100	450	1,000	39	740
Manganese (μg/L)	30	<10	20	<6	<1
Strontium (μg/L)	950	360	1,100	120	830
Vanadium (μg/L)	1.0	1	<1	<6	<1
Uranium (μg/L)	6.7	1.8	3.0	1.0	17
Uranium, maximum[b] (μg/L)	>1,000	>1,000	>1,000	>1,000	>1,000
Calculated Predominant Aqueous Species					
Nitrogen	NH_4^-	NH_4^-	NH_4^-	NH_4^-	NH_4^-
Uranium	$UO_2(CO_3)_2^{2-}$	$UO_2(CO_3)_3^{4-}$	$UO_2(CO_3)_2^{2-}$	$UO_2(HPO_4)_2^{2-}$	$UO_2(CO_3)_2^{2-}$ $UO_2(HPO_4)_2^{2-}$

TABLE D.2 (Cont.)

Property or Constituent	Monitoring Well				
	GT64-P (6/14/90)	MW-2002 (8/02/89)	MW-2003 (6/06/89)	MW-2005 6/06/89	MW-3003 (5/10/89)
	Saturation Indexes (Unitless)				
Calcite	0.33	0.40	0.15	-0.22	0.01
Dolomite	0.23	0.49	0.04	-0.53	-0.14
Siderite	-1.66	-1.39	-1.80	-2.37	-2.02
Strontianite	-1.85	-1.96	-2.04	-2.57	-2.06
Gypsum	-1.09	-1.31	-0.86	-2.71	-1.02
Celestite	-2.06	NA[c]	NA	NA	NA
Barite	0.24	0.75	0.87	-0.38	0.96
SiO_2 (amorphous)	-0.91	-0.80	-0.93	-0.99	-0.97
Quartz	0.42	0.53	0.41	0.35	0.38
$Fe(OH)_3$ (amorphous)	0.00	0.00	0.02	0.00	0.00
Rhodonchrosite	-1.39	-1.61	-1.82	-2.44	-0.78
Uraninite	-6.81	-8.90	-7.00	-9.59	-7.67
Uraninite (amorphous)	-12.0	-14.0	-12.8	-14.6	-12.7
Coffinite	-7.34	-9.92	-8.19	-10.2	-8.25
Carnotite	-7.92	-9.91	-7.44	-8.81	-6.23
Shoepite	-5.11	-5.86	-5.45	-6.20	-4.85
Autunite	-9.99	NA	NA	NA	NA
Sodium autunite	-8.39	NA	NA	NA	NA
Tyuyamunite	-5.78	-7.29	-6.09	-6.57	-4.98

TABLE D.2 (Cont.)

Property or Constituent	Monitoring Well				
	MW-3006 (6/12/90)	MW-3007 (6/18/86)	MW-3008 (6/06/89)	MW-3009 (6/06/89)	MW-4013 (6/01/90)
pH	7.2	7.0	6.2	7.5	7.0
Temperature (°C)	14.5	15.5	15.0	15.0	13.5
pE[a]	2.6	3.6	4.6	3.3	--
Cadmium (mg/L)	64	820	900	57	120
Magnesium (mg/L)	52	280	240	39	52
Sodium (mg/L)	19	340	260	10	29
Potassium (mg/L)	1.3	13	2.6	0.5	5.7
Hydrogen carbonate (mg/L)	493	270	300	200	387
Sulfate (mg/L)	23	320	43	65	40
Chlorine (mg/L)	4.6	22	20	1.8	9.9
Fluorine (mg/L)	0.20	0.20	0.10	0.20	0.20
Silica (mg/L)	12	10	12	8.4	8.3
Nitrate (mg/L)	62	4,120	4,870	106	288
Phosphate (mg/L)	0.15	0.24	0.03	0.03	1.8
Aluminum (μg/L)	<10	NA	<10	<10	<10
Barium (μg/L)	170	NA	500	450	150
Copper (μg/L)	110	NA	40	<3	3.0
Lithium (μg/L)	18	1,700	170	8	52
Manganese (μg/L)	200	NA	<20	8	3.0
Strontium (μg/L)	230	1,500	2,900	110	140
Vanadium (μg/L)	<6	1.0	<1	<6	1.0
Uranium (μg/L)	0.90	6.0	7.0	110	2.1
Uranium, maximum[b] (μg/L)	>1,000	>1,000	>1,000	>1,000	>1,000
Calculated Predominant Aqueous Species					
Nitrogen	NH_4^-	NH_4^-	NH_4^-	NH_4^-	NH_4^-
Uranium	$UO_2(CO_3)_2^{2-}$ $UO_2(CO_3)_3^{4-}$	$UO_2(CO_3)_3^{4-}$	$UO_2(CO_3)_2^{2-}$	$UO_2(CO_3)_2^{2-}$	$UO_2(HPO_4)_2^{2-}$

TABLE D.2 (Cont.)

Property or Constituent	Monitoring Well				
	MW-3006 (6/12/90)	MW-3007 (6/18/86)	MW-3008 (6/06/89)	MW-3009 (6/06/89)	MW-4013 (6/01/90)
	Saturation Indexes (Unitless)				
Calcite	0.05	0.41	0.22	-0.09	-0.01
Dolomite	0.24	0.56	0.08	-0.14	-0.21
Siderite	-0.60	-1.60	-1.94	-2.25	-2.55
Strontianite	-1.89	-1.82	-1.76	-2.30	-2.43
Gypsum	-2.34	-0.66	-1.47	-1.88	-1.87
Celestite	NA	-1.69	-2.27	-2.90	-3.10
Barite	0.09	NA	0.28	1.01	0.27
SiO_2 (amorphous)	-0.91	-0.98	-0.89	-1.06	-1.04
Quartz	0.42	0.36	0.44	0.29	0.30
$Fe(OH)_3$ (amorphous)	0.00	0.00	0.00	0.00	0.00
Rhodonchrosite	-0.10	NA	-1.95	-1.52	-2.20
Uraninite	-6.07	-6.70	-7.77	-5.01	-2.20
Uraninite (amorphous)	-11.2	-11.8	-12.9	-10.1	-16.5
Coffinite	-6.61	-7.30	-8.28	-5.69	-12.1
Camotite	-11.5	-7.56	-8.13	-6.24	-12.5
Shoepite	-6.37	-5.37	-5.06	-3.39	-7.83
Autunite	NA	-9.81	-10.5	-8.50	-12.9
Sodium autunite	NA	-8.22	-9.20	-8.89	-12.6
Tyuyamunite	-9.03	-6.08	-5.22	-3.03	-11.2

[a] pE determined by assuming dissolved iron is ferrous and in equilibrium with ferrihydrite.

[b] The maximum uranium concentration in solution assuming mineral equilibrium controls.

[c] NA = data not available.

Source: Schumacher et al. (1993).

TABLE D.3 Selected Physical Properties and Environmental Parameters for Nitroaromatic Compounds

Property or Parameter	TNT	2,4-DNT	2,6-DNT	1,3,5-TNB	1,3-DNB
CAS number	118-96-7	121-14-2	606-20-2	99-35-4	99-65-0
Molecular weight (g/mol)	227.13	182.14	182.14	213.11	168.11
Density (g/cm^3)	1.654-1.663	1.521 (4°C)	1.538 (4°C)	1.654-1.688	1.574 (18°C)
Melting point (°C)	80.1-80.65	-71°C	-65	122.0-122.5	89-90
Dipole moment	1.37D	3.78-4.33[a]	2.81-2.98[a]	~0	NA[b]
Henry's Law constant, K_H (atm-m^3/mol)	1.1E-8	1.86E-7	4.86-E-07	2.21E-09	8.07E-07
Vapor pressure, solid (torr)					
20°C	1.28E-06	1.3E-04	1.35E-04	NA	NA
25°C	5.51E-06	2.17E-04	5.67E-04	3.03E-06	1.93E-04
Water solubility (mg/L)					
0°C	100	NA	NA	NA	--
10°C	110	NA	NA	NA	--
15°C	120	NA	NA	NA	469
20°C	130	270 (22°C)	NA	NA	180-200
25°C	150	280 (est)	208	350-385	533
U.S. EPA Drinking Water Equivalent Level (mg/L)	0.02	NA	NA	NA	--
Partitioning coefficients (K_d values in mL/kg)	1.86-2.06	1.98	1.89-2.02	1.18	1.49
log K_{ow}	2.72	1.79 (est)-2.40	1.79(est)-1.89(est)	1.30	1.56(est)
log K_{oc}	2-56	NA	NA	NA	NA
K_d (WSTA, top soils; Fink [1992])	NA	1.8-3.9	0.6-2.9	NA	NA
K_d (WSTA, Ferrelview Fm-clay till; Fink 1992)	2.9-3.5	2.0-2.3	0.53-0.99	NA	NA
K_d (WSTA, near surface clay till; USGS unpublished	4.7	1.9-4.4	1.6	NA	NA
K_d (WSTA, residuum; USGS unpublished)	0.6	0.2	0.2	NA	NA
Diffusion (cm^2/s at 25°C)	6.71E-06 (water) 0.64 (air)	7.31E-06 (water) 0.67 (air)	7.31E-06 (water) 0.67 (air)	7.20E-06 (water) 0.068 (air)	7.94E-04 (water) 0.073 (air)
Photolysis (estimated half-life)	Significant	23-72 hours (water)	NA	photostable	0.029-0.043 per day (rate constant)

[a] Data from Fink (1992).

APPENDIX D REFERENCES

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