Appendix A
Background Information, Remedial Action Histories, Present Site Conditions

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A1.0 Weldon Spring Site Description and History

A1.1 Location and Property Ownership

The Weldon Spring Site is located in St. Charles County, Missouri, about 30 miles (48 kilometers) west of St. Louis (Figure A−1). The site comprises two geographically distinct U.S. Department of Energy (DOE)-owned properties: the Weldon Spring Chemical Plant and Raffinate Pit sites (Chemical Plant) and the Weldon Spring Quarry (Quarry). The Chemical Plant is located about 2 miles (2.3 kilometers) southwest of the junction of Missouri State Route 94 and U.S. Highway 40/61. The Quarry is about 4 miles southwest of the Chemical Plant. Both sites are accessible from Missouri State Route 94. Directions to the site from Lambert-St. Louis International Airport are provided in Table A−1.

Table A−1. Mileage and Directions from the Lambert-St. Louis International Airport to the Weldon Spring, Missouri, Site

Mileage	Route
0.0	At the Airport exit, take the I-70W on-ramp
11.3	On I-70W, take Exit 228 (Missouri State Route 94 and 1st Capital Drive)
11.9	Turn left on 1st Capital Drive and continue on South 1st Capital Drive (becomes Missouri State Route 94)
24.4	On Missouri State Route 94, turn right at the Interpretive Center entrance

During the early 1940s, the Department of the Army (DA) acquired 17,232 acres (6,974 hectares) of private land in St. Charles County for construction of the Weldon Spring Ordnance Works facility. The former ordnance works site has since been divided into several contiguous areas under different ownership as depicted in Figure A−2. Current land use of the former ordnance works area includes the DOE Weldon Spring Chemical Plant and Weldon Spring Quarry, the U.S. Army Reserve Weldon Spring Training area, lands managed by the Missouri Department of Conservation (MDC) and Missouri Department Natural Resources (MDNR)-Division of State Parks, the Francis Howell High School, a Missouri Department of Transportation (MoDOT) maintenance facility, the St. Charles County water treatment facility and law enforcement training center, the village of Weldon Spring Heights, and a University of Missouri research park.

The Chemical Plant and Quarry areas total 228.16 acres (92.33 hectares). The Chemical Plant property is located on 219.50 acres (88.83 hectares), and the Quarry occupies 8.66 acres (3.50 hectares). Legal descriptions of the two parcels are presented in Appendix D. DOE maintains real estate correspondence and instruments as part of the Long-Term Surveillance and Maintenance (LTSM) Program records at the DOE Grand Junction Office.

Most of the land consists of two state conservation areas managed by the MDC, which employs about 50 people at their facilities (DOE 2003c). The August A. Busch Memorial Conservation Area, located north of the Chemical Plant, includes about 6,987 acres (2,828 hectares) of actively managed grassland and forest. The Weldon Spring Conservation Area comprises about 7,356 acres (2,977 hectares) of primarily forested land located south and east of the Chemical Plant.

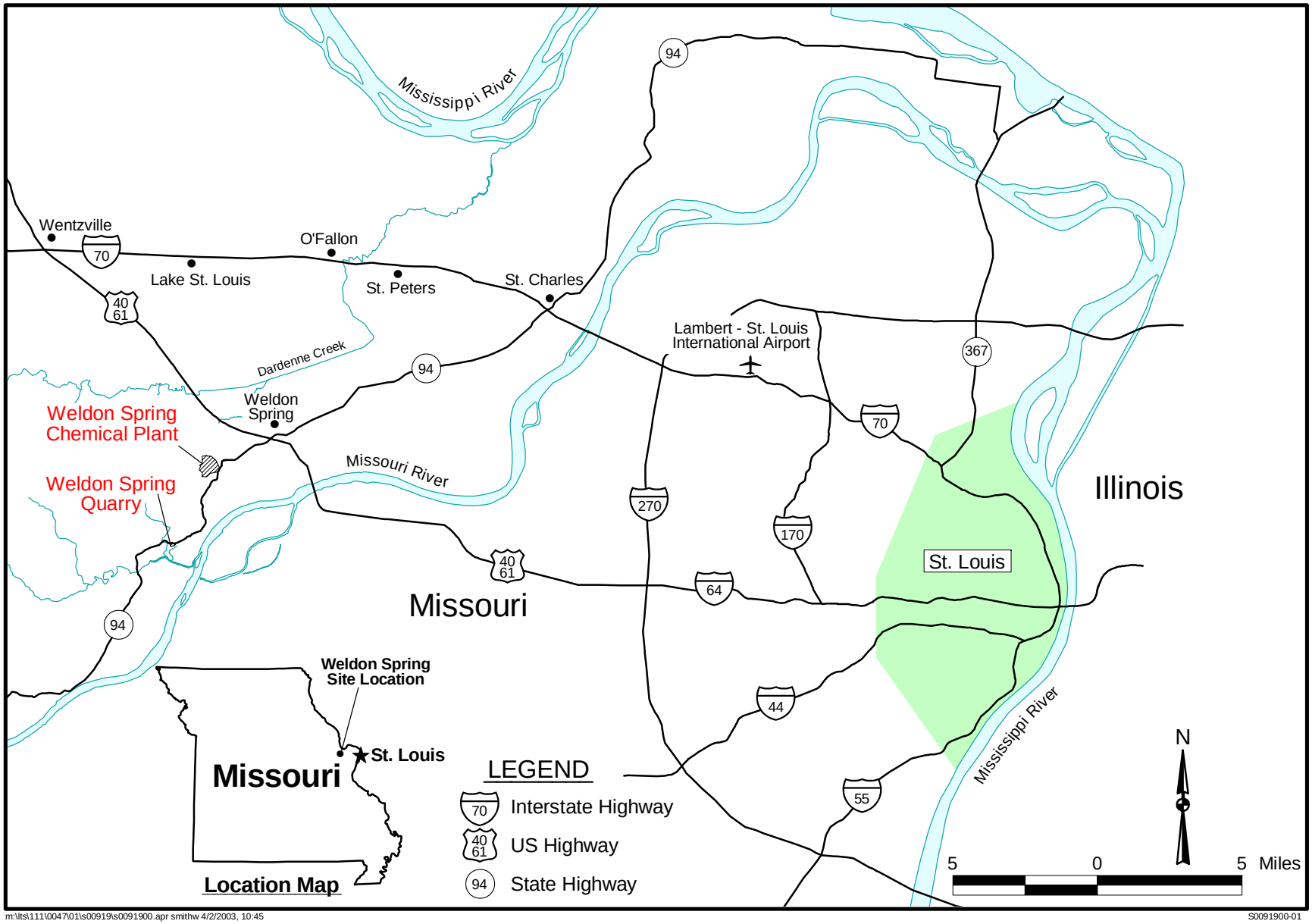

Figure A−1. Location of the Weldon Spring, Missouri, Site

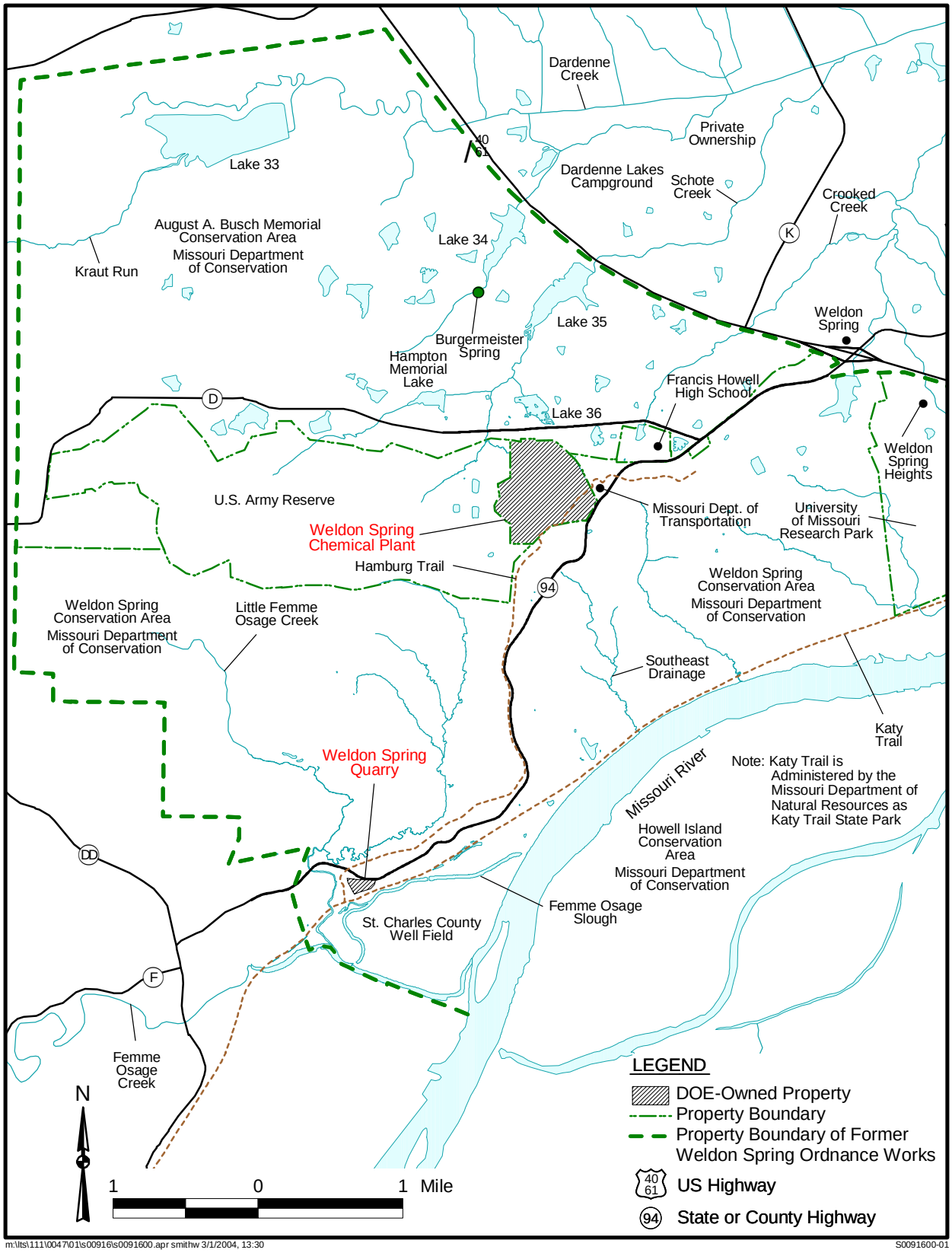

Figure A−2. Vicinity Map of the Weldon Spring, Missouri, Site

The Quarry is located within this conservation area. Both conservation areas are actively managed for fish and wildlife production and are used annually by more than 1,200,000 visitors for fishing, hunting, and hiking (DOE 2003c).

The Francis Howell High School occupies approximately 61 acres (25 hectares) and is located about 0.6 mile (1.0 kilometer) northeast of the Chemical Plant. The school employs approximately 150 faculty and staff, and about 1,600 students attend school. The MoDOT facility, located adjacent to the northeast side of the Chemical Plant, employs about 10 workers (DOE 2003c).

The two communities closest to the Chemical Plant are Weldon Spring and Weldon Spring Heights, located about 2 miles (3.2 kilometers) to the northeast. The combined population of these two communities is about 5,000 (DOE 2003c). No private residences are located between the Chemical Plant and these two communities; however, two residences owned by the MDC are located north of the Chemical Plant. These two residences are connected to the potable water system for the county. The closest private residence to the Quarry is located approximately 1 mile (0.6 kilometer) to the west. Residential and commercial growth is occurring in the communities surrounding the conservation areas, particularly in the city of O'Fallon, an area of growing residential population north of U.S. Highway 40/61.

A1.2 Physiography and Topography

The Weldon Spring Site, situated between the Mississippi and Missouri Rivers, is near the boundary between the Dissected Till Plains of the Central Lowland physiographic province to the north and the Salem Plateau of the Ozark Plateau physiographic province to the south. This boundary nearly coincides with the southern edge of Pleistocene glaciation that covered the northern half of Missouri more than 10,000 years ago.

The Chemical Plant is located on the east-west Missouri-Mississippi River surface drainage divide. Elevations at the site range from approximately 610 feet (186 meters) above mean sea level near the northern edge of the site to 650 feet (198 meters) above mean sea level near the southern edge. The topography of the site is gently undulating and generally slopes northward to the Mississippi River and, more steeply, southward to the Missouri River.

No natural drainage channels traverse the Chemical Plant, but because the site is topographically higher than surrounding areas, drainageways originate on the property and convey storm water off the site. Drainage from the southeastern portion of the site generally flows southward to a tributary referred to as the Southeast Drainage, which flows to the Missouri River. The northern and western portions of the site drain to tributaries to the Busch Lakes and Schote Creek, which in turn enter Dardenne Creek and, ultimately, the Mississippi River. Surface water can be lost to the subsurface through losing stream segments and discharges to Burgermeister Spring. These tributaries are shown on Figure A–2. Surface water from these watersheds is not used as a public drinking water supply. Dardenne Creek is used for irrigation purposes.

The Quarry is situated on a bluff of the Missouri River valley approximately 1 mile (1.6 kilometers) northwest of the Missouri River. Elevations in the Quarry area range from approximately 450 to 570 feet (149 to 174 meters) above mean sea level. Most surface runoff in the area is captured by Little Femme Osage Creek and Femme Osage Creek (Figure A–2). Below

their confluence, Femme Osage Creek flows east to the Missouri River, which flows in a northeasterly direction approximately 1 mile south of the Quarry. The average surface elevation of the Missouri River near the St. Charles County well field is 450 feet (137 meters). No direct surface water runoff enters the Quarry due to the topography of the area. The Quarry has been partially backfilled with low-permeability soils and has been graded to direct storm water off the area to prevent ponding and limit recharge to the contaminated limestone aquifer. Femme Osage Slough, approximately 700 feet (213 meters) south of the Quarry, is a 1.5-mile (2.4-kilometer) -long section of the original Femme Osage Creek and Little Femme Osage Creek and is currently used for recreational fishing.

A1.3 Hydrogeology

A1.3.1 Regional

In the Weldon Spring area, Quaternary alluvium and glacial deposits of varying thickness overlie a sequence of Mississippian through Cambrian formations consisting primarily of limestone and dolomite. The aquifers in these carbonate strata are separated by confining units that include layers of limestone, sandstone, siltstone, and shale. General stratigraphy and associated hydrology of the Weldon Spring area are summarized in Table A–2.

Aquifers in Quaternary alluvium are present near the Missouri River. Three bedrock aquifers are present in the region (Table A–2). The shallow bedrock aquifer system consists of limestones of the Mississippian Burlington-Keokuk and Fern Glen Formations. Regionally, the total thickness of these formations ranges from 145 to 270 feet (44 to 82 meters). The middle aquifer system is present in the Ordovician Kimmswick Limestone, which is 70 to 100 feet (21 to 30 meters) thick. The shallow and middle aquifers are separated by 60 to 135 feet (18 to 41 meters) of fine-grained limestone, shaley sandstone, and shale, which form a leaky confining unit over the middle bedrock aquifer. The deep aquifer system comprises eight formations ranging from the top of the Ordovician St. Peter Sandstone to the base of the Cambrian Potosi Dolomite. It is separated from the middle aquifer by 210 to 295 feet (64 to 90 meters) of shale and fine-grained limestone that form a confining unit between the two aquifers.

A1.3.2 Chemical Plant

Two major geologic units are present beneath the Chemical Plant: unconsolidated surface materials and underlying carbonate bedrock (Figure A–3). Unconsolidated surficial materials as much as 60 feet (18 meters) thick are clay-rich and mostly of glacial origin. The uppermost bedrock unit in the area, the Burlington-Keokuk Limestone, has been separated into two zones with different physical characteristics: a shallow, weathered zone underlain by an unweathered zone. The weathered portion of this formation consists of highly fractured limestone and has solution voids and enlarged fractures. These features are also present on a limited scale in the unweathered zone, which consists of thinly to massively bedded limestone.
The three regional bedrock aquifers are present beneath the Chemical Plant and are separated by the upper leaky and lower confining units above and below the middle aquifer system. The shallow unconfined bedrock aquifer, which occurs in the Burlington-Keokuk

Table A−2. Generalized Stratigraphy and Hydrostratigraphy of the Weldon Spring, Missouri, Site

System	Series	Stratigraphic Unit	Typical Thickness (feet)[a]	Physical Characteristics	Hydrostratigraphic Unit
Quaternary	Holocene	Alluvium	0–120	Gravelly, silty loam	Alluvial aquifer
	Pleistocene	Loess and glacial drift[b]	10–60	Silty clay, gravelly clay, silty loam, or loam over residuum from weathered bedrock	Locally a leaky confining unit[c]
Mississippian	Meramecian	Salem Formation[c]	0–15	Limestone, limey dolomite, finely to coarsely crystalline, massively bedded, and thin bedded shale	
		Warsaw Formation[c]	0–80	Shale and thin to medium bedded finely crystalline limestone with interbedded chert	
	Osagean	Burlington-Keokuk Limestone	100–200	Cherty limestone, very fine to very coarsely crystalline, fossiliferous, thickly bedded to massive	Shallow aquifer system
		Fern Glen Limestone	45–70	Cherty limestone, dolomitic in part, very fine to very coarsely crystalline, medium to thickly bedded	
	Kinderhookian	Chouteau Limestone	20–50	Dolomitic argillaceous limestone, finely crystalline, thin to medium bedded	Upper leaky confining unit
Devonian	Upper	Sulphur Springs Group Bushberg Sandstone[d]	40–55	Quartz arenite, fine to medium grained, friable	
		Lower part of Sulphur Springs Group undifferentiated		Calcareous siltstone, sandstone, oolitic limestone, and hard carbonaceous shale	
Ordovician	Cincinnatian	Maquoketa Shale[e]	0–30	Calcareous to dolomitic silty shale and mudstone, thinly laminated to massive	
	Champlainian	Kimmswick Limestone	70–100	Limestone, coarsely crystalline, medium to thickly bedded, fossiliferous and cherty near base	Middle aquifer system
		Decorah Group	30–60	Shale with thin interbeds of very finely crystalline limestone	Lower confining unit
		Plattin Limestone	100–130	Dolomitic limestone, very finely crystalline, fossiliferous, thinly bedded	
		Joachim Dolomite	80–105	Interbedded very finely cystalline, thinly bedded dolomite, limestone, and shale; sandy at base	
		St. Peter Sandstone	120–150	Quartz arenite, fine to medium grained, massive	Deep aquifer system
	Canadian	Powell Dolomite	50–60	Sandy dolomite, medium to finely 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	250	Cherty dolomite and arenaceous dolomite (Gunter Member)	
Cambrian	Upper	Eminence Dolomite	200	Dolomite, medium to coarsely crystalline, medium bedded to massive	
		Potosi Dolomite	100	Dolomite, fine to medium crystalline, thickly bedded to massive; drusy quartz common	

[a]Thickness data sources vary.
[b]Glacial drift unit includes the Ferrelview Formation and is saturated in the northern portion of the Ordnance Works where this unit behaves locally as a leaky confining unit.
[c]The Warsaw and Salem Formations are not present in the Weldon Spring area.
[d]The Sulphur Springs Group also includes the Bachelor Sandstone and the Glen Park Limestone.
[e]The Maquoketa Shale is not present in the Weldon Spring Area.

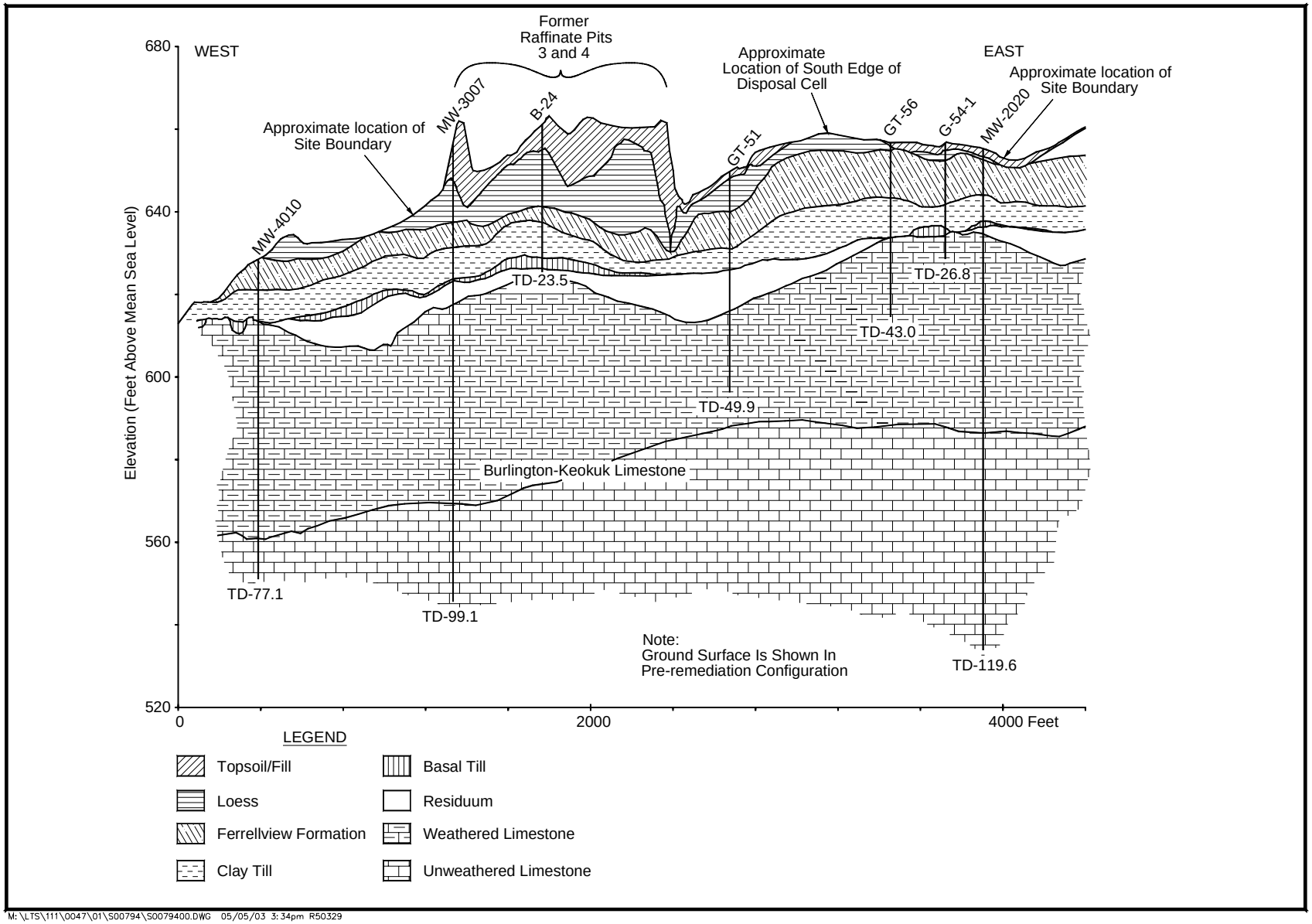

Figure A−3. Geologic Cross Section of the Weldon Spring, Missouri, Site Chemical Plant Area

Limestone, is the only aquifer affected by site-related contamination (DOE 1997d) and is therefore of primary interest for groundwater monitoring. Localized aquifer properties are controlled by fracture spacing and solution voids in the weathered zone of the formation. Groundwater movement is controlled primarily by horizontal bedding planes, fractures, and solution features, resulting in limited downward movement into deeper formations. The underlying unweathered zone has decreased secondary porosity and lower hydraulic conductivity. Recharge to this aquifer is mainly through infiltration of precipitation from overburden and from streams where they cross limestone fractures and solution voids (i.e., "losing streams"). The water table at the Chemical Plant remains within the bedrock.

Regional groundwater flow for St. Charles County is toward the east. However, an east-west-trending groundwater divide, which coincides with the topographic high located immediately south of the Chemical Plant, separates two distinct local drainage systems. North of the divide groundwater flows north and west toward Burgermeister Spring and eventually toward Dardenne Creek. South of the divide groundwater flows southeast toward the Missouri River. Localized flow is controlled largely by bedrock structure and by surface water drainages. The potentiometric surface of the shallow unconfined aquifer is shown on Figure A–4. Groundwater movement is generally by diffuse flow with localized zones of discrete flow controlled by solution conduits or paleochannels. Springs, a common feature in the vicinity of the Chemical Plant site, are located where groundwater emerges through solution channels or at topographic low points (i.e., "gaining streams"). The springs in the Southeast Drainage, which is located south of the groundwater divide, contribute to intermittent flow in the drainage.

A1.3.3 Quarry

The Quarry is located in low limestone hills near the northern bank of the Missouri River. Mississippian through Upper Ordovician formations, present in the Chemical Plant, are absent in the Quarry (Figure A–5). Limestone was quarried from the Ordovician Kimmswick Limestone, which is exposed in the Quarry walls. Before the Quarry was backfilled and regraded, the bedrock floor of the Quarry exposed the underlying shale and thinly bedded limestone of the Decorah Group. Unconsolidated deposits of windblown glacial materials overlie the Kimmswick Limestone in the upland areas near the Quarry, and substantial deposits of Quaternary Missouri River alluvium cover the Plattin Limestone to the south and east of the Quarry.

Two of the regional bedrock aquifers are present in the vicinity of the Quarry. The shallow aquifers of interest occur in the Kimmswick Limestone and in the alluvium of the Missouri River. The Kimmswick Limestone aquifer has low yield and is not used as a drinking water source in the Quarry vicinity. Recharge to the limestone bedrock is from infiltration of precipitation through overburden and upland recharge. Groundwater generally flows from north to south in the vicinity of the Quarry, toward the alluvium the Missouri River. Some Quarry groundwater flows westward from the Quarry to Little Femme Osage Creek. The potentiometric surface of the shallow aquifer is shown on Figure A–6.

The predominant aquifer system in the Quarry area is the Missouri River alluvium, which is a source of drinking water for residents of St. Charles County. The alluvial aquifer is recharged by infiltration of surface water (principally from the Missouri River) and precipitation, and by discharge from the Plattin Limestone where it contacts the alluvium south and east of the Quarry.

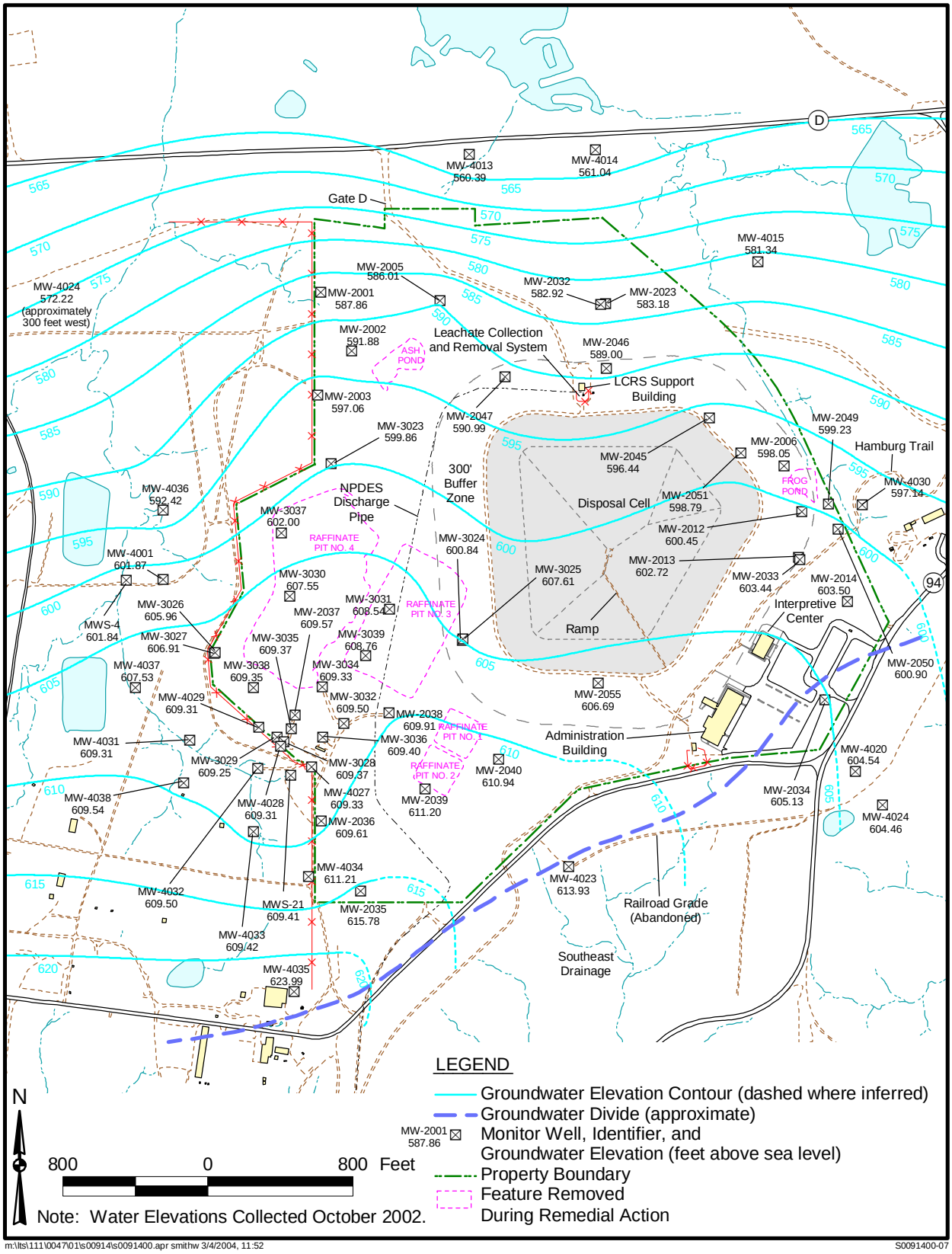

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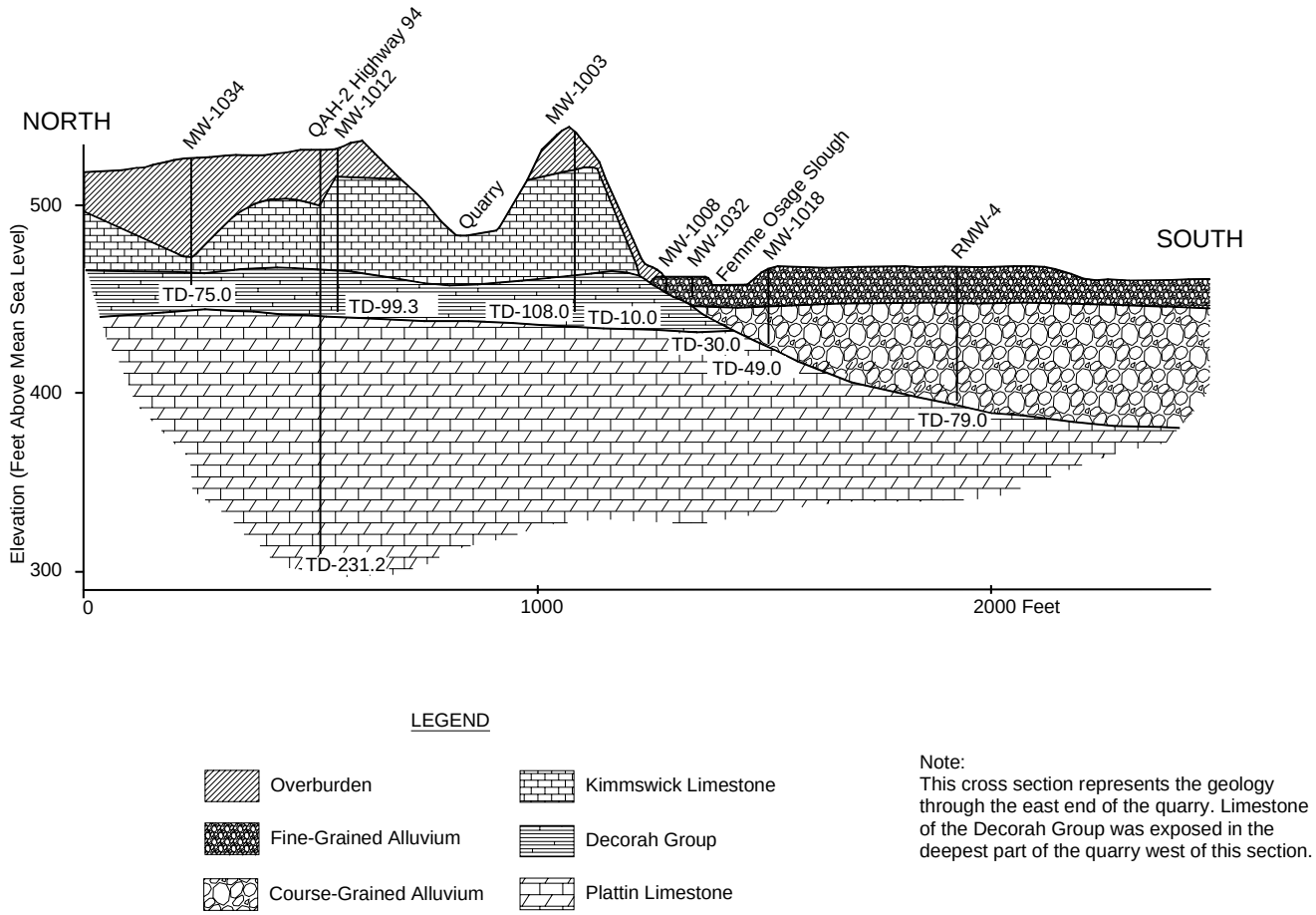
Figure A−4. Groundwater Contour Map of the Weldon Spring, Missouri, Site Chemical Plant Area



Note:
This cross section represents the geology through the east end of the quarry. Limestone of the Decorah Group was exposed in the deepest part of the quarry west of this section.

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Figure A–5. Geologic Cross Section of the Weldon Spring, Missouri, Site Quarry Area

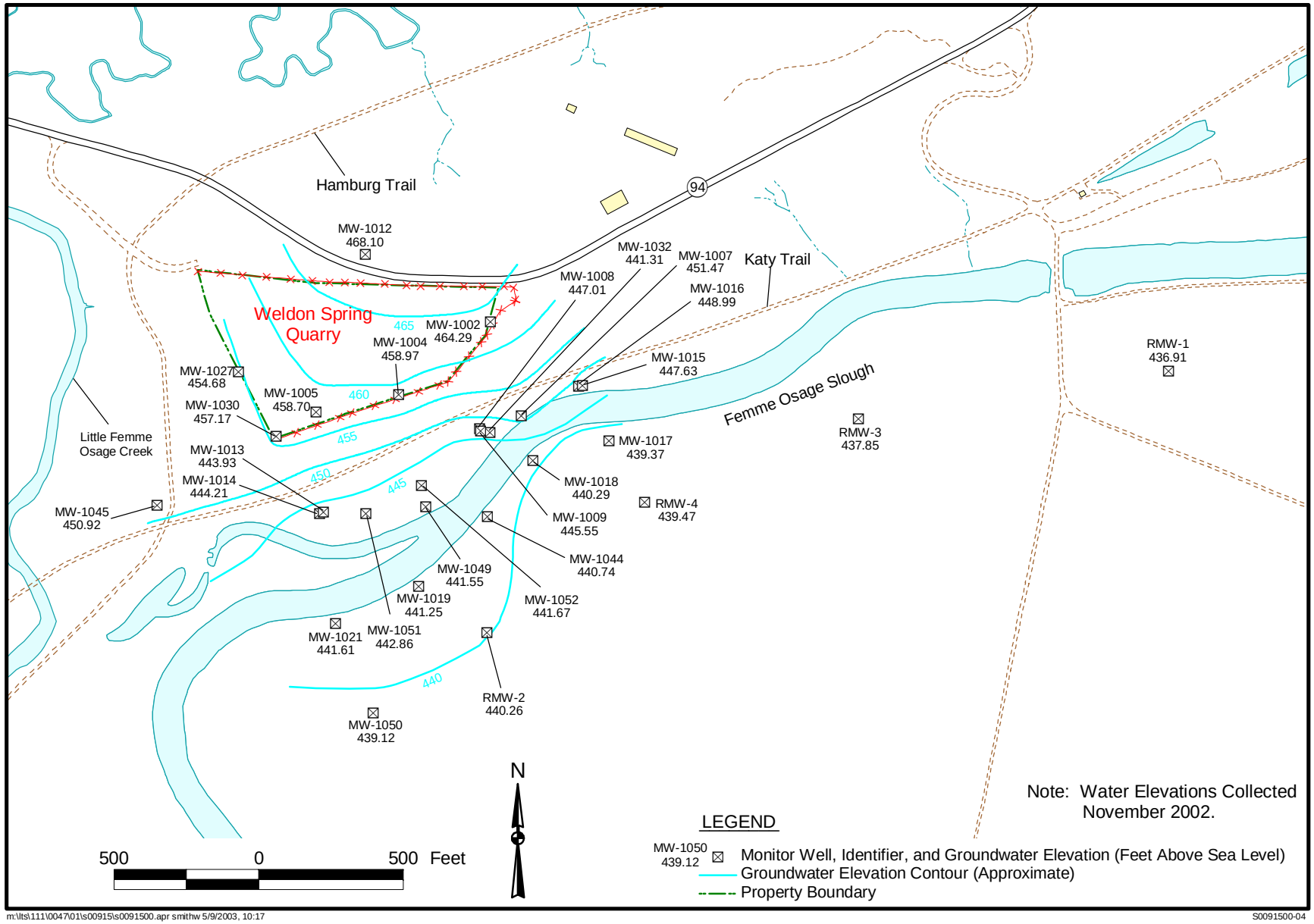


Figure A−6. Groundwater Contour Map of the Weldon Spring, Missouri, Site Quarry Area

Groundwater flow in the area of the St. Charles County well field, which is located between Femme Osage Slough and the Missouri River, generally is in an eastward direction. The flow is influenced by the Missouri River and by pumping from the eight production wells in the well field.

A1.4 Climate and Vegetation

A continental climate with warm to hot summers and moderately cold winters prevails in the Weldon Spring area. Average daily maximum and minimum temperatures are 65.4°F (18.6°C) and 46.7°F (8.2°C), respectively. Mean annual precipitation is 37.5 inches (95.0 centimeters). Winds measured at the site flow predominantly from the south and southwest at an average velocity of 6.3 miles per hour (2.8 meters per second).

State conservation areas surround most of the Chemical Plant (Figure A–2). These areas are managed for multiple uses, including timber, fish and wildlife habitat, and recreation. Open fields in these areas are leased to sharecroppers for agricultural production; portions of the crops are left for wildlife use. The main agricultural products are corn, soybeans, milo, winter wheat, and legumes.

The Quarry is surrounded by the Weldon Spring Conservation Area, which consists primarily of deciduous forest with some old field habitat of grasses, herbs, and scattered wooded areas. Slope and upland forest, including cottonwood, sycamore, and oak, is present along the rim and upper portions of the Quarry.

A1.5 Site History

A1.5.1 Operations History

In 1941, the U.S. Government acquired 17,232 acres (6,974 hectares) of rural land in St. Charles County to establish the Weldon Spring Ordnance Works. In the process, the towns of Hamburg, Howell, and Toonerville and 576 citizens of the area were displaced (U.S. Department of the Army undated). From 1941 to 1945, the DA manufactured trinitrotoluene (TNT) and dinitrotoluene (DNT) at the Ordnance Works site. Four TNT production lines were situated on what was to be the Chemical Plant. These operations resulted in nitroaromatic contamination of soil, sediments, and some off-site springs.

Following a considerable amount of explosives decontamination of the facility by the Army and the Atlas Powder Company, 205 acres (83.0 hectares) of the former ordnance works property were transferred to the U.S. Atomic Energy Commission (AEC) in 1956 for construction of the Weldon Spring Uranium Feed Materials Plant, now referred to as the Weldon Spring Chemical Plant. An additional 14.88 acres (6.02 hectares) were transferred to the AEC in 1964. The plant converted processed uranium ore concentrates to pure uranium trioxide, intermediate compounds, and uranium metal. A small amount of thorium was also processed. Wastes generated during these operations were stored in four raffinate pits located on the plant property. Uranium processing operations resulted in radioactive contamination of the same locations previously contaminated by former Army operations.

The Weldon Spring Quarry was mined for limestone aggregate used in construction of the ordnance works. The Army also used the Quarry for burning wastes from explosives manufacturing and disposal of TNT-contaminated rubble during the operation of the ordnance

works. These activities resulted in nitroaromatic contamination of the soil and groundwater at the Quarry.

In 1960, the Army transferred the Quarry to AEC, who used it from 1963 to 1969 as a disposal area for uranium and thorium residues from the Chemical Plant (both drummed and uncontained), and for disposal of contaminated building rubble, process equipment, and soils from demolition of a uranium processing facility in St. Louis. Radiological contamination occurred in the same locations as the nitroaromatic contamination.

Uranium processing operations ceased in 1966, and on December 31, 1967, AEC returned the facility to the Army for use as a defoliant production plant. In preparation for the defoliant process, the Army removed equipment and materials from some of the buildings and disposed of them principally in Raffinate Pit 4. The defoliant project was canceled before any process equipment was installed, and the Army transferred 50.65 acres (20.50 hectares) of land encompassing the raffinate pits back to AEC while retaining the Chemical Plant. AEC and subsequently DOE managed the site, including the Army-owned Chemical Plant, under caretaker status from 1968 through 1985. Caretaker activities included site security oversight, fence maintenance, grass cutting, and other incidental maintenance. In 1984, the Army repaired several of the buildings at the Chemical Plant, decontaminated some of the floors, walls, and ceilings, and isolated some equipment. In 1985, the Army transferred full custody of the Chemical Plant to DOE, at which time DOE designated control and decontamination of the Chemical Plant, raffinate pits, and Quarry as a major project.

A1.5.2 Remedial Action History

DOE established an on-site project office in 1986, and the Quarry and Chemical Plant were placed on the National Priorities List in 1987 and 1989, respectively. Initial remedial activities at the Chemical Plant site consisted of a series of Interim Response Actions (IRAs) authorized through the use of Engineering Evaluation/Cost Analysis (EE/CA) reports. Electrical transformers, electrical poles and lines, and overhead piping and asbestos were removed by IRAs because they presented an immediate threat to workers and the environment. An isolation dike was built to divert runoff around the Ash Pond area to reduce the concentration of contaminants going off site in surface water. The Debris Consolidation IRA consisted of detailed characterization of on-site debris, separation of radioactive and nonradioactive debris, and transport of materials to designated staging areas for interim storage. Four separate IRAs authorized the dismantling of 44 Chemical Plant buildings.

The treatment of water was another major activity addressed by IRAs. Separate EE/CAs were prepared for the site and Quarry water treatment plants. The first batch of water from the Quarry water treatment plant was discharged in January 1993. The first batch of water from the site water treatment plant was discharged in May of the same year. Water was treated at both sites to remove chemical and radiological contaminants. The water was tested prior to batch discharge. Two hundred seventy-six million gallons of water meeting the National Pollutant Discharge Elimination System discharge criteria were treated and released. Dewatering of the four raffinate pits was completed in September 1999. Demolition of the site water treatment plant was completed on July 6, 2000, and the Quarry water treatment plant demolition was completed in May 2001. Both plants were disposed of in the on-site disposal cell.

Remediation of the Weldon Spring Site was administratively divided into four Operable Units (OUs): Quarry Bulk Waste OU, Quarry Residuals OU, Chemical Plant OU, and Groundwater OU. The Southeast Drainage was remediated as a separate action through an EE/CA report (DOE 1996).

A2.0 Remedial Action Descriptions

A2.1 Chemical Plant OU

In September 1993, DOE finalized the *Record of Decision for Remedial Action at the Chemical Plant Area of the Weldon Spring Site* (DOE 1993) for managing contaminated materials (except groundwater) at the Chemical Plant. The Chemical Plant OU addressed the various sources of contamination in the Chemical Plant including soils, sludge, sediment, and materials placed in short-term storage as a result of previous response actions. The remedial action included in the Chemical Plant Record of Decision (ROD) was the major component of site cleanup and addressed comprehensive disposal options for the project. The primary focus was the contaminated material in the Chemical Plant, including that generated as a result of previous response actions, but it also addressed disposal of materials generated by the other OUs in order to facilitate a disposal decision that would integrate all the OUs. The three key components of the remedy were:

- Remove the contaminated materials.
- Treat the wastes as appropriate by chemical stabilization/solidification (CSS).
- Dispose of the wastes in an engineered disposal facility constructed on site.

The remedy included remediation of 17 off-site vicinity properties affected by Chemical Plant operations. The vicinity properties were remediated in accordance with Chemical Plant ROD cleanup criteria. Detailed information regarding the vicinity properties is included in Section A2.1.5, “Vicinity Properties” of this Appendix.

A2.1.1 Present Conditions

The Chemical Plant property will remain under DOE jurisdiction. The disposal cell and a 300-foot (91-meter) buffer zone around the cell will be controlled by the U.S. government in perpetuity with no change in land use. The 300-foot buffer zone is a MDNR regulation under Title 10 *Code of State Regulations*, Division 25 (10 CSR 25-7.264). Any agreement to use DOE-controlled land between the buffer zone and the property boundary will invoke land use restrictions to prevent excavation or construction activities, preserve the site grading pattern that is designed to protect the cell, and protect long-term monitor wells located on the Chemical Plant property.

Contaminated groundwater remains in the shallow aquifer beneath the Chemical Plant, primarily in the western and northeastern portions of the site and beneath portions of adjacent property. Contaminants include uranium, nitrate, trichloroethylene (TCE), and nitroaromatic compounds, including TNT and 2,4-DNT. Burgermeister Spring (SP–6301), located approximately 1 mile (1.6 kilometers) northwest of the Chemical Plant, has elevated concentrations of contaminants of

concern related to Chemical Plant activities (uranium and nitrate). DOE will acquire the necessary restrictive rights with the landowner to ensure land use remains restricted.

Soil and sediment containing elevated concentrations of radium-226, thorium-230, and uranium-238 remain in the Southeast Drainage. Radionuclide concentrations in the soil, sediment, and spring water are below protective levels calculated using a hypothetical child-resident scenario. Exposure scenarios used for the risk assessment do not represent unrestricted use. Therefore, DOE will obtain a restrictive easement or will obtain an indefinite term license with the MDC to ensure that future land use remains consistent with the selected remedy provisions. Springs in the Southeast Drainage (i.e., the 5300 drainage) will be encompassed in the area of institutional control for the Southeast Drainage.

A corrugated metal culvert underneath Missouri State Route 94 at the Southeast Drainage (see the inspection base map, Figure 2–2) contains fixed residual radioactivity on its inner surfaces in excess of DOE Order 5400.5, *Radiation Protection of the Public and the Environment* generic surface contamination guidelines for natural uranium, uranium-238, and associated decay products. The maximum beta-gamma activity, measured inside the culvert, was 11,000 disintegrations per minute per 100 square centimeters (dpm/100 cm^2). A supplemental limit of 15,000 dpm/100 cm^2 was approved by the DOE Oak Ridge Operations Office, Oak Ridge, Tennessee (DOE–ORO) on the basis that the upper bounds potential dose to workers and the general public from the residual radioactivity is very low (more than an order of magnitude below the DOE guideline of 100 millirem per year), and additional remedial action would not be cost effective (DOE 2001b and DOE 2001c). Should future Missouri State Route 94 roadway modifications or other disturbance result in access to the culvert, DOE will remove the culvert and provide for its final disposal at an U.S. Environmental Protection Agency (EPA)-approved radioactive waste disposal site.

Soil containing elevated concentrations of uranium-238 was left under twin culverts in the Highway D right-of-way within the Frog Pond Outlet located north of the Chemical Plant (see the inspection base map, Figure 2–2). A summary of the risk assessment for these culverts is provided in Appendix B. DOE will provide long-term surveillance and maintenance oversight to manage this soil. The inside surfaces of the corrugated metal culverts contain fixed residual radioactivity in excess of DOE Order 5400.5 generic surface contamination guidelines for natural uranium, uranium-238, and associated decay products. The maximum beta-gamma activity was 10,800 dpm/100 cm^2. DOE–ORO approved a supplemental limit of 15,000 dpm/100 cm^2 because the maximum potential dose to workers and the general public from the residual radioactivity is very low (more than an order of magnitude below the DOE guideline of 100 millirem per year), and additional remedial action would not be cost effective (DOE 2001b and DOE 2001c). Should future Highway D roadway modifications result in access to the drainage culverts, DOE will remove both culverts and provide for their final disposal at an EPA-approved radioactive waste disposal site.

Institutional controls for management of the remaining contaminated groundwater, Burgermeister Spring and Southeast Drainage spring water, soil, sediment, and culverts are addressed in Section 3.0, “Institutional Controls” of this Long-Term Surveillance and Maintenance Plan.

Dedicated haul roads between the Chemical Plant and the Quarry and a borrow area have been reclaimed as a hiking and bike trail (the Hamburg Trail). DOE converted a metal building into an

interpretive center for the public and installed a ramp and platform on the disposal cell for public access. An administration building and wastewater treatment plant also remain on the site.

A2.1.2 Soil Confirmation

Cleanup criteria for the contaminants of concern in site soil were developed from environmental regulations and guidelines in combination with the results of site-specific risk assessments. As part of the latter, a site-specific analysis was conducted to address the reduction of residual risks to within a range from As Low As Reasonable Achievable (ALARA) levels for a residential scenario to an incremental increased risk of 1×10^{-6} for carcinogens and a hazard index of 1 for noncarcinogens. Table A−3 lists the cleanup criteria established in the Chemical Plant ROD. Following excavation of an area, the dimensions of which were based on extensive characterization data, DOE used several approaches to confirm that the cleanup criteria had been met. The area was walk-scanned using radiation detection monitors and was sampled using a grid established for the site. The data were then evaluated against specific not-to-exceed target levels, hot-spot evaluation procedures, average data target levels, and cumulative data goals based on all data collected to date. Additional details concerning how confirmation was conducted are presented in the *Chemical Plant Area Cleanup Attainment Confirmation Plan* (DOE 1995).

Table A−3. Weldon Spring, Missouri, Site Chemical Plant ROD Cleanup Criteria for Soils

	Surface		**Subsurface**	
Radionuclides (pCi/g)	ALARA	Criteria	ALARA	Criteria
Radium-226	5.0	6.2	5.0	16.2
Radium-228	5.0	6.2	5.0	16.2
Thorium-230	5.0	6.2	5.0	16.2
Thorium-232	5.0	6.2	5.0	16.2
Uranium-238	30	120	30	120
Chemicals (mg/kg)	ALARA	Criteria	ALARA	Criteria
Arsenic	45	75	75	750
Chromium	90	110	110	1,110
Lead	240	450	450	4,500
PAHs	0.44	5.6	5.6	56
PCBs	0.65	8.0	8.0	80
2,4,6-TNT	14	140	140	1,400

Key: mg/kg = milligram(s) per kilogram; PCBs = polychlorinated biphenyls; pCi/g = picocurie(s) per gram; TNT = trinitrotoluene; ALARA = As Low As Reasonably Achievable; PAHs = polycyclic aromatic hydrocarbons

Values listed for surface soils apply to contamination within the upper 15 centimeters (6 inches) of the soil column. Values for subsurface apply to contamination in soils below 15 centimeters (6 inches) unless otherwise noted.

Between 1995 and 2001, approximately 200 acres (81 hectares) were confirmed. Confirmation activities were conducted as detailed in the *Chemical Plant Area Cleanup Attainment Confirmation Plan* (DOE 1995). This plan presents the protocol to determine whether remediation efforts at the Chemical Plant of the Weldon Spring Site have been completed as required by the Chemical Plant ROD, including cleanup standards, sampling methods, sample frequency, analytical parameters, and the statistical evaluation to be performed to accomplish this determination.

In general, the confirmation process can be described as follows: Excavations were designed to remove contaminated soil where concentrations exceeded the ALARA cleanup goals. Once the contaminated soil was excavated to the design depths, walkover surveys were conducted to determine if soil samples could be collected. Walkover surveys were conducted using 2-inch by 2-inch (5-centimeter by 5-centimeter) sodium iodide scintillation detectors. During the walkovers, areas with gamma activity exceeding 1.5 times background received additional excavation. Once gamma activity in the areas being surveyed was less than 1.5 times background, confirmation soil samples were collected. Soil sample results were then compared against the cleanup standards in the Chemical Plant ROD.

Table A−4 provides a summary of cumulative confirmation results collected under the *Chemical Plant Area Cleanup Attainment Confirmation Plan* (DOE 1995). The table was generated using the final data sets compiled from all samples that represented soils left in place.

Table A−4. Final Soil Confirmation Statistics for the Weldon Spring, Missouri, Site Chemical Plant

Parameter	Number of Samples	Average Concentration	Background Concentration	ALARA Cleanup Goal	Percentage of Results below ALARA
Arsenic (mg/kg)	2,782	8.19	26	45	99.96%
Chromium (mg/kg)	3,090	17.37	36	90	100.00%
Lead (mg/kg)	2,687	18.22	34	240	99.70%
Thallium (mg/kg)	1,082	1.78	16	16	99.82%
Polycyclic aromatic hydrocarbons (mg/kg)	2,716	0.10	N/A	0.44	94.48%
PCBs (mg/kg)	3,111	0.04	N/A	0.65	98.46%
2,4,6-TNT (mg/kg)	1,514	0.17	N/A	14	99.80%
Uranium-238 (pCi/g)	9,193	2.91	1.2	30	99.13%
Radium-226 (pCi/g)	6,909	1.04	1.2	5	99.93%
Radium-228 (pCi/g)	6,731	1.04	1.2	5	99.96%
Thorium-230 (pCi/g)	6,183	1.56	1.2	5	97.99%
Thorium-232 (pCi/g)	6,731	1.04	1.2	5	99.93%

N/A - No background concentration is listed for the organic compounds because they are not naturally present in soil.
Key: mg/kg = milligram(s) per kilogram; PCBs = polychlorinated biphenyls; pCi/g = picocurie(s) per gram; TNT = trinitrotoluene

A2.1.3 Disposal Cell

Construction of an engineered disposal cell on the Chemical Plant property began in 1997. Approximately 1.48 million cubic yards (1.13 million cubic meters) of waste materials, including building debris, asbestos-containing materials, treated raffinate sludge, contaminated soils, drums, process equipment, and the Quarry bulk wastes, were disposed of in the cell. To form a structurally stable material, raffinate sludge was mixed with portland cement and fly ash in the engineered and constructed on-site chemical stabilization/solidification (CSS) plant to create grout that was pumped to the disposal cell. Disposal activities were completed in 2001. A detailed description of construction and waste disposal activities are included in the Chemical Plant Remedial Action Report.

The disposal cell is located on the northeastern portion of the Chemical Plant property, and the outer perimeter protection system encompasses an area of approximately 41 acres (16.6 hectares). The 5-sided cell has 4:1 side slopes over the clean-fill dike, and cover slopes of approximately 13:1 over the waste. The maximum width of the cell footprint, including the rock-covered apron, is approximately 1,500 feet (457 meters), and the maximum height above grade is approximately 91 feet (28 meters). The cell contains approximately 1.48 million cubic yards (1.13 million cubic meters) of contaminated waste, with a total activity of 6,570 curies. The waste column has a maximum thickness of 63 feet (19 meters), and the waste footprint, including the lower interior dike slopes, is approximately 24 acres (9.7 hectares).

Six primary systems were incorporated into the cell design: the cover, the waste, a surrounding clean-fill dike, a geochemical barrier, a basal liner system, and a leachate collection and removal system (LCRS) (Figure A–7).

The cell cover system is approximately 8.5 feet (2.6 meters) thick; the upper 3.5 feet (1.1 meters) of the top slope consists of limestone riprap with an average diameter of 8 inches (20 centimeters); the riprap is 2 feet thick on the side slopes (Figure A–8). The riprap layer protects the cover from erosion and restricts penetration of the cover by plant roots and burrowing animals. This riprap layer overlies a sequence of aggregate bedding and drainage layers. Beneath these layers is a high-density polyethylene (HDPE) liner with an attached layer of bentonite. The principal radon/infiltration barrier consists of a 3-foot (0.9-meter)-thick layer of compacted low-permeability clayey soil beneath the HDPE liner.

Three drainage bays were created at the cell bottom sloping toward two low points on the north side of the cell floor to facilitate leachate flow. The west bay includes a monolith of debris cemented with grout containing raffinate sludges.

The cell bottom liner incorporates two HDPE layers separated by a synthetic drainage layer consisting of geotextile and geonet (Figure A–9). The upper HDPE liner system is covered with drainage aggregate and a layer of peat mixed with low-radioactivity soil that will adsorb some leachate contaminants. The lower HDPE liner system was placed on a bentonite mat-covered 3-foot (0.9-meter)-thick layer of compacted clay. The mat and clay layer provide an additional low-permeability liner and geochemical barrier that will adsorb uranium and other constituents in leachate that potentially could leak through the HDPE liner system. The cell foundation complies with a siting requirement included in the Missouri regulations for the equivalent of a 30-foot thickness of clay with a permeability of 10^{-7} centimeters per second under the contained waste.

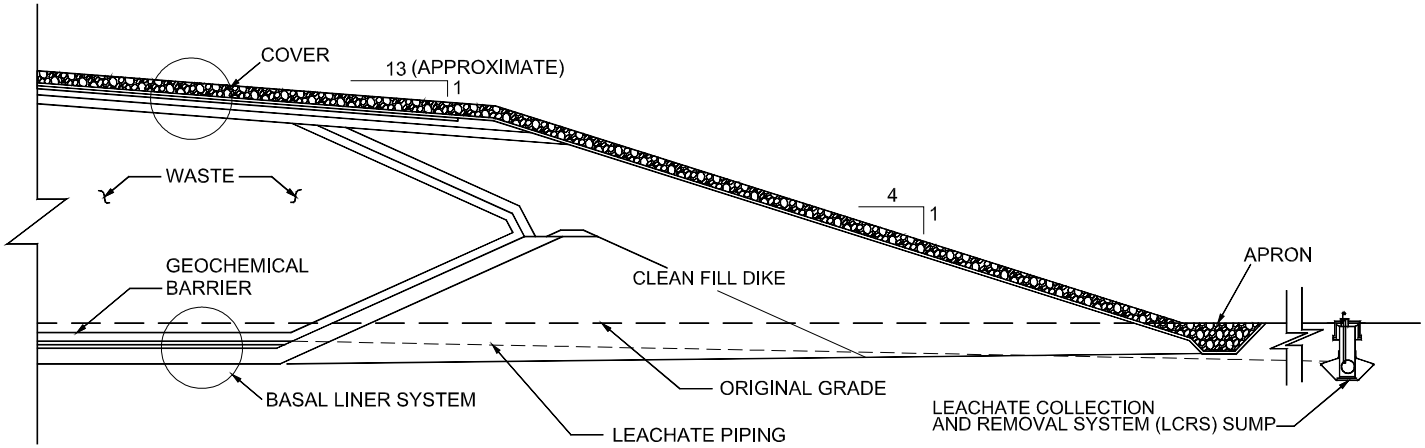
Specific performance and design criteria for the cell include:

- Seismic resistance: sustain a Maximum Credible Earthquake defined as:

  −Peak Ground Acceleration = 0.26 g (gravitation constant)

  −Period of the Design Ground Motion = 0.3 second

  −Duration of the Design Ground Motion = 24 to 30 seconds



CELL CONFIGURATION

AREA INCLUDING APRON = 41 ACRES
MAXIMUM WIDTH = 1,500 FEET
MAXIMUM HEIGHT = 91 FEET
WASTE VOLUME = 1.48 MILLION CUBIC YARDS

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Figure A−7. Primary Systems of the Weldon Spring, Missouri, Site Disposal Cell

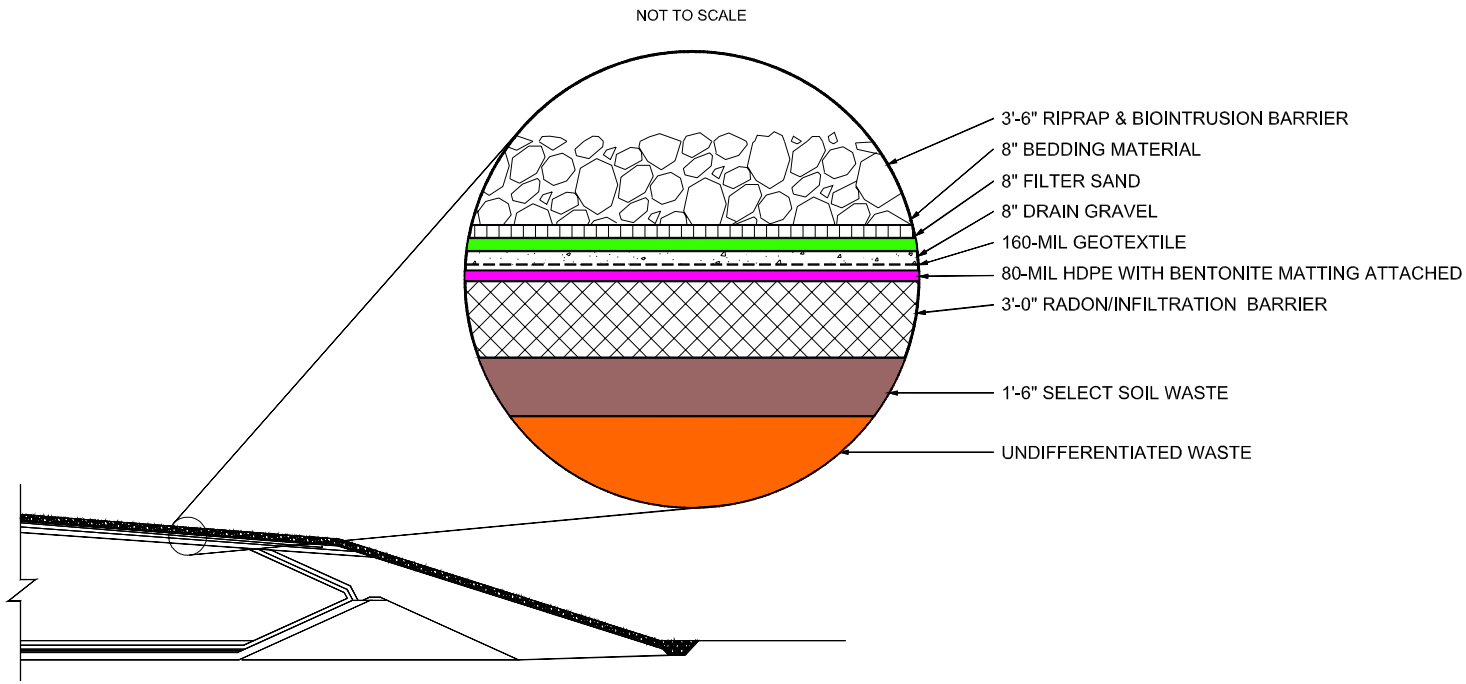

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Figure A−8. Cover System of the Weldon Spring, Missouri, Site Disposal Cell

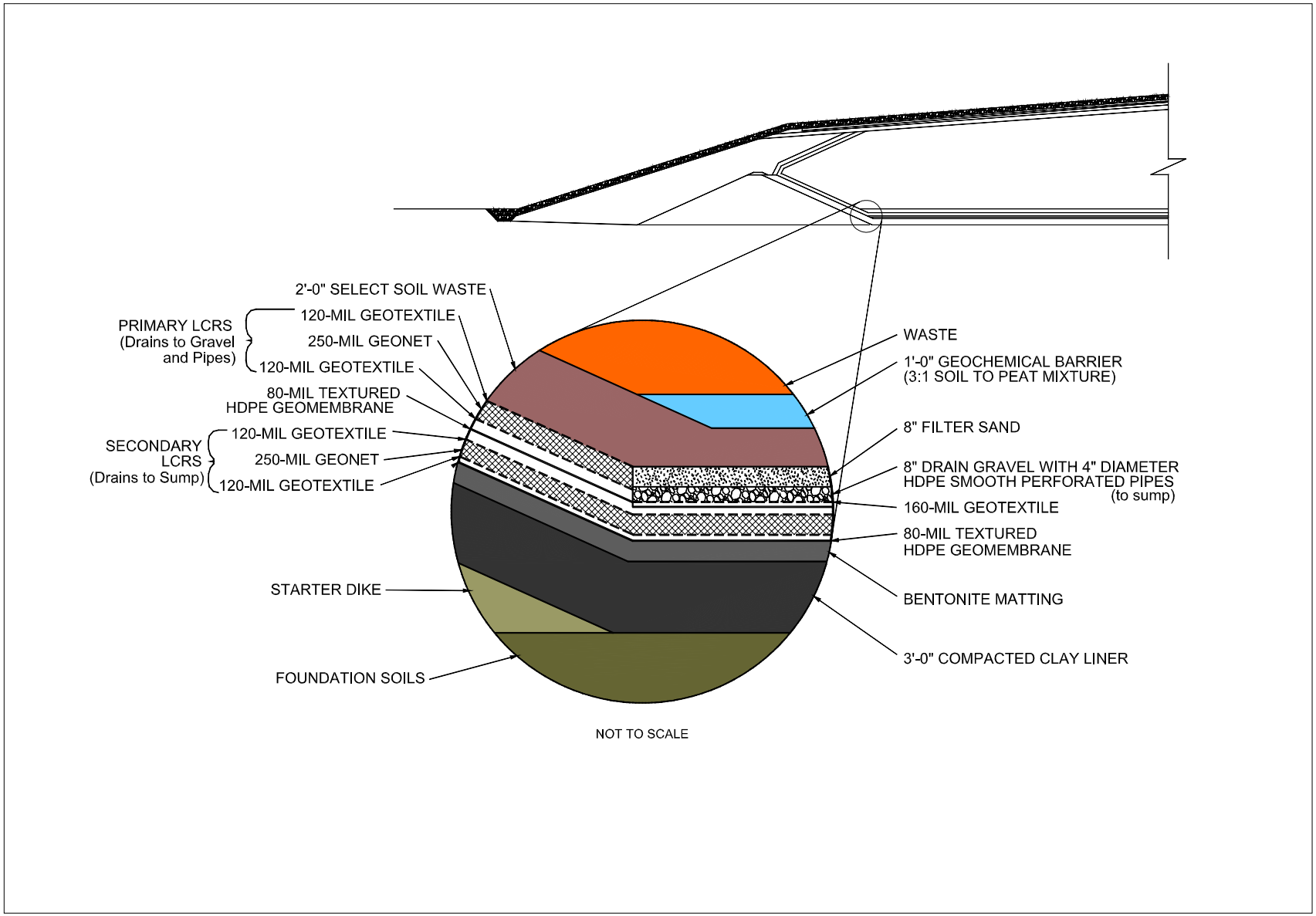

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Figure A−9. Basal Liner System of the Weldon Spring, Missouri, Site Disposal Cell

−Horizontal Seismic Acceleration Coefficient (long term) = 0.17

−Horizontal Seismic Acceleration Coefficient (short term) = 0.13

- Sustain a Probable Maximum Precipitation (PMP) event defined as 38.4 inches in 24 hours.

Leachate from the cell is collected in a primary collection system under the cell consisting of 4-inch (10-centimeter)-diameter perforated HDPE pipes placed in the drainage material on top of the primary liner (Figure A–9). The pipes convey leachate by gravity to a sump located north of the disposal cell (Figure A–10). The sump consists of a 200-foot (61-meter)-long, 42-inch (107-centimeter)-diameter HDPE pipe for storage and a 60-inch (152-centimeter)-diameter HDPE manhole for access. A zone of drain gravel in an annulus enclosed by an 80-mil (2-millimeter)-thick HDPE geomembrane liner was placed around the leachate piping between the cell liner and the sump and also around the sump itself to provide secondary containment. Within the cell, the primary collection pipes are configured to overflow into the drain gravel if they become clogged or if water levels exceed 12 inches (30 centimeters), to be conveyed inside the annulus to the secondary containment around the sump. A monitor well was installed adjacent to the sump manhole to detect leakage from the sump or overflow of the primary collection pipes into the secondary containment system. Primary collection system pipes converge at the sump.

A secondary collection system consists of an HDPE geonet placed between layers of geotextile (high-tensile strength filter fabric), which is placed between the primary and secondary bottom liners (Figure A–9). This system collects leakage through the primary liner. Fluids flow through the secondary collection system to two gravel-filled sumps, one for each basin, located along the north edge of the cell (Figure A–10). The fluids are then conveyed by HDPE pipe through the gravel-filled annulus to the HDPE sump north of the cell. Flows in secondary collection system pipes can be monitored individually at the sump.

Instrumentation sensors installed in the LCRS sump will be used to monitor the combined (primary and secondary) leachate volume. The east and west secondary leachate collection system flow is discretely monitored prior to being combined with the primary leachate through a system of volumetrically calibrated containers. These containers are equipped with level switches and dump valves. The container fills with secondary leachate to a predetermined level, and a valve is actuated that dumps the contents. The number of dumps is recorded electronically and displayed at the LCRS monitoring cabinet. The flow rates will be calculated from these data. The LCRS monitoring cabinet is installed in the LCRS Support Building and displays the combined sump level and the discrete secondary collection system number of dumps. The operational capacity of the combined sump is approximately 11,200 gallons, and the sump secondary containment is approximately the same. The operation and maintenance plan for the LCRS is provided in Appendix I.

A summary of analytical results for leachate samples collected between January 2002 and January 2003 is provided as an attachment to Appendix I. These data will be reported in the annual environmental report.

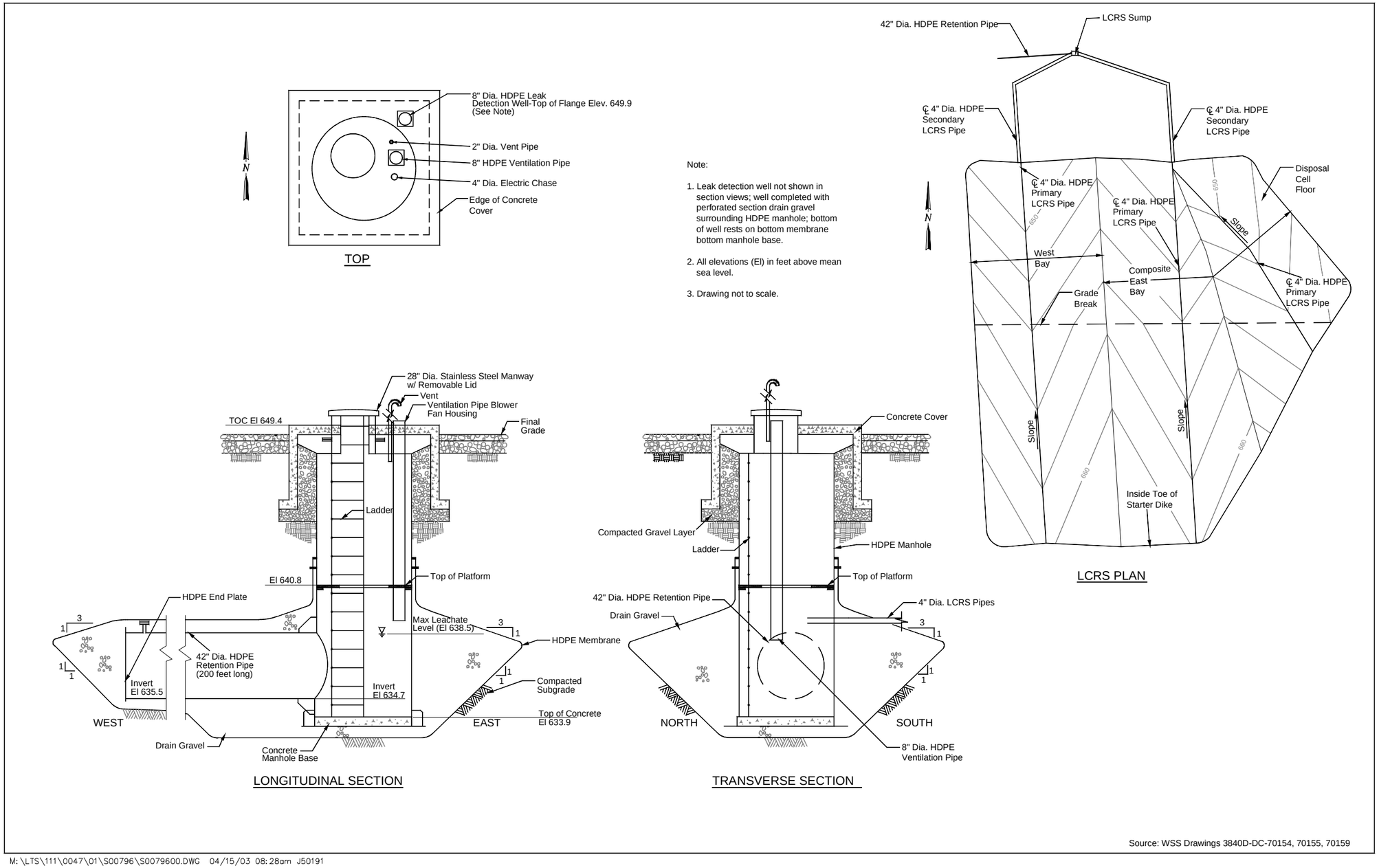

Figure A−10. Leachate Collection and Removal System of the Weldon Spring, Missouri, Site Disposal Cell

A rock apron at the toe of the side slope is 16 feet wide and 4 feet deep and filled with rock with a median diameter of 8 inches. The apron protects the cell from gullying or erosion progressing upslope (headward erosion) toward the cell. It also dissipates energy and redistributes flow off the cell. Positive grading directs runoff from the disposal cell and the immediate surrounding area away from the cell. Final grading of the Chemical Plant incorporates the natural drainage patterns to the greatest extent practical to promote drainage and prevent scouring and erosion. Beyond the cell, surface water is controlled using V-shaped surface swales designed to accommodate runoff from a PMP 24-hour storm event.

DOE established a detection-monitoring network (Figure A−11) around the cell to monitor cell performance, as required under Title 40 *Code of Federal Regulations* Part 264 (40 CFR 264) Subpart F and 10 CSR 25–7.264(2)(F). The network originally consisted of five wells and Burgermeister Spring. All wells are completed in the weathered portion of the Burlington-Keokuk Limestone. In 2001, monitor well MW–2048 was damaged and replaced with MW−2055. Also, MW–2051 was installed to replace MW−2045, where anomalous, elevated metal concentrations were attributed to poor hydraulic performance. Burgermeister Spring (SP−6301) is a perennial downgradient point of emergence for groundwater from the Chemical Plant area.

A2.1.4 Surface Water

Streams do not run through the property, but because the site is topographically higher than the surrounding areas, drainageways originate on the property and convey storm water off site. Prior to remediation, surface drainage from the western portion of the site, which included Ash Pond, the south and north dump areas, and the raffinate pits, drained to tributaries of Busch Lake 35 and then to Schote Creek and Dardenne Creek (Figure A–12). In this watershed during 1999, Ash Pond, Raffinate Pits 3 and 4, the chipped wood storage area, and the south end of the temporary storage area (TSA) were remediated and confirmed to meet Chemical Plant ROD cleanup criteria. The remainder of this watershed was remediated and confirmed to meet cleanup criteria during 2000. Final grading was completed during 2001, and the area was seeded.

Surface water drainage from the northeast portion of the Chemical Plant, which included the administration building and subcontractor parking lots, Frog Pond, the material staging area, and part of the disposal cell, discharged to Dardenne Creek from Schote Creek after first flowing through Busch Lakes 36 and 35 (Figure A–12). During cell construction, storm water runoff from open portions of the cell was collected in Retention Basin 2 for treatment before discharge by pipeline to the Missouri River. The cell was closed during 2001 and the basin was removed.

In 2002, average uranium levels at the off-site surface water locations were lower than the 2000 annual averages at three of five locations and slightly higher at two locations. Average annual uranium concentrations for surface water are provided in Table A–5, along with the historical high concentrations for each location. The historical concentrations for the background location, SW–2007, are also shown. Uranium levels at the Busch Lake Outlets have shown an overall decline since remediation started. The Schote Creek and Dardenne Creek locations are downstream of the lakes and have always shown relatively low concentrations because the Chemical Plant portion of the watershed is much smaller than the total watershed area. The slightly higher levels reported for these two creeks in 2001 are within the range reported at the background location. Surface water bodies downstream of the Chemical Plant continue to show declining uranium levels.

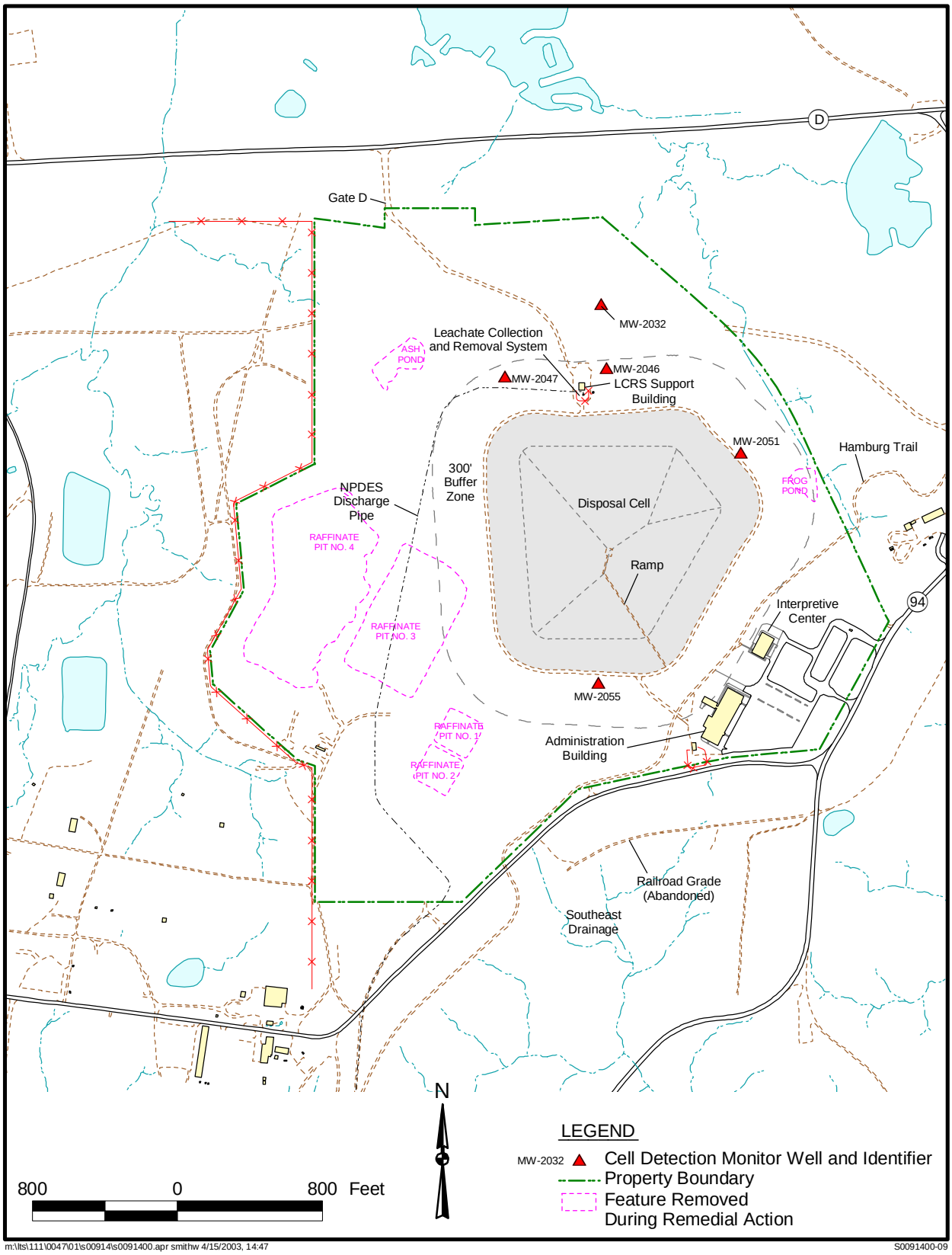

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Figure A−11. Cell Performance Well Locations at the Weldon Spring, Missouri, Site

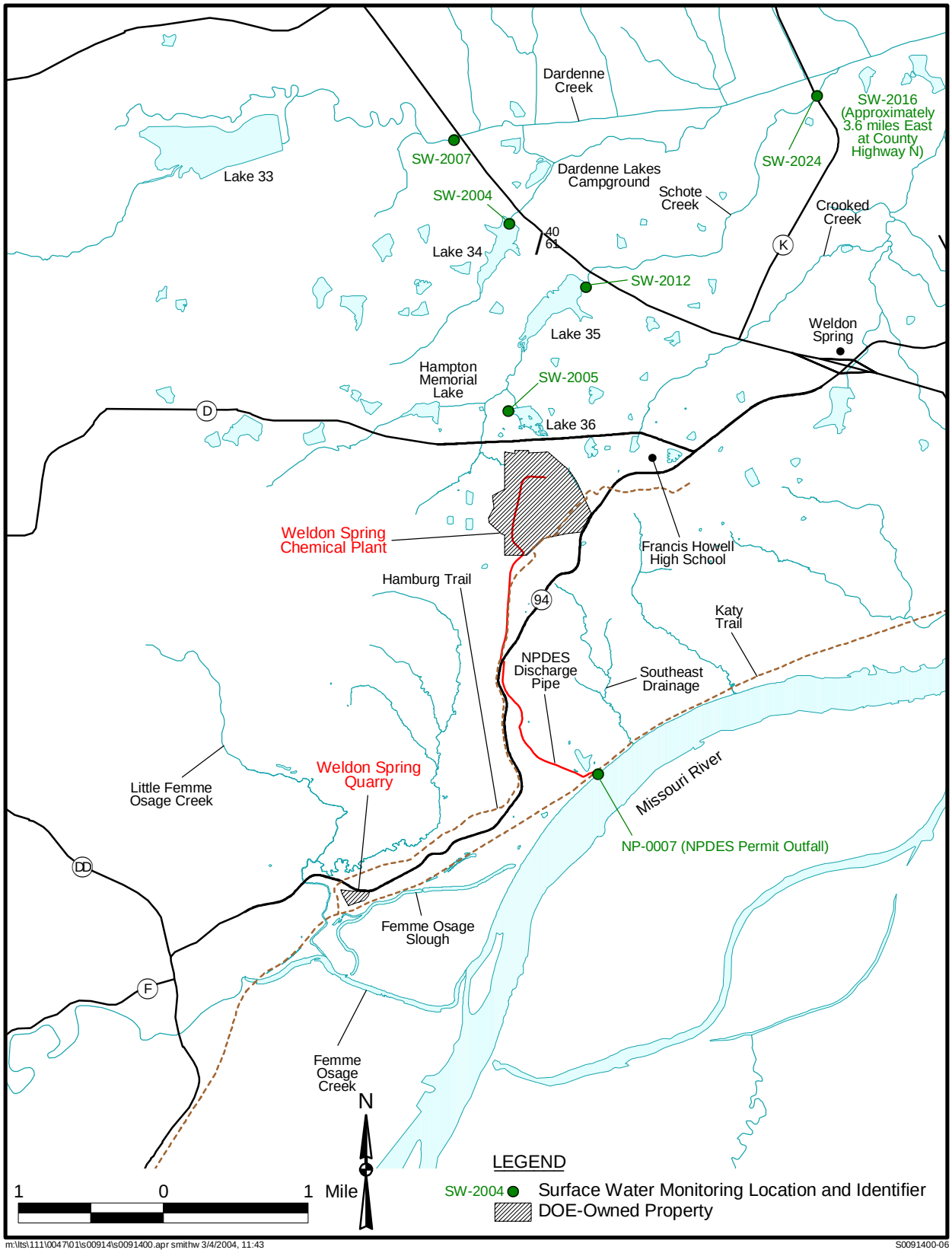

Figure A−12. Surface Water Monitoring Locations at the Chemical Plant Area of the Weldon Spring, Missouri, Site

Table A−5. 2002 Annual Averages for Total Uranium Concentrations at Chemical Plant Area Surface Water Locations at the Weldon Spring, Missouri, Site

Identifier	Location	Average[a]	Maximum[a]	Minimum[a]	Historical Maximum[a] (year)
SW–2004	Lake 34	4.3	6.7	2.6	39.0 (1989)
SW–2005	Lake 36	3.1	4.1	2.5	53.7 (1996)
SW–2012	Lake 35	2.4	4.5	1.0	326.0 (1991)[b]
SW–2016	Dardenne Creek	0.9	1.4	0.3	7.8 (1994)
SW–2024	Schote Creek	1.9	2.8	0.8	5.3 (1999)
SW–2007[c]	Background		8.2	0.1	8.2 (1990)

[a]All concentrations in picocurie(s) per liter (pCi/L).
[b]Result considered an outlier.
[c]Location was not sampled in 2001.

Runoff from the southern portion of the Chemical Plant (Figure A–12), which historically included the site water treatment plant, Building 434 (where legacy process chemicals were stored), and parking and equipment areas for the former CSS facility, flows southeast to the Missouri River via the Southeast Drainage. Prior to remedial action, overflow from Raffinate Pits 1, 2, and 3 and the Chemical Plant process sewer line discharged to the Southeast Drainage. Raffinate Pit 3 was removed in 1999. The site water treatment plant, effluent basins, equalization basin, Raffinate Pits 1 and 2, and Building 434 were removed, and the area was remediated and confirmed to meet Chemical Plant ROD cleanup criteria during 2000. By the end of 2001, final grade was established and the area was seeded.

A2.1.5 Vicinity Properties

In 1985, Oak Ridge Associated Universities (ORAU) conducted a comprehensive radiological survey of all areas outside the Chemical Plant boundary and within the ordnance works area (Boerner 1986). The purpose of the study was to assess the extent and levels of off-site radioactive contamination resulting from operation of the uranium feed materials plant. Radiologically contaminated areas outside the boundaries of the Chemical Plant and Quarry were defined by ORAU as vicinity properties. Vicinity properties that required remedial action are shown in Figure A−13. The radiological surveys included surface and subsurface soils, water, and sediment on the properties surrounding the Chemical Plant. Background levels and baseline concentrations were established for each medium in the vicinity of the area. These concentrations were used to determine the extent of radioactive contamination within a surveyed area. ORAU used the following threshold concentrations to determine radioactively contaminated soil: radium-226 and thorium-232 concentrations of 5 picocuries per gram (pCi/g) averaged over the first 6 inches (15 centimeters) of soil depth and 15 pCi/g for soil more than 6 inches (15 centimeters) deep; uranium-238 concentration of 60 pCi/g averaged over the area of interest. Results of the study indicated that soils in small areas in the Chemical Plant area and the MDC conservation areas had generally low levels of radioactivity as a result of previous site activities. In total, ORAU identified 17 vicinity properties, of which seven were in the DA Weldon Spring Training Area (DA−1 through DA−7), and 10 were in the MDC wildlife areas (MDC−1 through MDC−10). The properties and descriptions are listed in Table A−6.

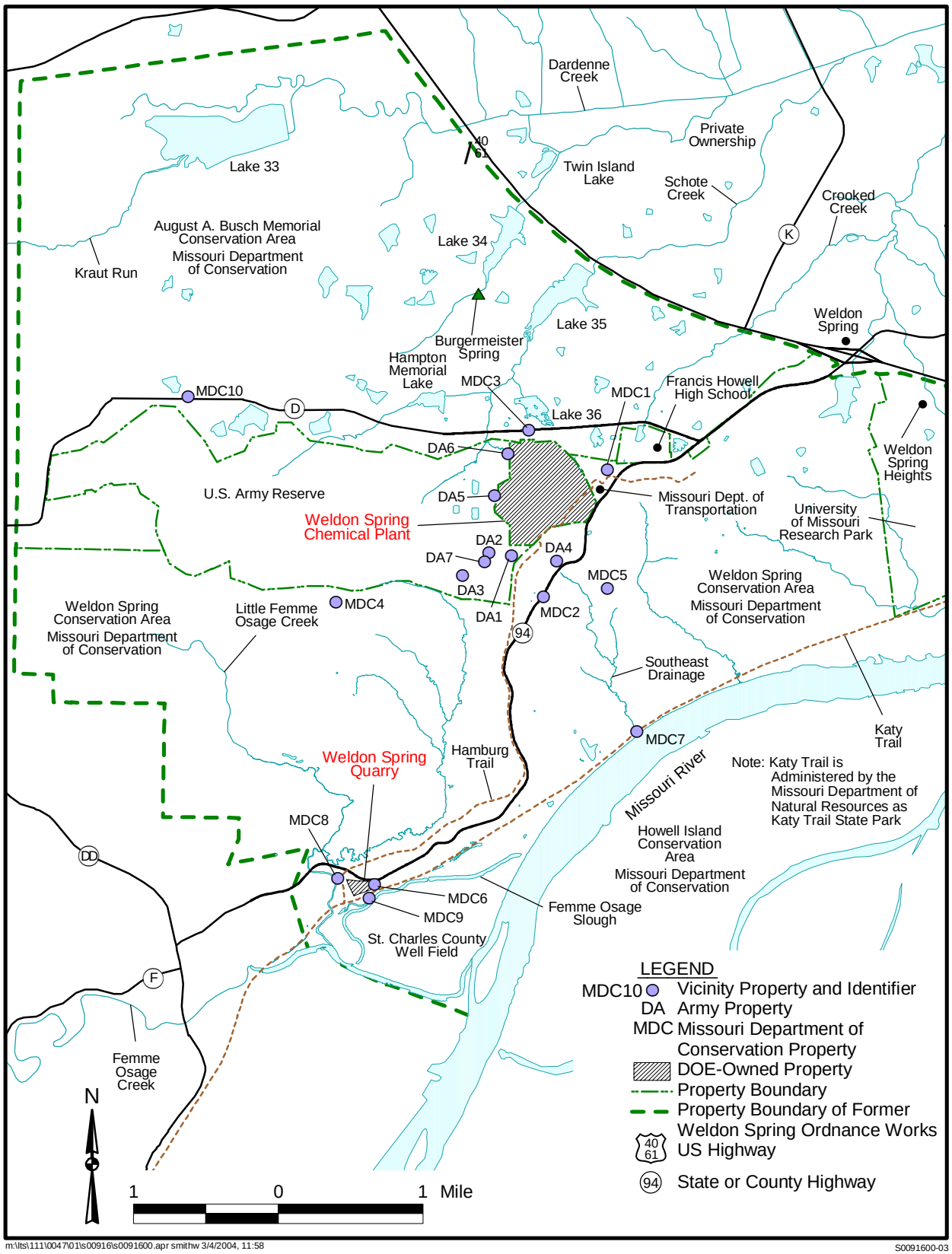

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Figure A−13. Vicinity Property Location Map of the Weldon Spring, Missouri, Site

The Chemical Plant ROD is the remedial action decision document for most of the vicinity properties. Specific cleanup decisions for DA−7, MDC−8, and the Southeast Drainage (DA−4 and MDC−7) were addressed either before or after the ROD was signed under the following documentation:

- DA−7: Interim Response Action 4 (IRA−4) Army Property No. 7
- MDC−8: *Engineering Evaluation/Cost Analysis for the Proposed Management of Contaminated Water in the Weldon Spring Quarry* (DOE 1989)
- DA−4/MDC−7: *Engineering Evaluation/Cost Analysis for the Proposed Removal Action at the Southeast Drainage near the Weldon Spring Site, Weldon Spring, Missouri* (DOE 1996)

Table A−6. Vicinity Properties Associated with the Weldon Spring, Missouri, Site

Vicinity Property	ROD Designation	Description
DA−1	A1	Located on approximately 7 acres (3 hectares) of wooded field, the contaminated area consisted of a soil-covered mound and surrounding area, an approximately 4-foot (1.2-meter)-wide ditch adjacent to a railroad track east of the wooded field and a drainage ditch flowing northwest.
DA−2	A2	Located adjacent to a railroad track in a grass field approximately 400 feet (122 meters) north of the Weldon Spring Training Area entrance road and about 3,802 feet (1,159 meters) from the entrance off Missouri State Route 94. The area was rectangular, measuring 70 feet (21.4 meters) by 260 feet (79.3 meters).
DA−3	A3	Wooden loading dock, approximately 246 feet (75 meters) to the south of the Weldon Spring Training Area entrance road and 4,528 feet (1,380 meters) from the entrance off Missouri State Route 94. The dock rose approximately 15 feet (4.6 meters) above an abandoned railroad track.
DA−4	A4	Short segment of Southeast Drainage running from the Imhoff Tanks within the Weldon Spring Chemical Plant to the Missouri River.
DA−5	A5	Surface drainage ditch leading west from raffinate pits across a part of the Weldon Spring Training Area.
DA−6	A6	About 660 feet (201 meters) of a drainage ditch beginning at Ash Pond, which crosses a portion of the Weldon Spring Training Area.
DA−7	A7	Isolated area about 3 feet (1 meter) north of the Weldon Spring Training Area entrance road about 3,793 feet (1,156 meters) from the entrance off Missouri State Route 94. The area was rectangular, measuring roughly 6.9 feet (2.1 meters) by 4.9 feet (1.5 meters).
MDC−1	B1	An area of soil approximately 1,798 square feet (167 square meters) on the west side of Missouri State Route 94 just north of the entrance to the Missouri Highway Department property.
MDC−2	B2	Small piece of pipe on the surface approximately 3 feet (1 meter) off Missouri State Route 94 to the east and about 11,478 feet (3,498.4 meters) from U.S. Highway 40/61.
MDC−3	B3	Two small isolated areas of contamination south of Highway D at the 24,482 feet (7,462.1 meters) reference marker.
MDC−4	B4	Situated near an access road to the radio tower (Road C) and the DA property perimeter fence. Consisted of mounds of soil and miscellaneous wood, metal, and other debris.
MDC−5	B5	Located 1,545 feet (471 meters) from the intersection of Highway D and Missouri State Route 94 and was in a drainageway along an eroded gravel road. Consisted of abandoned drums and adjacent soil.

Table A−6 (continued). Vicinity Properties Associated with the Weldon Spring, Missouri, Site

Vicinity Property	ROD Designation	Description
MDC−6	B6	An isolated spot of contamination adjacent to the Quarry perimeter fence. Consisted of an area of soil approximately 10.8 square feet (1 square meter).
MDC−7	B7	The main Southeast Drainage area running from the MDC perimeter fence through the Weldon Spring Wildlife Area to the Missouri River.
MDC−8	B8	Three isolated spots near a railroad bridge spanning the Little Femme Osage Creek. One measuring 5.4 square feet (0.5 square meter), two measuring 10.8 square feet (1 square meter).
MDC−9	B9	Located between the abandoned Missouri-Kansas-Texas Railroad and Femme Osage Slough, south of the Weldon Spring Quarry.
MDC−10	B10	Old DA disposal area along Highway D adjacent to an access road. Isolated area of soil estimated to be 1.6 square feet (0.15 square meter).

MDC−1 was remediated in accordance with DOE Formerly Utilized Sites Remedial Action Program protocols prior to ROD signature. MDC−2 was remediated prior to ROD signature by ORAU during the initial identification campaign.

A2.1.5.1 DA−1, DA−2, DA−3, and DA−5

Remediation of DA−1, DA−2, DA−3, and DA−5 began on December 16, 1997, and was completed on July 9, 1998. Contaminated soil, root balls, and miscellaneous materials were excavated and transported to the Ash Pond storage area, the chipped wood storage area, and the material staging area, respectively, and were eventually placed in the disposal cell. Quantities were estimated as follows: DA−1: 1,715 cubic yards (1,311 cubic meters), DA−2: 731 cubic yards (559 cubic meters), DA−3: 65 cubic yards (50 cubic meters), and DA−5: 1,250 cubic yards (956 cubic meters). After contaminated soil within the vicinity property had been excavated, confirmation sampling was conducted to verify that the contaminant concentrations were less than Chemical Plant ROD cleanup criteria. Cleanup criteria are included in Section A2.1.2, “Soil Confirmation.” Compete details of the remediation are in the *Closeout Report for Vicinity Properties DA−1, DA−2, DA−3, DA−5, and DA−7* (DOE 1999c).

A2.1.5.2 DA−6

Vicinity Property DA−6 consists of a losing-stream reach of the Ash Pond drainage extending 1,132 feet (345 meters) west of the DOE fence line. The extent of this drainage was initially characterized to provide data regarding potential contamination of surface and shallow subsurface sediments and soils. Results of the soil sampling indicated the presence of uranium-238 above ALARA goals at the westernmost sampling location. On the basis of these data, walkover/hotspot sampling was conducted along the length of the drainage extending northward to the Busch Lake 35 inlet, as well as south to the previously remediated portion of Vicinity Property DA−5. Walkover surveys and hotspot sampling were also performed in DA−6 proper to verify uranium-238 levels. Both DOE and the Oak Ridge Institute for Science and Education (formerly ORAU) conducted these surveys.

Data results indicated that all uranium-238 concentrations within the extended drainage were at or below the surface ALARA goal of 30 pCi/g. Uranium-238 concentrations within the DA−6 drainage proper were below or at the surface criterion of 120 pCi/g. Thorium-230 was analyzed

in sediment samples obtained after a contaminated surface water discharge into the drainage. Results showed that levels of thorium-230 were below the surface ALARA goal of 5.0 pCi/g.

No remediation was required for DA−6 based on the additional characterization performed on the vicinity property. The analytical results are documented in *Analytical Data Results for Engineering Characterization of Vicinity Property DA−6; Ash Pond Drainage* (DOE 2001a).

A2.1.5.3 MDC−3, MDC−4, MDC−5, and MDC−10

Remediation of MDC−3, MDC−4, MDC−5, and MDC−10 began on October 26, 1997, and was completed on June 22, 1998. Contaminated soils were transported to the Ash Pond storage area, root balls were taken to the chipped wood storage area, and miscellaneous materials were taken to the material staging area. These wastes were eventually placed in the disposal cell. The quantities were estimated as follows: MDC−3: 13 cubic yards (10 cubic meters), MDC−4: 534 cubic yards (408 cubic meters), MDC−5: 137 cubic yards (105 cubic meters), and MDC−10: 74 cubic yards (57 cubic meters). After contaminated soil within the vicinity property had been excavated, confirmation sampling was conducted to verify that the contaminants with concentrations exceeding Chemical Plant ROD cleanup levels had been removed. Complete details of the remediation are in the *Closeout Report for Vicinity Properties MDC−3, MDC−4, MDC−5, and MDC−10* (DOE 1999d).

A2.1.5.4 MDC−6

Remediation of MDC−6 was conducted in November 1993 as part of bulk waste removal from the Quarry. The soil volume removed was 219 cubic yards (167 cubic meters), and it was staged within the Quarry and disposed of according to the *Record of Decision for the Management of the Bulk Wastes at the Weldon Spring Quarry* (DOE 1990). The soil was removed at a later date and transported to the TSA to await final disposal in the cell.

A2.1.5.5 MDC−9

Remediation of MDC−9 began on January 4, 1996, and was completed on February 29, 1996. Contaminated soil (approximately 4,450 cubic yards [3,402 cubic meters]) and root balls were staged at the Ash Pond storage area or chipped wood storage area and eventually placed in the disposal cell.

Complete details of the remediation of MDC−6 and MDC−9 are in the *Closeout Report for Vicinity Properties MDC−6 and MDC−9* (DOE 1999b).

A2.1.5.6 MDC−8

The Quarry construction staging area, including vicinity property MDC−8, was remediated on August 8, 1990. The excavated soil (approximately 2 cubic yards [1.5 cubic meters]) was staged within the Quarry area for removal with Quarry bulk waste, temporary storage at the TSA, and eventual disposal within the disposal cell. After soil removal, the area was confirmed clean. Complete details of the remediation of MDC−8 are included in the *Vicinity Property DOC−8 Close-Out Report* (DOE 1997a).

A2.1.5.7 Southeast Drainage

The Southeast Drainage is a natural drainage area with intermittent flow that traverses both the Army property and the Weldon Spring Conservation Area from the Chemical Plant site to the Missouri River (Figure A−2). Both the Army and AEC used the drainage to discharge water from sanitary and process sewers to the Missouri River. Also, contaminated liquids in the raffinate pits were decanted to the plant process sewer and subsequently discharged to the Southeast Drainage; overflow from the raffinate pits continued to discharge into the drainage after plant operations ceased. As a result, sediments and soils in the Southeast Drainage were contaminated. Radioactive contaminants of concern were uranium-238, radium-226, thorium-232, and thorium-230. Spring water in the Southeast Drainage (springs SP−5303 and SP−5304) was contaminated with uranium and low concentrations of nitroaromatic compounds from the contaminated sediment.

Remedial action for the Southeast Drainage was addressed as a separate action under Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The *Engineering Evaluation/Cost Analysis for the Proposed Removal Action at the Southeast Drainage near the Weldon Spring Site, Weldon Spring, Missouri* (DOE 1996) was prepared in August 1996 to evaluate the human and ecological health risks within the drainage. The EE/CA recommended that selected sediment in accessible areas of the drainage should be removed with track-mounted equipment and transported by off-road haul trucks to the Chemical Plant. The excavated materials would be stored temporarily at an on-site storage area until final disposal in the disposal cell.

Soil removal was in two phases: 1997−98 and again in 1999. A total of 1,931 cubic yards (1,476 cubic meters) was excavated in the first phase, and about 22.5 cubic yards (17.2 cubic meters) was excavated in the second phase.

Post-remediation soil sampling was conducted at Southeast Drainage locations after the soil was excavated. The purpose of this sampling was to determine the remaining concentrations of radionuclides within the soil and sediment and to calculate the risk reduction achieved from soil removal. Sampling was conducted in accordance with the *Post-Remediation Sampling Plan for the Southeast Drainage* (DOE 1997c). All post-remediation data results were used by Argonne National Laboratory to calculate risk reduction achieved by the removal action.

Complete details of the remediation as well as the post-cleanup risk assessment of the Southeast Drainage are in the *Southeast Drainage Closeout Report Vicinity Properties DA−4 and MDC−7* (DOE 1999g).

A2.1.5.8 Busch Lakes

Busch Lakes 34, 35, and 36 are man-made bodies in the eastern portion of the August A. Busch Memorial Conservation Area and were constructed in the 1960s when the feed materials plant was in operation.

Lakes 35 and 36 are part of the Schote Creek surface water drainage, which collects storm water runoff from the Chemical Plant. Water flows to Lake 36 via a natural drainage from the Chemical Plant. From Lake 36, the water flows through an overflow structure into another drainage that flows into Lake 35. Lake 34 is in a surface water drainage that receives no direct

runoff from the Chemical Plant, but does receive groundwater that flows beneath the Chemical Plant and discharges from Burgermeister Spring.

When the sediments in these lakes were characterized in 1989, it was determined that the radioactive contamination in them was limited to uranium-238. Lake 36 sediments were sampled again in 1997 after it had been drained by the MDC for scheduled restoration. Lakes 34 and 35 were sampled again in 1998 using a floating drill rig.

None of the samples obtained from Lakes 34 and 35 had uranium-238 concentrations greater than the cleanup criterion of 120 pCi/g. The data indicated that remediation of the sediments in these lakes was not warranted; therefore, no further action was required. Additional details are presented in the *Completion Report for Sediment Sampling at Busch Lakes 34 and 35* (DOE 1999a).

Characterization results from Lake 36 indicated that approximately 10,000 cubic yards (7,600 cubic meters) of sediment within the lake bed had uranium concentrations exceeding the ALARA goal of 30 pCi/g but below the cleanup criterion of 120 pCi/g. Because these sediments were accessible due to the lake drainage, DOE agreed to excavate this volume and place it on the Chemical Plant property. Although not required, DOE subsequently placed these sediments in the disposal cell. Details of characterization results are provided in the *Busch Lake 36 Summary Closeout Report* (DOE 1997e).

A2.1.5.9 Frog Pond Drainage Area

The following information was incorporated from the *Closeout Report for the Frog Pond Drainage* (DOE 2000c). The Frog Pond drainage begins at the north boundary of the Chemical Plant site and ends at Busch Lake 36.

ORAU sampled the Frog Pond areas during the vicinity property study conducted in 1985. Elevated levels of uranium-238 were identified within the Frog Pond drainage; however, the levels did not exceed DOE residual contamination criteria for classification as a contaminated MDC vicinity property. Therefore, they were not included in the Chemical Plant ROD as a vicinity property. In 1997 and 1998, additional sampling in the Frog Pond drainage area indicated that concentrations of uranium at locations in the drainage north of Highway D at the inlet area of Busch Lake 36 exceeded the ROD uranium-238 cleanup criterion of 120 pCi/g (DOE 1999f). This area was designated the Frog Pond Outlet vicinity property.

Remediation of the Frog Pond Outlet began on July 7, 1999, and was completed on October 7, 1999. Approximately 2,864 cubic yards (2,190 cubic meters) of contaminated soil and root balls were excavated and transported directly to the disposal cell. Analytical results of post-cleanup confirmation samples in the excavated areas averaged less than ALARA and no results exceeded criteria.

Excavation at the Frog Pond Outlet included removing approximately 20 feet (6 meters) of both 60-inch (152-centimeter)-diameter Highway D culverts and underlying soil from the eastern end of the outlet. Measurements of radioactivity indicated that soils remaining under the culverts still had elevated beta-gamma activity (500 to 800 counts per minute). Additional excavation would have been close to the MoDOT right-of-way and the utility corridor, which included a fiber optics line. Therefore, excavation ceased at the eastern end of the Frog Pond Outlet. Soil samples

were collected under both culverts, and the edge of the excavation was surveyed for future reference. After the samples had been collected, 70-inch- (178-centimeter-) diameter extensions were fit over the 60-inch (152-centimeter)-diameter culverts and encased in concrete at the culvert joints. The area was then backfilled to the original grade. Analytical results of the samples indicated that soil under the easternmost culvert had a uranium-238 concentration of 310 pCi/g, which is above the ROD cleanup criterion; uranium concentration in soil under the westernmost culvert was below the cleanup criterion. Further details of this sampling are presented in the *Closure Report for Soil Sampling at the Frog Pond Outlet, Addendum 6 of the Engineering Soil Sampling Plan for Army and MDC Vicinity Properties* (DOE 2000a). Residual contamination associated with these two culverts is the subject of an institutional control (see Appendix E).

A2.2 Groundwater OU

The Groundwater OU is the second of two OUs established for the Chemical Plant area of the Weldon Spring Site. The Groundwater OU addresses contaminated groundwater and springs in the Chemical Plant area.

A2.2.1 Present Conditions

A2.2.1.1 Groundwater

Contaminated groundwater remains beneath the Chemical Plant, primarily in the western and southwestern portions of the site and beneath portions of adjacent Army property (Figure A–14 through Figure A–19). Contaminants include uranium, TCE, nitrate, and nitroaromatic compounds. Nitroaromatic compounds also occur in groundwater in the east and northeast portion of the site. Contamination in groundwater is generally confined to the shallow, weathered portion of the Burlington-Keokuk Limestone. Some contamination occurs in the unweathered portion of the Burlington-Keokuk Limestone beneath the former raffinate pits. Groundwater from the Chemical Plant also discharges to springs in the August A. Busch Memorial Area.

Since the Groundwater OU project began in 1987, more than 100 wells and 15 springs have been used for groundwater monitoring and sampling. A total of 68 wells and 5 springs (SP−6301, SP−6303, SP−6306, SP−5303, and SP−5304) were sampled in 2002 to monitor the affects from historical Chemical Plant operation, recent remedial activities, and groundwater field studies. Monitor well locations are shown on Figure A–20. Spring monitoring locations are shown on Figure A−21.

Monitor wells at the Chemical Plant are completed in the Burlington-Keokuk Limestone. Most of the wells are completed in the weathered unit of the bedrock where most contaminated groundwater has been found. Some wells are screened in the unweathered zone of the Burlington-Keokuk Limestone and are used to assess the downward migration of contaminants. Where possible, monitor wells within the boundaries of the Chemical Plant are located near historical contaminant sources and preferential flow paths to assess migration into the groundwater system. Additional wells are located outside the Chemical Plant boundary to detect and evaluate potential off-site migration of contaminants (Figure A–20).

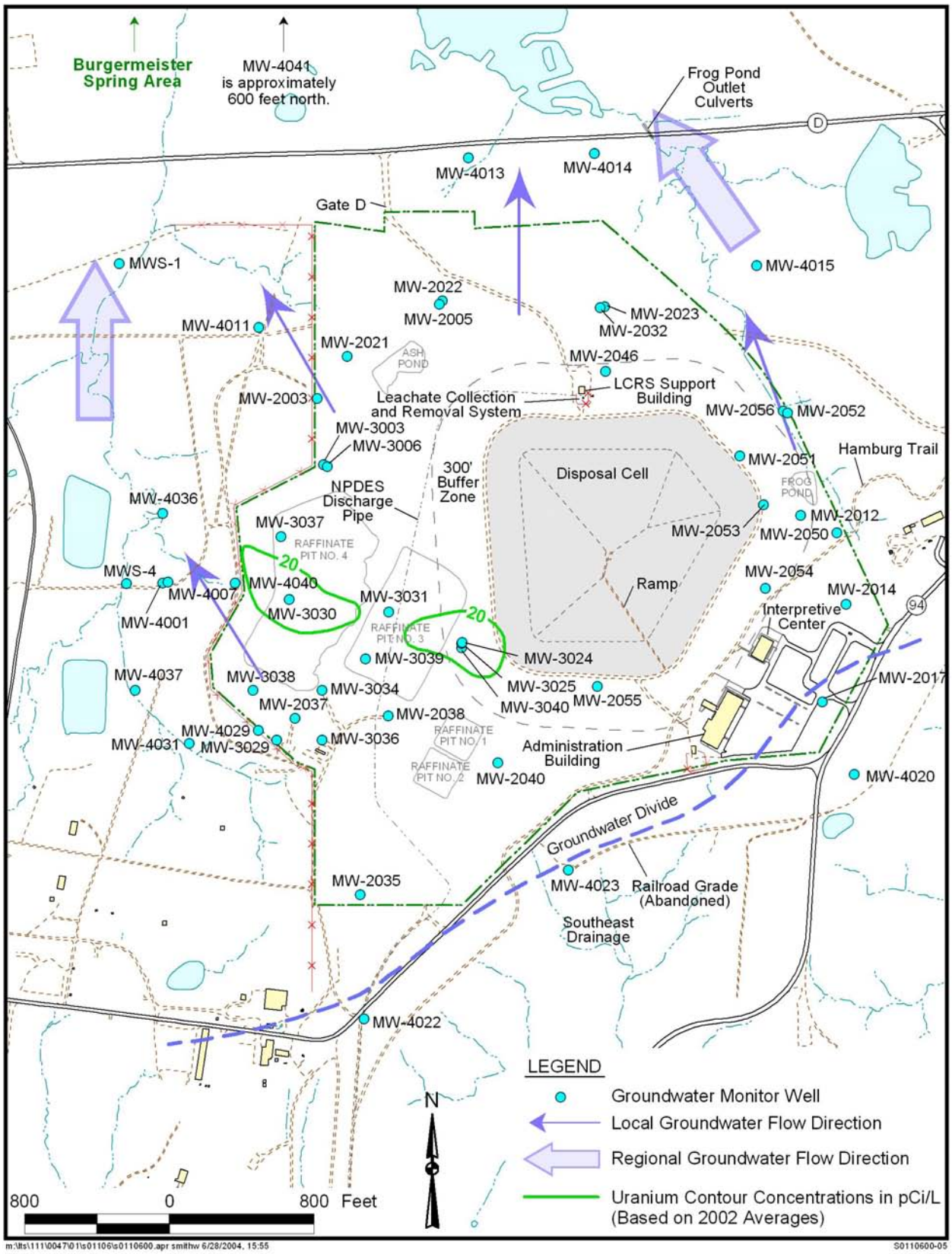

Figure A−14. Uranium Distribution in the Shallow Aquifer at the Weldon Spring, Missouri, Site Chemical Plant Area

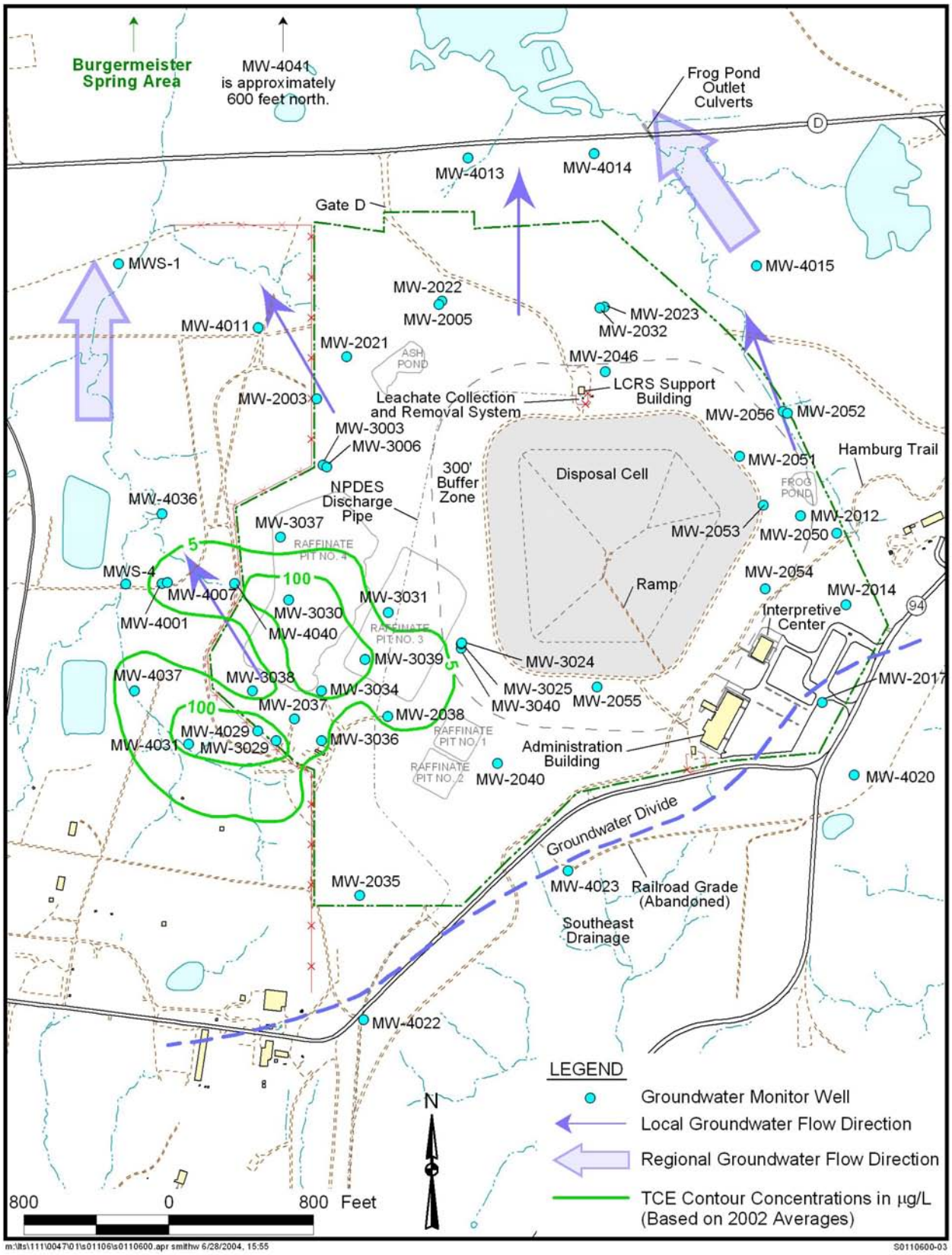

Figure A−15. TCE Distribution in the Shallow Aquifer at the Weldon Spring, Missouri, Site Chemical Plant Area

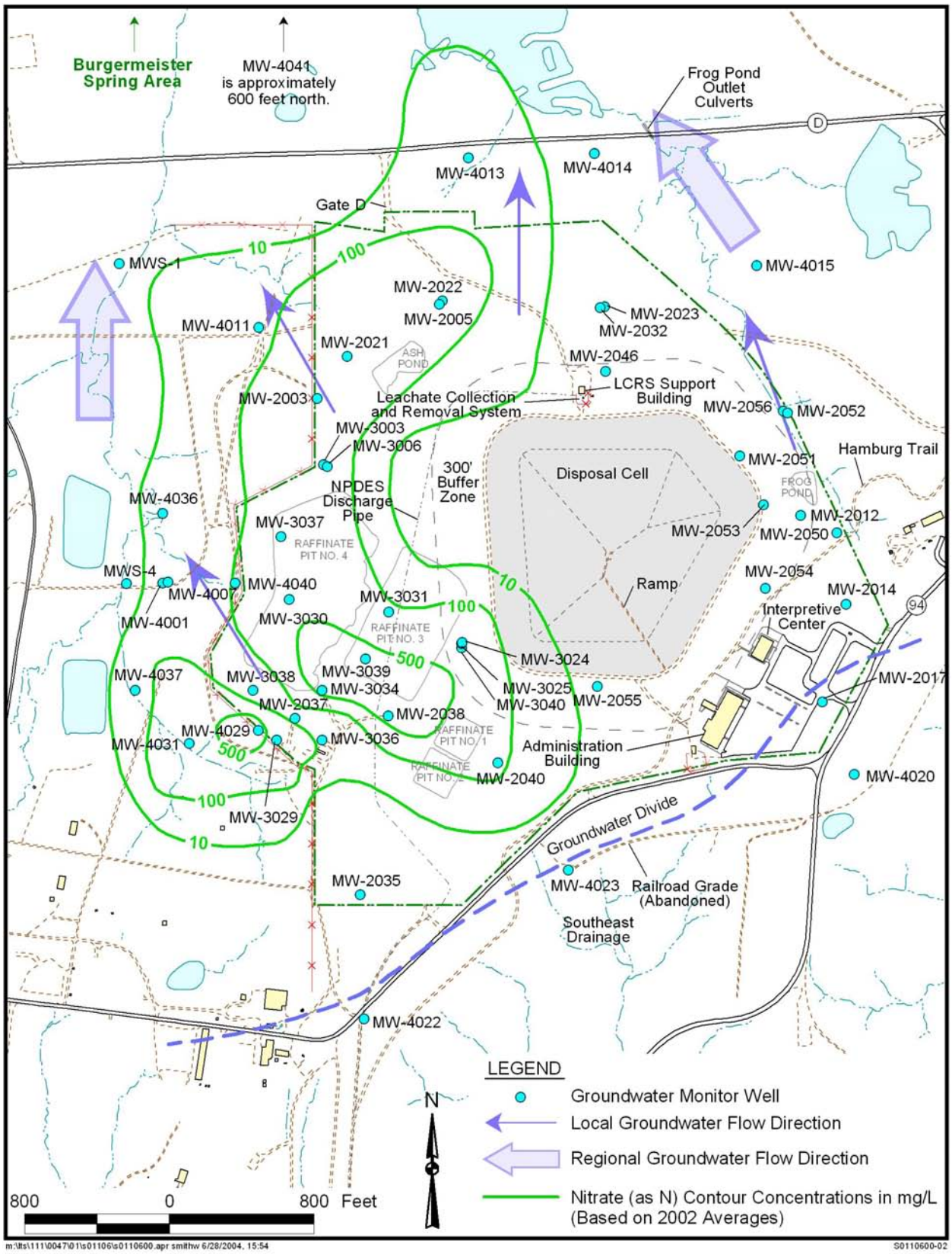

Figure A−16. Nitrate Distribution in the Shallow Aquifer at the Weldon Spring, Missouri, Site Chemical Plant Area

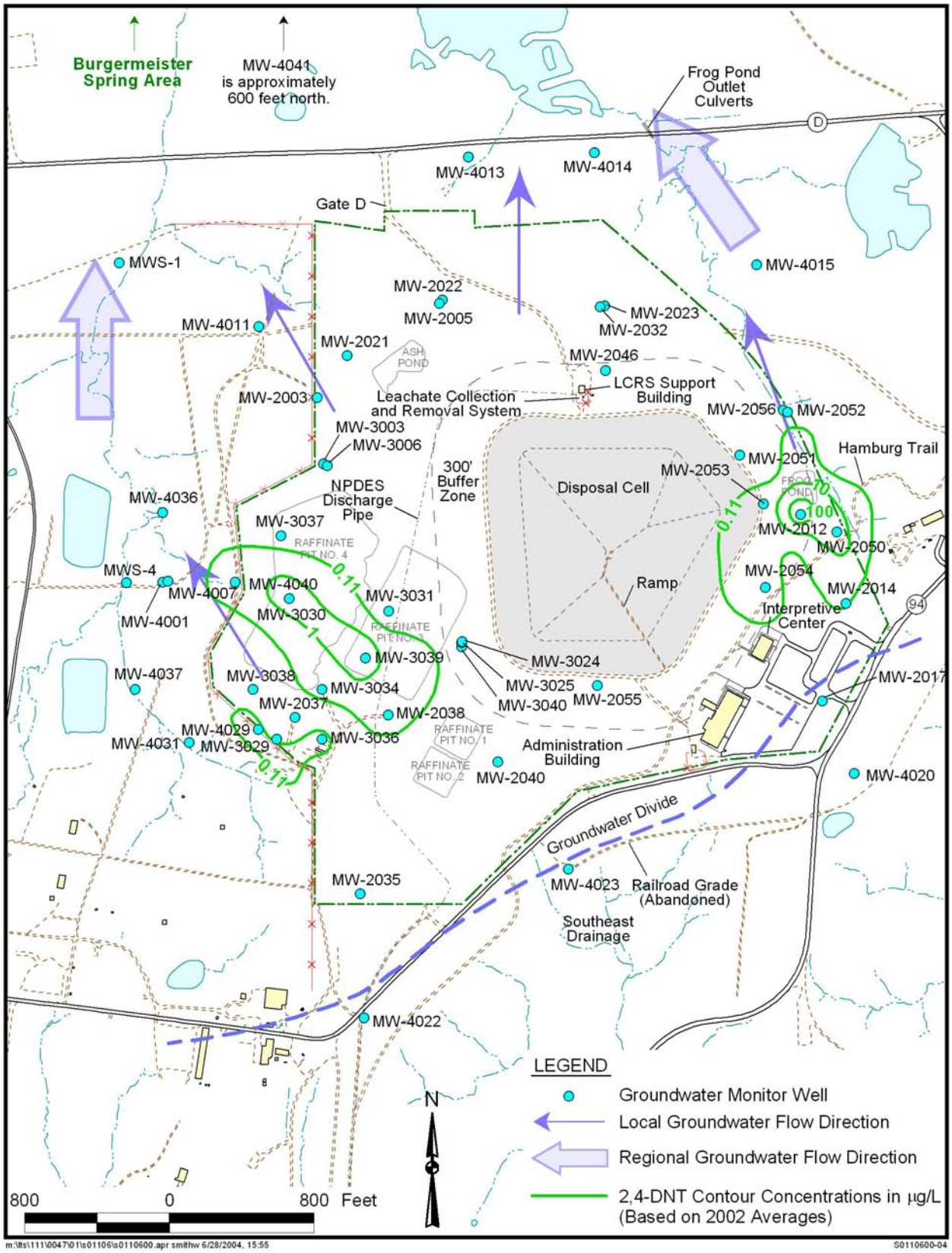

Figure A−17. 2,4-DNT Distribution in the Shallow Aquifer at the Weldon Spring, Missouri, Site Chemical Plant Area

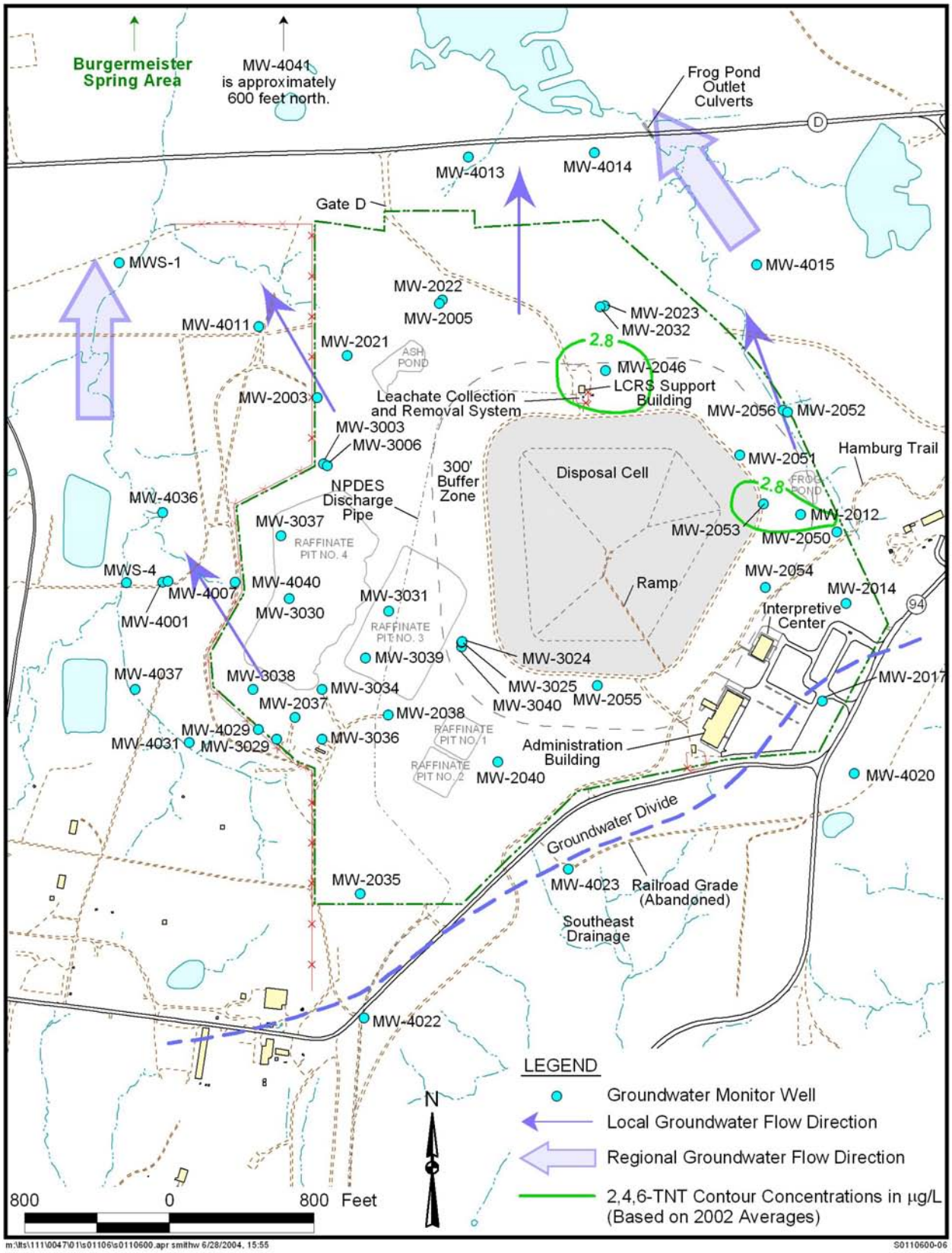

Figure A−18. 2,4,6-TNT Distribution in the Shallow Aquifer at the Weldon Spring, Missouri, Site Chemical Plant Area

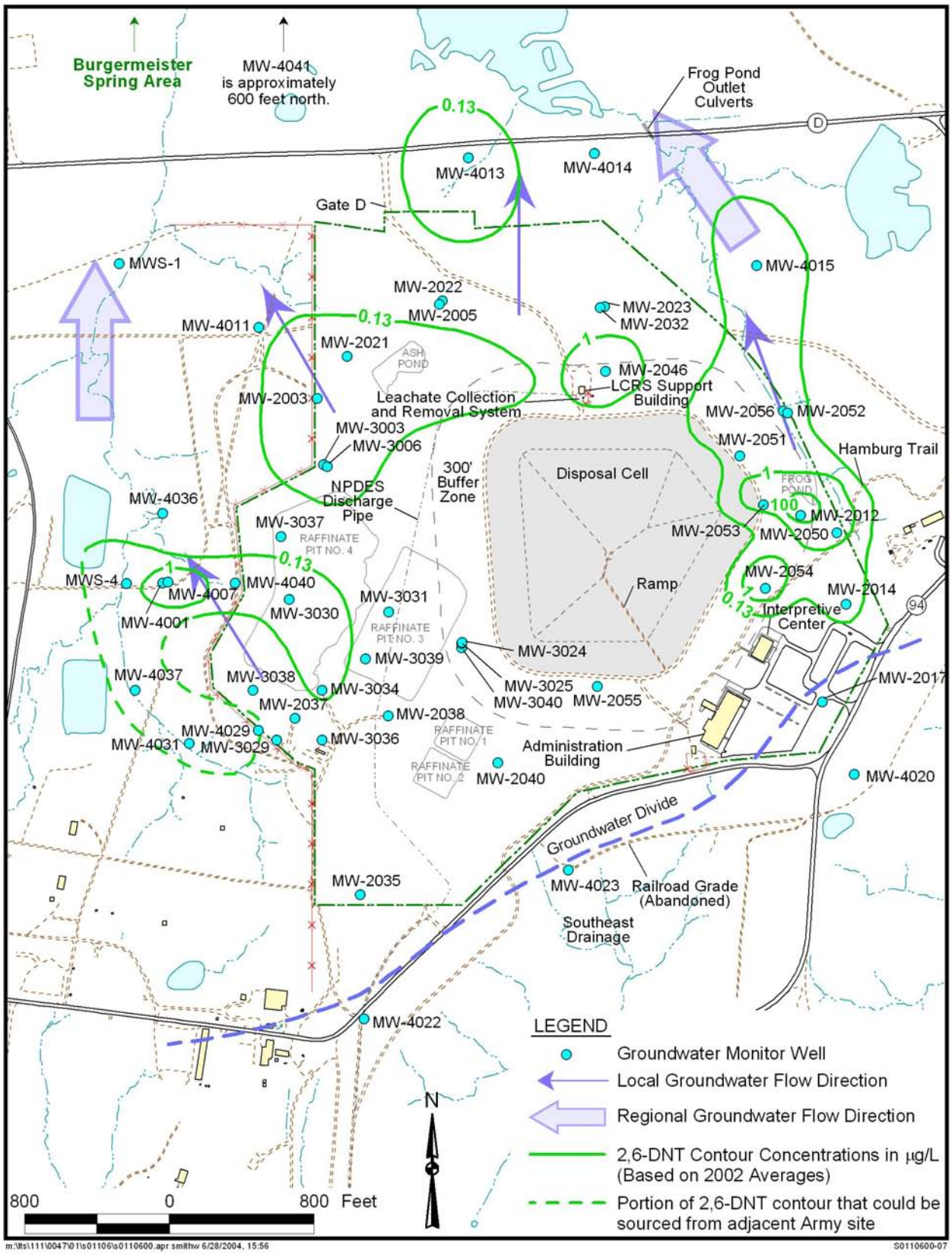

Figure A−19. 2,6-DNT Distribution in the Shallow Aquifer at the Weldon Spring, Missouri, Site Chemical Plant Area

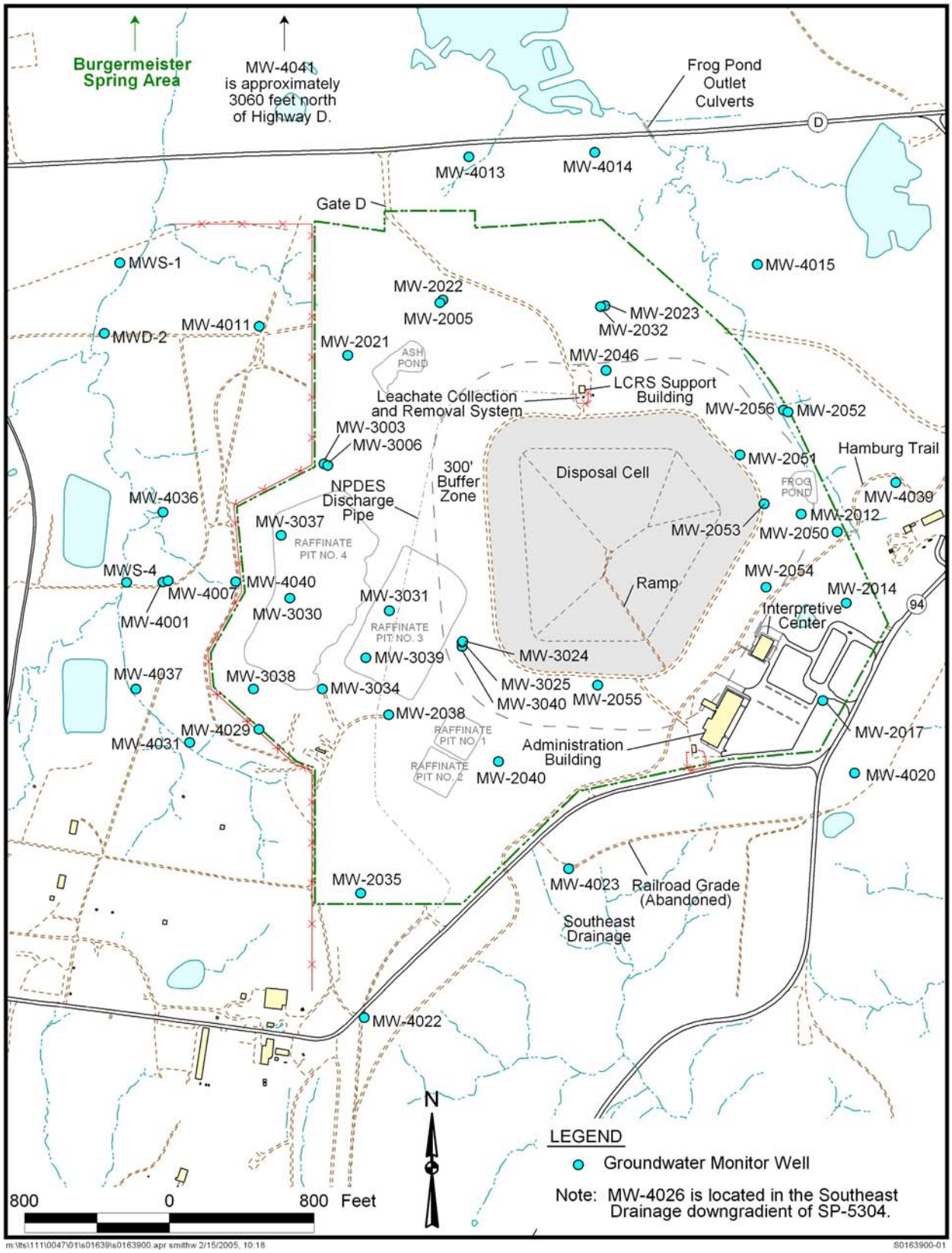

Figure A−20. Groundwater Monitor Well Locations at the Chemical Plant Area of the Weldon Spring, Missouri, Site

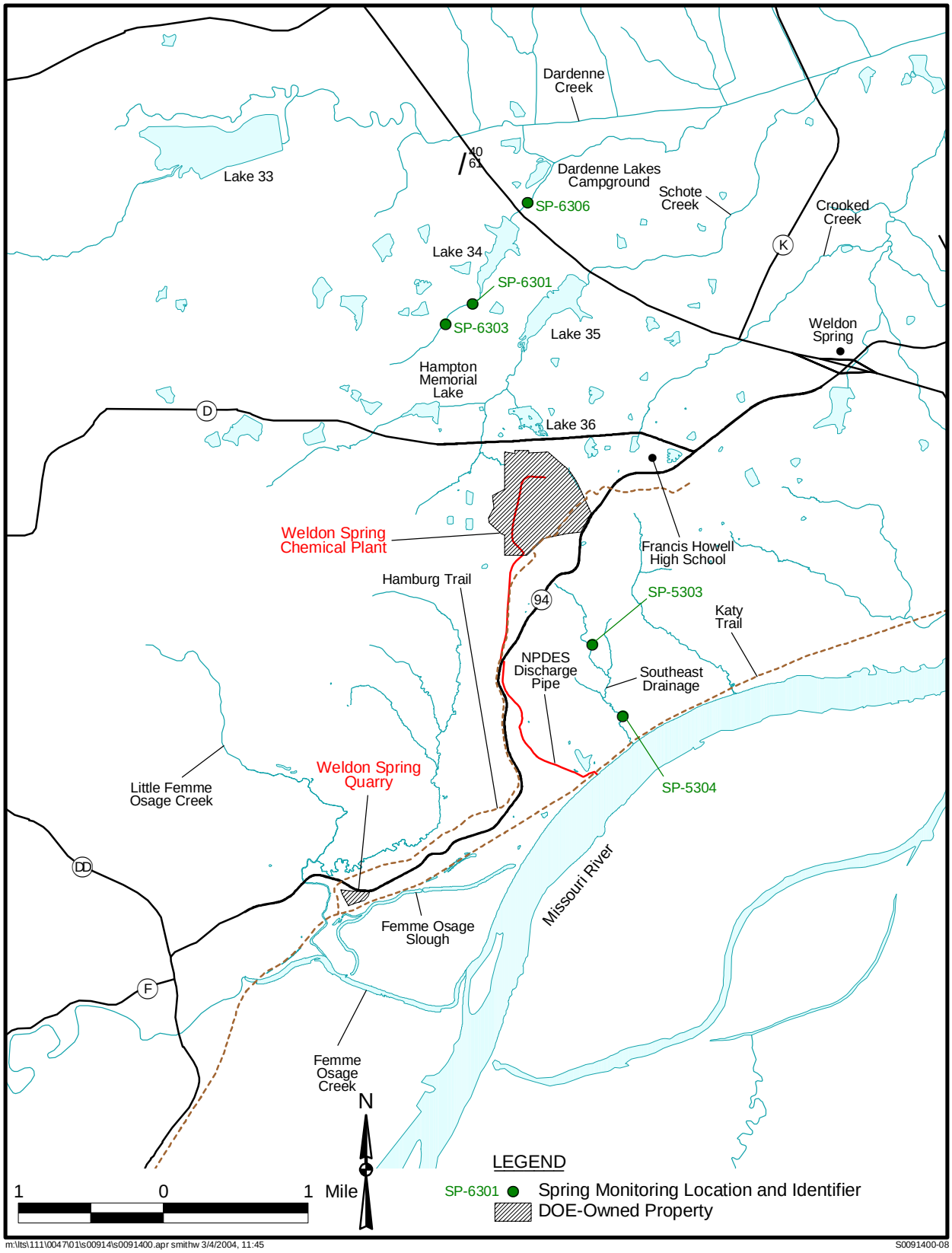

Figure A−21. Spring Monitoring Locations at the Chemical Plant Area of the Weldon Spring, Missouri, Site

Upgradient-downgradient water quality comparisons are not feasible for the Chemical Plant because it is located on the regional groundwater divide. Site-specific background levels were established during the Groundwater OU remedial investigation (DOE 1997d) and will be used for future comparisons.

A summary of analytical results for groundwater samples collected from the Chemical Plant in 2002 is provided in Table A–7.

Table A−7. Summary of 2002 Groundwater Analytical Results at the Chemical Plant

Constituent	Unit of Measure	Minimum	Maximum	Average
Nitrate (as N)	mg/L	<0.05	826	167.2
Sulfate	mg/L	23.5	334	105.3
Total Uranium	pCi/L	<0.68	59.9	4.6
2,4,6-TNT	µg/L	<0.03	290	6.1
2,4-DNT	µg/L	<0.04	1,600	32.2
2,6-DNT	µg/L	<0.06	1,300	27.5
1,3,5-TNB	µg/L	<0.03	280	7.5
1,3-DNB	µg/L	<0.09	0.097	0.1
Nitrobenzene	µg/L	<0.03	69	0.4
TCE	µg/L	<1.0	580	80.2
DCE	µg/L	<2.0	25	3.6
PCE	µg/L	<1.0	50	2.2

Key: DCE = dichloroethylene; DNB = dinitrobenzene; DNT = dinitrotoluene; mg/L = milligram per liter; µg/L = microgram per liter; PCE = tetrachloroethylene (perchloroethylene); pCi/L = picocurie per liter; TCE = trichloroethylene; TNB = trinitrobenzene; TNT = trinitrotoluene

Uranium, nitrate, and TCE concentrations remained within recent historical ranges in the monitor wells sampled in 2002, and concentrations at source areas decreased. Nitroaromatic compounds at the site indicate upward trends and new historical highs at some locations. An upward trend is not unusual following significant soil disturbances such as the large-volume excavations and regrading in this area.

The groundwater at the Chemical Plant has been contaminated by past operations that resulted in multiple source areas. The raffinate pits were the primary historical source of uranium contamination in groundwater. Uranium entered the shallow aquifer via infiltration through the overburden. The concentration of uranium in Chemical Plant groundwater was limited because uranium in the raffinate was partially adsorbed to the overburden materials (DOE 1997d). Uranium-contaminated groundwater is beneath the former raffinate pits.

During 2002, concentrations of uranium in groundwater from 34 of 68 wells exceeded the statistical (95-percent upper confidence limit) background level of 0.93 pCi/L. However, the uranium drinking water standard of 20 pCi/L was exceeded only in monitor wells MW–3024 and MW–3030, which are installed in the former locations of Raffinate Pits 3 and 4. Little attenuation of uranium occurs in the bedrock aquifer; therefore, upon reaching the conduit system, uranium-affected groundwater discharges to Burgermeister Spring.

Nitrate is present in the groundwater near the former raffinate pits and Ash Pond area, which are the historical sources of this contaminant. Nitrate is mobile in the shallow groundwater system. Conditions for natural denitrification have not been identified in the shallow aquifer, so nitrate persists in groundwater and enters the limestone conduit system and subsequently discharges to springs north of the Chemical Plant.

Nitrate was monitored at 68 wells in the Chemical Plant in 2002. Concentrations (reported as N) exceeded the federal drinking water standard of 10 milligrams per liter (mg/L) at 36 of these monitor well locations.

Nitroaromatic compounds in the groundwater system coincide with former production line locations. The presence of nitroaromatic compounds in groundwater is a result of leakage from former TNT and DNT process lines, discharges from wastewater lines, and leaching from contaminated soils and waste lagoons. The distribution of nitroaromatic compounds in the shallow aquifer at the Chemical Plant is controlled by several processes, such as transformation, adsorption, desorption, dilution, and dispersion; the primary attenuating mechanisms are dilution and dispersion. The mobility of nitroaromatic compounds in the bedrock aquifer is high due to their low distribution coefficients. Biotransformation processes also affect the distribution of nitroaromatic compounds in the subsurface. Microorganisms indigenous to the soils and the shallow aquifer have the ability to transform and degrade TNT and DNT (DOE 1997d), and the presence of nitroaromatic compound breakdown products (4-amino-2,6-DNT and 2-amino-2,6-DNT) in the shallow aquifer indicate that degradation is occurring.

Nitroaromatic compounds were detected in 45 wells during 2002. New historical highs occurred in several wells in the vicinity of Frog Pond, most notably MW–2012. Levels of nitroaromatics have increased at this well since 1999. Excavation of contaminated soil in the Frog Pond area by DOE and the excavation in the cross-gradient Lagoon 1 by the DA most likely caused mobilization of these compounds and subsequent concentration increases in the groundwater in this area. Additional wells were installed in the vicinity of Frog Pond in 2000 and 2001 to further determine extent of contamination in this area. The Missouri drinking water standard for 2,4-DNT (0.11 microgram per liter [µg/L]) was equaled or exceeded at 15 monitor well locations at the Chemical Plant.

Groundwater contaminated with the volatile organic compounds (VOCs) TCE, tetrachloroethylene (PCE), and 1,2-dichloroethylene (DCE) is localized primarily in the weathered portion of the bedrock aquifer in the vicinity of Raffinate Pits 3 and 4. The source of TCE contamination was drums that were disposed of in Raffinate Pit 4.

Sampling for VOCs continued through 2002 to monitor the extent of contamination and changes in concentration that may have resulted from remediation activities and groundwater field studies. Samples from 25 wells in the raffinate pits area had detectable concentrations of at least one VOC (TCE, PCE, or 1,2-DCE). Concentrations of TCE in fifteen of these wells exceeded the federal water quality standard of 5 µg/L.

A2.2.1.2 Springs

Springs, a common feature in carbonate terrains, are present in the vicinity of the site. Five springs have been routinely monitored (Figure A−21). These springs are influenced by historical

Chemical Plant surface water runoff, historical process sewer effluent, or groundwater that contains one or more of the contaminants of concern. Springs are sampled during high-flow and low-flow conditions to assess the surface water and groundwater contributions, respectively. Nitrate, nitroaromatic compounds, and uranium are present at Burgermeister Spring (SP–6301) and at SP−6303 located north of the Chemical Plant; uranium and nitroaromatic compounds have been detected in springs in the Southeast Drainage.

Historical data on concentrations of uranium in nearby surface water, including Burgermeister Spring, indicate that during storm events, contaminated soils were transported from the Ash Pond and Frog Pond areas in surface water runoff. The uranium was transported in both dissolved and particulate forms. In the drainages downstream from Ash Pond and Frog Pond, surface water infiltrates the subsurface through stream bottoms, where a portion of the contaminated sediment was deposited in fractures and solution features.

The presence of elevated uranium and nitrate levels at Burgermeister Spring (SP–6301), which is 1.2 miles (1.9 kilometers) north of the site, indicates that discrete flow paths are present in the vicinity of the site. Groundwater tracer tests performed in 1995 (DOE 1997d) indicated that a discrete and rapid hydraulic connection exists between the northern portion of the Chemical Plant and Burgermeister Spring. However, uranium presence was predominantly the result of historical surface water runoff and resultant residual contamination in the fractured bedrock.

Burgermeister Spring is a perennial spring that represents a primary localized emergence of groundwater affected by a recognizable contribution of contaminants from the Chemical Plant. A summary of analytical results for samples collected at Burgermeister Spring is provided in Table A–8. Compared to 2001 results, concentrations in 2002 were in the same general range, although uranium levels were slightly lower during base flow and slightly higher during high flow. Of the nitroaromatic compounds analyzed, only 2,6-DNT was reported above detection limits. No VOCs were reported above detection limits at this spring.

Table A−8. Summary of 2002 Analytical Results for Samples from Burgermeister Spring (SP–6301) Located North of the Weldon Spring, Missouri, Site Chemical Plant

Constituent	Unit of Measure	High Flow			Low (Base) Flow		
		Min.	Max.	Avg.	Min.	Max.	Avg.
Nitrate (as N)	mg/L	0.94	1.1	1.0	0.97	10.9	5.1
Total Uranium	pCi/L	8.6	9.7	9.2	11.4	100	51.0
2,6-DNT	µg/L	<0.1	<0.1	<1.0	<0.1	0.17	0.12

Key: DNT = dinitroluene

Four additional springs, two located in the Southeast Drainage (SP−5303 and SP−5304) and two located in the Burgermeister Spring drainage (SP−6303 and SP−6306), were monitored in 2002 to assess the emergence of contaminated groundwater at possible exposure points. Annual average concentrations of constituents that exceeded detection limits are presented in Table A−9. No VOCs or the nitroaromatic compounds 1,3-DNT or 2,4-DNT were reported above detection limits at any of the springs.

Table A−9. Summary of 2002 Average Analytical Results for Samples from Other Springs in the Vicinity of the Weldon Spring, Missouri, Site Chemical Plant

Constituent	Unit of Measure	High Flow				Low (Base) Flow			
		SP–5303	SP–5304	SP–6303	SP–6306	SP–5303	SP–5304	SP–6303	SP–6306
Total Uranium	pCi/L	34.6	29.6	0.97	0.26	82.8	65.2	1.2	0.34
1,3,5-TNB	µg/L	<0.04	<0.04	0.11	< 0.04	0.34	<0.04	0.22	< 0.04
2,4,6-TNT	µg/L	2.0	0.10	0.10	< 0.08	42.6	0.10	0.09	< 0.08
2,4-DNT	µg/L	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	0.06	<0.06
2,6-DNT	µg/L	<0.10	<0.10	0.17	< 0.10	0.17	<0.10	0.30	< 0.10

Key: DNT = dinitrotoluene; TNB = trinitrobenzene; TNT = trinitrotoluene

A2.2.2 Remedial Activities

Remedial activities at the site were conducted in accordance with CERCLA, as amended. DOE, in conjunction with the DA, conducted a joint remedial investigation/feasibility study (RI/FS) to allow for a comprehensive evaluation of groundwater conditions at the Weldon Spring Chemical Plant area and the Weldon Spring Ordnance Works area, which is an Army site adjacent to the Chemical Plant. Consistent with DOE policy, National Environmental Policy Act (NEPA) values were incorporated into the CERCLA process, meaning that the analysis conducted and presented in the RI/FS reports (DOE 1997d and DOE 1998b) included an evaluation of environmental impacts similar to that performed under NEPA. After completion of the feasibility study, DOE and DA prepared separate CERCLA documentation for their respective projects.

A proposed plan (DOE 1999e) to address all the contaminants of concern in groundwater at the Chemical Plant was released to the public on August 3, 1999. This plan identified the proposed action of active remediation of TCE in groundwater and long-term monitoring for the remaining contaminants of concern. The MDNR would not concur with this remedy until additional pump and treat alternatives had been field tested. Following an informal dispute process and additional public comment, DOE agreed to conduct additional field tests and to conduct the TCE remedial action as planned under an interim ROD (DOE 2000b).

The *Record of Decision for the Final Remedial Action for the Groundwater Operable Unit at the Chemical Plant Area of the Weldon Spring Site* (DOE 2004a) was signed in February 2004. The selected remedy provides for monitored natural attenuation (MNA) for all the contaminants of concern, including TCE, with institutional controls (ICs) to limit groundwater use. The ultimate objective for the groundwater portion of this remedial action is to restore contaminated groundwater in the shallow aquifer to its beneficial use. The aquifer could potentially be used as a drinking water source; however, it is not currently being used as such. Groundwater and springs in the Chemical Plant will be monitored and groundwater use will be limited until contaminant concentrations decrease to cleanup standards. A detailed discussion about the activities performed under the Groundwater OU is presented in the draft *Remedial Design/Remedial Action Work Plan for the Final Remedial Action for the Groundwater Operable Unit at the Weldon Spring Site* (DOE 2004b).

A2.2.2.1 Additional Groundwater Field Studies

Results of the field studies conducted in 2001 indicate that the modifications to conventional pump and treat that were implemented did not increase the mass of contaminants removed as compared with a conventional vertical well system with no artificial recharge. Consequently, the amount of water extracted from the area due to artificial recharge (injection of potable water) would not reduce the remediation time frames for TCE, nitrate, uranium, or nitroaromatic compounds. Another modification, the use of an angled well, likewise failed to produce results comparable to the vertical extraction well. These results reflect the difficulty involved in siting productive wells in the complex geology of the site.

The hydrogeologic data obtained from these studies are consistent with the data collected during a previous study performed in 1998. The results from these field studies support the conceptual model, which is that the sustainable yields are low, and localized dewatering would likely occur. Recharge of the aquifer is very slow, as indicated by the long recovery time of the monitor wells after the study.

The distribution of the contaminants did not change as a result of the field studies, with the exception of significant dilution in the vicinity of the injection wells. The majority of the wells returned to baseline concentrations or were showing increasing trends at the end of the monitoring period, which could be attributed to several mechanisms. One mechanism may be the transport of upgradient contaminated groundwater into the study area because of the low hydraulic gradient across the Chemical Plant. Another mechanism may be the diffusion of contaminants from poorly connected or dead-end fractures and solution features into the more transmissive portions of the aquifer (i.e., paleochannels). Either scenario would indicate that most of the contaminated groundwater removed was from the interconnected secondary porosity features (likely paleochannels). This would indicate that extracting the water from the more transmissive portions of the shallow aquifer would effectively remediate the groundwater within the paleochanel, and that desorption and/or slower groundwater movement from the lower conductivity portions of the aquifer would control the remediation time frames.

A2.2.2.2 In Situ Chemical Oxidation

Bench-scale testing was conducted in the spring of 2001 to evaluate the effectiveness of several different oxidants in destroying TCE in groundwater samples collected from the site. Tests by four different subcontractors demonstrated that, under laboratory conditions, oxidation chemistry was able to destroy TCE without significantly affecting the concentrations of the other contaminants.

The development of the design to achieve full-scale treatment of TCE throughout the plume was not possible at the outset due to uncertainties associated with the hydrogeology of the site that influenced design elements such as spacing of the injection wells, the zone of influence of these wells, and the amount of oxidant needed to be injected to achieve the reduction of TCE. Consequently, a phased approach was taken to allow for a pilot-scale test to be performed before a decision could be made regarding full implementation.

Pilot-scale treatment was performed in April and May 2002 to evaluate the effectiveness of the in situ chemical oxidation (ICO) process under actual field conditions and to assess the feasibility of implementing a full-scale system. The pilot-scale testing was performed at two

locations, representing the upper and lower limits of hydraulic conductivity, in the bedrock aquifer within the area of higher TCE concentrations. Two injections were performed at each location.

During Phase I, only the minimum calculated amount of sodium permanganate that might result in efficient distribution through the aquifer was injected. Based on the results of the Phase I injection, the target injection values were revised for Phase II injection.

The pilot-scale ICO appears to have achieved reduction of TCE in the area of influence. The oxidizing solution (sodium permanganate) was distributed to a distance of about 100 feet (30 meters) from the injection point, where the dispersion of the permanganate favored a downgradient direction toward the paleochannel features of the site. Uniform distribution of the injection solution was not achieved. The pilot-scale ICO also indicated that the injection volume at each point that would be required to achieve a radius of influence greater than 100 feet (30 meters) could average 20,000 gallons (75,708 liters). This value is 20 times greater than that estimated based on the results of the bench-scale testing and 5 times greater than that used during the first injection of the pilot-scale ICO.

The results of the pilot-scale ICO can not be directly applied to the whole TCE area because of the heterogeneity of the aquifer. The study was designed to perform the field tests at two locations bounding the range of hydraulic conductivities of the bedrock aquifer within the affected area. However, this may not have been achieved during implementation, because other areas with lower hydraulic conductivities and TCE concentrations that exceed the maximum contaminant level (MCL) are known to be present. Consequently, uncertainties associated with defining the zone of influence of the injection points and the volume of oxidants needed to achieve the required reduction of TCE across the affected area would still have to be addressed in designing a full-scale remediation effort.

It was envisioned in the feasibility study and the interim ROD that two sets of wells and two injections would achieve the MCL. These specifications were based on the understanding of the site and the knowledge regarding the innovative nature of the ICO technology at that time. Preliminary remedial design based on the results of the pilot-scale ICO indicated that at least 20 times as many injection wells would be needed and, therefore, 20 times as much volume of oxidant would need to be injected for a full-scale implementation. These estimates constitute the amounts needed at the initial phase of implementation with possibly additional injection wells and/or injections needed to attain the MCL throughout the entire area of impact. Due to the increased scope and uncertainties of a full-scale approach, DOE decided to address TCE within the context of a final remedy for all of the groundwater contaminants.

A2.2.2.3 Monitored Natural Attenuation

The groundwater monitoring program for the Groundwater OU has been developed to meet the following performance goals:

1. Contaminants will attenuate at a rate sufficient to meet cleanup standards in approximately 100 years.

2. Contaminant migration will remain confined to the currently impacted groundwater system.

3. Contaminant levels at potential exposure points (springs) will not pose unacceptable risks to receptors.

4. Contaminant levels at the springs will decline over time.

A2.3 Quarry Bulk Waste OU

Remedial activities under the Quarry Bulk Waste OU were performed under the *Record of Decision for Management of Bulk Wastes at the Weldon Spring Quarry* (DOE 1990). The Quarry Bulk Waste OU ROD was signed by EPA on September 28, 1990, and by DOE on March 7, 1991. The primary activities established were to:

- Excavate and remove bulk waste (i.e., structural debris, drummed and unconfirmed waste, process equipment, sludge, and soil).
- Transport the waste along a dedicated haul road to the TSA, which was located within the boundary of the Chemical Plant OU.
- Stage bulk wastes at the TSA for ultimate disposal in the on-site disposal cell.

Removal of the bulk waste was performed in a multitiered process similar to the one used at the Chemical Plant. In the first tier, the Quarry water treatment plant, which was designed to treat contaminated water from the Quarry sump, was constructed. In the second tier, the basic infrastructure, including decontamination facilities, a haul road, and the utilities needed to excavate and transport the waste from the Quarry to the Chemical Plant, was built. In the final tier, the waste was excavated.

The waste was removed with conventional equipment and excavation techniques, placed in covered trucks, and hauled via the haul road to the TSA at the Chemical Plant. The waste was retained in the temporary facility until it could be placed in the disposal cell. From May 1993 to October 1995, approximately 144,000 cubic yards (110,000 cubic meters) of soil and waste material were removed from the Quarry, transported to the Chemical Plant area, and placed in the TSA. All of the wastes were directly placed or treated and placed in the disposal cell by March 1999.

A2.4 Quarry Residuals OU

The Quarry Residuals OU was the second of two OUs established for the Quarry area of the Weldon Spring Site. The Quarry Residuals OU addresses the residual soil contamination in the Quarry proper, surface water and sediments in Femme Osage Slough and nearby creeks, and contaminated groundwater.

A2.4.1 Present Conditions

A2.4.1.1 Groundwater

Uranium and nitroaromatic compounds leached from the wastes in the Quarry proper and contaminated groundwater beneath the site. Uranium concentrations in groundwater have decreased in the area north of Femme Osage Slough by adsorption onto aquifer materials and precipitation by a naturally occurring chemical reduction process (DOE 1998a). The reduction zone is located north of Femme Osage Slough and extends south of the slough. The greatest effect is observed north of the slough where geochemical conditions change from oxidizing to reducing. A distinct contact separating alluvial soils with characteristics indicative of oxidizing conditions from those indicating reducing conditions is evident in this area. Uranium results from soil samples indicate a rapid precipitation of uranium at this location.

DOE sampled 34 wells in the Quarry area in 2002, which are completed in either bedrock or alluvium (Figure A−22). Sample results are summarized in Table A−10. All minimum results were below detection limits, and 1,3-dinitrobenzene was not detected in any of the wells.

Table A−10. Summary of 2002 Groundwater Analytical Results at the Weldon Spring, Missouri, Site Quarry

Constituent	Unit of Measure	Minimum	Maximum	Average
Sulfate	mg/L	<0.50	321	69.6
Iron	µg/L	4.1	46,300	6,894
Total Uranium	pCi/L	<0.68	4,420	301
2,4,6-TNT	µg/L	<0.03	2.2	0.11
2,4-DNT	µg/L	<0.04	2.5	0.07
2,6-DNT	µg/L	<0.06	2.6	0.16
1,3,5-TNB	µg/L	<0.03	18	0.27
1,3-DNB	µg/L	<0.09	0.14	<0.09
Nitrobenzene	µg/L	<0.03	3.1	0.07

Key: DNB = dinitrobenzene; DNT = dinitrotoluene; TNB = trinitrobenzene; TNT = trinitrotoluene

The highest uranium concentrations in groundwater continue to occur in the bedrock downgradient from the Quarry and in the alluvial material north of Femme Osage Slough. The groundwater standard of 20 pCi/L was exceeded at 13 locations, all located north of Femme Osage Slough (Figure A–23). The standard, although used as a reference level, is not applicable to groundwater north of the slough because this area is not considered a usable groundwater source due to low yield (DOE 2003c).

Background uranium concentrations in the Missouri River alluvium groundwater in the upgradient Darst Bottoms range up to 14.3 pCi/L, and background concentrations average 2.77 pCi/L. Historically, one location south of Femme Osage Slough (MW−1011) had uranium levels that exceeded the background range for a short time, but returned to levels less than 14.3 pCi/L. However, 90 percent of the historical samples from south of the slough have had uranium concentrations less than 2.77 pCi/L. Therefore, contamination north of the slough has no measurable impact on the drinking water source in the Missouri River alluvium.

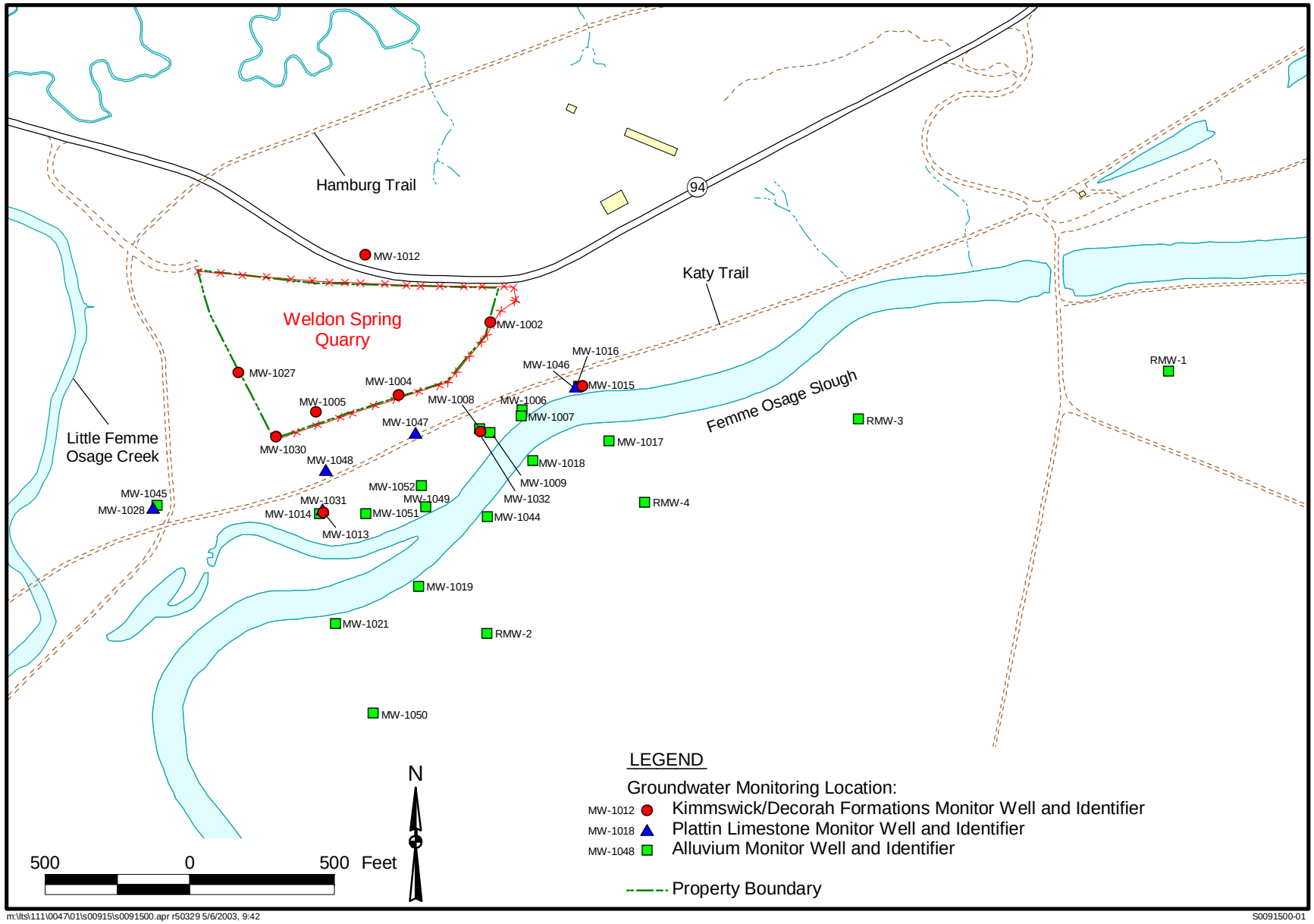

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Figure A–22. Groundwater Monitor Well Locations at the Quarry Area of the Weldon Spring, Missouri, Site

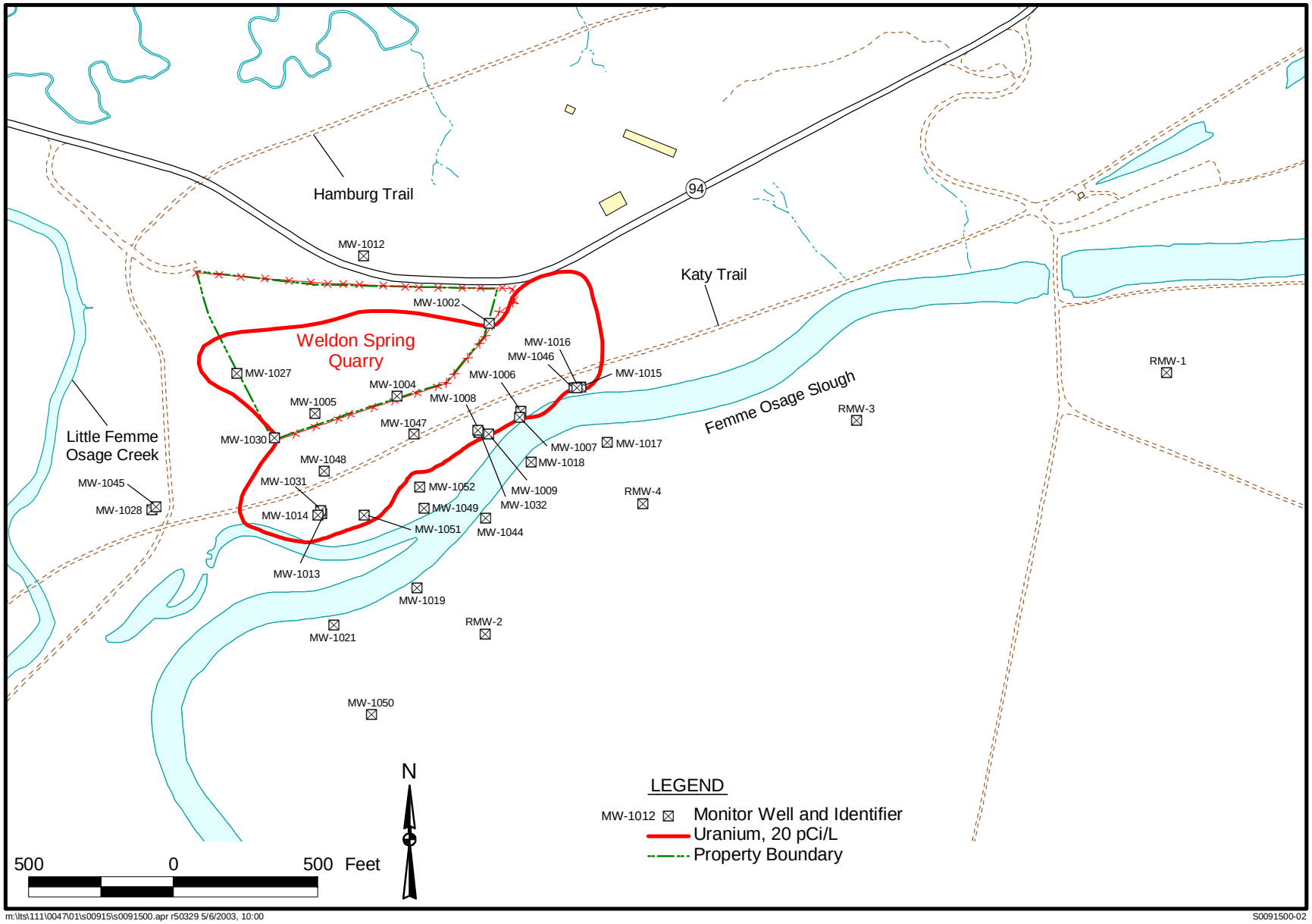

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Figure A−23. Extent of Uranium Contamination in Groundwater at the Weldon Spring, Missouri, Site Quarry Area

Nitroaromatic compounds in groundwater also were analyzed in 2002. These contaminants occur in the bedrock and alluvium downgradient of the Quarry and north of Femme Osage Slough. All concentrations were below detection limits in samples from locations south of Femme Osage slough. The average 2,4-DNT concentration for location MW–1027 remained above the Missouri drinking water standard of 0.11 µg/L in 2002 (DOE 2003c).

Groundwater analyses in 2002 continued to indicate elevated sulfate levels in monitor wells in the bedrock of the Quarry rim and in the alluvial material north of Femme Osage slough. Eleven wells had averages above background, and one location, MW–1005, had an annual average that exceeded the Missouri secondary MCL of 250 mg/L. Sulfate is used as an indicator of the geochemical conditions of the aquifer, and the 2002 concentrations continue to provide evidence of the reduction zone.

A2.4.1.2 Surface Water

Surface water bodies in the Quarry are Femme Osage Slough, Little Femme Osage Creek, and Femme Osage Creek. These water bodies do not receive direct runoff from the Quarry but were sampled to monitor water quality due to possible movement of contaminated groundwater from the fractured bedrock of the Quarry through fine-grained alluvial materials. Femme Osage Slough is directly south of the Quarry and is known to receive contaminated groundwater through subsurface recharge. There is no natural surface flow from the slough; however, water can be introduced into the slough from the Missouri River through a gate valve. Little Femme Osage Creek, located west of the Quarry, discharges into Femme Osage Creek approximately 0.3 mile (0.5 kilometer) southwest of the Quarry. Femme Osage Creek flows into the Missouri River.

Annual average uranium concentrations for the surface water locations sampled in 2002 are summarized in Table A−11. Uranium levels in Femme Osage Slough remain within historical ranges. All maximum total uranium concentrations were below historical maximum concentrations for Quarry surface water during 2002. The slough continues to show declining uranium levels (DOE 2003c). Uranium concentrations in the slough do not pose a risk to recreational users or to the aquatic and terrestrial life associated with the slough.

Table A−11. 2002 Annual Averages for Total Uranium Concentrations at Weldon Spring, Missouri, Site Quarry Area Surface Water Locations

Identifier	Location	Average[a]	Maximum[a]	Minimum[a]	Historical Maximum[a] (year)
SW–1003	Femme Osage Slough	14.8	17.7	11.3	252.0 (1989)
SW–1004	Femme Osage Slough	16.4	17.4	14.4	362.0 (1991)
SW–1005	Femme Osage Slough	11.1	12.2	10.2	116.0 (1991)
SW–1007	Femme Osage Slough	7.1	9.3	6.3	69.0 (1992)
SW–1009	Femme Osage Slough	6.3	8.6	4.9	28.6 (1991)
SW–1010	Femme Osage Slough	15.0	19.3	12.3	156.0 (1991)

[a]All concentrations in pCi/L. Locations shown in DOE 2003c.

A2.4.1.3 Sediments

Sediments in Femme Osage Slough and nearby creeks were characterized during the RI (DOE 1998a). The 95-percent upper confidence limit background value for uranium in the creek and slough sediment is 4.35 pCi/g. Sediments in the creeks and lower portion of the slough have uranium levels similar to background. The upper portion of the slough, directly south of the Quarry, has uranium levels slightly greater than background (5.41 pCi/g). These levels pose no human health or ecological risks under a recreational scenario (see Appendix B).

A2.4.1.4 Soil in the Quarry Proper

Some areas of residual radioactive contamination remain in the Quarry proper. These areas were not targeted for removal because risk levels are within the acceptable range for a recreational visitor, and the areas were not easily accessible during previous soil removal activities (i.e., limited access for equipment, or soil in cracks and fissures). Some residually contaminated soils were removed from the Quarry proper under the Quarry Residuals OU. Since removal of contaminated structures and materials would be performed during the early stages of Quarry restoration, it was decided to remove soils from selected areas.

The locations within the Quarry proper that still have residual radioactive soil include the southeast slope, the knoll, wall and floor fractures, and the northeast slope (Figure A−24). Soil in these locations was not targeted for removal due to inaccessibility or extreme difficulty in excavation. A summary of the levels of contamination is presented in Table A−12.

Table A−12. Maximum Radionuclide Concentrations in Soil at Areas in the Weldon Spring, Missouri, Site Quarry Proper

Location	Radium-226[a]	Radium-228[a]	Thorium-230[a]	Uranium-238[a]	Notes
Northeast Slope	12.7	9.87	77.9	3.91	(1)
Southeast Slope	8.20	2.79	42.0	35.1	(2)
Knoll	1.70	1.39	12.9	2.33	(1)
Wall Fractures	7.07	8.77	81.1	32.7	(1)
Floor Fractures	9.44	7.53	396	202	(1)

[a]All concentrations in pCi/g .
Notes: (1) Below Soil Backfill >2 feet.
(2) Below Soil Backfill < 1 foot.

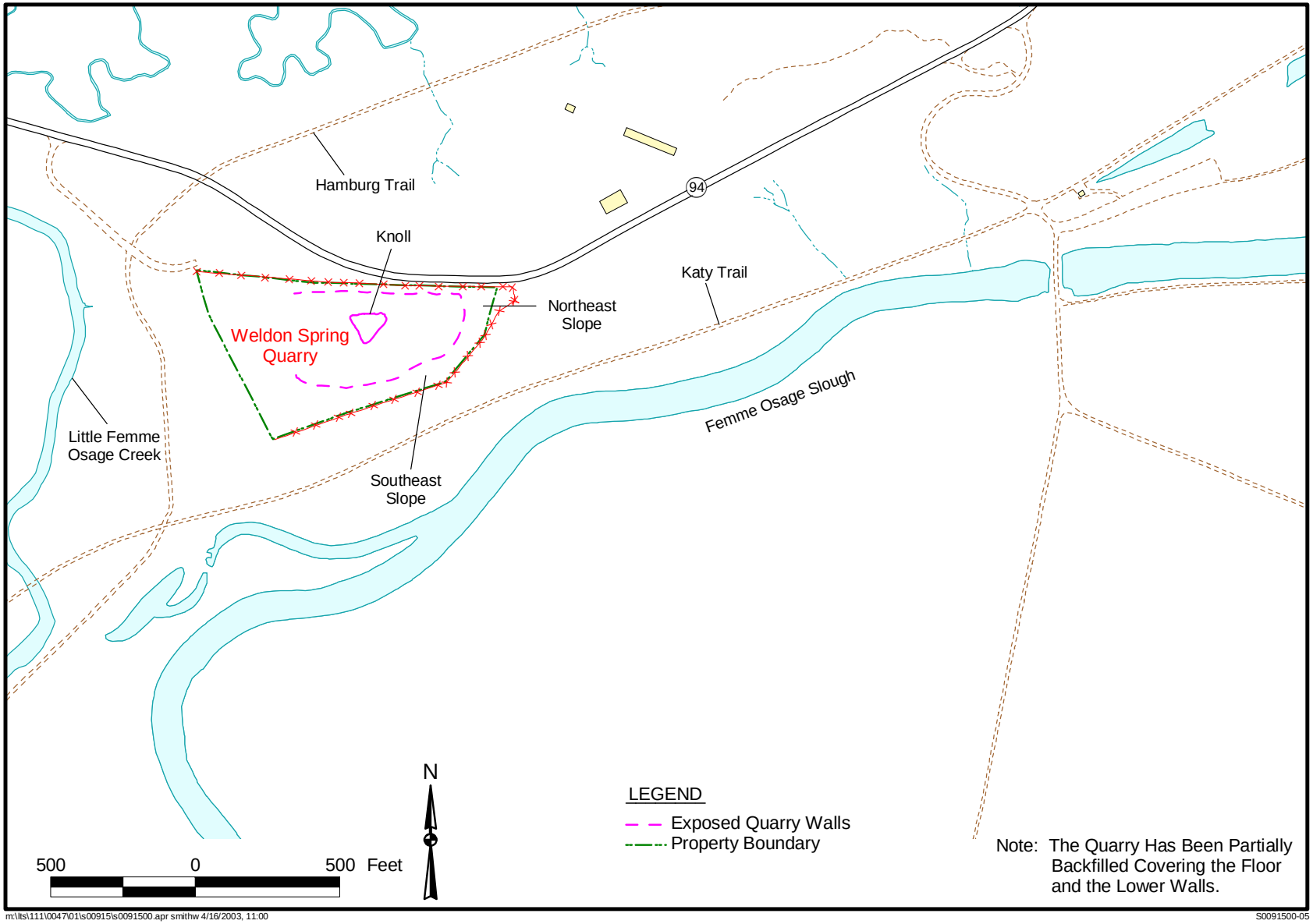

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Figure A–24. Features of the Weldon Spring, Missouri, Site Quarry

A2.4.2 Remedial Activities

A RI/FS process was conducted for the Quarry Residuals OU in accordance with the requirements of CERCLA, as amended, to document the proposed management of the Quarry proper, Femme Osage Slough and nearby creeks, and contaminated groundwater. This process incorporated the values of NEPA and represented a level of analysis consistent with an environmental impact statement.

DOE and EPA signed the Quarry Residuals OU ROD for management of residual contamination in September 1998 (DOE 1998c). Components of the remedy for the Quarry Residuals OU were long-term monitoring and institutional controls to address contaminated groundwater north of Femme Osage Slough. Based on exposure assessments under current and reasonably anticipated recreational land uses, no further soil remediation inside or outside of the Quarry proper was necessary to protect human health and the environment (DOE 1997b). The selected remedy outlined the performance of two field studies to support the decision for long-term monitoring of groundwater. These studies would be used to verify predictive models on the effectiveness of uranium removal by groundwater extraction and support the hydrogeological conceptual model regarding natural attenuation of uranium north of the slough. An additional component of the Quarry Residuals OU was the reclamation of the Quarry area, including restoration of the Quarry proper, demolition of the Quarry water treatment plant, and dismantlement of facilities used during bulk waste removal activities. A detailed discussion about the activities performed under the Quarry Residuals OU is presented in the *Quarry Residuals Operable Unit Interim Remedial Action Report* (DOE 2003b).

A2.4.2.1 Long-Term Groundwater Monitoring

Long-term groundwater monitoring for the Quarry Residuals OU consists of two separate programs. The first program details the monitoring of uranium and 2,4-DNT south of the slough to ensure that levels remain protective of human health and the environment. The second program consists of monitoring groundwater contaminant levels within the area north of the slough until they attain a predetermined target level indicating negligible potential to affect groundwater south of the slough.

Groundwater monitoring is necessary to continue to ensure that uranium-contaminated groundwater has a negligible potential to affect the St. Charles County well field. Under current conditions, groundwater north of the slough poses no imminent risk to human health from water obtained from the well field. A target level of 300 pCi/L for uranium (10 percent of the 1999 maximum) was established to represent a significant reduction in the contaminant levels north of the slough. The target level for 2,4-DNT has been set at 0.11 µg/L, the Missouri Water Quality standard. Upon attainment of these target levels, it will be determined that the goal for the monitoring program has been met, and the long-term monitoring activities for this OU will be concluded. Following attainment of the long-term monitoring target levels in groundwater north of the slough, an assessment of the residual risks based on actual groundwater concentrations will be performed to determine the need for future institutional controls.

A2.4.2.2 Quarry Interceptor Trench Field Study

The selected remedy in the Quarry Residuals OU ROD (DOE 1998c) outlined the performance of two field studies to support the decision for long-term monitoring of groundwater and reliance on natural conditions to limit potential migration of uranium south of the slough. These field studies consisted of the installation and operation of an interceptor trench and hydrologic/geochemical sampling within the area of uranium impact to verify the effectiveness of uranium removal by groundwater extraction methods and support the conceptual fate and transport model for the Quarry.

The interceptor trench was constructed to support the action in the ROD. This field study was performed southeast of the Quarry to quantify the mass of uranium that could be removed from the alluvial aquifer by groundwater extraction. The trench was constructed to represent a cross-section of alluvial material and was optimally located to extract groundwater from the areas with high uranium concentrations. The trench was approximately 550 feet (168 meters) in length, and water produced from the trench was routed underground to the Quarry water treatment plant. The system was evaluated and monitored for 2 years (April 27, 2000, to April 26, 2002) to confirm model predictions. A total 1,666,234 gallons (6,307,382 liters) of water was pumped from the interceptor trench. Samples were collected daily from the operating pumps to determine the mass of uranium removed.

The objective of the interceptor trench field study was to confirm model predictions of the effectiveness of groundwater extraction systems to remove uranium from the shallow aquifer on the basis of field data. If the performance of the trench was not more effective than modeled (i.e., less than 10 percent of the mass of uranium removed within the 2-year testing period), further evaluation of groundwater treatment would not be necessary. If the performance of the trench exceeded the modeled values (greater than 10 percent of the mass of uranium removed within the 2-year testing period), the effectiveness and benefit of groundwater extraction would be reevaluated.

The efficiency of the interceptor trench system was defined as the ratio of the cumulative mass of uranium removed to the initial mass present within the capture zone of the trench. By the end of the 2-year study period, the interceptor trench had removed 14.0 kg of uranium. This accounted for 1.5 percent of the mass available to the interceptor trench. The predicted percent of removal for the 2-year operation was 10 percent. The percent removed was significantly below the predicted performance of the trench, which indicates that the modeled predictions were optimistic and that further evaluation of groundwater treatment was not warranted. A summary of the field study is provided in the *Evaluation of the Performance of the Interceptor Trench Field Study* (DOE 2003a).

A2.4.2.3 Hydrological and Geochemical Field Studies

The conceptual model for the Quarry is that sorption of uranium onto the aquifer matrix and organic material and precipitation of dissolved uranium from groundwater are responsible for the notable decrease of uranium concentrations (from 3,000 pCi/L to less than 1 pCi/L) over a short distance (100 to 300 feet, or 30 to 91 meters) north of the slough. The sharp decrease in uranium levels indicates that dispersion and dilution, which typically generate more diffuse boundaries, are not the primary processes attenuating the uranium in groundwater.

Several investigations were performed in the area north of the slough to evaluate uranium attenuation mechanisms. Oxidation state and redox-sensitive parameter data defined the oxidizing and reducing zones of the alluvial aquifer and the boundary between them. Distribution coefficients were estimated from depth-discrete sampling data to determine the sorption/desorption capacity of the aquifer matrix (both alluvial and bedrock). The distribution of uranium in soil across the reducing front was quantified where uranium was concentrated in a narrow band beneath the oxidized/reduced contact.

The results of the investigations provided a better understanding of the natural geochemistry of the alluvial aquifer north of the slough. The area contains a naturally occurring oxidation/reduction front, which acts as a barrier to the migration of dissolved uranium by inducing its precipitation. The physical and chemical parameters measured in groundwater samples were successfully correlated with the physical properties of the aquifer material and support the conceptual fate and transport model presented in the Quarry Residuals OU RI (DOE 1998a). Specific details are presented in the C*ompletion Report for the Geochemical Characterization Performed in Support of the QROU Field Studies* (DOE 2002).

A2.4.2.4 Quarry Reclamation

Reclamation of the Quarry included backfilling the Quarry proper, demolition of the Quarry treatment plant, removal of the Quarry interceptor trench system, and dismantlement of facilities used during bulk waste removal. Backfilling of the Quarry was designed to reduce physical hazards associated with an open Quarry, eliminate the ponding of water, and reduce infiltration of precipitation water into the groundwater system.

In 2000, DOE completed characterization of contamination remaining at the northeast slope and several other locations in the Quarry proper. Soil was excavated from three locations within the Quarry proper (1,574 cubic yards, or 1,203 cubic meters) during 2000 and placed in the permanent disposal cell at the Chemical Plant. Cleanup criteria for the Quarry proper soil were taken from the Chemical Plant ROD (DOE 1993), as specified in the Quarry Residuals OU ROD (DOE 1998c). Based on previous characterization activities, only radioactive contaminants of concern were targeted.

Backfill for the Quarry was acquired from an off-site borrow area, consisting of approximately 17 acres (6.9 hectares) of land on the MDC property. Approximately 76,400 cubic yards (58,400 cubic meters) of soil was excavated and transported to the Quarry for use as backfill. Uncontaminated soils from within the Quarry and the Quarry staging area were also used as backfill materials for the Quarry.

Fill material was placed and compacted to design elevations within the Quarry proper. During backfilling of the Quarry, selected wall and floor fractures were sealed to prevent infiltration of water and reduce the likelihood of later subsidence of the backfill. Upon completion of backfill activities, final grading and seeding were performed. Reclamation of the Quarry was completed on September 6, 2002.

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