COMPILATION AND PRELIMINARY INTERPRETATION OF HYDROLOGIC DATA FOR THE WELDON SPRING RADIOACTIVE WASTE-DISPOSAL SITES, ST. CHARLES COUNTY, MISSOURI--A PROGRESS REPORT

By M. J. Kleeschulte and L. F. Emmett

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain SI unit
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
yard	0.9141	meter
acre	0.4047	hectare
square foot	0.09294	square meter
square mile	2.590	square kilometer
cubic foot	0.02832	cubic meter
cubic yard	0.7645	cubic meter
cubic foot per second	0.02832	cubic meter per second
gallon	3.785	liter
gallon per minute	0.06308	liter per second
gallon per minute per foot	0.2070	liter per second per meter
million gallon per day	0.003785	cubic meter per day
ton	0.9072	megagram
curie	3.7×10^{10}	becquerel
tritium unit	0.12	becquerel per liter
foot squared per day	0.09290	meter squared per day
foot per day	0.3048	meter per day

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°F = 1.8\ °C + 32$$

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Michael J. Kleeschulte and Leo F. Emmett

ABSTRACT

The Weldon Spring Chemical Plant is located just north of the drainage divide separating the Mississippi River and the Missouri River in St. Charles County, Missouri. From 1957 to 1966 the plant converted uranium-ore concentrates and recycled scrap to pure uranium trioxide, uranium tetrafluoride, and uranium metal. Residues from these operations were pumped to four large pits that had been excavated near the plant.

The overburden in which the pits were excavated primarily consists of clay, ranges in thickness from 10 to 50 feet, and overlies a permeable limestone. Small springs and losing streams are present in the area. Water overlying the residue in the pits has a large concentration of dissolved solids and a different chemical composition compared to the native ground water and surface water. This difference is indicated by the concentrations of calcium, sodium, sulfate, nitrate, fluoride, uranium, radium, lithium, molybdenum, strontium, and vanadium, all of which are greater than natural or background concentrations.

Water from Burgermeister Spring, located about 1.5 miles north of the chemical-plant area, contains uranium and nitrate concentrations greater than background concentrations. Ground water in the shallow bedrock aquifer moves northward from the vicinity of the chemical plant toward Dardenne Creek.

An abandoned limestone quarry several miles southwest of the chemical plant also has been used for the disposal of radioactive waste and rubble. The quarry is in a bluff adjacent to the Missouri River flood plain and contains water with a large concentration of uranium. Ground-water flow from the quarry area is southward through the alluvium, away from the quarry and toward the Missouri River. The St. Charles County well field is located in the Missouri River flood plain near the quarry and the large-yield wells are open to the Missouri River alluvial aquifer. Water from a well 4,000 feet southeast of the quarry was analyzed; there was no indication of contamination from the quarry. Analysis of water from a slough, locally referred to as Femme Osage slough, which is between the quarry and the well field, indicated uranium concentrations greater than background. Additional water-quality and water-level data are needed to determine if water from the quarry moves toward the well field.

Observation wells need to be installed in the area between the chemical plant, pits, and Dardenne Creek. The wells would be used to provide access for measurements of depth to ground water and for the collection of water samples from the shallow bedrock aquifer. Water-level data would be used to refine the map showing direction of ground-water movement. Chemical and radiological analyses of the water samples would assist in defining the plume of contaminated water.

INTRODUCTION

The Uranium Division of the Mallinckrodt Chemical Works operated the Weldon Spring Chemical Plant for the U.S. Atomic Energy Commission (later reorganized to form the U.S. Energy Research and Development Administration and the Nuclear Regulatory Commission) from 1957 to 1966. The Weldon Spring Chemical Plant converted uranium ore concentrates and recycled scrap to pure uranium trioxide, uranium tetrafluoride, and uranium metal. Some thorium residues also were processed. Waste from the plant operation is referred to as raffinate and includes the waste from the extraction step and the solids that result from the neutralization of the waste (Weidner and Boback, 1982). These wastes were pumped as a slurry to four large pits (hereafter called raffinate pits) that were constructed near the plant. An abandoned limestone quarry about 3 miles southwest of the plant also has been used for the burial of contaminated solids and radioactive residues from various processing sites. Disposal of these radioactive wastes in an area underlain by carbonate rocks has created the potential for contamination of the ground water. There also is the potential for contamination of surface water by seepage from the pits to discharging springs and streams, and from surface runoff transporting contaminated soil.

Purpose and Scope

A 3-year study was begun during October 1983, to determine the extent and magnitude of ground- and surface-water contamination that has been caused by operation of the chemical plant and by disposal of waste in the pits and in the quarry. The results of the first year of the study are presented in this report, which summarizes extensive data already collected by a number of investigators, and outlines needed additional data collection and analysis.

Interpretations in this report, which are based on previous data that were compiled and evaluated during the first year of the study, are considered to be preliminary and may be subject to change as additional detailed field data are collected and evaluated during the next 2 years. The final 2 years of the study will include an analysis and description of the ground-water flow system and of the hydrogeologic and water-quality characteristics of the aquifers underlying the area. The surface- and ground-water relationships and the chemical quality of the surface water also will be determined.

Description of Study Area

The study area consists of about 280 square miles in St. Charles County in eastern Missouri (fig. 1). The study-area boundaries are Big Creek, Cuivre River, and the Mississippi River to the north and the Missouri River to the south. The western boundary is the St. Charles-Warren County line. The eastern boundary is the eastern edge of Range 4 east.

The study area is located in two physiographic areas (fig. 1). The southern one-third of the area lies on the northeastern flank of the Salem Plateau and is characterized by rugged topography; narrow, irregular drainage divides; and is drained by many short, steep gradient streams, the largest being the Femme Osage Creek. Surface drainage is toward the Missouri River. The rest of the area is in the Dissected Till Plains, which is characterized

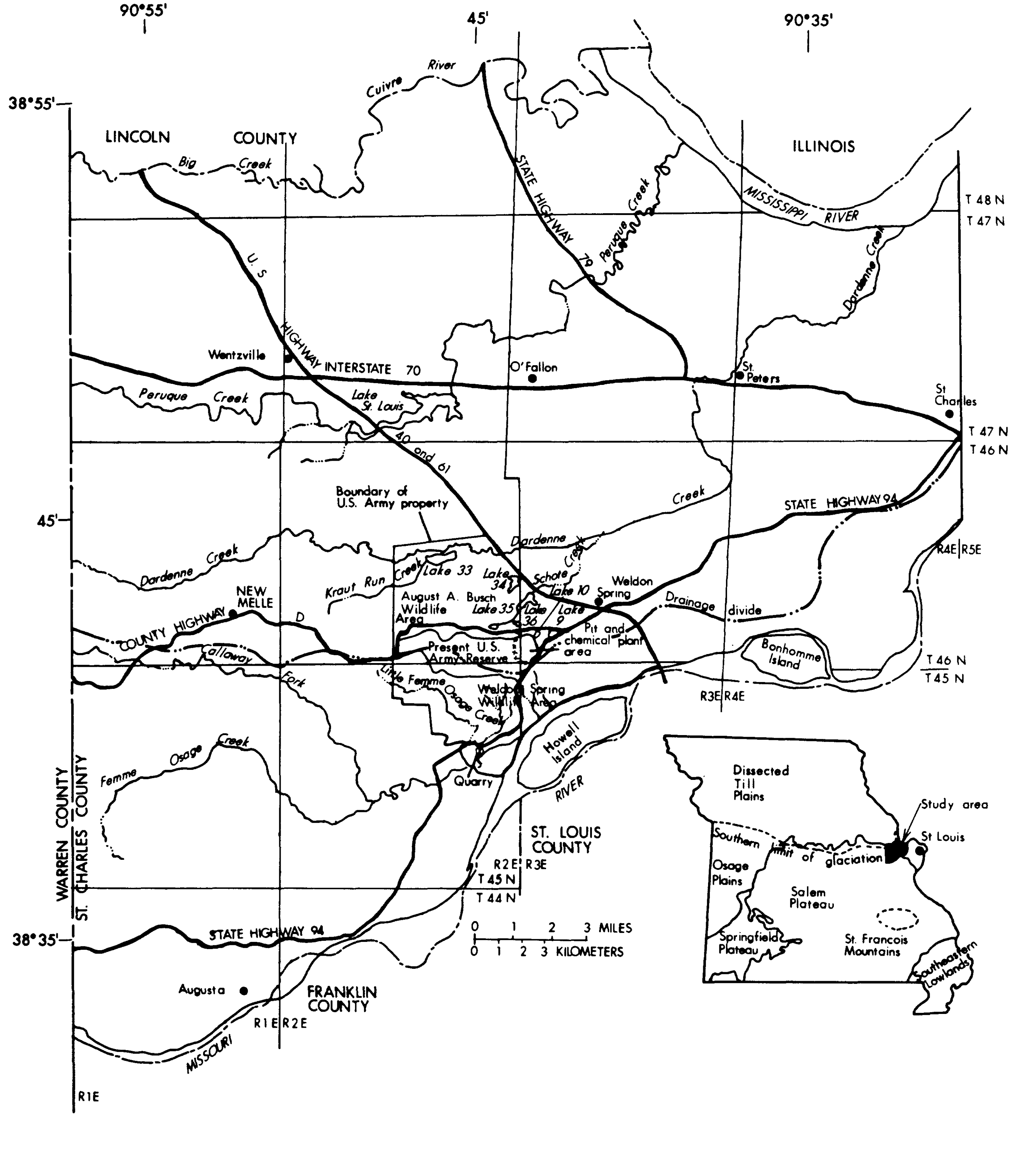

Figure 1.--Location of study area and drainage network.

by moderately to slightly undulating topography. Surface drainage in the northern part of the county is toward the northeast into the Mississippi River. The two major tributaries draining the northern two-thirds of the area are Dardenne and Peruque Creeks. This part of Missouri was glaciated twice during Pleistocene time, but the till deposits typically are thin and dissected.

The midcontinent location of the study area exposes it to cold air from the north, dry air from the west, and warm, moist air from the Gulf of Mexico. Consequently, there are frequent changes in the weather both diurnally and seasonally. In the study area the average annual precipitation is 38 inches. Temperatures range from an average daily minimum of 21 °F in January to an average daily maximum in July of more than 90 °F (Rafferty and others, 1970).

Population in the study area is increasing due to its proximity to St. Louis. The largest towns (and their populations) within the study area are St. Charles (37,379), a part of which lies just inside the eastern boundary; St. Peters (15,700); O'Fallon (8,654); and Wentzville (3,193).

The Weldon Spring Chemical Plant and the four raffinate pits (fig. 2) are located just north of the drainage divide separating the Missouri River basin to the south from the Mississippi River basin to the north. Drainage at the plant and pits is toward the north by intermittent tributaries. These tributaries flow into the August A. Busch Wildlife Area lakes 35 or 36 or both, then into Schote Creek, then Dardenne Creek, and eventually into the Mississippi River (fig. 1). The drainage divide also corresponds to the transition area where the terrane changes from that of the Salem Plateau to that of the Dissected Till Plains.

The 9-acre Weldon Spring quarry site is located along the limestone bluffs that are adjacent to the Missouri River flood plain about 3 miles southwest of the chemical plant. The site boundary to the north is State Highway 94 and to the south it is the Missouri-Kansas-Texas Railroad line (fig. 2). The lowest part of the quarry covers about 0.5 acre and is about 100 to 120 feet lower in altitude than the high wall. The main floor is 70 to 90 feet below the high-wall rim and covers about 2 acres.

The downstream reaches of Femme Osage and Little Femme Osage Creeks were cut off from their natural channels by the levee constructed by the University of Missouri between 1959 and 1961. The new channel diverted the flow in both creeks outside the levee system to prevent annual flooding of the farmland and the Ordnance Works well field located inside the levee system. The downstream reaches of these creeks now form an isolated body of water locally known as the Femme Osage slough (fig. 2). This slough lies between the Weldon Spring quarry site and the well field. A part of this slough locally is known as Little Femme Osage slough. The well field is now under the jurisdiction of St. Charles County and is used as a public water supply.

History of the Site

"In April 1941, the Department of the Army acquired 17,232 acres surrounding what is now the WSCP [Weldon Spring Chemical Plant] as the site for an explosives production facility known as the Weldon Spring Ordnance Works." (Ryckman, Edgerley, Tomlinson, and Assoc., 1978, p. 5). The national emergency

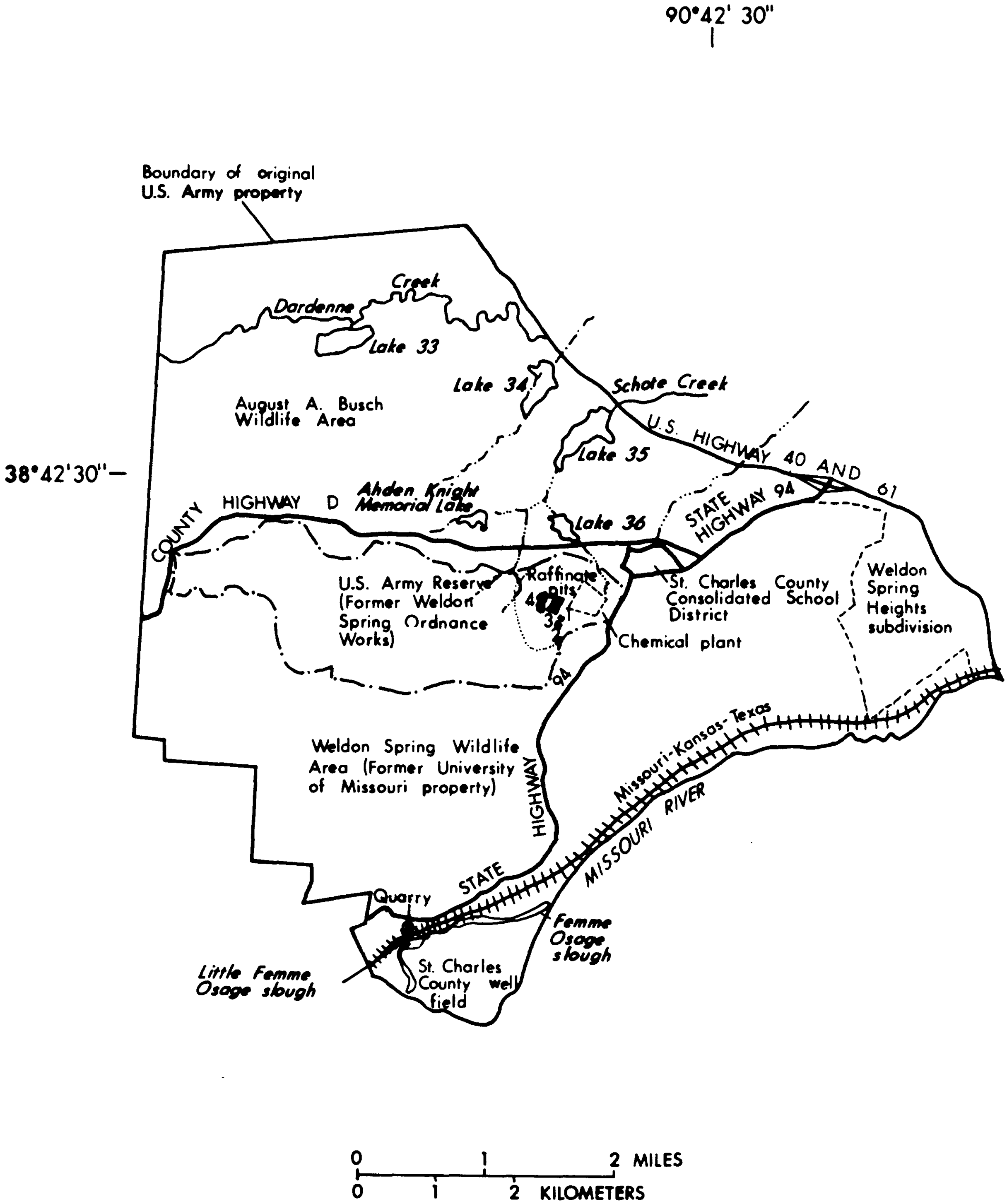

Figure 2.--Division of original U.S. Army property.

during the summer and fall of 1941 made it necessary to begin the manufacture of trinitrotoluene (TNT) and dinitrotoluene (DNT) before adequate arrangements could be made for the disposal of the processes' waste liquids. As a result, frequent spillovers of production-line disposal pipes and overflows of the catchment tanks occurred during the plants' production years from November 1941 through January 1944. Red wastewaters containing sulfonate derivatives contaminated both surface- and ground-water supplies in the area causing several springs near the Ordnance Works, Dardenne Creek, Schote Creek, and several of their tributaries to flow visibly red at times (Fischel and Williams, U.S. Geological Survey, written commun., 1944). The U.S. Army also used the abandoned Weldon Spring quarry site for disposal of residues from the manufacture of TNT.

At the end of World War II, the Weldon Spring Ordnance Works closed and the processing structures were abandoned. The Ordnance Works was declared surplus to U.S. Army needs during April 1946, and by the end of 1949, 15,169 acres had either been transferred to the Missouri Department of Conservation (the August A. Busch Wildlife Area) and the St. Charles County Consolidated School District, deeded to the University of Missouri, or sold to Weldon Spring Heights subdivision. About 2,000 acres remained under the jurisdiction of the U.S. Army (fig. 2).

In 1955, the U.S. Atomic Energy Commission authorized the Weldon Spring Feed Material Plant. The following year the U.S. Army transferred about 205 acres to the Commission for the construction of a uranium feed-materials plant at the site of the old Weldon Spring Ordnance Works [Ann Hood, St. Charles Countians Against Hazardous Waste (SCCAHW) written commun., 1984]. The TNT processing equipment and structures were demolished and removed prior to construction. Materials from this cleanup period were dumped into the deepest part of the quarry as well as over the high wall in the northeast corner. Construction on the plant was completed and Mallinckrodt Chemical Works, Uranium Division, began operating the plant for the Commission during 1957. The Weldon Spring plant converted previously extracted impure uranium concentrates to pure uranium salts and metal. During 1958 to 1964 the plant processed three times the quantity of materials it was designed to handle. This overtaxed the equipment and the general on-site housekeeping; the result was radiological contamination of the five major process buildings, most of the support buildings, and the land behind the plant with uranium and its decay products (Ryckman, Edgerley, Tomlinson, and Assoc., 1978). Raffinate pits were excavated for disposal of waste from processing uranium and thorium concentrates. Pits 1 and 2, each 1.2 acres in area, were constructed during 1958, but were soon full, requiring the construction of a third pit (8.4 acres) during 1959, and a fourth pit (15.0 acres) during 1964 (National Lead Company of Ohio, Inc., 1977).

In 1958, the Atomic Energy Commission also acquired the abandoned quarry, which the U.S. Army had used for disposal of TNT-contaminated materials, for a low-level radioactive waste-disposal site. Radioactive wastes of unknown origin began arriving at the quarry during 1959, when thorium residues contained in drums were deposited. Mallinckrodt Chemical Works was dismantling its Destrehan Street uranium processing plant in St. Louis and needed a waste-disposal site for the debris (Berkeley Geosciences Assoc., 1984). Wastes from this plant began arriving at the quarry by truck during 1960 and the transfer of rubble was completed during 1963 (Ann Hood, written commun., 1984).

During 1963 to 1965, permission was given by the Atomic Energy Commission for the disposal of several thousand barrels of low-level radioactive waste containing uranium and thorium from the U.S. Army Granite City Arsenal in Granite City, Illinois. After disposal began, a local company purchased the entire quantity of waste for rare-earths recovery and further dumping was suspended. The purchaser then removed as much of the dumped material as was practical from the quarry.

During 1965 and 1966, thorium residues were brought to the quarry by railroad from the U.S. defense contractor's plants in the Cincinnati, Ohio, area. The material is thought to have consisted of several hundred drums (Lenhard and others, 1967) constituting about 15,000 cubic feet (Ann Hood, written commun., 1984). During 1966, the U.S. Army disposed of stone and earth contaminated by TNT; this addition physically covers the thorium residues from the Cincinnati area.

Thorium oxide was processed at the plant during 1965 and 1966 and the wastes were deposited in raffinate pit 4 (Ryckman, Edgerley, Tomlinson, and Assoc., 1978). The Atomic Energy Commission decided to close the Weldon Spring plant at the end of 1966 because the plant was obsolete. Shut-down procedures included emptying hoppers and process lines and cleaning out dust collectors and other points of material accumulation, and removal of as much of the pure uranium compounds as possible from the production equipment. Drums and trash were dumped in pit 4 during close-out operations (Pennak and others, 1975).

In 1967, the Atomic Energy Commission transferred about 169 acres of the plant back to the U.S. Army after the U.S. Army decided to use parts of the feed-materials plant for the production of the herbicide known as "Agent Orange." The Commission kept control of 2 buildings, one of which had been used for storage of ore concentrates, and a 51-acre tract that included the 4 raffinate pits.

Decontamination and equipment removal started during March 1968 in the two buildings selected for herbicide production. The radioactive-contaminated equipment and rubble were deposited in the quarry (Pennak, 1975). Construction of the herbicide-production facility started during December 1968, but the project was canceled during early 1969. Clean-up and shut-down work at the plant continued until June 1969, when the U.S. Army, Corps of Engineers obtained custody of the 169-acre tract containing the plant.

The last-known disposal of radioactive wastes into the quarry occurred during 1969 when 10,000 tons of radioactively contaminated barium sulfate cake from the Destrehan Street uranium processing plant were spread over the quarry floor. Several piles of debris located in the northeast corner of the quarry have a larger radioactive content than most of the waste in the quarry. These piles are thought to have been brought in at this time (Berkeley Geosciences Assoc., 1984). A summary of waste disposal in the quarry is given in table 1.

In 1972, St. Charles County purchased the well field previously used to supply the Ordnance Works with water. When the Ordnance Works was in operation, the well field consisted of 13 large-capacity wells in a 344-acre tract. It is reported that the wells supplied water from the Missouri River alluvium at a rate of more than 44 million gallons per day (Searcy and others, 1952). In

Table 1.--Waste inventory at quarry

[(E), estimated]

Type	Date emplaced	Quantity	Comments
TNT-contaminated residues from Weldon Spring Ordnance Works [1,2,3,4,5]	Prior to 1958	No data	Residues and rubble dumped in deepest part of quarry and over high rim at northeast corner.
Residues containing waste from the thorium-232 decay series [2,3,4,5]	1959	185 cubic yards	Drums containing residues assayed at 3.8-percent thorium, probably placed below present quarry water level. Radium-228 content estimated at 0.25 curie.
Rubble from demolition of Destrehan Street uranium-processing plant [6]	1960-63	55,000 cubic yards (E)	Building rubble, processing equipment and soil contaminated with uranium and radium-226. Radium-226 content estimated at 1 curie; debris dumped in deepest part of quarry.
Waste from Granite City Arsenal-U.S. Army, thorium and uranium [1]	1963-65	No data	Several thousand barrels of waste were purchased for recovery. As much of the emplaced waste was removed as was possible.
Residues from Cincinnati, Ohio, containing waste from the thorium-232 decay series [1,3,6]	1966	550 cubic yards	Drums containing residues assayed at 3-percent thorium. Radium-228 content estimated at 1 curie.
Residue from the Weldon Spring Chemical Plant containing waste from the thorium-232 decay series [2,4]	1966	No data	Drums and uncontained residues of thorium from shutdown and cleanout of process equipment at chemical plant.

Table 1.--Waste inventory at quarry--Continued

Type	Date emplaced	Quantity	Comments
TNT residues from U.S. Army[2,3,4,5]	1966	No data	Contaminated stone and earth covers thorium residues from Cincinnati.
Uranium and thorium contaminated debris from Weldon Spring Chemical Plant[1,2,4,5]	1967-68	6,000 cubic yards	Contaminated process-equipment and building rubble.
Residues from Destrehan Street uranium processing plant consisting of barium sulfate cake containing waste from uranium-238 decay series[1]	1969	10,000 tons	Less active residues spread on quarry floor; active residues piled in northeast corner of quarry.

[1]Berkeley Geosciences Assoc.(1984).
[2]Bechtel National, Inc. (1983b).
[3]Lenhard and others (1967).
[4]Weidner and Boback (1982).
[5]Pennak (1975).
[6]St. Charles Countians Against Hazardous Waste (written commun., 1983).

1975, the U.S. Army assessed the environmental conditions at the Weldon Spring Chemical Plant. This preliminary assessment indicated that the plant could not be released for unrestricted use without decontamination of land and buildings. However, insufficient data were available to make a decision about what was needed to return the area to unrestricted-use status (Ryckman, Edgerley, Tomlinson, and Assoc., 1978, p. 8-9).

A similar conclusion was reached in a report to the U.S. Energy Research and Development Administration, now the U.S. Department of Energy, concerning the land under their control and a recommendation was made that additional data be collected (National Lead Company of Ohio, Inc., 1977, p. 49). Thus began the environmental monitoring programs and reports by private consultants concerning radioactive contamination at the chemical plant and quarry.

Previous Investigations

In October 1943, the chief of engineers of the War Department requested the U.S. Geological Survey to investigate the extent of contamination by an alkaline, intensely red water resulting from sulfite purification caused by the U.S. Army's TNT production at the Weldon Spring Ordnance Works. V. C. Fishel and C. C. Williams (U.S. Geological Survey, written commun., 1944) visited 63 wells and springs and were able to draw a water-table map from measurements of water-level, spring-orifice altitudes, and streambed altitudes. Their water-table map indicated ground water north of the drainage divide between the Mississippi River and the Missouri River moved northward toward Dardenne Creek. A systematic sampling program indicated contamination that seemed to be limited to streams, springs, and wells south of Dardenne Creek and northwest of Schote Creek (fig. 1). Streams entering Dardenne Creek from the north contained uncontaminated water, as did the flowing tributaries downstream from Schote Creek that entered Dardenne Creek from the south. Dardenne Creek, which appeared to be a ground-water drain for the area, contained red water from a point about 2,000 feet downstream of its junction with Kraut Run Creek to its junction with the Mississippi River.

The U.S. Geological Survey (Roberts, 1951) made a preliminary investigation of ground-water occurrence in the Weldon Spring area as a prerequisite to the location and design of special structures for the U.S. Atomic Energy Commission. Roberts (1951) confirmed the earlier work by V. C. Fishel and C. C. Williams (written commun., 1944) concerning the northward direction of groundwater movement north of the Mississippi-Missouri drainage divide and ground-water discharge to Dardenne Creek. Roberts (1951) also collected additional water-level data that indicated that ground water south of the divide at altitudes less than 580 feet above sea level moves toward the Missouri River.

A number of reports relating to radioactive wastes at the Weldon Spring sites have been prepared by consultants under contract to the Department of the Army or the Department of Energy and its predecessor agencies (AEC and ERDA). Because most of these reports were prepared for the Department of Energy, they primarily are concerned with the raffinate pits and the abandoned quarry site. The following are the more significant or detailed reports concerning the Weldon Spring sites.

In 1960, the U.S. Atomic Energy Commission requested the U.S. Geological Survey to evaluate the hydrology of the quarry site at Weldon Spring for the possibility of using the quarry as a disposal site for uranium- and thorium-contaminated building debris, residues, and raffinates. R. M. Richardson, (U.S. Geological Survey, written commun., 1960) pumped the quarry sump, made water-level measurements in surrounding wells, and pressure tested the formations. His preliminary conclusions were that ground water moved from north to south through the quarry area and that the quarry is hydraulically connected to the Missouri River alluvium. Richardson periodically lowered the water level in the quarry sump, causing reversals of ground-water gradients so that ground water began flowing into the quarry instead of through it. R. M. Richardson (written commun., 1960) concluded that leaving the water level in the quarry sump at equilibrium would cause flow through the quarry toward the Missouri River alluvium, and possibly would contaminate the water being pumped from the St. Charles County well field.

The National Lead Company of Ohio, Inc. (1977), investigated the potential hazards created by the four raffinate pits and the quarry in a decommissioning study. They installed several monitoring wells for water-quality sampling. Their conclusions regarding the raffinate pits were: the risks of contaminating aquifers used for drinking water is minimal, and seepage or leakage either under or through the embankments is virtually nonexistent and not related to low-level radioactivity found in local surface drainage. Their conclusions regarding the quarry site were: the risk of contaminating aquifers used for drinking water is negligible; uranium and thorium concentrations in the quarry sump water are greater than background levels, but less than U.S. Department of Energy's maximum concentration guides for waters in uncontrolled areas; the quarry sump is hydraulically connected to adjacent surface waters, especially the Femme Osage slough, which has uranium concentrations that exceed background concentrations, but were within Federal water-quality standards.

Huey (1978) collected data for use in determining what future action was needed to protect the environment from contaminated solids buried at the Weldon Spring quarry site. Huey (1978, p.2) concluded from the data that "***there is no doubt that soluble contaminants have and will continue to escape from the quarry via ground water through fissures, voids, etc.***". However, he did point out that "Semiannual water samples have been taken since June 27, 1974, at various locations around the quarry. The concentration of contaminants has always been well within specified [U.S. Department of Energy's standard for controlled and uncontrolled areas] limits."

Ryckman, Edgerley, Tomlinson, and Assoc. (1978), under contract to the U.S. Army, assessed the possible alternatives available for optimizing the Weldon Spring Chemical Plant's usefulness and its compatibility with surrounding land uses. During their study, extensive sampling was done on and off site to define the extent of radioactive contamination. They also made an extensive inventory of radioactive contaminants on the property.

During 1979-81, Berkeley Geosciences Assoc., at the request of the Department of Energy, investigated contamination problems associated with the quarry site. Berkeley Geosciences Assoc. (1984) estimated, based on a waste inventory for the quarry site, that radioactive waste covered an area of 30,000 square feet on the quarry floor to a depth of 40 feet. They suggested the bulk of radionuclides migrating from the quarry would move into the alluvium because of fractures in the limestone and the substantial permeability of the alluvium. Uranium concentrations greater than background were found in soil from the area between the Femme Osage slough and the quarry and in soil and water samples from the quarry and the slough. However, ground-water samples collected from the area between the slough and Missouri River indicated approximately background uranium concentrations. Uranium concentrations in nearby streams, including the Femme Osage Creek and the Missouri River, were at background concentrations. Berkeley Geosciences Assoc. (1984), also made a ground-water simulation model for the quarry site, in which different proposed engineering operations for the site were considered.

Prior to October 1981, the National Lead Company of Ohio, Inc., was under contract to the U.S. Department of Energy to provide environmental control sampling and caretaking activities at the Weldon Spring sites. Air and water samples were collected for information pertaining to radionuclide transfer to the off-site environment. Weidner and Boback (1982) summarized the results that indicated uranium and radium concentrations in off-site surface and ground water, and radon-222 concentrations in air at off-site locations were within the Department's guide values for uncontrolled areas.

Bechtel National, Inc., began environmental monitoring at the Weldon Spring site during October 1981. Since that time they have published several annual environmental-monitoring reports pertaining to the site. The monitoring report for 1981 and 1982 (Bechtel National, Inc., 1983a and 1983b) stated that the annual average radon released from the Weldon Spring site boundaries have not exceeded established guidelines. The maximum uranium concentration in surface water was 115 percent of the Department of Energy's guide limit during 1981 in the raffinate-pit area; at the quarry site, all concentrations in surface-water samples were less than 5 percent of the applicable Department of Energy's guide limit. During 1982, concentrations of uranium migrating from the quarry area and nitrates migrating from the raffinate-pit area exceeded the Department's guide limits.

Well-Numbering System

In this report, the locations of wells and test holes are numbered in the manner shown in figure 3. According to this system the first three sets of numbers of the well number designate the township, range, and section, in that order. The letters that follow indicate the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section. The quarter sections are lettered a, b, c, and d in counterclockwise order starting in the northeast quadrant. When two or more wells or test holes are located within the same division, they are numbered serially in the order in which they were inventoried.

Acknowledgments

The authors are grateful to the many residents of St. Charles County and public water-supply operators who allowed access to their wells. Without their cooperation the current water-level data could not have been obtained. We especially acknowledge the help provided by John Henry, the Weldon Spring site manager, for allowing us frequent access to the pit and quarry area for sampling

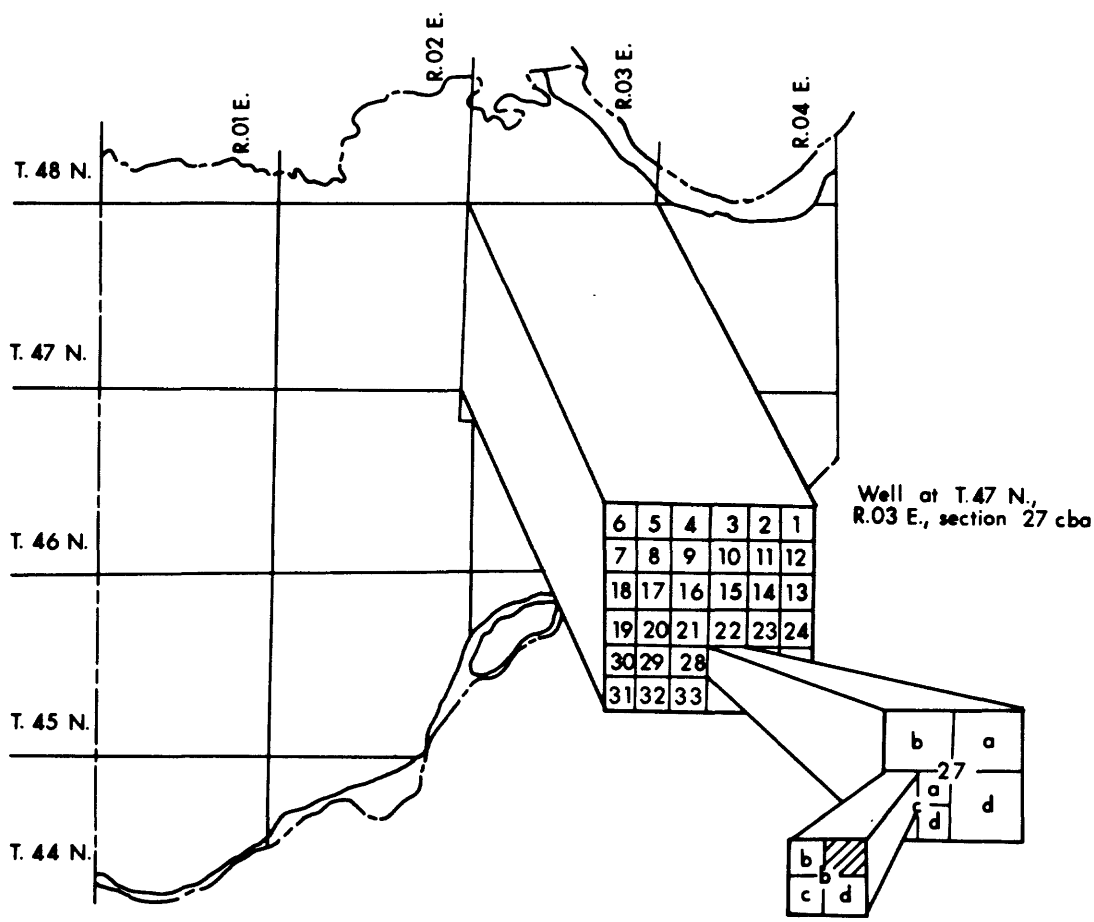

Figure 3.--Well-numbering system.

and measuring water levels in the observation wells; Perley Cassady and the other conservation agents at the August A. Busch Wildlife Area for their help and cooperation during our frequent visits to the wildlife area; Dallas Hovatter for allowing us access to the St. Charles County Water Department files and wells; and to the St. Charles Countians Against Hazardous Waste committee for access to their files.

GEOLOGIC BACKGROUND

Stratigraphy

Geologic formations ranging in age from Holocene (alluvium) to Early Ordovician (Cotter Dolomite) crop out in the area. Formations older than the Cotter Dolomite are only in the subsurface. A generalized description of geologic formations that may be in the area is shown in table 2.

The unconsolidated formations are alluvial deposits, loess, and glacial deposits, and are composed of varying proportions of clay, silt, sand, and gravel. The consolidated formations primarily are dolomite and limestone with minor quantities of shale and sandstone.

The information in table 2 represents composite lithologic descriptions of the formations found in the study area, but some of the stratigraphic units listed in the table are not present throughout the area. The stratigraphy and structural relationships of the geologic formations down to the St. Peter Sandstone are shown in figure 4. Formations younger than the Kimmswick Limestone are not present in the southwestern part of the study area. The Fern Glen Limestone and Maquoketa Shale pinch out in the central and northeastern part of the section shown in figure 4.

Structure

The consolidated rocks in St. Charles County have a regional dip of about 1° northeast as a result of being on the northeast flank of the Ozark uplift, but a small northwesterly trending geologic structure known as the Eureka-House Springs anticline (fig. 4) extends into St. Charles County north of New Melle on Dardenne Creek. "While not one of the larger structures of the state, the persistence of this and other northwest-southeast structures has been determined by the predominant grain of structure within the state." (McCracken, 1971, p. 29).

In St. Charles County, jointing in rocks is common. The Keokuk and Burlington Limestones, the Chouteau Limestone, and the Kimmswick Limestone have two sets of distinct joints: one set varies from N. 30° E. to N. 72° E., the other varies from N. 30° W. to N. 65° W. (Roberts, 1951.) These joints generally are vertical. A map of the limestone bluffs at the Weldon Spring quarry site prepared by Berkeley Geosciences Assoc. (1984) also shows a dominant set of joints oriented about N. 70° W. and two minor sets oriented about N.60° E. and northerly. Joint openings at the quarry site vary from less than 1 inch to several feet with the larger zones coinciding with gullies and ravines on top of the bluffs. Many of these joints have clay fillings at their base, which may be from either residual material from the dissolution of limestone or from soils that had been washed down. These observations probably are typical of jointed areas throughout the county.

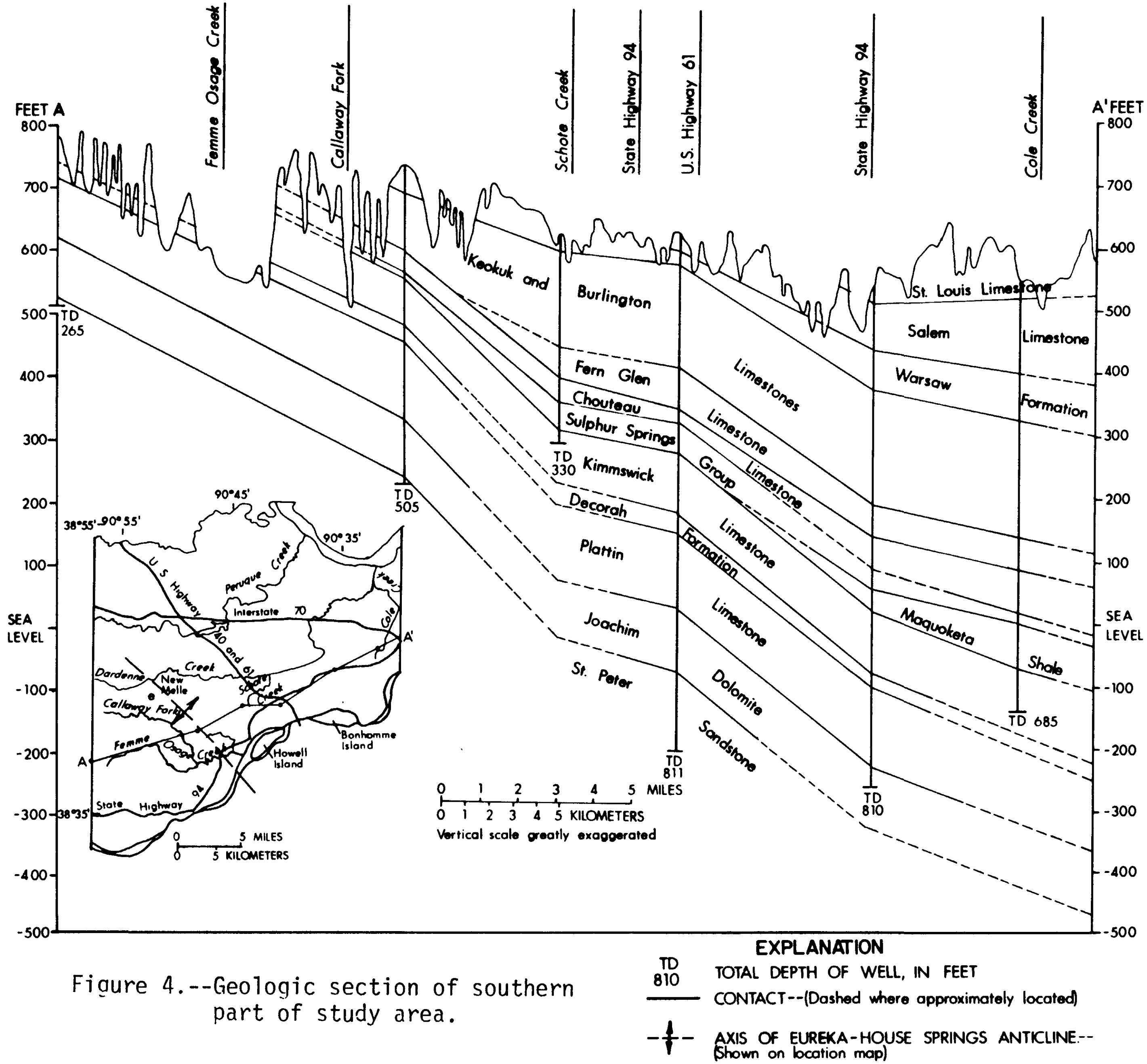

Figure 4.--Geologic section of southern part of study area.

Table 2.--Generalized lithologic description of geologic formations

[Modified from Howe and Koenig, (1961); Miller and others, (1974); gal/min, gallons per minute; --, insufficient data for estimate; <, less than. Typical thickness refers to thickness of formation normally encountered while drilling and does not include extremes]

System	Series	Stratigraphic unit	Depth from ground level to top of formation, in feet	Thickness, in feet	Typical thickness, in feet	Physical characteristics	Aquifer	Remarks
QUATERNARY	HOLOCENE	Alluvium	0	0- 65	10- 30	Gravelly, silty loam over occasionally gravelly, silty clay loam.	Alluvial aquifers	Deposits underlie tributaries to Missouri and Mississippi rivers.
				65-120	100-110	Silty loam, clay, and sand over sand and gravelly sand.	Alluvial aquifers	Deposits underlying Missouri and Mississippi River flood plains generally yield large quantities of water to wells. (600-2,600 gal/min).
	PLEISTOCENE	Loess and glacial drift	0	0-150	5-30 30-60	Silty clay, silty loam, clay, or loam over residuum and bedrock, or both.		Yields little water to wells (<5 gal/min).
PENNSYLVANIAN		Undifferentiated	0-120	0-75	--	Partly silty red shale with purplish-red to light gray clay.	Shallow bedrock aquifer	Limited occurrence. Yields small quantities of water to wells (<1-10 gal/min).
MISSISSIPPIAN	MERAMECIAN	St. Louis Limestone	0-120	0-105	70-75	Limestone; white to light gray, lithographic to finely crystalline, medium to thick bedded. Conteins some shale.	Shallow bedrock aquifer	Individually, the rock units yield small to moderate quantities of water to wells (5-50 gal/min). Collectively, these units yield sufficient water to supply most domestic and stock needs.
	MERAMECIAN	Salem Limestone	0-225	0-140	90-130	Limestone; light gray to white, fine to coarsely crystalline, cross-bedded. Some siltstone and shale in lower part.	Shallow bedrock aquifer	
	MERAMECIAN	Warsaw Formation	0-345	0-95	70-90	Calcareous shale; and interbedded shaly limestone, grades downward to shaly dolomitic limestone.	Shallow bedrock aquifer	
	OSAGEAN	Keokuk and Burlington Limestones	0-405	0-220	160-200	Limestone; white to bluish-gray, medium to coarsely crystalline, thick-bedded. Cherty.	Shallow bedrock aquifer	
	OSAGEAN	Fern Glen Limestone	0-500	0-85	50-70	Limestone; yellow-brown, fine grained, medium to thick-bedded. Contains appreciable chert.	Shallow bedrock aquifer	
	KINDERHOOKIAN	Chouteau Limestone	0-580	0-105	50-70	Dolomitic limestone; gray to yellowish-brown, fine-grained, thin to medium-bedded.	Shallow bedrock aquifer	
DEVONIAN	UPPER	Bushberg Sandstone	0-625	0-20	5-15	Quartz sandstone, reddish-brown, fine to medium grained, friable.	Shallow bedrock aquifer	Yields small to moderate quantities of water to wells (5-50 gal/min).
	UPPER	Lower part of Sulphur Spring Group undifferentiated	0-625	0-60	35-40	Calcareous siltstone, and sandstone with oolitic limestone with some dark, hard, carbonaceous shale.	Shallow bedrock aquifer	Group also includes Glen Park and Grassy Creek Formations.

ORDOVICIAN	CINCINNATIAN	Maquoketa Shale	0-650	0-75	30-50	Calcareous or dolomitic shale, typically thinly laminated, silty, with shaly limestone lenses.		Yields small quantities of water to wells.
	CHAMPLAINIAN	Kimmswick Limestone	0-710	0-140	90-100	Limestone; white to light gray, coarsely crystalline, medium to thick-bedded. Cherty near base.	Leaky confining layer	Yields small to moderate quantities of water to wells (10-50 gal/min).
		Decorah Formation	0-810	0-35	30	Interbedded green and yellow shale with thin beds of limestone.		
		Plattin Limestone	0-840	0-195	100-125	Limestone; light to dark gray, finely crystalline. Thinly bedded; weathers with pitted surface.		
		Joachim Dolomite	0-950	0-135	90-110	Dolomite; yellowish-brown, silty, thin to thick-bedded. Grades into siltstone, shales common.		
		St. Peter Sandstone	0-1070	0-250	120-150	Quartz sandstone; yellowish white to to white, fine to medium grained, massive bedded.	Deep bedrock aquifer	Yields moderate quantities of water to wells (10-140 gal/min). Everton Formation discontinuous.
		Everton Formation	0-850	0-65	0	Sandy dolomite.		
	CANADIAN	Powell Dolomite	0-950	0-65	50-60	Dolomite; medium to finely crystalline, often sandy, occasionally cherty or shaly.		Generally yields small quantities of water to wells (<10 gal/min).
		Cotter Dolomite	0-1250	75-275	200-250	Dolomite; light gray to light brown, medium to finely crystalline, cherty. Argillaceous, interbedded with green shale.		
		Jefferson City Dolomite	100-1500	145-225	160-180	Dolomite; light brown to brown, medium to finely crystalline.		
		Roubidoux Formation	350-1700	150-170	150-170	Dolomitic sandstone.		Yields moderate to large quantities of water to wells (10-300 gal/min).
		Gasconade Dolomite	500-1850	250	250	Cherty Dolomite-Gunter Member is arenaceous dolomite.		Gunter Member is about 30 feet thick.
CAMBRIAN	UPPER	Eminence Dolomite	750-2100	190	200	Dolomite; medium to massively bedded, light gray, medium to coarse-grained.		Yields moderate to large quantities of water to wells (10-500 gal/min)
		Potosi Dolomite	950-2250	100	100	Dolomite; massive, thickly bedded, medium- to fine-grained. Abundant quartz druse.		Freshwater only in southwest part of St. Charles County and saline water elsewhere in county.
		Derby and Doe Run Dolomites[1]	1050-2350	140	150	Dolomite; thin to medium-bedded alternating with thin bedded siltstone and shale.		Hydrologic characteristics unknown in St. Charles County. Is a confining bed elsewhere in State.
		Davis Formation	1200-2500	170	170	Contains shale, siltstone, fine-grained sandstone, dolomite, and limestone conglomerate.		
		Bonneterre Dolomite	1350-2650	430	400	Dolomite; typically a light gray, medium to fine-grained, medium-bedded.		Yields unknown in St. Charles County; however, water probably is saline.
		Lamotte Sandstone	1800-3100	460	450	Predominantly quartzose sandstone.		
PRECAMBRIAN			2200-3500			Igneous rocks.		Yields no water.

[1]Designated Derby-Doerun Dolomite by the Missouri Division of Geology and Land Survey.

Several tributaries of Dardenne Creek trend from N. 10° E. to N. 45° E. and appear to have developed channels along former fracture lines or solution channels (V. C. Fishel and C. C. Williams, written commun., 1944). Surface drainage in this case may approximately reflect the structure of the rock.

Joints in the limestone provide channels for the downward movement of water. Movement of water through joints and bedding planes dissolves limestone thereby enlarging the openings and improving the capability of the rock to transmit water. Evidence of limestone solution is shown by the presence of caves at different levels in the limestone and by the presence of small springs.

HYDROLOGY

Surface Water

The capacity of streams to maintain flow and to transport sediments is important in determining potential transport routes of radionuclides. St. Charles County is bounded by the Missouri and Mississippi rivers, which provide an abundant supply of surface water. However, these streams are not as significant in this study as the smaller tributaries that drain the area.

Flow-duration curves are good indicators of variability of streamflow and hydrologic characteristics of drainage basins. The small tributary streams in most of St. Charles County and surrounding areas characteristically have flow-duration curves that represent highly variable streams that derive much of their flow from direct runoff (Miller and others, 1974).

Hydrologic patterns in the area are related to physiography. Drainage-basin characteristics vary between the Salem Plateau and the Dissected Till Plains. Differences associated with the regions include main-channel slope, forest cover, and the soil-infiltration index (Miller and others, 1974). Generally, low-flow potential of most streams in the Dissected Till Plains is minimal because of the minimal permeability of the clay and shale. Streams with drainage areas of 100 square miles or less usually are dry at some time during each year. Streams in the Salem Plateau area can have sustained low flows due to inflow of water from the carbonate rocks (gaining stream). However, it is not uncommon for streams in the Salem Plateau to lose water to the streambed (losing stream) through solution cavities.

The three streams of primary importance due to their proximity to the radioactive waste-disposal sites are: Femme Osage and Little Femme Osage Creeks that drain the southern part of the study area in the Salem Plateau and Dardenne Creek that is north of the radioactive waste-disposal sites in the Dissected Till Plains. Low-flow frequency data for two of these streams were computed from a series of low-flow discharge measurements and are presented in table 3.

Generally, the 7-day, 2-year low flow for small, unregulated streams ranges from 0 to 0.005 cubic foot per second per square mile; however, this range can change where sewage-treatment plants are operating. "Theoretically, urbanization will decrease the low flows of streams because of decreased soil-moisture storage, improvement of drainage, and lowering of ground-water levels...In St. Charles County, however, low flows of many small (drainage areas less than 50 square miles) tributary streams are greatly augmented, mostly by domestic effluents, and the net result is an increase in dry-weather flow." (Miller, 1977, p. 58). Dardenne Creek is a good example of increased low flow due to urbanization. Femme Osage and Little Femme Osage Creeks are not located in the rapidly developing part of St. Charles County, so the low-flow frequency of these two streams probably has not changed significantly.

Table 3.--Low-flow frequency data at selected St. Charles County streams

[Modified from Miller and others, 1974; sites shown in figure 5]

Map no. (fig. 5)	Station name	Period of record used in analysis	Period (days)	Low-flow frequency: Annual low flow, in cubic feet per second, for indicated recurrence interval, in years	
				2	10
4	Dardenne Creek near Weldon Spring	1942-43 1945-46 1948, 1953 1961-63, 1967	7	0.1	0
10	Femme Osage Creek near Weldon Spring	1961-63, 1967	7	0.2	0

In 1967, seepage runs (a series of discharge measurements along a stream reach made in a short time to identify where gains or losses in flow occur) were made on several of the streams in St. Charles County, including Dardenne and Femme Osage Creeks and some of their tributaries (table 4). The September 1967 seepage-run data show that Dardenne Creek gradually gains flow between the County Highway Z crossing, 2 miles north of New Melle; and the County Highway K crossing, 2 miles north of Weldon Spring (fig. 5). However, between the County Highway K site and where County Highway C crosses Dardenne Creek at St. Peters the entire flow of 0.2 cubic foot per second was lost to the streambed and to evapotranspiration. The data for Femme Osage Creek indicate discharge continually increases downstream.

On December 11, 1984, seepage runs were made on the small tributaries that drain into Schote Creek from the Weldon Spring Ordnance Works property and the August A. Busch Wildlife Area, on an unnamed tributary of Dardenne Creek, and on the unnamed Missouri River tributary that was used as the sewage-outfall discharge point. During the seepage runs, visual estimates of discharge, and measurements of specific conductance and water temperature were made at selected sites on the streams and their tributaries; the results are shown in figure 6. Discharge values were derived by taking the product of the visually estimated mean width, depth, and velocity of the flowing cross section. These data were collected when streamflow in the area was greater than the 7-day, 2-year low flow, but not affected by storm runoff and at a time of small evapotranspiration losses, making the data good indicators of gaining and losing reaches.

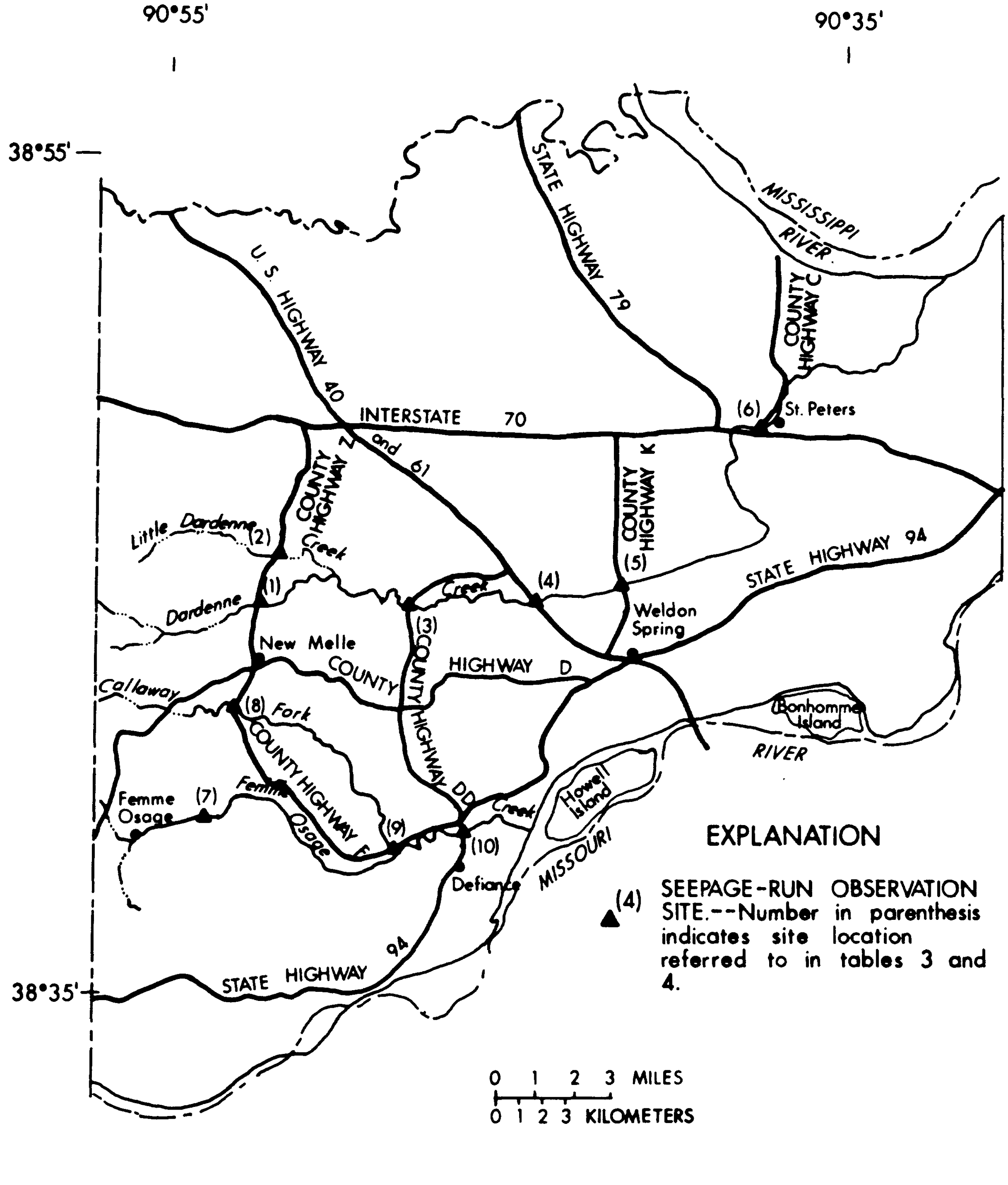

Figure 5.--Stream sites where streamflow was measured during 1967 seepage runs.

Table 4.--Results of hydrologic reconnaissance on streams during 1967

[Modified from Miller and others (1974 p. 61-62). ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25° C; °C, degrees Celsius; mg/L, milligrams per liter; < , less than; --, no data; observation sites shown in figure 5]

Map no. (fig.4)	Station name	Location	Date	Discharge (ft^3/s)	Specific conductanc (µS/cm)	Dissolved oxygen (mg/L)	Water temper-ature (°C)	Air temper-ature (°C)	Remarks
1	Dardenne Creek near New Melle	NW¼ sec. 23, T. 46 N., R. 1 E., at bridge on County Highway Z, 2 miles north of New Melle, St. Charles County.	9-13-67	<0.05	--	--	--	--	Mostly scattered pools. Large piles of crushed lime on right bank below bridge.
2	Little Dardenne Creek near New Melle	SW¼ sec. 12, T. 46 N., R. 1 E., at bridge on County Highway Z, 4 miles north of New Melle, St. Charles County.	9-13-67	0	--	--	--	--	--
3	Dardenne Creek near New Melle	NE¼ sec. 21, T. 46 N., R. 2 E., at bridge on County Highway DD, 5 miles northeast of New Melle, St. Charles County.	9-13-67	0.1	--	--	--	--	--
4	Dardenne Creek near Weldon Spring	T. 46 N., R. 3 E., at bridge on U.S. Highway 40 and 61, 3 miles north-west of Weldon Spring, St. Charles County.	9-12-67	0.2	400	7.5	19	--	Water clear
5	Dardenne Creek near Weldon Spring	SW¼ sec. 16, T. 46 N., R. 3 E., at bridge on County Highway K, 2 miles north of Weldon Spring, St. Charles County.	9-12-67	0.2	400	7.5	19	--	--
6	Dardenne Creek at St. Peters	T. 47 N., R. 3 E., at bridge on County Highway C at St. Peters, St. Charles County.	9-12-67	0	--	--	--	--	Shallow pools with no flow.
7	Femme Osage Creek near Femme Osage	T. 45 N., R. 1 E., at bridge on county road, 2 miles northeast of Femme Osage, St. Charles County.	9-13-67	0	370 (in pool)	6.5 (in pool)	20 (in pool)	25	Bed mostly dry, but had scattered pools.

Table 4.--Results of hydrologic reconnaissance on streams during 1967--Continued

Map no. (fig.4)	Station name	Location	Date	Discharge (ft^3/s)	Specific conductanc (μS/cm)	Dissolved oxygen (mg/L)	Water temperature (°C)	Air temperature (°C)	Remarks
8	Callaway Fork near New Melle	SE¼, sec. 34 T. 46 N., R. 1 E., at bridge on County Highway F, 1.5 miles southwest of New Melle, St. Charles County.	9-13-67	0	--	--	--	--	--
9	Callaway Fork near Defiance	T. 45 N., R. 2 E., at bridge on County Highway F, 1.5 miles northwest of Defiance, St. Charles County.	9-13-67	0.3	490	7.5	19	25	About 95 percent of the flow from a small drain entering entering creek 50 feet downstream from ford on county road in SW¼ sec. 16, T. 45 N., R. 2 E. Drain choked with water-cress; water temperature 15°C and specific conductance 490 μS/cm.
10	Femme Osage Creek near Weldon Spring	T. 45 N., R. 2 E., at bridge on State Highway 94, 1 mile north of Defiance and 7 miles southwest of Weldon Spring, St. Charles County.	9-13-67	0.6	490	9	20	26	--

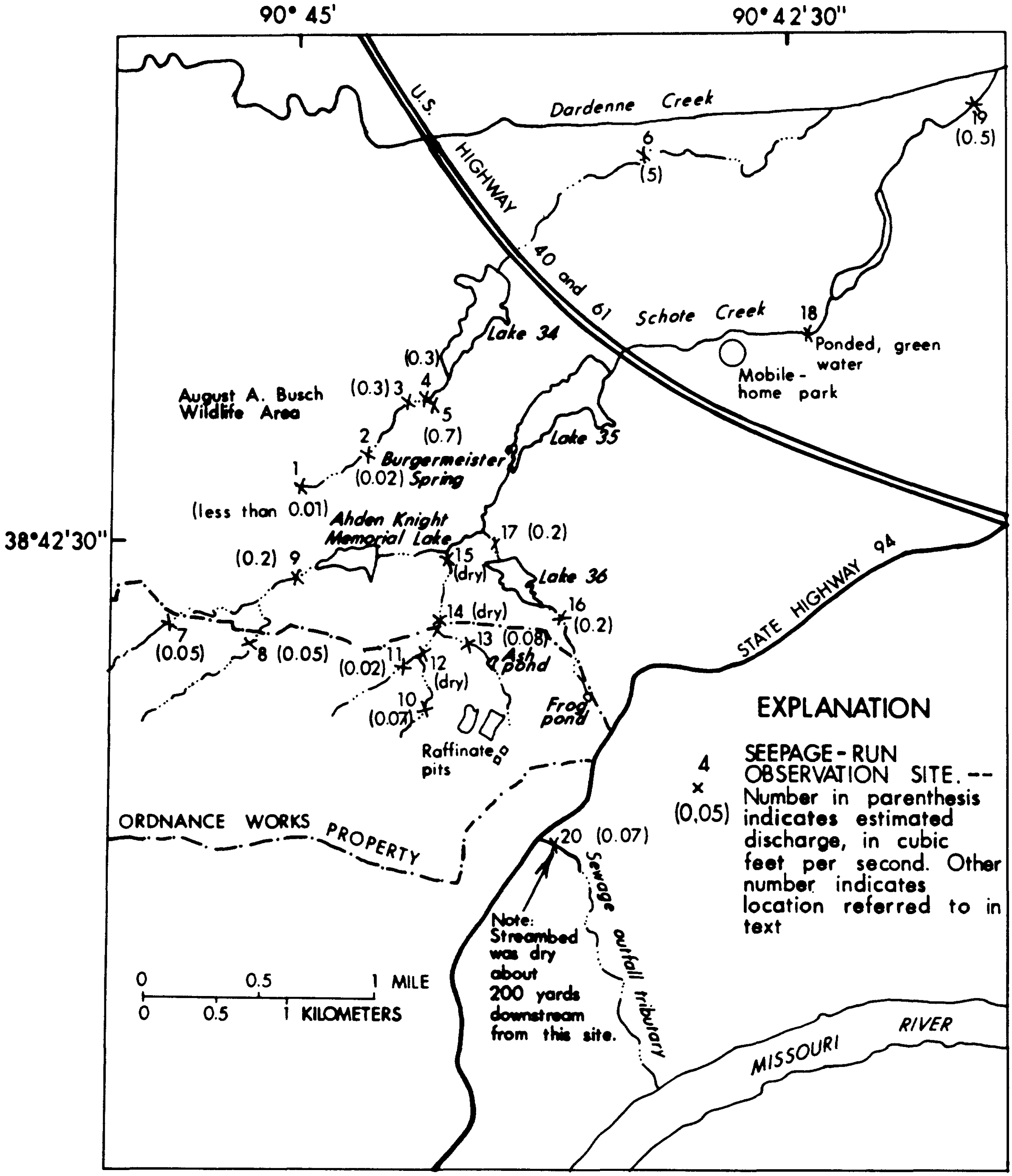

Figure 6.--Results of seepage run made on Schote Creek and vicinity, December 11, 1984.

Several observations were made on the tributaries in the headwaters of Schote Creek. Both tributaries that form the west fork of Schote Creek within the Ordnance Works boundaries (sites 7 and 8) had an estimated flow of 0.05 cubic foot per second. Downstream from where the two tributaries join, but upstream of Ahden Knight Memorial Lake (site 9), the discharge had increased to an estimated 0.2 cubic foot per second.

The headwaters of the middle fork of Schote Creek also begin on the Ordnance Works property and include drainage from the raffinate-pits area and the locally referred to Ash pond. Flow was observed in the two tributaries to the west of the raffinate-pits area (sites 10 and 11); however, both of these tributaries became dry immediately upstream from where they converge, and the streambed of this fork remained dry to its mouth (sites 12, 14, and 15). The small tributary that drains the area to the east of the raffinate-pits area contains Ash pond. Flow downstream from Ash pond was estimated as 0.08 cubic foot per second (site 13); however, before this tributary converged with the two tributaries to the west of the raffinate pits, it lost its entire flow to the streambed.

The east fork of Schote Creek contains drainage from the locally referred to Frog pond. Flow in this tributary was estimated at 0.2 cubic foot per second downstream from Frog pond (site 16), and had a specific conductance of 1,420 microsiemens per centimeter. Flow in this tributary was observed after it came out of lake 36 (site 17); the discharge was estimated to be the same as site 16, but the specific conductance had decreased to 520 microsiemens per centimeter.

The main stem of Schote Creek was observed downstream from a mobile-home park located north of U.S. Highway 40 and 61 (site 18). Water was ponded at this location and was noticeably green, probably due to effluent from the mobile-home park's sewage lagoon. Flow near the mouth of Schote Creek (site 19) was estimated at 0.5 cubic foot per second.

From these seepage-run data it appears that the middle fork of Schote Creek, which is the fork draining the raffinate-pits area and Ash pond, has losing reaches, but the east and west forks do not. The main stem of Schote Creek does not appear to be losing, but this is inconclusive because flow estimates were made at only one site.

The unnamed tributary, which drains into lake 34 and eventually into Dardenne Creek, appeared to be gaining discharge throughout its length. In the headwaters of the tributary (site 1) the flow was less than 0.01 cubic foot per second; however, flow continually increased in a downstream direction (site 2, 3, 4, and 6) and flow was estimated to be 5 cubic feet per second near its mouth. Part of the increased flow between sites 4 and 6 may be attributed to change in storage of lake 34. Burgermeister Spring (site 5) was flowing about 0.7 cubic foot per second.

The unnamed tributary of the Missouri River that was used as a sewage outfall appeared to be an interrupted stream. This stream contains perennial reaches with intervening intermittent reaches. About 100 yards downstream from State Highway 94 (site 20), flow was estimated at 0.07 cubic foot per second. Flow was visually observed as increasing in a downstream direction, but about 200 yards downstream of site 20 the streambed became dry. The streambed remained dry for about another 200 yards before seeps began emerging, causing flow to begin again in the tributary. A gaining-losing-gaining sequence occurred again within the next 0.5 mile. The length of this tributary to its mouth was not traveled and it was not determined if the water in the losing reaches was lost to the aquifer or reappeared downstream.

Ground Water

The aquifers used in the study area are the alluvial aquifers along the Missouri and Mississippi Rivers; the aquifer primarily comprised of rocks of Mississippian and Devonian age, called the shallow bedrock aquifer in this report; and the aquifer comprised of rocks of Ordovician age, called the deep bedrock aquifer in this report.

Alluvial Aquifers

The major alluvial aquifers in the area consist of the saturated sand and gravel in the alluvium of the Missouri River and the Mississippi River flood plains. The alluvium of the small creeks and tributaries are not a dependable source of ground water because of small yield due to variable thickness and poorly sorted sediments. At one time, farms along the streambanks did get some water from shallow-dug wells; however, well yields were not dependable.

The Missouri River and the Mississippi River alluvium typically ranges from 100 to 120 feet thick; however, the composition and layering of the deposits can vary considerably in a short distance. Generally, alluvial deposits are composed of clay, silt, sand, and gravel. The Missouri River alluvium primarily consists of silt and sand at the surface with sand and gravel at depth, whereas the alluvial surface soil of the Mississippi River flood plain has a clay layer of low hydraulic conductivity overlying sands and gravels.

Wells in both the Missouri River and the Mississippi River flood plains typically are 100 to 110 feet deep. Data from an aquifer test made during 1967 by the U.S. Geological Survey in the St. Charles County well field show the transmissivity and storage coefficient of the alluvial aquifer were 36,000 feet squared per day and 0.2, respectively. During this test, the well was pumped at about 2,600 gallons per minute for 47 hours. The average hydraulic conductivity is about 400 feet per day (transmissivity and hydraulic conductivity are converted from values given in Emmett and Jeffery, 1968). Irrigation wells completed in the Mississippi River alluvium have been reported to yield more than 3,300 gallons per minute.

Water from the alluvial aquifers predominantly is a calcium bicarbonate type. Locally, the water may contain significant quantities of sulfate. The water also is characterized by a large hardness and iron concentrations and variable dissolved-solids concentration.

Recharge to the alluvial aquifers occurs from precipitation on the alluvium, from flooding that causes surface water to go into bank storage, and as underflow from underlying and adjacent bedrock aquifers. Recharge also may be induced from the river into the alluvium by pumping of large-capacity wells close to the river.

Water in the alluvial aquifers normally moves toward, and discharges into, the major streams with which they are hydraulically connected. Discharge from the alluvial aquifers also occurs by evaporation, plant transpiration, and by pumpage from wells.

Water levels measured in wells in the St. Charles County well field and in observations wells around the quarry were used to construct the water-table map shown in figure 7. Water levels indicate that there is flow from the north toward the pumped wells and that water may be induced from the Missouri River toward the wells. Additional water-level measurements are needed to verify this.

Shallow Bedrock Aquifer

The shallow bedrock aquifer primarily consists of limestone of Mississippian and Devonian age, with minor quantities of sandstone. This aquifer is absent in the southwestern part of the study area, but gradually increases in thickness to the northeast. Some of the formations of the shallow aquifer are hydraulically more significant than others, although all appear to be hydraulically connected.

Well yields reported by drillers to the Missouri Division of Geology and Land Survey, ranged from 5 to 50 gallons per minute, but typically were from 5 to 15 gallons per minute. The larger-yield wells are those that intercept extensive secondary openings, such as joints and solution openings. There are no available data for aquifer tests made in the shallow bedrock aquifer.

The rocks of the Meramecian Series yield minimal quantities of water to wells. Only one well in the study area withdraws water only from this series, and its yield was reported as 0.5 gallon per minute. Because the hydraulic conductivity of these rocks are less than the underlying formations, the Meramecian Series, where present, may be a confining layer for water in the shallow bedrock aquifer.

The sequence of rocks from the Keokuk and Burlington Limestones to the top of the Maquoketa Shale forms the more permeable part of the shallow bedrock aquifer. Usually, the Keokuk and Burlington Limestones locally are fractured, contain numerous clay-filled voids, and yield small to moderate quantities of water to wells. The Fern Glen Limestone, when considered by itself, is not significant as a ground-water source. The Fern Glen Limestone may be deeply weathered in outcrop and may transmit water through joints and solution openings. The Chouteau Limestone yields small quantities of water to wells. The Bushberg Sandstone of the Sulphur Springs Group is porous and permeable and generally supplies moderate yields to wells. The lower part of the Sulphur Springs Group is not as permeable as the Bushberg Sandstone, but probably still yields small to moderate quantities of water to wells, depending on the sand content.

Water from the shallow bedrock aquifer varies from a calcium magnesium bicarbonate type to a sodium sulfate, sodium bicarbonate, or a sodium chloride type in St. Charles County. Dissolved-solids and chloride concentrations increase from west to east. Variations in the chemical characteristics between the calcium magnesium bicarbonate type water and the sodium chloride type are

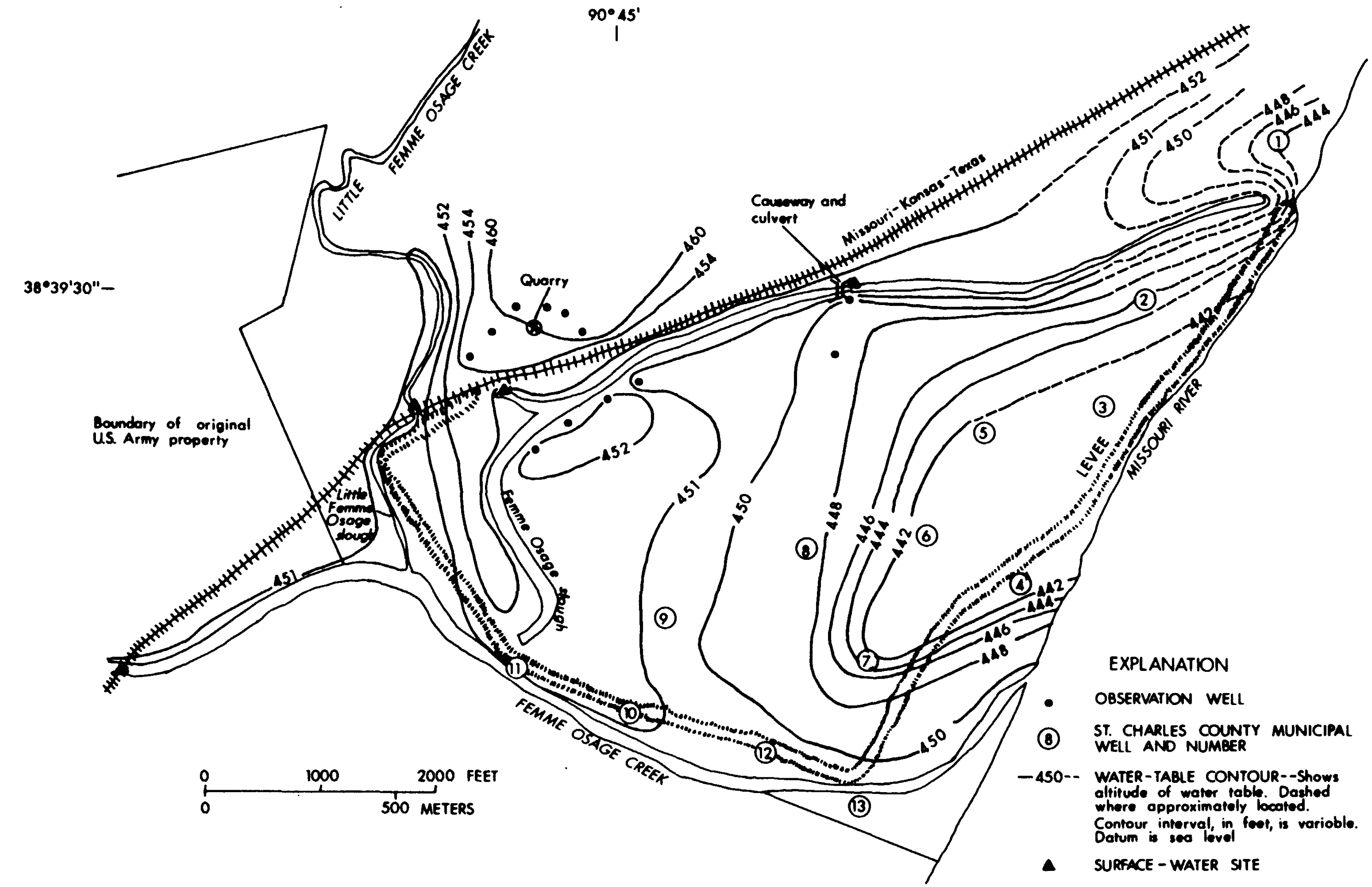

Figure 7.--Altitude of water table for the quarry and St. Charles County well-field area, October 30, 1984.

believed to be related to geologic structure affecting upward movement of more mineralized water from underlying formations. Water with large sulfate concentrations is limited to the area underlain by Pennsylvanian shale, sandstone, and siltstone (Miller, 1977).

Precipitation on the area where these bedrock formations are near surface is the principal source of recharge to the aquifer. This water moves through permeable soils and into bedrock along fractures, bedding planes, and solution openings. Another source of recharge is water entering the aquifer through losing streams. An example of this is the middle fork of Schote Creek, which drains the raffinate-pits area and Ash pond. Water flows in this tributary near its headwaters, but flow gradually is lost to the streambed before reaching the tributary mouth.

During the summer of 1984, the depth to water was measured in about 75 wells that are completed in the shallow bedrock aquifer to determine the direction of water movement through the study area. These water-level measurements are listed in table 12 of the "Supplemental Data" section at the back of the report. From these measurements, a potentiometric-surface map of the shallow bedrock aquifer was drawn (fig. 8). No contours appear near Femme Osage Creek and to the south because this is an area of Ordovician outcrop, and rocks of that age are not considered part of the shallow bedrock aquifer.

Several features appear on this map. A ground-water divide is located along a ridge that also defines the surface-water divide. Dardenne Creek is a major drain for the area north of the divide. There are several local ground-water highs in the northern one-half of the county, but in general the ground water north of the divide moves in a northeasterly direction toward the Mississippi River. Ground water to the south of the divide moves in a southerly direction toward the Missouri River.

Data collected by V. C. Fishel and C. C. Williams (written commun., 1944) and Roberts (1951) were plotted on a current base map (fig. 9). Their data included depth-to-water measurements in wells open to the shallow bedrock aquifer; spring-orifice altitudes, and streambed altitudes from which a potentiometric-surface map was drawn. This map is similar to the potentiometric-surface map using the current data, in that the ground-water divide coincides with the surface-water divide and the ground-water trough coincides with Dardenne Creek. The potentiometric-surface map, using the historical data, shows more detail than the current potentiometric-surface map along the divide and in the August A. Busch Wildlife Area because many of the wells in which depth to water was reported in 1944 and 1951 have since been destroyed.

Discharge from the shallow bedrock aquifer occurs as springs, seeps, evapotranspiration, and underflow. Some water may move downward into the underlying deep bedrock aquifer where the potentiometric surface of the shallow bedrock aquifer is higher than that of the deep bedrock aquifer due to a vertical-flow component resulting from fractures in the confining beds. Discharge also occurs by pumpage from wells completed in the shallow bedrock aquifer.

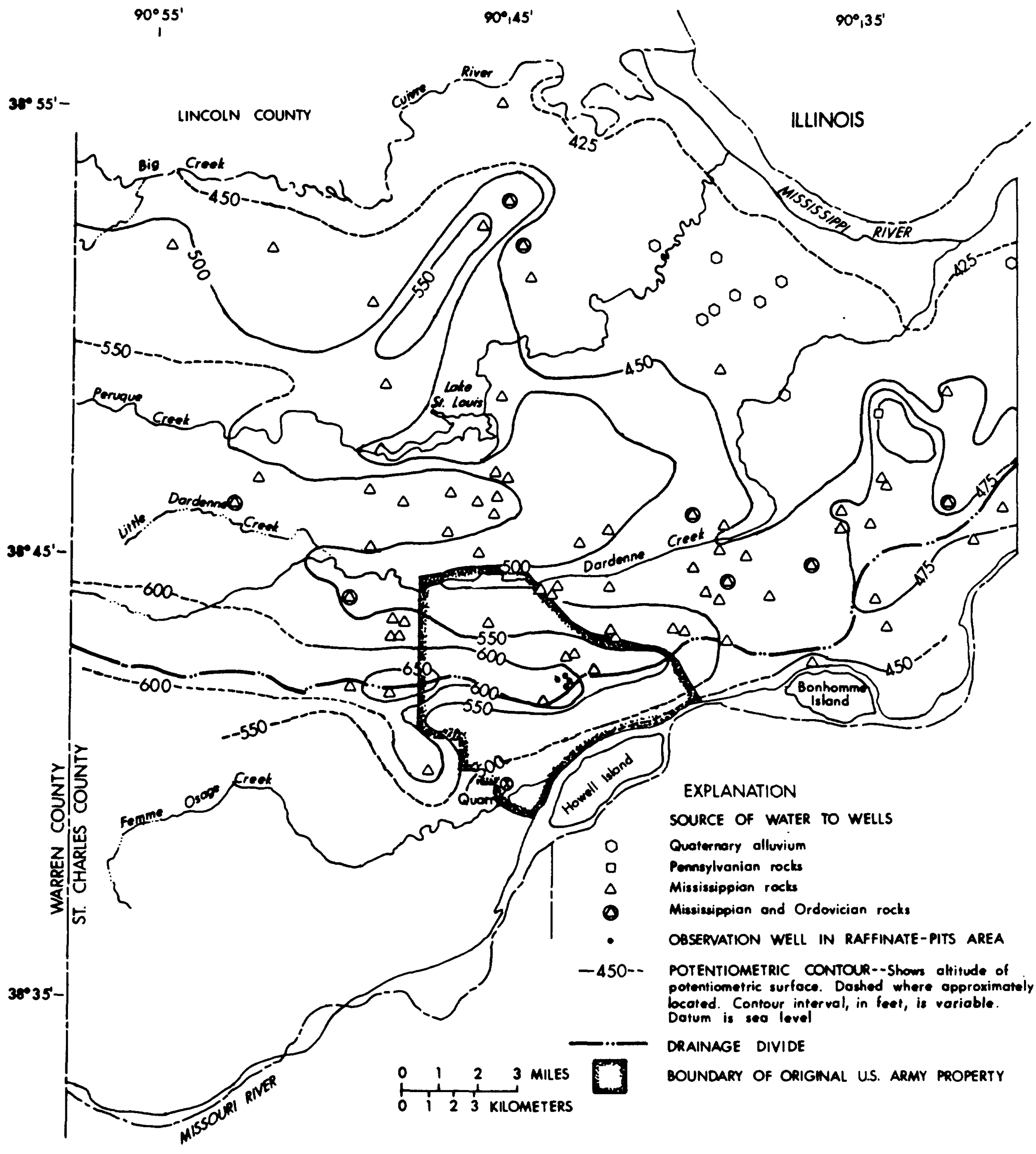

Figure 8.--Potentiometric surface of the shallow bedrock aquifer, summer 1984.

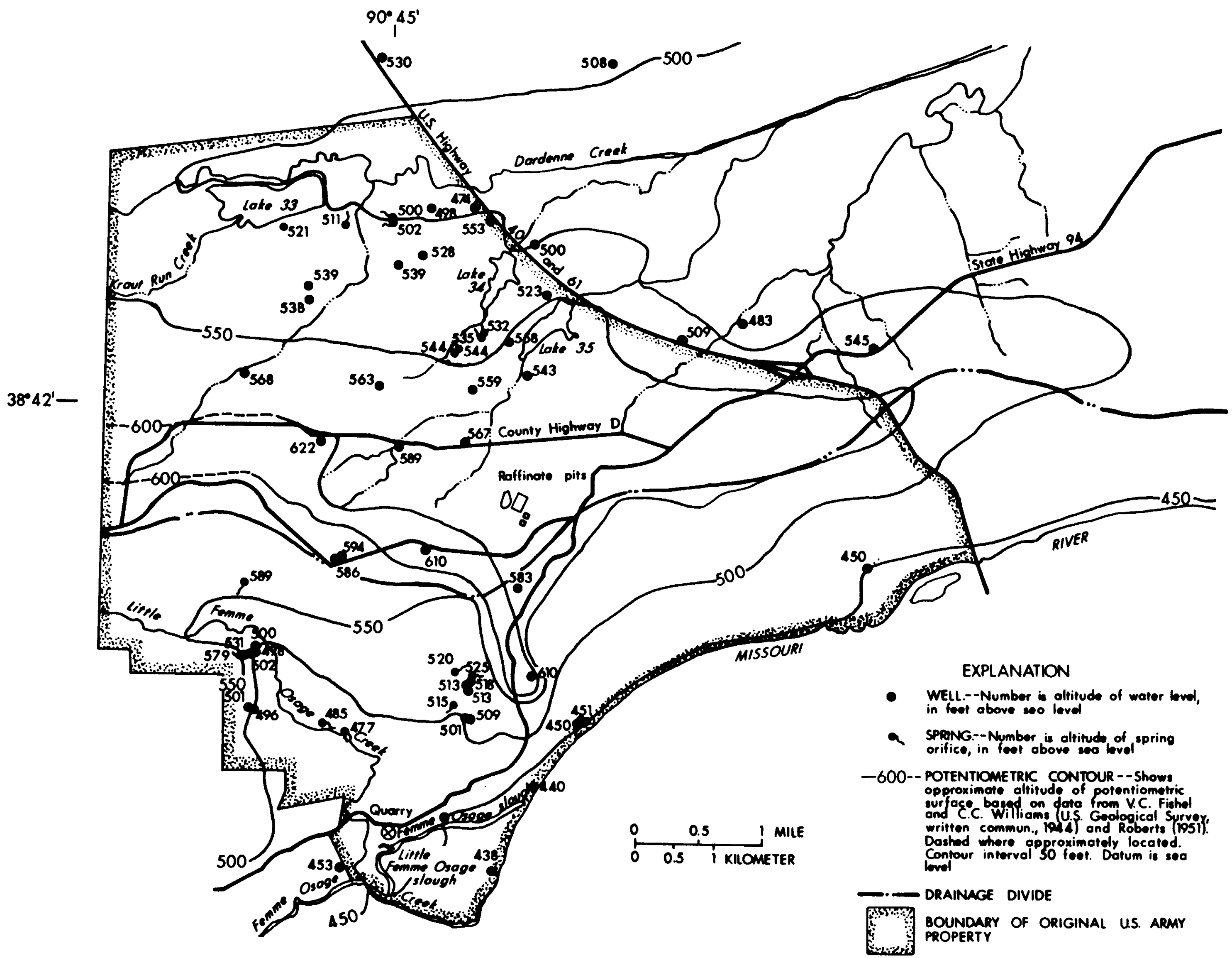

Figure 9.--Potentiometric-surface of the shallow bedrock aquifer based on historical water levels.

Deep Bedrock Aquifer and Confining Layer

The deep bedrock aquifer and its upper confining layer in this report include the Ordovician shale, limestone, dolomite, and sandstone from the Maquoketa Shale to the bottom of the Potosi Dolomite. This aquifer has a uniform thickness throughout the county ranging from 1,300 to 1,400 feet. Large yields can be obtained from some of these formations; however, in eastern St. Charles County these formations generally yield saline (dissolved-solids concentration greater than 1,000 milligrams per liter) water. The oldest formation typically used in the study area for public water supply is the Gasconade Dolomite.

The Maquoketa Shale, Kimmswick Limestone, Decorah Formation, Plattin Limestone, and Joachim Dolomite form a less permeable part of the aquifer and are a confining layer for the more permeable underlying formations. The confining sequence generally is about 300 feet thick on the western side of the study area and increases to about 400 feet on the eastern side. The Maquoketa Shale is the youngest formation of the confining sequence, but it is present only on the eastern side of the county. Generally, where the Maquoketa Shale is intact, it can impede ground-water movement between formations. The Kimmswick Limestone, in outcrop, is characterized by solution-enlarged joints and springs; however, it normally yields only small quantities of water to wells. The Decorah Formation, a shale and fine-grained limestone, does not yield significant quantities of water and primarily can be considered a leaky confining layer. The Plattin Limestone has the same weathering features in outcrop as the Kimmswick Limestone but the formation yields only small to moderate quantities of water to wells. The Joachim Dolomite is argillaceous and yields small quantities of water to wells. It is the oldest formation in the sequence forming the confining layer for the deep bedrock aquifer.

The more permeable sequence of the deep bedrock aquifer is about 1,000 feet thick and this thickness is uniform throughout the county where all the formations are intact. The permeability of the St. Peter Sandstone varies with the degree of cementation of the sand grains, but generally yields moderate quantities of water to wells (10 to 140 gallons per minute). The Everton Formation is only occasionally present in the study area and is not hydraulically significant. The Powell, Cotter, and Jefferson City Dolomites are argillaceous and cherty and generally yield small quantities of water to wells (less than 10 gallons per minute). The Roubidoux Formation and Gasconade Dolomite have interbedded sandstone and yield moderate to large quantities of water to wells (10 to 300 gallons per minute).

Yields from wells in the more permeable part of the deep bedrock aquifer average more than 100 gallons per minute, as reported by drillers to the Missouri Division of Geology and Land Survey. However, wells completed in the less permeable zone between the Maquoketa and Joachim yielded only 3 to 50 gallons per minute (Miller and others, 1977). From aquifer tests made on wells in St. Charles County, specific capacities for wells penetrating formations from the Kimmswick to the St. Peter ranged from 0.07 to 0.25 gallon per minute per foot of drawdown, whereas wells penetrating deeper formations had specific capacities ranging from 0.53 to 2.64 gallons per minute per foot of drawdown.

Water quality varies with depth and lateral extent of the deep bedrock aquifer. Water samples from the Maquoketa-Joachim sequence have a dissolved-solids concentration ranging from 305 to more than 4,700 milligrams per liter. Water in the north and northeast parts of the county has a large dissolved-solids concentration and is a sodium chloride type, whereas the potable water to the west generally is a calcium magnesium bicarbonate type. Water from the St. Peter-Gasconade sequence has dissolved-solids concentrations ranging from 252 to 915 milligrams per liter. The eastern one-half of the county generally yields excessively mineralized sodium chloride type water, whereas the western one-half yields moderately mineralized calcium magnesium bicarbonate type water (Miller, 1977).

Sources of recharge to the deep bedrock aquifer are similar to those for the shallow bedrock aquifer. Referring to the Ordovician rocks as the deep bedrock aquifer can be misleading because in the southwestern part of the study area these rocks are exposed at the land surface. The need for differentiating between the two becomes apparent north of the Ordovician outcrop area. Precipitation directly on the area where the deep bedrock aquifer is overlain by permeable soils is a principal source of recharge to the aquifer. Other sources of recharge are losing streams where the losing reach penetrates the aquifer and by downward leakage from the shallow bedrock aquifer into the deep bedrock aquifer due to the confining sequence being too thin, fractured, or open because of well penetration.

Data from the depth-to-water measurements made in wells during the summer of 1984 are listed in table 13 of the "Supplemental Data" section at the back of the report and were used to draw a potentiometric-surface map of the deep bedrock aquifer (fig. 10). Several features are shown on this map. Femme Osage Creek, which is located in the Ordovician outcrop area, appears to be a major drain for the deep bedrock aquifer. A large drawdown cone in the northern part of the study area extends from the Wentzville area to the city of St. Peters and is caused by pumpage from public-supply wells. The general direction of ground-water movement is toward the northeast, except where the north side of the drawdown cone causes local southerly ground-water flow. The hydraulic-head gradient outside the pumping area does not appear to be as steep or as variable as in the shallow bedrock aquifer.

Discharge from the deep bedrock aquifer principally occurs as underflow. Other sources of discharge are evapotranspiration and seepage to springs and streams where the aquifer crops out. Discharge occurs artificially as pumpage from wells. A consequence of pumpage is a lowering of water levels as shown by the drawdown cone that has formed (fig. 10).

RADIOACTIVE WASTE-DISPOSAL SITES: HYDROGEOLOGIC AND RADIOLOGIC INFORMATION

Two distinct radioactive waste-disposal sites are located in the Weldon Spring area. One site consists of the Weldon Spring Chemical Plant and the four raffinate pits that are located on slightly rolling terrain just north of the Mississippi-Missouri River drainage divide. The other site is an abandoned rock quarry in the bluff adjacent to the Missouri River flood plain and about 3 miles southwest of the chemical plant (see fig. 2).

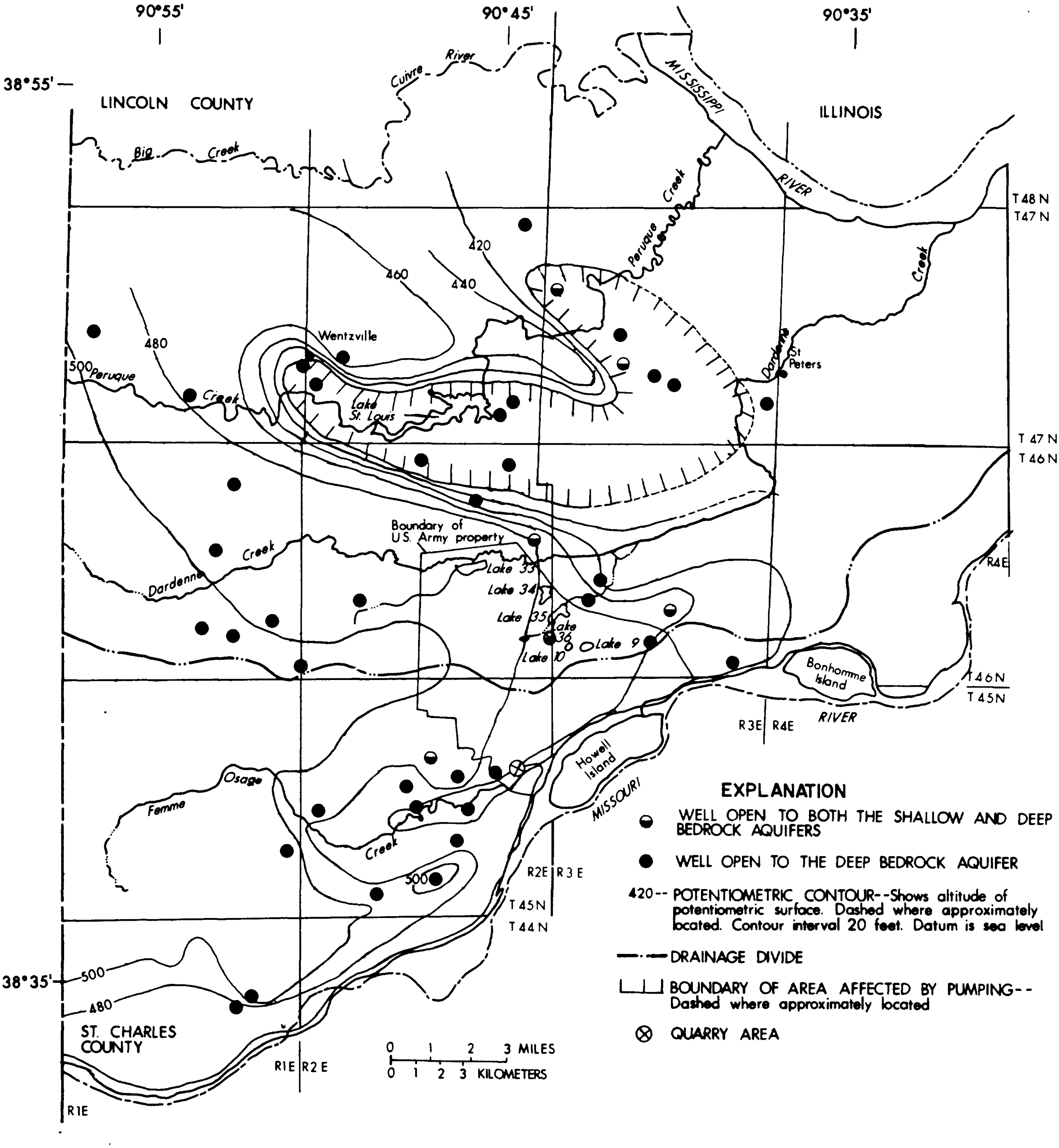

Figure 10.--Potentiometric surface of the deep bedrock aquifer, summer 1984.

Raffinate Pits and Chemical Plant

The four raffinate pits (fig. 11), which stored the wastes generated from the chemical plant, were constructed by excavating part of the surface clay from the site. The removed clay was then used for the levees surrounding the pits. Pits 1 and 2 were constructed on fairly level ground and a levee 3 feet higher than the original land surface was placed around them. The top of the waste in these two pits is below the original land surface and normally under water. However, during dry weather these pits have become dry, exposing the bottom sediments. Pits 3 and 4 were constructed where the natural slope of the land is toward the west, but the elevation of the top of the levees around them is approximately the same as the top of the levees around pits 1 and 2. The northeast corner of pit 3 was built on the original land surface with the height of the levee being about 23 feet. Pit 3 is estimated to be 78-percent full (Weidner and Boback, 1982); this means that the top of the wastes are above the original land surface. The waste in pit 3 is covered by water. The levee on the west side of pit 4 was built approximately on the original land surface. The levee has a maximum height of 35 feet. Most of the excavation done during construction of pit 4 appears to have been on the northern, eastern, and probably southern parts.

Pit 4 is only 12-percent full of waste; however, these wastes were not spread uniformly across the bottom (Weidner and Boback, 1982). If some of the waste is located on the west side of pit 4, it is assumed the top of the waste is above the base of the levee. The waste in pit 4 is covered by water. However, many 55-gallon barrels (contents unknown) that lie at the base of the east levee are sometimes totally submerged and other times completely exposed because of seasonal water-level fluctuations. Construction data for the raffinate pits are given in table 5.

The excavation of surface clay during pit construction has created concern about the thickness of clay remaining beneath pit 4. Borehole data collected during 1964, prior to construction of pit 4, indicates there is a minimum of 10 feet of clay remaining above the bedrock where the maximum excavation occurred in pit 4. A thickness map of remaining overburden beneath pits 3 and 4 was computer generated by Bechtel National, Inc., using borehole and seismic-refraction data. Overburden thickness ranged from 10 to 25 feet within the pits and ranged from 17 to 50 feet outside the pit area (Bechtel National, Inc., 1984b). A description of the six units that form the overburden is presented in table 14 in the "Supplemental Data" section at the back of this report.

"The residues discharged to the pits consisted of raffinate from uranium refining operations, washed magnesium fluoride slag residues from uranium metal production, and raffinate solids from the processing of thorium recycle materials...The raffinates were neutralized with lime and pumped to the pits as a slurry. The solids, principally acid-insoluble compounds in the feed materials (chiefly silica) settled in the pits. The supernatant liquid overflowed to the Chemical Plant process sewer, where it was mixed with storm water and sewage treatment effluent. It was then discharged from the sewer outfall into a small stream that flows approximately 2.4 km (1.5 mi) to the Missouri River." (Bechtel National, Inc., 1984c, p. 6-7). The radionuclide concentration of the raffinate in the pits is given in table 6.

Table 5.--Construction data for Weldon Spring raffinate pits

(Modified from Bechtel National, Inc., 1984a, p. 8; ft, feet; yd^3, cubic yards)

Pit	Year constructed	Maximum length (ft)	Maximum width (ft)	Surface area (acres)	Total pit volume (yd^3)	Total waste volume (yd^3)	Percent filled
1	1958	230	230	1.2	18,500	17,400	94
2	1958	230	230	1.2	18,500	17,400	94
3	1959	790	460	8.4	166,700	129,600	78
4	1964	1,120	700	15.0	444,400	55,600	12
Total				25.8	648,100	220,000	

Table 6.--Radionuclide concentrations in raffinate from the pits at the Weldon Spring site

[From Bechtel National, Inc., 1984c, p. 31; all values given in picocuries per gram]

Radionuclide	Pit 1	Pit 2	Pit 3	Pit 4
Radium-226	430±130	440±130	460±130	11±3
Radium-228	850±85	200±20	100±10	60±10
Thorium-230	24,000±1,000	24,000±1,000	14,000±1,000	1,600±100
Thorium-232	100±20	120±20	120±20	120±20
Uranium-234	810±80	560±50	570±50	610±60
Uranium-235	40±5	30±4	30±4	30±4
Uranium-238	710±70	470±40	520±50	620±60

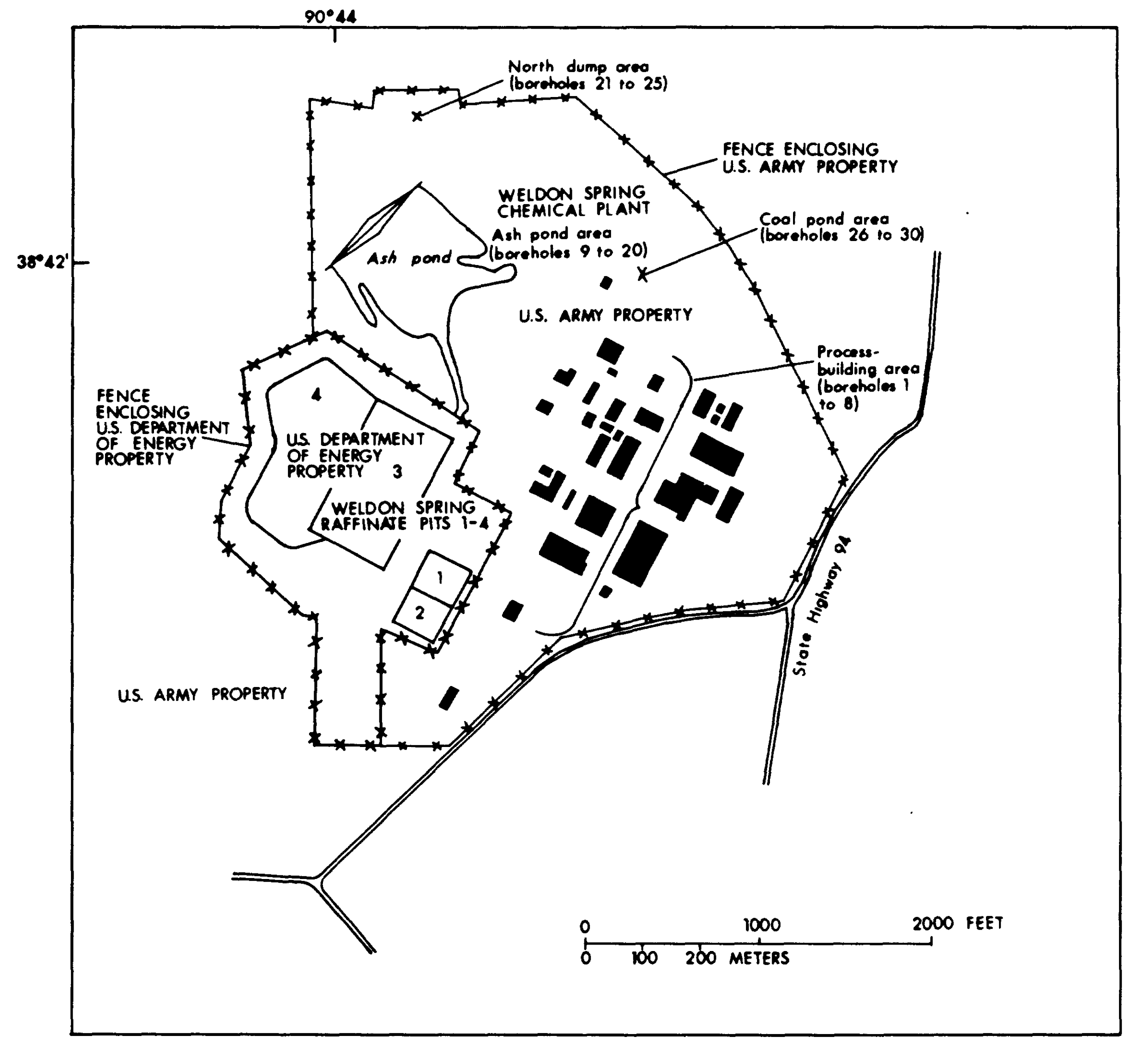

Figure 11.--Weldon Spring raffinate pits, Weldon Spring Chemical Plant, and boreholes where soil samples were collected (modified from Bechtel National, Inc., 1984b).

During May 1984, water-level measurements were made by the U.S. Geological Survey in four observation wells surrounding raffinate pits 3 and 4. These measurements indicated the overburden was not saturated and the water-table altitude was in the Burlington and Keokuk Limestones. The water-table altitude ranged from 616 feet above sea level south of pits 3 and 4 to 604 feet northwest of the pits. The local water-table gradient was about 32 feet per mile toward the north.

The bottoms of raffinate pits 3 and 4 at their lowest altitudes are about 638 and 628 feet above sea level, respectively (Bechtel National, Inc., 1984b). The water-level measurements made during May 1984 indicate there are 22 to 34 feet of unsaturated overburden and bedrock beneath pit 3 and 12 to 24 feet beneath pit 4. Reportedly (Bechtel National Inc., 1984b, p. 43) "***the overburden is unsaturated beneath pit 4 and portions of pit 3 and generally outside the pits, especially in the western half of the site around pit 4. Seismically detected areas of saturation exist beneath the center of pit 3 and as thin, shallow layers (south and east of pit 3)***. The [thin saturated] layer appears to be a naturally occurring perched water table that is possibly receiving some recharge from pit 3, but there are few data to confirm this." Another possible area of overburden saturation is near the toe of the north levee of pit 3 where the ground has been disturbed by dumping or landfilling or both since pit 3 was constructed (Bechtel National, Inc., 1984b).

Anomalously high water-level altitudes have been measured in an observation well located at the toe of the west levee of pit 4. Field-radiation tests on water from this well were made to determine if pit 4 was contributing water to the well. The test results did not exceed background limits. Water-level altitudes measured in this well are above the limestone bedrock, but geophysical data indicate the overburden beneath and around pit 4 is not saturated. "It is not clear at this time what the water level in this well represents (water table, piezometric surface perched water, or raffinate pit water)." (Bechtel National, Inc., 1984b, p. 36).

Keokuk and Burlington Limestones (table 2) underlie the overburden. "The upper***40 ft or so of the limestone are gradationally weathered and exhibit a consequent irregular rock surface***. The uppermost parts of the limestone form a ***1- to 5-ft thick zone of highly weathered residual limestone. The zone consists of cobbles and boulders of limestone in a loess, silty, sandy, clay matrix.*** The permeability of the weathered residual limestone is not known, although drilling losses were variable (zero to 100 percent)." (Bechtel National, Inc., 1984b, p. 22-23).

During 1978, an assessment was made of radiological contamination at the Weldon Spring Chemical Plant for the U.S. Army (Ryckman, Edgerley, Tomlinson, and Assoc., 1978). As part of that study, 160 soil samples were collected from 30 boreholes and analyzed for uranium concentration. The boreholes were drilled to a maximum depth of 10 feet and soil samples were collected from different depths at some holes.

Locations of the 30 boreholes were divided between the following four areas (fig. 11): boreholes 1 to 8 are in the process-building area; boreholes 9 to 20 are in the Ash pond area; boreholes 21 to 25 are in an area referred to as the North dump; and boreholes 26 to 30 are in an area referred to as the Coal pond. Data in table 7, modified from Ryckman, Edgerley, Tomlinson, and Assoc., (1978,

Table 7.--Summary of borehole-sampling data

[Modified from Ryckmann, Edgerley, Tomlinson, and Assoc., 1978, p. 20; in., inches; ppm, parts per million; <, less than; --, no data]

Hole number	Bore depth (in.)	Surface soil type	Depth to undisturbed clay (in.)	Uranium maximum concentration (ppm)	Depth of sample (in.)
1	120	Gravel	5	469	12
3	110	Muck	8	3,242	4
4	120	Gravel	2	36,060	12
5	112	Muck	16	1,757	4
7	118	Clay	0	<224	0
8	120	Clay	0	<50	0
10	120	Cinders	2	225	12
11	120	Cinders	2	<224	0
13	71	Clay	0	51	6
14	96	Clay	0	70	2
15	120	Silt	2	9,606	2
16	114	Ash	47	137	4
18	120	Cinders	4	87	4
19	120	Cinders	20	1,145	2
20	120	Cinders	47	<22	--
21	114	Clay	0	3,485	2
23	120	Cinders	2	1,382	2
24	120	Clay	0	7,030	2
25	71	Clay	0	138,800	2
27	108	Clay	0	132	8
29	120	Clay	0	<117	0
30	120	Cinders	8	<50	0

p. 20) includes depth and maximum uranium concentrations for 22 of the samples. Sediment samples also were collected from several streams and impoundments and analyzed for uranium (Ryckman, Edgerley, Tomlinson, and Assoc., 1978, p. 26-27). Results of these analyses are given in table 8. Ryckman, Edgerley, Tomlinson, and Assoc. (1978, p. 73), estimated that about "***5,000 cubic yards of soil and sediment are contaminated at concentrations above 500 ppm uranium." About 80 percent of this quantity is located near the Ash pond and North dump areas (fig. 11). A radiological survey of the area surrounding the Weldon Spring raffinate pits was made for the Department of Energy during 1982-83 (Bechtel National, Inc., 1984a). As part of that study, 120 surface and 34 trench-sidewall soil samples were collected; the samples were analyzed for uranium-238, radium-226, and thorium-232. In addition, 19 of the 120 surface samples were analyzed for thorium-230. The following is a summary of the results of those analyses. "Uranium-238 concentrations in surface soil samples ranged from 2 to 34,090 p Ci/gm [picocuries per gram] ***The highest radium-226 concentration was 261.8 p Ci/gm *** Resampling ***reduced the concentration of radium-226 to 8.3 p Ci/gm. This is indicative of the inhomogeneity of the contamination in the area. The highest thorium-230 concentration, 370 p Ci/gm, and the highest thorium-232 concentration, 459.9 p Ci/gm, were from [the same sample]." (Bechtel National,Inc., 1984c, p. 16).

Runoff from the raffinate pits and chemical-plant area flows into the middle and east forks of Schote Creek (see previous section, "Surface Water," for seepage-run data). These tributaries flow into lakes 35 and 36 in the August A. Busch Wildlife Area. The Missouri Department of Conservation sampled 7 sites in the August A. Busch and Weldon Spring Wildlife Areas during the spring of 1983. Lakes 35 and 36 had been previously sampled by consultants (table 8). The samples collected during the spring of 1983 were analyzed for gross alpha and gross beta radioactivity and the results are shown in table 9. Samples collected from lakes 9 and 10 and from Little Femme Osage Creek upstream from the quarry are unaffected by runoff from the raffinate pits and chemical-plant area and are presumed to represent background. The gross alpha and gross beta activities in the water samples from the Femme Osage slough, lakes 35 and 36, and Little Femme Osage Creek downstream from the quarry were larger than background activities. Results of the sediment sampling indicated larger-than-background activities of gross alpha and gross beta in lakes 35 and 36. (J. R. Whiteley, Missouri Conservation Commission, written commun., 1983). Ten sediment samples were collected from the drainage easement to the Missouri River, referred to as "the outfall sewer". Analysis of the samples showed that uranium-238 contents were as much as 900 parts per million. Two samples had contents of uranium-238 more than 500 parts per million (Ryckman, Edgerley, Tomlinson, and Assoc., 1978).

The Missouri Department of Natural Resources, Division of Geology and Land Survey, made water-tracing studies on several tributaries that drain the Weldon Spring Chemical Plant property and become losing streams where the streambed penetrates the overlying clay cap (fig. 6). These studies were made to correlate surface runoff from the chemical-plant property and outflow from springs in the area, which may be contaminated. During the first phase of the study, dye was placed in a north-flowing stream west of the raffinate pits. The dye emerged after 48 to 72 hours at, or in the vicinity of, Burgermeister Spring in an adjacent basin. The straight-line flow distance is about 6,500 feet. It was concluded by the State agency that runoff from the chemical-plant area west of the pits and the drainage through Ash pond would be expected to eventually flow underground and emerge at or near Burgermeister Spring to the northwest.

Table 8.--Uranium concentration in sediment samples

[Data from Ryckman, Edgerley, Tomlinson, and Assoc., 1978, p. 26-27; ppm, parts per million]

Sample location	Uranium concentration (ppm)
Dardenne Creek	27 to 70
Ash pond	70 to 1;145
Frog pond	473; 858
Lake 36	13 to 287
Below lake 36 drain	88
Lake 35	11; 19; 42; 44
Drainage easement to Missouri River	900

Table 9.--Gross alpha and beta activity in water and sediment

[Data from Missouri Department of Conservation; pCi/L, picocuries per liter; pCi/g, picocuries per gram; <, less than]

Sample location (fig. 1)	Water		Sediment	
	Gross alpha (pCi/L)	Gross beta (pCi/L)	Gross alpha (pCi/g)	Gross beta (pCi/g)
Lake 9[a]	<0.4	2.5	0.84	13
Lake 10[a]	<.4	3.9	.48	13
Little Femme Osage Creek upstream from quarry[a]	<.4	<2.0	<.4	5.3
Little Femme Osage Creek downstream from quarry	2.8	10	<.4	11
Femme Osage slough	7.1	20	.07	15
Lake 36	6.0	18	1.3	55
Lake 35	3.6	8.0	.95	26

[a]Data represent background radioactivity.

The second phase of the study was made to determine if surface water lost to the bedrock south of the chemical plant reverses flow direction and moves northward following the dip of the bedrock. It was concluded by the State agency that the surface runoff from the outfall drainage valley and the discharge from the outfall sewer line that entered the subsurface stay within the confines of the valley and continue to move to the south. The water does not appear to move northward downdip with the bedrock, but instead it emerges in at least two springs in the outfall valley and possibly in the Missouri River about 1.5 miles from the point of water loss (T. J. Dean, Missouri Department of Natural Resources, Division of Geology and Land Survey, written commun., 1984).

Quarry

The presence of radioactive wastes stored in the Weldon Spring quarry poses a potential water-quality hazard to the local ground-water and surface-water systems. The proximity of the St. Charles County well field to the quarry "***could be a matter of potential concern; however, samples of incoming water to the Waterworks taken by NLO [National Lead Company of Ohio, Inc.] indicate no contamination of the well field exists." (Pennak, 1975, p. 20].

The abandoned quarry is located between Missouri State Highway 94 and the Missouri, Kansas, and Texas Railroad line (fig. 2), and in the limestone bluff adjacent to the Missouri River flood plain. The limestone quarry is in a high outcropping of the Kimmswick Limestone and was mined using open-pit methods. The altitude of the quarry's high rim is from 540 to 560 feet above sea level, the 2-acre main floor is at about 483 feet above sea level, and the 0.5-acre sump originally was completed at about 446 feet above sea level (Bechtel National, Inc., 1983a).

A generalized north-trending geologic section through the quarry (fig. 12) was prepared by Berkeley Geosciences Assoc. (1984). This section shows the ridges and bluffs surrounding the quarry are overlain by silty clay-loess deposits. Core samples from the test wells in the quarry show the loess has a maximum thickness of 3 feet. The quarry sump is completed in the Decorah Formation. Samples from the quarry observation wells show the Decorah ranges from 14 to 20 feet thick and is a limestone that grades downward to a shale (Weidner and Boback, 1982). The bedrock at the quarry dips to the northeast at 60 to 80 feet per mile.

The streams in the immediate vicinity of the quarry ultimately flow into the Missouri River and include Femme Osage Creek, Little Femme Osage Creek, and an unnamed tributary to Little Femme Osage Creek (fig. 1). Femme Osage slough and Little Femme Osage slough are ponded surface-water bodies (fig. 13) that were formed by the construction of the University of Missouri levee system during 1959-60. The levee cut off the downstream reach of Femme Osage Creek and the downstream reach of Little Femme Osage Creek just upstream from its confluence with Femme Osage Creek. A new channel was developed for each, diverting both creeks outside the levee. The sloughs are about 500 feet south of the quarry. The topography surrounding the quarry is such that precipitation accumulating inside the quarry rim cannot flow by surface routes directly from the site.

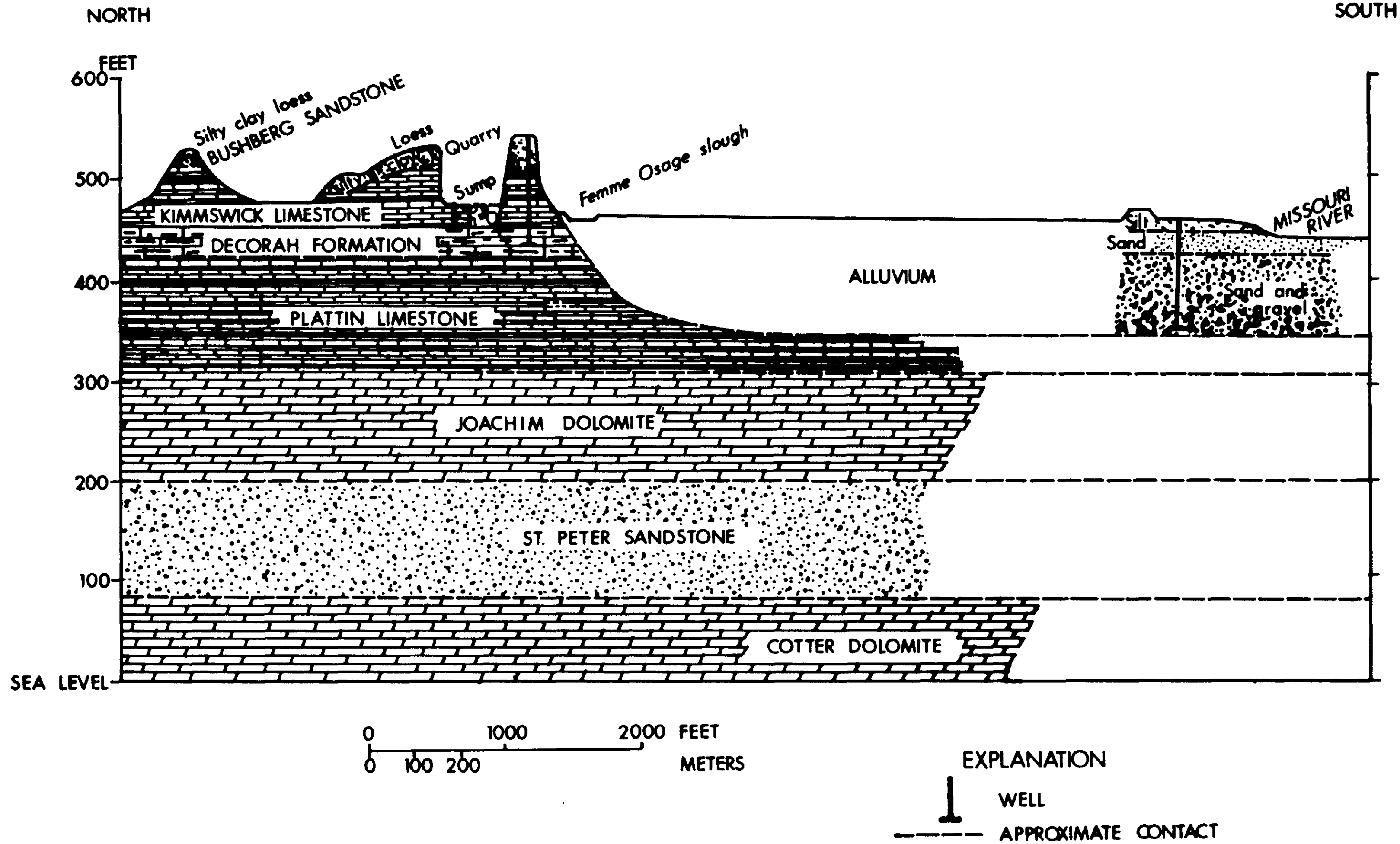

Figure 12.--Generalized north-trending geologic section through the Weldon Spring quarry area (modified from Berkeley Geosciences Assoc., 1984).

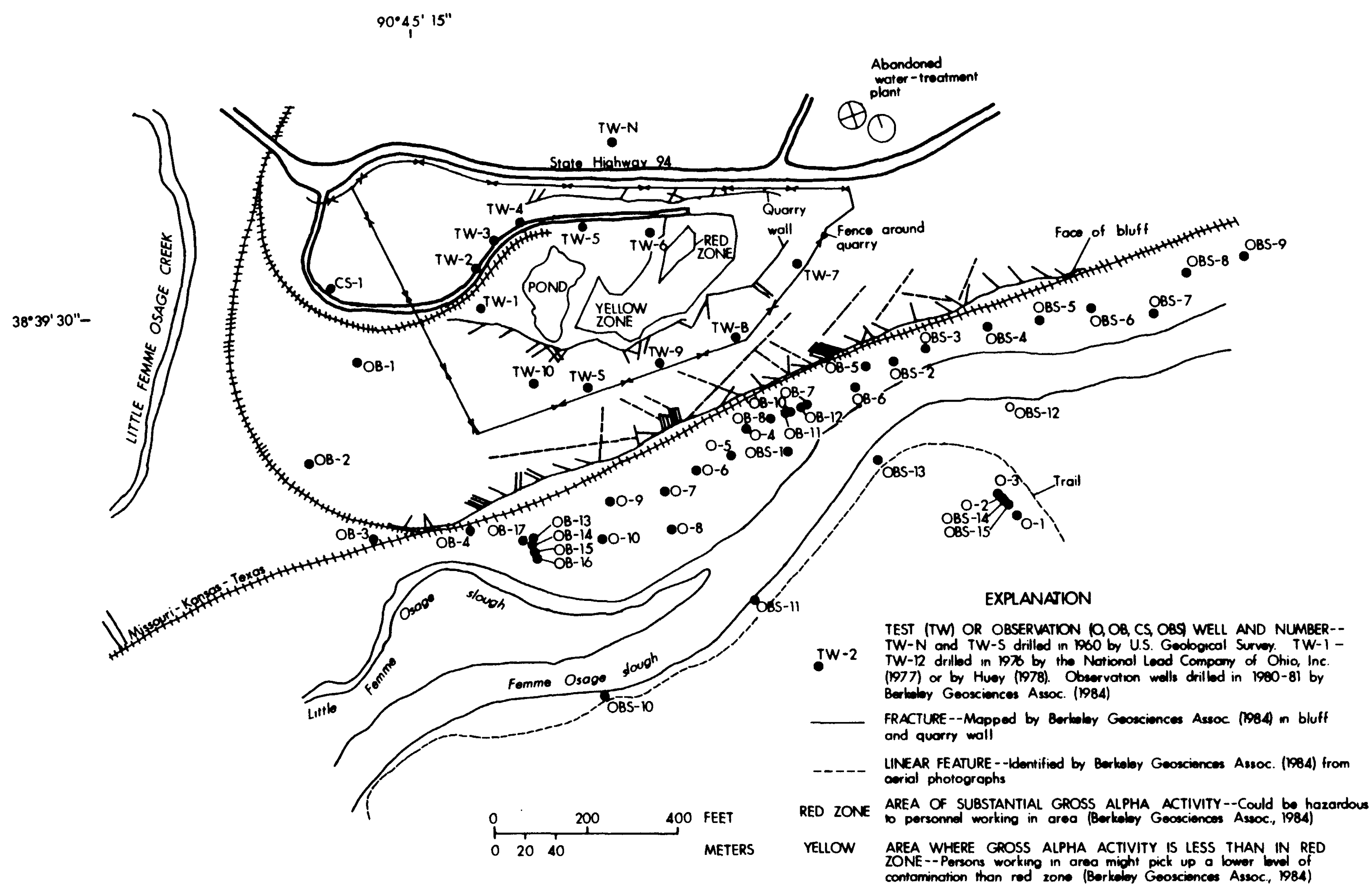

Figure 13.--Surface drainage, location of test holes, bedrock fractures, and linear features in vicinity of quarry (modified from Berkeley Geosciences Assoc., 1984).

Disposal of wastes into the quarry has posed potential ground-water contamination problems since the 1940's, resulting in numerous investigations. R. M. Richardson (written commun., 1960) made several preliminary conclusions regarding the hydrology of the quarry. He concluded that water-level measurements made in two wells located about 300 feet north and 50 feet south of the quarry sump indicated ground-water movement is in a southerly direction. He identified a solid rock sequence "***incapable of transmitting much water***" between 430 and 470 feet above sea level from pressure tests made on the two wells. The quarry sump is completed at an altitude of 446 feet, which reportedly is in this solid-rock sequence. He observed a high-water mark in the quarry sump at elevation 467 feet above sea level, but the frequency at which this mark is attained or exceeded is unknown. R. M. Richardson (written commun., 1960) states that results of pressure tests indicate that the permeability of the quarry walls above this mark due to fracturing and solution activity is large enough to permit equilibrium conditions between surface runoff into the sump and ground-water outflow.

During tests made by R. M. Richardson (written commun., 1960) in 1959 and 1960, water was pumped from the quarry sump for extended periods into Little Femme Osage Creek. By lowering the water level in the sump, Richardson made the sump respond as a large-diameter well. Ground water began flowing into the sump. From 1960 to 1963, the water level in the sump was kept at a predetermined level of 445 feet above sea level (Lenhard and others, 1967) by pumping the excess water into Little Femme Osage Creek. The present sloughs were the active channels for Little Femme Osage and Femme Osage Creeks prior to May 1961. Pumping ceased in 1963 allowing water in the sump to reach equilibrium with the surrounding ground water because uranium was leaching into the sump from the surrounding rubble, thus increasing the uranium concentrations of the sump water. A quarry-sump water sample collected in 1960 had a uranium concentration of 0.01×10^{-7} microcurie per cubic centimeter. Concentrations gradually increased until, in 1963, a water sample had a uranium concentration of 83.5×10^{-7} microcurie per cubic centimeter. In 1964, after the sump water was in equilibrium with the surrounding ground water, a water sample collected from the sump indicated the uranium concentration had decreased to 22×10^{-7} microcurie per cubic centimeter (Lenhard and others, 1967).

The National Lead Company of Ohio, Inc., began preliminary monitoring of the site during 1976 by drilling 12 test holes on the quarry site. During the drilling, numerous cavities were encountered. Fractures and solution-enlarged joints can be seen in the Kimmswick Limestone in the quarry face and along the bluffs facing the Missouri River. These joints extend into the subsurface, and this became evident during drilling of a slant test hole under the quarry sump. While an air drilling rig was being used, air bubbled through fractures to the surface of the pond, with the air bubbles following a jagged line extending into the sump from the shore about 10 feet (Huey, 1978, Exhibit C). This is apparently different than R. M. Richardson's (written commun., 1960) observation of a "sound" rock interval existing between 430 and 470 feet above sea level.

Berkeley Geosciences Assoc. (1984), concluded that the larger joints and solution openings in the quarry face provided a major pathway for ground-water movement from the quarry. They mapped the location, orientation and width of the joints and noted the nature of filling of all joints with traces more than 10 feet in the quarry face and in the bluffs facing the slough. The major set of joints is oriented N. 70° W., and two minor sets are oriented N.60° E., and northerly. The joints generally were vertical and the openings ranged from less than 1 inch to several feet, with some coinciding with gullies, ravines, or other linear features observed on top of the bluffs. Many of the fractures contained partial clay filling that is either residual material from solution activity or material washed down from overlying soil. They also concluded that these fractures extend downward through at least the Decorah Formation, making the Kimmswick Limestone, Decorah Formation, and probably the Plattin Limestone, hydraulically connected (Berkeley Geosciences Assoc., 1984).

Berkeley Geosciences Assoc. (1984), drilled several series of test holes (fig. 13) principally in the Missouri River flood plain between the slough system and the Missouri-Kansas-Texas Railroad line. Borings from wells OB-1 through OB-17 indicate the alluvium in the area north of the sloughs consists of fine-grained clay and silt which extends down to bedrock. Bedrock was encountered at depths ranging from 10 to 26 feet, and the alluvium thickens toward the sloughs. "Pumping of wells completed in the alluvium in this area resulted in emptying the wellbores with very long projected recovery times. Because of the apparent tightness of this alluvium and because of its relatively limited extent***" no further hydrologic testing was done in this area (Berkeley Geosciences Assoc., 1984, p. 4-7).

Berkeley Geosciences Assoc. (1984), also made 10 aquifer tests in fractured limestone. In all the tests steady state was achieved about 5 to 10 minutes after pumping started and the water recovered to at least 90 percent of the original potentiometric level in about 10 to 15 minutes. Generally, flow rates gradually decreased to a steady value within about 5 minutes from when pumping started. "These types of phenomena are common in fracture testing and are often associated with low storativity and the presence of constant head boundaries." (Berkeley Geosciences Assoc., 1984, p. 4-8). Core logging of these holes indicated virtually all the fractures intersecting these holes were horizontal.

On October 30, 1984, U.S. Geological Survey personnel made water-level measurements in observation wells in the vicinity of the quarry and in the St. Charles County well field. A water-table map made from the measurements is shown in figure 7. Measurements of the water-level altitudes of Femme Osage Creek and the sloughs also were made. These measurements indicate ground water from the quarry flows toward the Femme Osage slough. The observation wells on the north side of the slough and several wells on the south side have water-level altitudes that were higher than the altitude of the water surface in the slough. These measurements indicate the slough is a drain for the land adjacent to both banks at the western end of the slough. Conditions appear to be different in the central and eastern part of the slough. In these areas, the altitude of the water table immediately south of the slough is lower than the water surface in the slough so that there is a potential for water from the slough to infiltrate the alluvium and flow southward and eastward. A 10-foot difference in the altitude of the water table was determined between the west side and the east side of the municipal well field, indicating a general flow direction in the well field toward the east. There also is an indication that water may be induced from the Missouri River toward the wells, depending on the stage of the river.

Berkeley Geosciences Assoc. (1984), sampled 27 surface sites, 2 boreholes, and 3 streams in the vicinity of the quarry but not contaminated by the quarry waste, to determine the natural environmental radiation concentrations in the study area (table 10). The materials collected at the surface sites consisted of 23 soil and clay samples and 4 limestone and chert samples. The soil and clay samples had uranium and thorium contents ranging from about 2.4 to 3.8 parts per million uranium and 5.9 to 11.5 parts per million thorium. The limestone and chert surface samples had uranium contents ranging from 0.6 to 1.2 parts per million and thorium contents ranging from 0.1 to 0.2 part per million. The sampled boreholes were 20.4 and 24.0 feet deep. Radionuclide contents of the cuttings were reported as radium-226 and radium-228. Converting to uranium and thorium contents, the samples had from 3.0 to 4.8 parts per million uranium and 11.0 to 31.2 parts per million thorium. Water samples collected from the Missouri River, Femme Osage Creek, and Little Femme Osage Creek had uranium concentrations ranging from 0.001 to 0.002 part per million. Thorium concentrations were not reported (Berkeley Geosciences Assoc., 1984).

Water from 21 wells in the study area were sampled by the Missouri Division of Health and gross alpha and beta activities were determined. The gross alpha and beta activity is a count of the respective radiation, either alpha or beta, given off by the sample. This analysis does not identify specific isotopes and was used for screening purposes to determine if further sampling was needed at each site. Gross alpha activity ranged from about 1.0 to 5.7 picocuries per liter and gross beta activity ranged from 0 to 5.1 picocuries per liter (Missouri Department of Health, written commun., 1983). These samples are assumed to represent background radioactivity for water in the bedrock aquifer.

Sampling on the quarry property by Berkeley Geosciences Assoc., in 1979 and 1980 included water from auger holes and water and sediment from the sump. Uranium concentrations in water from the auger holes ranged from 3 to 11 parts per million and water from the quarry sump ranged from 3 to 5 parts per million. An 18-inch thick sediment sample collected from below the water level on the south edge of the quarry sump consisted of a clayey material. This sample had a uranium content of 69 parts per million nearest the surface, and the content decreased with depth to a minimum of 3 parts per million. Another set of samples was collected from four locations in the quarry pond and consisted of mud and organic sediment. Uranium contents of these samples ranged from 84 to 660 parts per million. These large contents indicate that uranium has been precipitated out of solution because of the reducing environment caused by the decaying organic matter at the bottom of the pond (Berkeley Geosciences Assoc., 1984).

The National Lead Company of Ohio, Inc., sampled water from Little Femme Osage Creek, the alluvial well field, Little Femme Osage slough, and Femme Osage slough in 1975. These analyses indicated that the uranium concentrations in the sloughs were about 200 times larger than in Little Femme Osage Creek. The National Lead Company of Ohio, Inc., drilled monitoring wells into the limestone bluff south of the quarry and north of the Missouri-Kansas-Texas Railroad line, and into the quarry floor around the sump, to determine if radionuclides were migrating from the quarry to the sloughs. Water from the wells in the limestone bluff had uranium concentrations ranging from 0.01 to 13 parts per million. These data were interpreted by the National Lead Company of Ohio, Inc., as implying a hydraulic connection between the quarry and the slough. (National Lead Company of Ohio, Inc., 1977).

Table 10.--Background radioactivity in the vicinity of the quarry

[Data from Berkeley Geosciences Assoc., 1984; ppm, parts per million]

Number of samples analyzed	Sample type	Uranium (ppm)	Thorium (ppm)
23	Residuum-soil and clay	2.4-3.8	5.9-11.5
4	Bedrock-limestone and chert	0.6-1.2	0.1-0.2
2	Borehole soil	3.0-4.8	11.0-31.2
3	Surface water	0.001-0.002	Not reported

Because the hydraulic connection between the quarry and the sloughs had been indicated by the National Lead Company of Ohio, Inc. (1977), Berkeley Geosciences Assoc. (1984), sampled the alluvium located between the Missouri-Kansas-Texas Railroad line and the sloughs. Ten borehole soil samples had uranium contents ranging from 2.1 to 4.2 parts per million. These values were determined by measuring radium-226 contents and inferring uranium contents by assuming equilibrium conditions exist. Uranium contents also were measured in selective borehole soil samples with a germanium crystal gamma-spectrometer. These measurements are considered to provide a better estimate of uranium contents than by measuring radium-226. Uranium contents ranged from 1.8 to 177 parts per million in the 21 borehole soil samples. Berkeley Geosciences Assoc. (1984), determined that the largest uranium contents were detected in the boreholes opposite a major fracture zone in the limestone bluff (boreholes OB-7, OB-8, OB-10, and O-4). Near-surface soil samples were collected from the area of large uranium content opposite the fracture zone with a coring tool and a profile of the uranium distribution at depth was determined. The largest uranium contents were detected in the top 6 to 9 inches of soil; the smallest contents were detected in the second and third 6- to 9-inch sections; and intermediate contents were detected in all deeper sections. Further soil sampling of the top one-eighth to one-fourth inch layer indicated that uranium content decreases rapidly towards the slough. Soil samples collected from the south side of the slough had uranium contents of approximately 3 parts per million at all depths. (Berkeley Geosciences Assoc., 1984).

Water sampling in the alluvium located between the Missouri-Kansas-Texas Railroad line and the sloughs by Berkeley Geosciences Assoc. (1984), indicated variable uranium concentrations. Some of these wells were sampled as many as six times in 1980 and 1981. The samples for each well were averaged. Average uranium concentration for one well was 0.004 part per million; however, concentrations ranged from 0.02 to 0.97 part per million in 6 wells, and 1.2 to 9.9 parts per million in 11 wells. Water samples from five wells south of the sloughs and east of the quarry had uranium concentrations ranging from less than 0.002 to 0.008 part per million (Berkeley Geosciences Assoc., 1984).

Water samples collected during 1979 by Berkeley Geosciences Assoc. (1984), indicated uranium concentrations in the section of the Femme Osage slough west of the causeway and culvert (see fig. 7) to be 0.07 part per million and the concentration in the eastern section was 0.03 part per million. The largest values, ranging from 0.16 to 0.31 part per million, were detected in Little Femme Osage slough. Background concentrations of uranium in area streams are 0.002 part per million. Contents in sediment samples collected from below the water level in Femme Osage slough ranged between 2 and 10 parts per million uranium. One sediment sample collected from Little Femme Osage slough had a uranium concentration of 30 parts per million. Five of the seven slough-sediment samples had more than background uranium concentration (Berkeley Geosciences Assoc., 1984).

Berkeley Geosciences Assoc. (1984), offers two explanations as to why the sloughs have large uranium concentrations. One explanation is that the ground-water movement through fractures in the limestone is transporting uranium from the quarry. This reasoning is supported by analysis of data from test holes that shows the largest uranium concentrations are north of the slough and opposite the fractures in the limestone bluff. The other explanation is radioactive contamination of the sloughs by R.M. Richardson's work during 1960-61, when he pumped water from the quarry sump into Little Femme Osage Creek prior to the completion of the University of Missouri levee.

Water samples were collected from the quarry sump, the TW series wells that surround the quarry, and the OB series wells that are located between the quarry and the slough (fig. 13) by Berkeley Geosciences Assoc. (1984), from November 1979 to April 1981. The purpose of this sampling was to determine if certain ions could be used as tracers to identify the ground-water movement pattern. They determined that water samples with large uranium concentrations also had large dissolved-solids concentrations, except for bicarbonate. However, only sulfate was conclusively correlated with large uranium concentrations. Dr. Alden Carpenter, University of Missouri, made the field measurements of alkalinity, pH, pE (negative log of the electron activity), dissolved oxygen, ammonium, and specific conductance for Berkeley Geosciences Assoc., and noted the alkalinity and dissolved oxygen of the water are large enough to allow the water to transport uranium in solution without difficulty (Berkeley Geosciences Assoc., 1984).

Available data indicate that radioactive-contaminated water is leaving the quarry-sump area and the direction of movement is south toward the sloughs. The most plausible transport mechanism for the quarry-sump water is movement with ground water through fractures in the limestone. Concentrations of uranium larger than 0.002 part per million have been detected in wells north of the sloughs. Water samples from three test wells on the quarry property (test wells TW-6, TW-8, and TW-9, fig. 14), and five observation wells completed in the alluvium north of the sloughs (observation wells OB-5, OB-6, OB-7, OB-8, and OB-10, fig. 13) had uranium concentrations greater than that of the water in the sump. This indicates that either the uranium concentrations in the quarry-sump water previously were larger, or contents of uranium in the residues on the quarry main floor may be greater than in the sump and leaching is occurring from these residues into the ground water down gradient from the sump. Small concentrations of uranium were detected in water samples from boreholes south of the sloughs. It is speculated that the clay at the bottom of the sloughs extends down to the bedrock and thus may force the ground water to move through the fractured bedrock under the sloughs rather than through the alluvium (Berkeley Geosciences Assoc., 1984). An alternative explanation can be derived by an analysis of water levels in the area (fig. 7). The water levels in some observation wells located on the western side of and south of the sloughs are higher than the altitude of the water in the sloughs. This indicates that the direction of water movement is from these wells northward toward the sloughs, not from the sloughs to the wells.

SEPTEMBER 1984 WATER-QUALITY DATA

Water samples were collected by the U.S. Geological Survey during September 1984 for stable-ion and radiological analysis from the four raffinate pits, the quarry disposal site, three wells, one spring, and Femme Osage slough (fig. 14). These samples were collected to identify particular tracer elements that could economically "fingerprint" the contamination plume from the storage sites. Included with this sampling was an organic-compound scan. The scan showed no significant concentrations of organic compounds in any of the samples, and no correlation could be made between the organic compounds in the quarry and raffinate-pits areas as compared to those at the off-site sampling locations. Results of the 10 analyses are shown in table 11.

Water in the raffinate pits has a large concentration of dissolved solids and a different chemical composition than the natural ground water and surface water. This is reflected by the increased concentrations of some of the commonly occurring ions (especially calcium, sodium, sulfate, nitrate, and fluoride) and by the presence in large concentrations of trace elements (lithium, molybdenum, strontium, and vanadium).

The analyses of water from Burgermeister Spring indicates that the water has larger concentrations of uranium, nitrate, and lithium than the other three ground-water sources analyzed by the U.S. Geological Survey. Burgermeister Spring is north of the pits and chemical-plant area and, according to the Missouri Department of Natural Resources dye traces, is hydraulically connected to the losing reaches of Schote Creek that drain the pits and chemical-plant area. Evidence indicates that the source of contamination in the spring is from the vicinity of the raffinate pits and chemical plant.

The well at the August A. Busch Wildlife Area headquarters (fig. 14, site 8) also is located north of the raffinate pits and chemical-plant area. The well was reported to the Missouri Department of Natural Resources, Division of Geology and Land Survey, by the well driller to have been drilled during 1950 to a depth of 330 feet and cased to a depth of 84 feet. Analysis of water from the well did not indicate radioactive contamination. In addition, the small tritium concentration (1.3 tritium units) from the well indicates that the water does not contain post-1954 precipitation. Beginning in 1954 tritium in the atmosphere was greatly increased because of fallout from nuclear weapons testing. This resulted in the precipitation in the northern hemisphere having excess tritium. Consequently, small concentrations, such as found in the water sample from the well at the August A. Busch Wildlife Area headquarters, indicate the water does not contain any post-1954 precipitation. In contrast, the larger tritium concentration from the pits and spring indicate post-1954 precipitation. A public-supply well (Belleau Gardens well) is more than 6 miles north-northeast of the chemical plant. Water from the well is similar to water from the well at the August A. Busch Wildlife Area headquarters, except that it has slightly larger sodium, potassium, and chloride concentrations, indicating its proximity to the fresh-saltwater transition zone. In St. Charles County the transition from fresh to saline ground water in the St. Peter Sandstone and older formations occurs in R. 3 E. Fresh ground water is present in the west; saline ground water is present in the east. The Belleau Gardens well is one of 33 public water supplies in the State, 5 of which are in St. Charles County, that

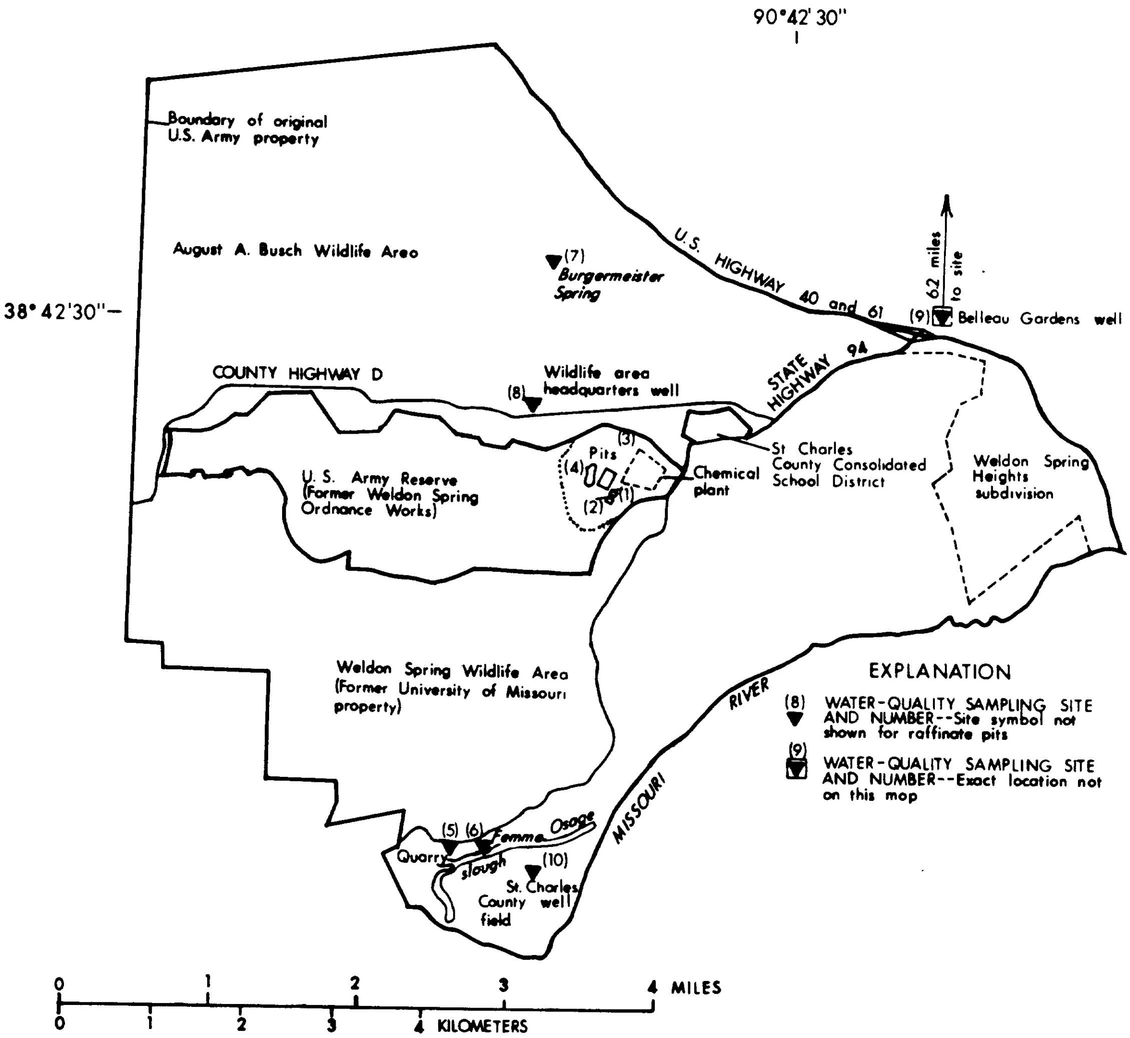

Figure 14.--U.S. Geological Survey water-quality sampling sites, September 1984.

Table 11.--Water-quality data

[Data collected by the U.S. Geological Survey, September 1984. µs/cm, microsiemens per centimeter at 25 °Celsius; deg C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pci/L, picocuries per liter; TU, tritium units; per mil, parts per thousand; <, less than; site number in fig. 14]

Physical Properties and Major Inorganic Constituents

Station name	Site number	Date of sample	Specific conductance (µs/cm)	pH (standard units)	Temperature (deg C)	Oxygen, dissolved (mg/L)	Solids, residue at 180 deg. C dissolved (mg/L)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)
Raffinate pit 1	1	84-09-05	6,100	8.9	22.5	10.8	5,110	668	32.0
Raffinate pit 2	2	84-09-05	3,200	9.3	22.0	9.7	2,770	205	5.40
Raffinate pit 3	3	84-09-05	13,000	8.6	22.0	12.2	12,700	1,890	15.0
Raffinate pit 4	4	84-09-05	1,430	9.6	24.5	8.9	1,030	91.6	3.40
Quarry site	5	84-09-05	600	7.7	23.5	5.0	387	2.34	.060
Femme Osage slough	6	84-09-06	532	8.2	24.5	7.1	299	--	<.010
Burgermeister Spring	7	84-09-04	1,090	6.9	12.0	8.5	682	--	<.010
Busch Wildlife Headquarters well	8	84-09-04	550	7.3	15.5	--	290	--	<.010
Belleau Gardens well	9	84-09-04	555	7.5	15.5	--	292	--	<.010
St. Charles County well 5	10	84-09-06	752	7.1	14.0	--	456	--	<.010

Table 11.--Water-quality data--Continued

Physical Properties and Major Inorganic Constituents--Continued

Station name	Site number	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
Raffinate pit 1	1	560	26	520	48	34	400	17	2.5	5.4
Raffinate pit 2	2	380	66	180	33	37	990	5.7	2.7	2.2
Raffinate pit 3	3	880	320	1,500	150	37	640	25	8.9	2.8
Raffinate pit 4	4	17	52	190	23	240	150	7.7	7.8	1.7
Quarry site	5	70	19	14	11	172	120	16	.90	14
Femme Osage slough	6	73	18	9.1	7.5	269	24	6.9	.30	5.5
Burgermeister Spring	7	120	30	47	3.2	243	48	37	.20	11
Busch Wildlife Headquarters well	8	50	37	5.5	1.3	289	18	1.3	.20	8.0
Belleau Gardens well	9	49	27	25	5.2	250	22	20	.70	8.5
St. Charles County well 5	10	110	24	15	4.1	385	42	7.2	.30	25

Table 11.--Water-quality data--Continued

Trace Elements

Station name	Site number	Date sampled	Aluminum, dissolved (µg/L as Al)	Arsenic dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)
Raffinate pit 1	1	84-09-05	30	6	90	12	<3	<1	<9	4	15
Raffinate pit 2	2	84-09-05	40	15	72	8	<3	<1	<9	4	<9
Raffinate pit 3	3	84-09-05	30	4	170	<5	<10	<1	<30	7	<30
Raffinate pit 4	4	84-09-05	10	2	100	<.0	<1	<1	<3	1	<3
Quarry site	5	84-09-05	<10	<1	79	<.0	<1	<1	<3	<1	3
Femme Osage slough	6	84-09-06	<10	2	170	<.0	1	<1	<3	<1	10
Burgermeister Spring	7	84-09-04	<10	<1	150	2	<1	<1	<3	<1	<3
Busch Wildlife Headquarters well	8	84-09-04	<10	<1	130	2	1	<1	<3	<1	<3
Belleau Gardens well	9	84-09-04	<10	<1	96	2	<1	<1	<3	<1	59
St. Charles County well 5	10	84-09-06	<10	1	480	<.0	1	<1	9	<1	7,000

Table 11.--Water-quality data--Continued

Trace Elements--Continued

Station name	Site number	Lead, dissolved (µg/L as Pb)	Lithium dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Mercury dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
Raffinate pit 1	1	<1	140	9	<.1	3,000	<1	<1	<1	1,400	32,000	45
Raffinate pit 2	2	<1	140	9	<.1	7,100	<1	<1	<1	780	2,000	25
Raffinate pit 3	3	11	460	35	<.1	3,600	<1	<1	<1	2,800	810	66
Raffinate pit 4	4	17	660	7	<.1	670	<1	<1	<1	190	79	5
Quarry site	5	2	24	190	<.1	<10	<1	<5	<1	370	<6	5
Femme Osage slough	6	<1	12	390	<.1	<10	<1	<1	<1	290	<6	14
Burgermeister Spring	7	<1	77	4	<.1	<10	<1	3	<1	220	<6	17
Busch Wildlife Headquarters well	8	<1	8	8	<.1	<10	<1	<1	<1	150	<6	40
Belleau Gardens well	9	<1	32	7	<.1	<10	<1	<1	<1	740	<6	33
St. Charles County well 5	10	<1	33	810	<.1	<10	<1	<1	<1	580	<6	9

Table 11.--Water-quality data--Continued

Stable Isotope Ratios

Station name	Site number	Date sampled	H-2/H-1 stable isotope ratio (per mil)	0-18/0-16 stable isotope ratio (per mil)
Raffinate pit 1	1	84-09-05	0.0	4.9
Raffinate pit 2	2	84-09-05	5.0	5.2
Raffinate pit 3	3	84-09-05	7.5	4.9
Raffinate pit 4	4	84-09-05	-10.5	.4
Quarry site	5	84-09-05	-29.5	-3.4
Femme Osage slough	6	84-09-06	-22.0	-1.7
Burgermeister Spring	7	84-09-04	-41.0	-5.8
Busch Wildlife Headquarters well	8	84-09-04	-44.0	-7.1
Belleau Gardens well	9	84-09-04	-43.5	-7.3
St. Charles County well 5	10	84-09-06	-47.5	-7.0

Table 11.--Water-quality data--Continued

Radioactive Substances

Station name	Site number	Gross alpha, dis- solved (μg/L as U-NAT)	Gross alpha, susp. total (μg/L as U-NAT)	Gross beta, dis- solved (pci/L as Cs-137)	Gross beta, susp. total (pci/L as Cs-137)	Ra-226, dis- solved plan- chet count (pci/L)	Uranium, dis- solved (μg/L as U)	Tritium in water mole- cules (TU)
Raffinate pit 1	1	690	34	220	18	290	26	24.0
Raffinate pit 2	2	580	51	180	39	120	28	22.0
Raffinate pit 3	3	800	13	560	34	180	350	24.0
Raffinate pit 4	4	4,500	46	1,000	780	8.4	3,500	20.0
Quarry site	5	2,700	11	300	180	<.7	2,100	23.0
Femme Osage slough	6	89	2.1	17	12	.7	77	23.0
Burgermeister Spring	7	190	3.0	28	41	.2	190	22.0
Busch Wildlife Headquarters well	8	12	.9	<4.6	1.2	.5	.9	1.3
Belleau Gardens well	9	27	1.0	9.8	1.0	6.6	<.4	1.5
St. Charles County well 5	10	<8.7	.8	<6.2	.7	.3	<2.1	31.0

have been identified as exceeding the radionuclide maximum contaminant level established by the U.S. Environmental Protection Agency (1976) for public water supplies (Missouri Department of Natural Resources, Division of Environmental Quality, written commun., 1983). The 1.5 tritium units in the well water date the water as being pre-1954, which indicates the source of the radionuclide contamination in this well probably is natural.

Analyses of water from the quarry indicate large concentrations of uranium and sulfate. The source of uranium obviously is from the radioactive waste that has been dumped there. The large sulfate concentration may be due to dumping of wastes and also to oxidation and dissolution of sulfide minerals in the exposed rock faces of the quarry. Because ground water moves southward from the quarry toward the Missouri River, the Femme Osage slough and St. Charles County well 5 were selected for sampling. Water from Femme Osage slough contains uranium (77 micrograms per liter) significantly more than the 1 microgram per liter background determined by Berkeley Geosciences Assoc. (1984), for area surface water. Water from St. Charles County well 5 had a uranium concentration of less than 2.1 micrograms per liter (table 11).

CONCLUSIONS AND PLANS FOR FUTURE WORK

The most obvious indicator of contamination from the pits, chemical-plant area, and quarry is increased uranium concentrations in surface- or ground-water samples. Other indicators of contaminated water from the pits may include anomalously large dissolved-solids concentrations, and greater-than background concentrations of fluoride, nitrate, lithium, molybdenum, gross alpha, and gross beta emissions.

Soil around the chemical plant and raffinate pits contains radionuclides that are transported by runoff to either the east or middle fork of Schote Creek. Both of these forks have losing reaches, which have a probable point of emergence at or in the vicinity of Burgermeister Spring. Off-site transport of radiologically contaminated sediment by way of these two drainageways also is indicated by samples from lake 36, downstream from lake 36, and from lake 35, which are in the August A. Busch Wildilfe Area.

The Missouri River drainage easement (outfall drainage valley) also contains radiologically contaminated sediment as a result of wastewater disposal into the tributary during the chemical-plant operation. A dye-trace study indicated that water did not move out of the basin even though this tributary has losing reaches. Instead, the water continued to move southward ultimately to the Missouri River. Sediment transported by water also would remain within the basin or ultimately move toward the Missouri River.

Potentiometric-surface maps indicate ground water in the shallow aquifer moves northward away from the pits and chemical plant toward Dardenne Creek, which appears to be a ground-water drain. Water samples from two shallow-aquifer sources located between the pit area and Dardenne Creek were collected and analyzed. The sample from the August A. Busch Wildlife Area headquarters well, which is open to about 220 feet of the shallow bedrock aquifer and 25 feet of the deep bedrock aquifer, indicated no increased concentrations of radionuclides, and tritium analysis indicates the water can be dated as pre-1954. Water from Burgermeister Spring, however, has increased concentrations of uranium and nitrate, and the tritium analysis indicates post-1954 water. From these data it can be surmised that the transport routes for contaminated materials leaving the site through the shallow ground-water system may be controlled by natural drainageways that normally form in carbonate terrane (solution openings, losing streams, and springs) rather than a dispersion of contaminated material throughout the aquifer. Water sampling also was done in a public-supply well (Belleau Gardens well) in St. Charles County, which had a radium-226 concentration that exceeded the radionuclide maximum contaminant level (U.S. Environmental Protection Agency, 1976). Tritium dating of the water (as pre-1954) indicates that there is no connection between the radionuclides present at the Weldon Spring waste-disposal site and the Belleau Gardens well.

It is uncertain whether the radionuclide contamination at Burgermeister Spring is caused by seepage from the pits or other surface impoundments on the chemical-plant property or whether it is caused by contaminated sediments entering the ground-water system through losing stream reaches. Additional water sampling and dye tracing need to be done of both surface and ground water. The surface-water sampling would be done in conjunction with detailed seepage runs on streams draining the site. Water samples would be collected from the tributaries, upstream from losing reaches during base flow and storm runoff to determine what relationship exists between this surface water and the water from Burgermeister Spring. The discharge from Burgermeister Spring would be continuously gaged to determine how the spring responds to climatic conditions.

About 10 observation wells need to be installed in the area between the Weldon Spring site and Dardenne Creek. The wells would be used to collect water samples for chemical analysis and to monitor water levels to more accurately determine the directions of movement of ground water in the shallow bedrock aquifer.

Water in the quarry has a large uranium concentration. Movement of water in the quarry area is southward toward the Missouri River. A detailed potentiometric-surface map needs to be prepared of the area between the quarry and the Missouri River to include the St. Charles County well field and to show the relationship of the sloughs to the water table in the alluvial aquifer. The map could be used in locating sites for wells to monitor water quality in the aquifer.

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SUPPLEMENTAL DATA

Table 12.--Summary of water-level measurements in shallow bedrock aquifer, summer 1984

[Formations open to well: ALVM, alluvium; PENN, Pennsylvanian System, exact formation unknown; STSL, St. Louis Limestone; SLEM, Salem Limestone; WRSW, Warsaw Formation; KKKB, Keokuk and Burlington Limestones; FRGL, Fern Glen Limestone; CHUT, Chouteau Limestone; MISS, Mississippian System, exact formation unknown; BBRG, Bushberg Sandstone of Sulphur Springs Group; SSPG, Sulphur Springs Group; KMCK, Kimmswick Limestone; --, no data; P, pumping level]

Location	Altitude of land surface (feet above sea level)	Well depth (feet)	Casing depth (feet)	Altitude of water level (feet above sea level)	Formations open to well
T.45 N., R.02 E., sec. 01aab	670	235	41.5	616	KKKB-SSPG
T.46 N., R.01 E., sec. 01bcc	667	--	--	564	MISS
T.46 N., R.02 E., sec. 11bba	670	425	85	488	KKKB-KMCK
T.46 N., R.02 E., sec. 01bcb	645	220	43	515	SLEM-KKKB
T.46 N., R.02 E., sec. 02ada	642	200	165	532	KKKB
T.46 N., R.02 E., sec. 02cdd	597	116	22	583	KKKB
T.46 N., R.02 E., sec. 02ddd	625	342	49	574	KKKB-SSPG
T.46 N., R.02 E., sec. 03dbd	633	103	40	573	KKKB
T.46 N., R.02 E., sec. 04dcc	645	--	--	565	MISS
T.46 N., R.02 E., sec. 05dac	585	205	30	556	KKKB-FRGL
T.46 N., R.02 E., sec. 10dcb	613	185	45	562	KKKB-FRGL
T.46 N., R.02 E., sec. 11ada	593	205	76	552	KKKB-FRGL
T.46 N., R.02 E., sec. 14bda	555	205	46	531	KKKB-FRGL
T.46 N., R.02 E., sec. 17aba	647	225	74	571	KKKB
T.46 N., R.02 E., sec. 20bcd	647	325	55	577	KKKB-KMCK
T.46 N., R.02 E., sec. 21cdc	650	228	--	589	MISS
T.46 N., R.02 E., sec. 26aba	595	360	--	535	MISS
T.46 N., R.02 E., sec. 28abb	612	105	62	568	KKKB
T.46 N., R.02 E., sec. 28acc	628	185	--	583	MISS
T.46 N., R.02 E., sec. 28bcd	622	265	84	592	MISS
T.46 N., R.02 E., sec. 31cbc	720	385	--	517	MISS
T.46 N., R.02 E., sec. 32cca	740	210	90	647	MISS
T.46 N., R.02 E., sec. 33ccd	740	--	--	695	MISS
T.46 N., R.02 E., sec. 36aaa	620	330	84	324 P	KKKB-KMCK
T.46 N., R.03 E., sec. 08dbd	555	165	45	502	WRSW-KKKB
T.46 N., R.03 E., sec. 11bcb	532	365	--	465	?-KMCK
T.46 N., R.03 E., sec. 11dba	475	300	58	457	KKKB-CHUT
T.46 N., R.03 E., sec. 13bdb	498	100	--	470	MISS
T.46 N., R.03 E., sec. 14abc	515	165	41	468	KKKB
T.46 N., R.03 E., sec. 14ddd	555	560	67	456	WRSW-KMCK

Table 12.--Summary of water-level measurements in shallow bedrock aquifer, summer 1984--Continued

Location	Altitude of land surface (feet above sea level)	Well depth (feet)	Casing depth (feet)	Altitude of water level (feet above sea level)	Formations open to well
T.46 N., R.03 E., sec. 15dad	485	200	52	466	WRSW-KKKB
T.46 N., R.03 E., sec. 17bbb	553	130	43	510	KKKB
T.46 N., R.03 E., sec. 19bac	518	--	--	478	MISS
T.46 N., R.03 E., sec. 19bca	545	--	--	495	MISS
T.46 N., R.03 E., sec. 19bcb	551	305	45	500	KKKB-BBRG
T.46 N., R.03 E., sec. 20abb	531	300	22	476	KKKB-BBRG
T.46 N., R.03 E., sec. 23acc	600	275	40	442	SLEM-KKKB
T.46 N., R.03 E., sec. 23bac	559	225	28	481	SLEM-KKKB
T.46 N., R.03 E., sec. 24ada	487	150	40	470	WRSW-KKKB
T.46 N., R.03 E., sec. 26dab	643	300	--	462	MISS
T.46 N., R.03 E., sec. 27aac	597	200	--	553	WRSW-KKKB
T.46 N., R.03 E., sec. 27bad	542	125	41	519	KKKB
T.46 N., R.03 E., sec. 27bad	542	460	--	469	MISS-KMCK
T.46 N., R.03 E., sec. 29adb	570	215	41	532	KKKB-FRGL
T.46 N., R.03 E., sec. 29add	573	--	--	537	MISS
T.46 N., R.03 E., sec. 30ddb	640	260	--	569	KKKB
T.46 N., R.03 E., sec. 30ddc	637	--	--	587	MISS
T.46 N., R.03 E., sec. 31bdc	646	99	--	604	KKKB
T.46 N., R.03 E., sec. 31caa	645	101	--	615	KKKB
T.46 N., R.03 E., sec. 31cab	644	99	--	610	KKKB
T.46 N., R.03 E., sec. 31cad	665	91	--	616	KKKB
T.46 N., R.03 E., sec. 32bda	652	275	--	595	KKKB-FRGL
T.46 N., R.04 E., sec. 01dcd	515	375	44	494	STLS-KKKB
T.46 N., R.04 E., sec. 02cdb	558	685	290	468	KKKB-KMCK
T.46 N., R.04 E., sec. 04abc	592	240	125	484	WRSW-KKKB
T.46 N., R.04 E., sec. 04abd	573	275	60	476	SLEM-KKKB
T.46 N., R.04 E., sec. 08abb	613	500	--	482	MISS
T.46 N., R.04 E., sec. 09bdb	601	325	55	481	SLEM-KKKB
T.46 N., R.04 E., sec. 11dda	480	230	14	474	STLS-WRSW
T.46 N., R.04 E., sec. 17acc	590	425	--	473	?-KKKB
T.46 N., R.04 E., sec. 18adc	502	543	91	473	KKKB-KMCK
T.46 N., R.04 E., sec. 21bda	571	265	48	487	SLEM-KKKB
T.46 N., R.04 E., sec. 21dcd	630	250	67	471	SLEM-KKKB
T.46 N., R.04 E., sec. 31aac	450	75	24	437	KKKB
T.47 N., R.01 E., sec. 01cbb	540	160	--	468	KKKB

Table 12.--Summary of water-level measurements in shallow bedrock aquifer, summer 1984--Continued

Location	Altitude of land surface (feet above sea level)	Well depth (feet)	Casing depth (feet)	Altitude of water level (feet above sea level)	Formations open to well
T.47 N., R.01 E., sec. 04acc	581	200	70	502	KKKB
T.47 N., R.02 E., sec. 01bdd	533	435	267	414	CHUT-KMCK
T.47 N., R.02 E., sec. 02baa	590	215	--	577	KKKB
T.47 N., R.02 E., sec. 08dcd	580	135	20	492	KKKB
T.47 N., R.02 E., sec. 12aad	505	373	--	393	?-KMCK
T.47 N., R.02 E., sec. 21ccc	570	125	60	546	KKKB
T.47 N., R.02 E., sec. 26add	582	300	44	520	WRSW-KKKB
T.47 N., R.03 E., sec. 23caa	448	147	81	435	KKKB
T.47 N., R.04 E., sec. 26bab	545	400	103	462	STLS-KKKB
T.47 N., R.04 E., sec. 28cad	544	70	--	500	ALVM-PENN
T.48 N., R.02 E., sec. 14dcd	525	310	31	428	WRSW-KKKB
	Alluvial Wells				
T.47 N., R.03 E., sec. 02cdb	434	105	--	432	
T.47 N., R.03 E., sec. 04adc	440	79	--	433	
T.47 N., R.03 E., sec. 12ada	435	110	--	432	
T.47 N., R.03 E., sec. 12cdd	431	--	--	425	
T.47 N., R.03 E., sec. 13dac	435	90	--	423	
T.47 N., R.03 E., sec. 14bba	435	--	--	431	
T.47 N., R.03 E., sec. 15aad	436	89	--	429	
T.47 N., R.04 E., sec. 01ddd	440	75	--	426	
T.47 N., R.04 E., sec. 28cad	544	70	--	500	
T.47 N., R.04 E., sec. 30bbc	430	72	70	418	

Table 13.--Summary of water-level measurements in deep bedrock aquifer, summer 1984

[Formations open to well: BBRG, Bushberg Sandstone of Sulphur Springs Group; KMCK, Kimmswick Limestone; DCRH, Decorah Formation; PLTN, Plattin Limestone; JCHM, Joachim Dolomite; STPR, St. Peter Sandstone; PWLL, Powell Dolomite; CTTR, Cotter Dolomite; JFRC, Jefferson City Dolomite; RBDX, Roubidoux Formation; GSCD, Gasconade Dolomite; ODVC, Ordovician System, exact formation unknown; ?, insufficient data to determine; --, no data; A, airline measurement; R, recently pumped,; RP, reported open]

Location	Altitude of land surface (feet above sea level)	Well depth (feet)	Casing depth (feet)	Altitude of water level (feet above sea level)	Formations open to well
T.44 N., R.01 E., sec. 11dcd	588	352	85	537	CTTR-JFRC
T.44 N., R.01 E., sec. 14bdb	585	400	--	476	CTTR-JFRC
T.45 N., R.01 E., sec. 25abd	535	85	22	513	STPR-CTTR
T.45 N., R.02 E., sec. 14ada	522	285	55	464	DCRH-JCHM
T.45 N., R.02 E., sec. 14bcb	580	640	--	491	ODVC
T.45 N., R.02 E., sec. 15acc	665	350	45	560	ODVC
T.45 N., R.02 E., sec. 16dca	520	325	--	468	ODVC
T.45 N., R.02 E., sec. 19acb	505	--	--	485	ODVC
T.45 N., R.02 E., sec. 21ada	510	365	80	460	ODVC
T.45 N., R.02 E., sec. 23bbd	462	225	154	451	ODVC
T.45 N., R.02 E., sec. 26bbb	495	138	30	473	ODVC
T.45 N., R.02 E., sec. 33bcc	680	300	30	488	PLTN-STPR
T.45 N., R.02 E., sec. 34bab	575	--	--	517	ODVC
T.46 N., R.01 E., sec. 15dca	705	460	--	496	ODVC
T.46 N., R.01 E., sec. 25cba	720	325	--	492	?-PLTN
T.46 N., R.01 E., sec. 26ccd	785	515	271	515	PLTN-STPR
T.46 N., R.01 E., sec. 27cad	773	422	98	509	BBRG-STPR
T.46 N., R.02 E., sec. 03bcc	610	825	--	≈457 A	ODVC
T.46 N., R.02 E., sec. 11bdd	610	892	550	423 A	PLTN-PWLL
T.46 N., R.03 E., sec. 20cdd	550	735	376	358 A	KMCK-STPR
T.46 N., R.03 E., sec. 28ddd	633	811	409	473 RP	KMCK-STPR
T.46 N., R.03 E., sec. 35dca	565	740	--	436 R	?-STPR
T.47 N., R.01 E., sec. 19abc	703	770	339	495	KMCK-PWLL
T.47 N., R.01 E., sec. 25aaa	593	1,350	400	395 A	KMCK-RBDX
T.47 N., R.01 E., sec. 27ccc	623	710	--	473	?-STPR

Table 13.--Summary of water-level measurements in deep bedrock aquifer, summer 1984--Continued

Location	Altitude of land surface (feet above sea level)	Well depth (feet)	Casing depth (feet)	Altitude of water level (feet above sea level)	Formations open to well
T.47 N., R.02 E., sec. 19ddd	624	1,465	--	468 A	?-GSCD
T.47 N., R.02 E., sec. 25cdc	628	890	512	143 A	KMCK-STPR
T.47 N., R.02 E., sec. 30cba	623	745	366	283 A	KMCK-STPR
T.47 N., R.02 E., sec. 35ada	520	1,450	467	279 A	PLTN-GSCD
T.47 N., R.03 E., sec. 20ada	524	1,500	390	348	KMCK-GSCD
T.47 N., R.03 E., sec. 25ddc	486	860	475	406	KMCK-STPR
T.47 N., R.03 E., sec. 27cba	468	695	377	296 R	KMCK-STPR
T.47 N., R.03 E., sec. 28aac	515	1,420	418	235 A	KMCK-RBDX
T.47 N., R.03 E., sec. 28dda	548	830	450	-20 A	DCRH-CTTR
T.47 N., R.03 E., sec. 29bcb	604	1,500	448	445	DCRH-GSCD

Table 14.--Description of overburden

[Modified from Bechtel National, Inc., 1984b, p. 19-20]

Unit	Description	Range in thickness (feet)
Topsoil	Sandy clay, blackish-brown, organically enriched.	0.5 to 3.5
Modified loess	Clayey silt, mottled gray-dark yellowish-orange, becomes dense and plastic with depth, and is manganese stained. The loess is modified in the sense that it contains larger-than-average clay content for loess and has been leached of primary calcareous components.	2.5 to 10
Clay	Clay, mottled gray-dark yellowish-orange, plastic, dense, manganese stained, contains weathered nodules.	Variable to 10
Clay till	Clay, yellowish-brown, plastic, dense, manganese stained, shows blocky fractures, contains sand- to pebble-sized quartz, granitic rock, and chert dispersed throughout the clay matrix.	1 to 37
Basal till	Sandy, clayey silt, yellowish-brown broken chert nodules abundant, loosely bound by matrix.	1 to 5
Cherty clay	Multicolored brown, red, orange, and yellow, very dense, clay matrix with tightly bound abundant granule to cobble-sized chert particles.	3.5 to 15