I-3398

565

NLCO - 1176
Special
UC-11

WELDON SPRING STORAGE SITE ENVIRONMENTAL-MONITORING REPORT FOR 1979 & 1980

By

R. B. Weidner & M. W. Boback

April 19, 1982

MASTER

FEED MATERIALS PRODUCTION CENTER

NLO, Inc.

P. O. BOX 39158
CINCINNATI, OHIO 45239

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
WEAPONS DIVISION OF OAK RIDGE OPERATIONS
UNDER CONTRACT DE-AC05-76OR01156

DISCLAIMER

NOTICE

Printed in the United States of America

Available from:

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS Price Codes
Printed Copy: A04
Microfiche: A01

NLCO--1176

DE82 015033

NLCO-1176
SPECIAL
UC-11

WELDON SPRING STORAGE SITE ENVIRONMENTAL-MONITORING REPORT FOR 1979 AND 1980

by

Robert B. Weidner

and

Michael W. Boback

April 19, 1982

NLO, Inc.

P. O. Box 39158

Cincinnati, Ohio 45239

PREPARED FOR THE

U. S. DEPARTMENT OF ENERGY

WEAPONS GROUP

UNDER CONTRACT NO. DE-AC05-76OR01165

Approved:

M. W. Boback

Director, Health & Safety Division

Approved:

R M Spenceley

Manager

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

TABLES

FIGURES

FIGURES (CONT'D)

TABLES

FIGURES

INTRODUCTION

The U. S. Department of Energy (DOE) Weldon Spring Site (WSS) consists of two separate radioactive waste storage properties near Weldon Spring, Missouri: A 52-acre site which is a remnant of the Weldon Spring Feed Materials Plant; and a nine-acre abandoned rock quarry. The larger property has four pits which contain settled sludge from uranium and thorium processing operations. At the quarry, part of the excavation contains contaminated building rubble, scrap and various residues.

During 1979 and 1980 these storage locations were managed by NLO, Inc., contract operator of the DOE Feed Materials Production Center near Cincinnati, Ohio. Air and water samples were collected to provide information about the transfer of radionuclides in the offsite environment. Monitoring results, summarized in this report, show that uranium and radium concentrations in offsite surface and well water were within DOE Guide values for uncontrolled areas. At offsite locations, radon-222 concentrations in air were well within the Guide value.

I. WELDON SPRING SITE PIT AREA

History of Operations

The Weldon Spring Feed Materials Plant was built by the U. S. Atomic Energy Commission (AEC) and began operations in 1957. It occupied 220 acres in St. Charles County, Missouri, approximately 24 miles west of the city of St. Louis. The plant site is on State Route 94, near the community of Weldon Spring. The facility was operated for the AEC by the Uranium Division of the Mallinckrodt Chemical Works.

All operations of the Feed Materials Plant ceased in 1966 when the AEC decided the plant was excess to production requirements. In 1967, most of the inactive plant site was transferred to the U. S. Army because of an anticipated need for the production buildings. DOE, as successor to the AEC, retains custody of the 52-acre portion on which the four residue storage pits are located.

The Weldon Spring Feed Materials Plant produced purified uranium compounds and uranium metal. Both types of products were shipped for use at other AEC sites. The major plant processes were as follows:

- Uranium ore concentrates were dissolved in nitric acid to produce a uranyl nitrate solution.
- Uranyl nitrate was extracted into an organic solution.

- Uranyl nitrate was back-extracted into deionized water.

- The uranyl nitrate aqueous solution was evaporated to produce orange-colored uranium trioxide, UO_3, also called "orange oxide."

- The UO_3 was converted to green-colored uranium tetrafluoride UF_4, also called green salt.

- The UF_4 was reacted with magnesium metal to form uranium metal.

An average of 16,000 tons of uranium was processed at this plant per year. In addition to these principal uranium activities, a lesser quantity of thorium was also processed.

Wastes from these production operations were neutralized, if required, and pumped to the onsite storage pits described on page 4. In these pits, the solids settled out and the clear supernatant liquid was removed via a decant line. This water then mixed with storm sewer water and sewage treatment effluent before being discharged via the process sewer outfall into a small stream which flows about one mile to the Missouri River.

The term, "raffinate" is loosely applied to waste from the extraction step. Solids that result from the neutralization of this waste are also called "raffinates." Therefore, the Weldon Spring storage pits are often referred to as "raffinate pits" despite the admixture of sludges and residues from other processing steps.

Pit Construction

The waste storage pits (See Figure 1) were constructed by excavating down into the existing clay formation and using the removed clay for levee construction. Pits 1 and 2 were constructed in 1958, side by side, on rather level terrain (1.2 acres each). The levees around both pits are approximately 3 feet above the existing grade. Pits 1 and 2 each contain approximately 500,000 cubic feet of material, all of which is below grade.

The elevations of the levees around Pits 3 and 4 are basically the same as those around Pits 1 and 2. However, the terrain slopes downward toward the west boundary which means the levees at Pits 3 and 4 are much higher with respect to the original grade than are those at Pits 1 and 2.

Construction of Pit 3 took place in 1959 with a design volume of 4.5 million cubic feet and a surface area of approximately 8.4 acres. A portion of the levee in the northeast corner of the pit was constructed on existing terrain so that the levee is about 23 feet above original grade in that area. The inlet to Pit 3 was in the northeast corner of the pit. Residue levels slope from that corner downward approximately 6 feet to the opposite corner, and occupy about 78 percent of the pit volume.

Pit 4 was constructed in 1964 with a design volume of 12 million cubic feet and a surface area of about 15 acres. The east levee of Pit 4 is common to the west levee of Pit 3. The elevations of the tops of the levees of Pits 3 and 4 are the same. The west levee of Pit 4 extends about 35 feet above the existing grade at its maximum elevation. The residue fill in Pit 4 is irregular with about 10 percent of the total pit volume consumed, exclusive of standing water. If Pit 3 filled, it was designed to overflow into Pit 4 through a connecting pipe 7 feet below the top of the common levee. It is believed that the Pit contents have never reached that level.

Stored Wastes

Approximately 70 percent of the residues discharged to Pits 1, 2, and 3 were neutralized raffinates from refinery operations. These were pumped as a slurry to the pits where the solids settled out (stayed in the pits) and the supernatant liquid was discharged to the plant process sewer. The solids consisted primarily of: 1) acid insoluble compounds in the feed materials (chiefly silica), and 2) hydroxides and precipitates formed when the raffinates were neutralized with lime.

The remaining 30 percent of the contents of Pits 1, 2, and 3 consists primarily of washed slag residues from the uranium metal production operation. Magnesium fluoride slag was produced as a scrap during the reduction of UF_4 to metallic uranium using magnesium chips. This slag contained about 5 percent uranium which was recovered by leaching with nitric acid. A final water wash removed the remaining soluble uranyl nitrate. This washed slag, virtually uranium-free, was then pumped as a slurry to the pits where the solids remain as a settled sludge.

Pit 4 contains some of the same residues that are present in Pits 1, 2, and 3 plus the raffinate solids generated in the processing of thorium in the refinery.

All pit drains have been sealed and the residues are covered with water for most of the year. The amount of water in the pits varies greatly depending on the season of the year. In the hot, dry summer months, the surface water in pits 1 and 2 evaporates, leaving a dry and cracked surface. The level of water in Pits 3 and 4 varies also, but there always is some surface water present.

Table 1 lists the approximate depths of free water in the pits that are likely to occur over a period of time.[2] It is estimated, on the average, that there is a total of 20,000,000 gallons of free water atop the sludges in the four pits.

Table 2 lists approximate values for various parameters of the water in the pits.

Present Operations

No production wastes have been generated at this facility since the plant closed. Small amounts of debris from localized clean-up in the DOE pit area and Army plant area have been placed in pit 4 on several occasions. Since the plant closure, the only routine activities in the pit area have been for general grounds caretaking and maintenance.

When the pits were in use, supernatant liquid was removed from pits 1, 2 and 3 by decant systems. No water has ever been discharged from pit 4. The decanted water flowed via buried pipes into the plant's storm sewer system. Sewage treatment effluent added to this flow and the combined wastewater was discharged offsite into a natural stream bed. The discharge point, called the process sewer outfall, was within a fenced right-of-way on land which is now part of the Weldon Spring Wildlife Area. The fence enclosed the stream all the way to the Missouri River. Presently, the fence is intact and kept in good condition only between the process sewer outfall and State Route 94.

Although there are no operations in the storage area or in the Army plant area, there is a small but continuous discharge at the process sewer outfall. The flow consists of sewage treatment effluent and groundwater which collects in the storm sewer lines. All of the storm sewer lines and the sewage treatment facility are located in the plant area now under Army control. The buried sewer lines and manholes are intact and in good condition. The sewage facility is being utilized for the small volume generated by the Army caretaker and guard staffs.

Transfer lines from the pits to the storm sewer have been sealed. Despite the seals, there is a slight seepage of water from the lines into the sewer system. This seepage may be supernatant pit water or may be infiltrated groundwater. The seepage, plus leaching of solids deposited in the storm sewer lines when the plant was active, produces elevated concentrations of nitrate and radium-226 at the process sewer outfall. Uranium in the outfall flow is contributed by the entire storm sewer system as it collects water from throughout the former uranium production area.

Demography and Cultural Factors

The location of the Weldon Spring Production Center and its proximity to the population centers is shown in Figure 2. A vicinity map, Figure 3, shows that the DOE storage site is completely surrounded by Army-controlled areas. To the north of the site, beyond the Army area, is the August A. Busch Memorial Wildlife Area. This public park is operated by the Missouri Department of Conservation and is open to the public. The east side of the DOE site is bounded by the major portion of the former Weldon Spring Feed Materials Plant. On the south and east beyond the plant is the large Weldon Spring Wildlife Area. To the west is the U. S. Army Reserve Training Center.

Various activities are conducted in the area of the plant site. The University of Missouri operates an Agricultural Extension Office approximately one-half mile northeast of the site on State Route 94. The normal occupancy for this operation is about twelve people. Also northeast of the site along State Route 94 is a State of Missouri Highway Maintenance facility which has about six people involved. Within a mile radius of the site is the August A. Busch Wildlife Area Headquarters and the Administration Building for the U. S. Army Reserve Training Center.

Approximately one mile from the site on State Route 94 is the Francis Howell High School that has a student population of about 2,000.

The nearest communities to the site are Weldon Spring and Weldon Spring Heights (approximately two miles east of the site). Four miles northeast of the plant is the town of Cottleville. The nearest community that shows an active growth pattern is St. Charles, which is about 12 miles from the site on State Route 94. The largest metropolitan area is St. Louis and its surrounding communities. St. Louis is about 30 miles east of the site. Table 3 lists the population and number of housing units for these communities. At the present time, there is virtually no urban development or any industrialization in close proximity to the site.

The Weldon Spring Wildlife Area covers 7,356 acres east and south of the DOE site. Parking areas have been provided along Highway 94 to provide access for hunting, fishing and hiking. Until mid-1980 this land was the University of Missouri Experimental Farm and closed to the public.

Physiography

Topography to the north of the Weldon Spring plant is gently rolling. The area adjacent to the pits has a natural slope toward the west and north across the U. S. Army Reserve Training area as well as the Busch Wildlife area. Runoff from this area eventually reaches the Mississippi river northwest of St. Louis, Missouri. The first drainage basin it enters is Schote Creek and then on to Dardenne Creek from which it enters the Mississippi River.

The terrain to the south and east is considerably different. This public access land administered by the Missouri Conservation Department, is a most rugged ravined, heavily wooded area extending to the Missouri River.

Geology

The general surface in the Weldon Spring area is entirely covered by unconsolidated materials, consisting of alluvium, glacial drift and residium from weathering rock. The most conspicuous material making up the mantle is the zone of weathered limestone bedrock beneath. The residium is clayey, contains much chert and, in the lower part, contains fragments of limestone that have not yet been completely converted to residual soil material. The total overburden ranges from 17-60 feet in thickness in the general area. The uppermost bedrock in the area is the highly permeable Burlington Keokuk formation of the Mississippian age. This formation is reported to be 150-200 feet in thickness. Four other conformable formations of the Mississippian age underlie the Burlington Keokuk. They consist of (in descending order) the Fern Glen limestone (approximately 75 feet thick), the Chouteau limestone (approximately 25 feet thick), the thin Hannibal shale and the Sulfur Spring sandstone (8-30 feet thick).

The subsurface strata in the plant area were investigated prior to the AEC plant construction, and again, in more localized detail, before construction of Pit 4. This work showed there is a minimum of 10 feet of very impermeable clay underlying the pits. This clay, in turn, overlies about 3 feet of somewhat more permeable clay lying above the 150-200 feet of the permeable Burlington Keokuk limestone.

Hydrology

Surface water flow from most of the DOE storage pit area moves northwestwardly to the Army Reserve Training Area. A swale and ditch border the north side of the pits and carry water to the ash pond on Army property. The pond discharge forms the "Northwest Stream" which enters the Army Reserve Training Area. Here it joins with a small tributary that collects drainage from the west side of the pit area. The combined flow enters the August M. Busch Memorial Wildlife Area and discharges into one of the Busch lakes. Lake discharge eventually reaches Dardenne Creek and the Mississippi River.

The Weldon Spring upland or plateau area is classified as an area of poor recharge to groundwater because of the relatively thick and impermeable layer overlying the bedrock aquifers. There are various localized water tables below the storage pits. There is limited availability in the Burlington Keokuk limestone approximately 60 feet below the pit bottoms. Because this source of water is quite hard and in limited supply, it is not very desirable as a water source. At a depth of about 300 feet below the bottom of the pits is the Sulfur Spring (Bushberg Sandstone) formation which is capable of supplying large volumes. This source is generally not used in this area because it is naturally high in nitrates and chlorides. To get a reasonably soft water for large supplies, it is necessary to tap the St. Peter Sandstone aquifer which is artesian and is located some 700 feet below the pit bottoms.

Abundant potable groundwater is obtained from the alluvium of the Missouri River valley and lesser quantities from the Dardenne Creek alluvium. This groundwater is replenished by precipitation in the valleys and tributary watersheds and from the surface streams.

Meteorology

Table 4 lists the U. S. Weather Bureau meteorology data for St. Louis, Missouri. All averages are from the period of 1951-1970 (1961-1980 data not yet available). Almost half of the annual precipitation occurs in May through August (plant growing months). These summer rains frequently appear as thunderstorms, sometimes severe with high winds and hail. This area also is known for having localized rains in late spring and summer which are, at times, excessive. Ten inches of rainfall have been recorded in a 24-hour period.

An average of 171 tornadoes occur each year in the state of Missouri. These disturbances usually have a narrow path and disintegrate after a few miles. The tornado "season" is usually in April and May.[1] The winds in the area of the site are generally from the south during the summer months and from the west-northwest during the winter and early spring. The climate of the state is subject to much variation -- the lowest recordable temperature in the state was -40°F. in 1905 and the highest was 118°F. in 1936.

II. WELDON SPRING SITE QUARRY

Description

The DOE Quarry storage site is an abandoned rock quarry located about 4 miles from the Weldon Spring plant and 20 miles west of St. Louis (Figure 2). It is situated on an 8.6 acre site lying between Missouri State Route 94 and the Little Femme Osage Creek. The quarry itself was dug in a high outcropping of limestone, the upper elevations being well above the surrounding terrain. The upper rim of the quarry is at elevation 550-570' mean sea level (MSL), while the bottom of the original quarry was at 446' MSL. Water presently fills the quarry to an elevation of 457' MSL, covering approximately one-half acre. The main quarry hole below elevation 480' MSL covers an area close to two acres (see Figures 4 and 5). Originally it was used as a dump site by the U. S. Army for disposition of trinitrotoluol contaminated rubble from the Army Ordnance Works which preceded the Weldon Spring Feed Materials Plant.

The first usage for disposal of radioactive waste occurred in 1958 when the AEC acquired title and took possession. In 1959, the AEC used the quarry to dispose of drummed thorium residues, which were dumped at an elevation which is below the present quarry water level. In 1963 and 1964 the Mallinckrodt Destrehan Street Feed Plant in St. Louis was demolished and, as a result, about 1,350,000 cubic feet of uranium-and radium-contaminated building rubble, process equipment and contaminated soil was deposited in the quarry. The Destrehan Street Plant had been used as a production facility for UO_3, UF_4, and uranium metal. This buried rubble covers slightly over one acre of the quarry floor and is about 30 feet deep.

In 1966, additional drummed and uncontained thorium residues from the cleanout of process equipment at the Weldon Spring plant were deposited in the quarry. However, the Army also disposed of TNT-contaminated stone and earth the same year, which covered the thorium residues. Finally, in 1968-69, the Army deposited the last wastes in the quarry. This waste was uranium-and thorium-contaminated process equipment and building rubble which resulted from the Army's decontamination of portions of the Weldon Spring plant. Since then, no chemical or radioactive wastes have been disposed of at the quarry.

Table 5 lists average values for various parameters of the water in the quarry pond.

Geology

The geology of the quarry area has been well documented as a result of the data available from several studies and from U. S. Geological Survey reports.[3,4] A test drilling program was started in October, 1976. An overall plan view showing the location of the test wells is given in Figure 6. Core samples taken from the 12 test wells drilled around the lower elevations of the quarry area indicate that a top layer of silty clay extends from the ground surface in varying depths down to 3 feet.

Beneath this layer of silty clay is a layer of Kimmswick limestone (16-25 feet thick), which is typically a coarsely crystalline, white to light gray, medium bedded to massive limestone. A 14-20 feet layer of Decorrah shale underlies the Kimmswick formation. It consists of green and brown shales with numerous, thin, interbedded limestone layers in its lowest part that grade upward into a medium to thinly bedded, fossiliferous limestone which contains thin, shale partings.[4]

Hydrology

Groundwater in the quarry area is found in various strata -- in the solution channels and fractures in the limestone of Mississippian age, in the alluvium of the stream valleys, and in some of the older deeper rocks of Ordovician age. The water in the limestones and the alluvium has its origin in the rainfall from the surface of the immediate area. All surface runoff around the quarry is away from it because of the high rim around the quarry. The quarry only receives direct rainfall, which seeps or runs off into the quarry pool.

The characteristics of the quarry have been studied prior to and concurrent with the AEC use of the site for waste storage. These studies indicate that water in the quarry is in slow but continuous communication with local groundwater. Depending on the relative head developed by rainfall and water table conditions, water flows into or out of the quarry through horizontal bedding planes and vertical joints in the limestone. In July, 1960, tests indicated a head pressure of almost 3 feet of water would produce a flow rate of approximately 3 gallons per minute. Since this head pressure would hardly ever occur naturally, routine exchange rates in this region would be expected to be much lower than the test values.

An investigation of the exposed rocks as well as the topography in the vicinity of the quarry indicated the probability that the quarry was hydraulically connected with the surface bodies of water that bound the quarry ridge on three sides - the Femme Osage Slough, Little Femme Osage Creek, and an unnamed tributary of the Little Femme Osage Creek. A natural extension of this hypothesis is that water leaving the quarry would not have to travel over 1000 feet underground before reaching points of discharge at these surface bodies.

In October, 1960, the U.S. Geological Survey conducted a series of pressure tests on two core holes that were drilled at a distance of 300 feet to the north and 50 feet to the south of the quarry sump, respectively. These wells, shown on Figure 6 (identified as "N" and "S" locations), were drilled to depths of 427 feet and 430 feet MSL (mean sea level), respectively. The results of these drillings indicated a layer of rock between elevation 470 feet and 430 feet MSL, which is relatively incapable of transmitting large quantities of water. Tests conducted under an injection pressure of 50 pounds per square inch (psi) resulted in a flow of 1.5 gallons per minute (gpm), maximum.

Geologists familiar with the area are of the opinion that the groundwater under the quarry moves toward the south in the direction of the Femme Osage Slough. This opinion is supported by the presence of uranium in the slough water and the absence of quarry contaminants in the Little Femme Osage Creek.

III. ENVIRONMENTAL MONITORING

Surface Streams

Since the pits and quarry contain radioactive residues and contaminated soil and rubble, and because there is a potential for these contaminants to be transported offsite by means of a water route, a program of water sampling was instituted. The program involves the semi-annual collection of grab samples from the locations listed in Table 6 and shown in Figures 7, 8, and 9. All samples were analyzed by NLO, Inc. In addition to analysis for radionuclides, the samples were analyzed for pH, chloride and nitrate concentrations.

Water monitoring results for 1979 and 1980 are reported in Tables 7 to 12. These results show that uranium and radium concentrations in all samples were below the DOE Concentration Guide for water in uncontrolled areas.[5] The maximum uranium and radium concentrations were found in samples collected from the process sewer outfall and process sewer outfall stream.

In all other samples collected, the average uranium concentration did not exceed 0.11 milligrams per liter (mg/L), or 0.2% of the DOE Guide for water in uncontrolled areas. The average radium-226 concentrations were either 0.001 d/m/mL or less (1.5% or less of the DOE Guide) for all other samples collected. The sample for radium-228 from the St. Charles County Water Treatment Plant (incoming flow) had an average concentration of 0.002 d/m/mL (3% of the DOE Guide) whereas the remaining samples had average concentrations at or below 0.001 d/m/mL which is 1.5% or less of the DOE Guide.

River and Treated Water

Water samples were collected at various locations from the Mississippi and the Missouri Rivers (three at the inlets of three water treatment plants) on May 14-15, 1980. Samples were also collected of the finished water at these water treatment plants (see Figure 10). All samples were sent to a commercial laboratory for uranium and thorium analyses. Other analyses were made by NLO. Results of these analyses are given in Table 13.

Fish

For many years, the land along State Route 94 was a University of Missouri experimental area and access was restricted. On June 12, 1980, the land was opened to the public as the Weldon Spring Wildlife Area, administered by the Missouri Department of Conservation (MDC). Because the new land-use included fishing, arrangements were made with the MDC to collect fish specimens from the Femme Osage Slough for analysis.

On June 9, 1980, MDC personnel, using an electro-shocking technique, collected several species of Slough fish. The specimens were sent to a commercial laboratory where they were segregated according to species and disected. Samples of edible flesh and bone were taken for analysis. All samples were analyzed for total uranium, radium-226, lead-210, and thorium-232. Table 14 lists the results of these analyses.

Radon-222

On June 9, 1980, passive radon monitors were placed at 14 locations at and near the pit area and quarry and at 3 offsite locations (see Figures 11, 12 and 13). These monitors consist of a special dielectric detector which is sensitive only to alpha radiation, such as that emitted by radon and its daughter products. The detector is mounted inside the bottom of a light plastic cup, about 3.75 inches high and 2.9 inches at the widest diameter (at the top). A special filter, supplied with the cup and installed over the mouth of the cup when the sampler is installed, prevents the entry of dust.

Radon gas passes through the filter and decays through alpha particle emission. Each alpha particle reaching the detector produces a tiny radiation-damage track that is retained by the detector. An etching technique makes the tracks visible so that they can be counted automatically. The number of tracks per unit area is directly proportional to the integrated alpha exposure from the radon and its daughters to which the detector was exposed. A comparison with a standard and knowledge of the total exposure time gives the average radon concentrations for the exposure period. After it is processed, the detector constitutes a permanent record of the exposure. It can be reread at any time for verification or a larger area of the detector can be read to increase sensitivity.

Protective canisters for these detectors were fabricated from five-quart metal paint buckets. The handles were changed so that the buckets would hang upside down with the mouth of the bucket downward. A wooden plate was used to hold the samplers in the desired configuration. Each bucket was designed to hold two samplers but only one was used as part of this sampling program.

Table 15 presents the results of the samples collected from June 9, 1980, to November 11, 1980, and from November 11, 1980, to March 20, 1981. Figures 11, 12, and 13 show the monitoring locations for the pit area, quarry, and offsite locations, respectively. At all onsite sampling locations, the radon-222 concentrations were below the DOE Guide[5] for controlled areas, 100 picocuries per liter (pCi/L). At one location (R3), along the fence east of pits 1 and 2, the concentration was slightly above the guide for uncontrolled areas, 3 pCi/L (see Figure 11). However, this location is adjacent to the U. S. Army property where there is limited access and only occasional occupancy by personnel using the patrol road which parallels the fence. The filter on this monitor was frayed in spots and may not have functioned properly for the entire exposure period. All other pit and quarry results were below the guide value for uncontrolled areas.

Offsite sampling was done at the following locations (see Figure 13):

1. Busch Memorial Wildlife Area, 0.84 mile northeast of pits 1/2 (on fence at weather station).

2. University of Missouri Research Center, 0.84 mile northeast of pits 1/2 (on wood post at garden area).

3. U. S. Army Reserve Site, 0.35 mile south southeast of pits 1/2 (on fence behind guard office).

All offsite results were low ($\leq$0.24 pCi/L) and are similar to natural background concentrations found in parts of the United States.

IV. RADIATION DOSE ASSESSMENTS

Surface Streams

There is no known human consumption of water from the two surface streams which leave the plant site and which might contain contaminants from the stored residues. While any use is unlikely, bone dose estimates were made based on the assumption that a person occasionally using the nearby public land would consume 0.12 liters (4 oz.) of stream water once each week for 50 weeks per year. The streams considered were the process sewer outfall stream at State Route 94 (sampling point No. 2) and the Northwest stream at County Road D (sampling point No. 6). For an annual intake of 6 liters from sampling point No. 2, the 50-year bone dose commitment would be 8.1 mrem from uranium, 7.3 mrem from radium-226 and less than 0.3 mrem from radium-228. For an annual ingestion of 6 liters from sampling point No. 6, the 50-year bone dose commitment would be 2.4 mrem from uranium, less than 0.8 mrem from radium-226 and less than 0.3 mrem from radium-228. These doses were calculated using the average concentrations reported in Tables 10, 11 and 12 and radiation dose factors given in Table B.5 of reference 8.

The total 50-year bone dose commitments for this assumed ingestion of water from points 2 and 6 are <15.7 mrem and <3.5 mrem, respectively. These doses are <3% and <1% of the DOE standard for individuals at points of maximum probable exposure.[5]

Treated Water

Uranium and radium concentrations were at or near the analytical detection limits in samples of raw water from the St. Charles County water plant (sampling location No. 7). These low concentrations could be due entirely to natural conditions and would probably be reduced by the standard treatment plant processes of pH adjustments and solids removal. Dose estimates were made using the average concentrations found in the raw water. For an intake of 2.2 liters per day throughout the year, the 50-year bone dose commitment would be 1.5 mrem from uranium, 98.7 mrem from radium-226 and 72.7 mrem from radium-228. By comparison, for a radium-226 concentration at the U. S. EPA limit for drinking water, 0.011 d/m/mL[9], the calculated bone dose is 1095 mrem.

River Water

No dose estimates were made for the intake of water collected from the Missouri and Mississippi Rivers (Table 13). It is obvious the radionuclide concentrations are all low and are at natural background levels. Storage of DOE residues has no discernable effect on the quality of water in the two rivers.

Fish

Because of the ever-present turbidity, it is not likely that Slough water would be used directly by humans. Taking of fish from the Slough is more likely because of public access to the Wildlife Area. However, the occasional consumption of Slough fish will not cause a significant radiation dose. Table 16 shows calculated doses derived from published intake-dose values[6] and the analytical data in Table 14. For the ingestion of one kilogram (2.2 pounds) of edible fish tissue, the 50-year dose commitment is 2.4 millirems to the bone. This quantity is less than 0.2% of the DOE annual radiation protection guide for persons at points of maximum exposure; it is less than 0.6% of the guide for the general population.[5]

Most of the estimated radiation dose is due to radium-226, as shown in Table 16. In Slough water, however, the radium concentration has been at a background level ever since the start of the NLO semi-annual sampling in 1974. The average radium-226 concentration has been less than 0.001 disintegrations per minute per milliliter (d/m/mL). This level is exceeded in many U. S. surface waters.[7]

Many elements are concentrated in fish tissue and a bio-accumulation factor of 50 has been reported for radium.[8] This means that the radium content of fish could be 50 times greater than the radium content of the water in which the fish lived. Therefore, the calculated radiation dose shown in Table 16 is chiefly due to naturally-occurring radionuclides.

Radon-222

The six offsite radon-222 results reported in Table 15 are in the range of 0.08 to 0.24 pCi/L. All are well within the DOE Guide for uncontrolled areas, 3 pCi/L,[5] and are within the reported range for background concentrations in outdoor air, 0.1 to 0.5 pCi/L.[7] To estimate the possible contribution from the DOE site, a concentration of 0.1 pCi/L was assumed as the natural background level in the Weldon Spring area. If so, the maximum contribution from the DOE site at any offsite sampling location was 0.14 pCi/L at location R14 (0.24 pCi/L minus the assumed background of 0.1 pCi/L). Year-long intake of radon-222 at a concentration of 0.14 pCi/L would produce a radiation dose to the bronchial epithelium of 0.07 rem. This dose is 4.7% of the DOE standard for individuals at points of maximum probable exposure.

REFERENCES

1. Ryckman/Edgerly/Tomlinson & Associated for the Army, Office of the Project Manager for Chemical and Installation Restoration. National Disaster Report, Weldon Spring Chemical Plant Survey and Assessment. May, 1978.

2. Pennak, A. F., et al. ERDA-Weldon Spring; Weldon Spring Decommissioning Study, National Lead Company Of Ohio report NLCO-1121, Special, June 20, 1975.

3. Lenhard, L. A., et al. Weldon Spring Raffinate Pits and Quarry Task Force Report, Atomic Energy Commission, Oak Ridge Operations Office, June 1, 1967.

4. Richardson, R. M., Possible Use of Quarry at Mollinckrodt Chemical Works, Weldon Spring, Missouri, for the Disposal of Uranium Contaminated Building Debris and Rubble and Residues Containing Thorium and Uranium, U. S. Geological Survey, Oak Ridge, Tennessee, June, 1960.

5. USDOE Order No. 5480.1A, Environmental Protection, Safety and Health Protection Program, for DOE Operations Chapter XI, "Requirements for Radiation-Protection," 8/13/81.

6. G. K. Killough and L. R. McKay. A Method for Calculating Radiation Doses From Radioactivity Released to the Environment, USERDA Report ORNL-4992. March, 1976.

7. M. Eisenbaud. Environmental Radioactivity. Academic Press, New York, 1973.

8. J. P. Conley et al. A Guide for Environmental Radiological Surveillance at ERDA Installations, USERDA Report 77-24. March, 1977.

9. Code of Federal Regulations, Title 40, Part 141, National Interim Primary Drinking Water Regulations, U. S. Environmental Protection Agency, July 1, 1980.

Table 1. Maximum Depths of Free water in the Pits

Pit No.	Maximum Depth, Feet	Remarks
1	1.5	Occasionally entire pit is dry
2	1.5	Occasionally entire pit is dry
3	3	Portion of pit bottom may be exposed and dry in summer
4	3	"Shore" width increases in dry weather but deep water persists year round

Table 2. Weldon Spring Pits - Water Quality Data
(Typical Values)

Pit No. 1

NO_3	- 26,400	mg/L
U	- 0.031	mg/L
Ra-226	- 2.86	d/m/mL

Pit No. 2

NO_3	- 26,300	mg/L
U	- 0.046	mg/L
Ra-226	- 3.62	d/m/mL

Pit No. 3

pH	- 7.9	
Chloride	- 29.3	mg/L
NO_3	- 13,300	mg/L
F	- 7.4	mg/L
Total Solids	- 15,930	mg/L
Cu	- <1	mg/L
Ca	- 1,400	mg/L
Na	- 1,460	mg/L
Mg	- 440	mg/L
Ammonia Nitrogen	- <5	mg/L
Th	- 0.016	mg/L
U	- 0.15	mg/L
Ra-226	- 0.74	d/m/mL
Ra-228	- <0.1	d/m/mL

Pit No. 4

pH	- 9.7	
Chloride	- 12	mg/L
NO_3	- 55	mg/L
F	- 8.7	mg/L
Cu	- <1	mg/L
U	- 4.0	mg/L
Ra-226	- 0.02	d/m/mL
Ra-228	- 0.06	d/m/mL

Table 3. Local Demographics

Community	Population[1]			No. of Housing Units[1]		
	1980	1970	% Change	1980	1970	% Change
St. Louis (City)	453,085	622,236	-27.2	202,113	238,485	-15.3
St. Louis (SMA)	2,344,912	2,410,884	- 2.7	---[2]	---[2]	---[2]
St. Charles (City)	35,865	31,834	+12.7	13,648	10,122	+34.8
St. Charles (County)	143,455	92,954	+54.3	49,841	28,119	+77.3
Cottleville (Town)	184	230	-20.0	51	---[2]	---[2]
Weldon Spring Heights (Town)	144	135[3]	+ 6.7[4]	35	---[2]	---[2]
Weldon Spring	---[2]	70[3]	---[2]	---[2]	---[2]	---[2]

1. All data shown is taken from: U. S. Department of Commerce, Bureau of Census, "1980 Census of Population & Housing," Publication No. PHC80-V-27, except as otherwise noted.

2. Not available.

3. National Lead Company of Ohio publication, "Study of Radioactive Waste Storage Areas at ERDA-Weldon Spring Site," Publication No. NLCO-1144, April 25, 1977.

4. Calculated value.

Table 4. Meteorology Data For St. Louis, Missouri

Average Annual Precipitation	35.89 inches
Average Days of Measurable Precipitation	110
Average Wind Speed	9.5 mph from South
Average Temperature	55.9°F
Average High Temperature	65.6°F
Average Low Temperature	46.2°F
Record High Temperature	106°F, July 1966
Record Low Temperature	-11°F, January 1963
Average Number of Days Below Freezing	106

Table 5. Weldon Spring Quarry - Water Quality Data

(Typical Values)

pH	-	7.6	
Chloride	-	16.8	mg/L
NO_3	-	1.2	mg/L
Th	-	0.011	mg/L
U	-	5.3	
Ra-226	-	0.004	d/m/mL
Ra-228	-	<0.001	d/m/mL

Table 6. Weldon Spring Site Pit Area Water Sampling Locations

1. Process Sewer Outfall
2. Process Sewer Outfall Stream at St. Rt. No. 94
3. Process Sewer Outfall Stream near power line crossing
4. Process Sewer Outfall Stream near MK&T Railroad
5. Northwest Stream Onsite
6. Northwest Stream Offsite at County Road "D"
7. St. Charles County Water Treatment Plant (Incoming flow - groundwater)
8. Little Femme Osage Creek at Highway 94 (Upstream from quarry)
9. Little Femme Osage Creek at MK&T RR Bridge (Downstream from quarry)
10. Little Femme Osage Slough (670 feet southwest of quarry pool)
11. Femme Osage Slough (920 feet southeast of quarry pool)
12. Femme Osage Slough (2680 feet east of quarry pool at dirt road crossing)
13. Background Sample from Spring at Junction of Highway 94 and U. S. 40/61
    94 and U. S. 40/61

Table 7. Weldon Spring Site Pit Area Water Sampling Results

1979-1980

pH

Sample No. & Description	No. of Samples	RANGE
1. Process sewer outfall	4	8.0 to 8.2
2. Process sewer outfall stream at St. Rt. No. 94	3	7.6 to 7.9
3. Process sewer outfall stream-near power line crossing	1	7.8
4. Process sewer outfall stream-near MK&T railroad	1	8.0
5. Northwest stream-onsite	4	8.3 to 9.1
6. Northwest stream-offsite at County Road "D"	4	8.0 to 9.0
7. St. Charles Co. Water Treatment Plant-incoming flow	4	7.0 to 7.1
8. Little Femme Osage Creek-at St. Rt. No. 94, upstream from quarry	4	7.8 to 8.1
9. Little Femme Osage Creek-at MK&T RR Bridge, down-stream from quarry	4	7.7 to 8.4
10. Little Femme Osage Slough-670 feet southwest of quarry pool	3	7.5 to 7.9
11. Femme Osage Slough-920 feet southeast of quarry pool	4	7.5 to 8.3
12. Femme Osage Slough-2680 feet east of quarry pool at dirt road crossing	4	7.7 to 8.3
13. Background sample from spring-at junction of St. Rt. No. 94 & U.S. Rt. No. 40/61	4	6.2 to 7.0

Table 8. Weldon Spring Site Pit Area Water Sampling Results

1979-1980

Chloride

Sample No. & Description	No. of Samples	Concentration Found, mg/L Maximum	Minimum	Average
1. Process sewer outfall	4	19	15	17
2. Process sewer outfall stream at St. Rt. No. 94	3	18	16	17
3. Process sewer outfall stream-near power line crossing	1	--	--	14
4. Process sewer outfall stream-near MK&T railroad	1	--	--	3
5. Northwest stream-onsite	4	14	11	13
6. Northwest stream-offsite at County Road "D"	4	14	12	13.3
7. St. Charles Co. Water Treatment Plant-incoming flow	4	12	9	10.8
8. Little Femme Osage Creek-at St. Rt. No. 94, upstream from quarry	4	12	3	7.5
9. Little Femme Osage Creek-at MK&T RR Bridge, down-stream from quarry	4	10	4	7.5
10. Little Femme Osage Slough-670 feet southwest of quarry pool	3	14	4	9
11. Femme Osage Slough-920 feet southeast of quarry pool	4	9	5	7.5
12. Femme Osage Slough-2680 feet east of quarry pool at dirt road crossing	4	12	7	10.3
13. Background sample from spring-at junction of St. Rt. No. 94 & U.S. Rt. No. 40/61	4	17	6	12

Table 9. Weldon Spring Site Pit Area Water Sampling Results 1979-1980

NO_3

Sample No. & Description	Samples	Concentration Found, mg/L Maximum	Minimum	Average
1. Process sewer outfall	4	680	220	393
2. Process sewer outfall stream at St. Rt. No. 94	3	620	220	370
3. Process sewer outfall stream-near power line crossing	1	--	--	160
4. Process sewer outfall stream-near MK&T railroad	1	--	--	16
5. Northwest stream-onsite	4	3.1	1.3	2.3
6. Northwest stream-offsite at County Road "D"	4	2.6	0.8	1.9
7. St. Charles Co. Water Treatment Plant-incoming flow	4	1.6	1.0	1.3
8. Little Femme Osage Creek-at St. Rt. No. 94, upstream from quarry	4	1.7	1.0	1.4
9. Little Femme Osage Creek-at MK&T RR Bridge, down-stream from quarry	4	2.8	0.7	1.8
10. Little Femme Osage Slough-670 feet southwest of quarry pool	3	23	0.6	8.1
11. Femme Osage Slough-920 feet southeast of quarry pool	4	17	0.4	4.9
12. Femme Osage Slough-2680 feet east of quarry pool at dirt road crossing	4	3.7	0.4	1.8
13. Background sample from spring-at junction of St. Rt. No. 94 & U.S. Rt. No. 40/61	4	5.7	1.8	4.0

Table 10. Weldon Spring Site Pit Area Water Sampling Results

1979-1980

Uranium

Sample No. & Description	No. of Samples	Maximum Conc. Found mg/L	Minimum Conc. Found mg/L	Avg. mg/L	Conc. Found % of Std.*
1. Process sewer outfall	4	2.5	1.4	1.8	3.0
2. Process sewer outfall stream at St. Rt. No. 94	3	2.4	1.3	2.0.	3.3
3. Process sewer outfall stream-near power line crossing	1	--	--	1.2	2.0
4. Process sewer outfall stream-near MK&T railroad	1	--	--	0.4	0.7
5. Northwest stream-onsite	4	0.13	0.04	0.09	0.2
6. Northwest stream-offsite at County Road "D"	4	2.2	0.027	0.60	1.0
7. St. Charles Co. Water Treatment Plant-incoming flow	4	0.004	<0.003	<0.003	<0.005
8. Little Femme Osage Creek-at St. Rt. No. 94, upstream from quarry	4	0.005	0.002	<0.003	<0.005
9. Little Femme Osage Creek-at MK&T RR Bridge, down-stream from quarry	4	0.004	<0.003	<0.004	<0.007
10. Little Femme Osage Slough-670 feet southwest of quarry pool	3	0.30	0.10	0.18	0.3
11. Femme Osage Slough-920 feet southeast of quarry pool	4	0.16	0.06	0.11	0.2
12. Femme Osage Slough-2680 feet east of quarry pool at dirt road crossing	4	0.02	0.05	0.03	0.05
13. Background sample from spring-at junction of St. Rt. No. 94 & U.S. Rt. No. 40/61	4	0.009	<0.003	<0.005	<0.008

*DOE Standard = 60 mg/L(U)

Table 11. Weldon Spring Site Pit Area Water Sampling Results

1979-1980

Ra-226

Sample No. & Description	No. of Samples	Maximum Conc. Found d/m/mL	Minimum Conc. Found d/m/mL	Avg. Conc. Found d/m/mL	Avg. Conc. Found % of Std.*
1. Process sewer outfall	4	0.049	0.012	0.027	40.7
2. Process sewer outfall stream at St. Rt. No. 94	3	0.016	0.008	0.009.	13.6
3. Process sewer outfall stream-near power line crossing	1	--	--	0.007	10.6
4. Process sewer outfall stream-near MK&T railroad	1	--	--	0.006	9.1
5. Northwest stream-onsite	4	<0.001	<0.001	<0.001	< 1.5
6. Northwest stream-offsite at County Road "D"	4	<0.001	<0.001	<0.001	< 1.5
7. St. Charles Co. Water Treatment Plant-incoming flow	4	0.002	0.001	0.001	1.5
8. Little Femme Osage Creek-at St. Rt. No. 94, upstream from quarry	4	<0.001	<0.001	<0.001	< 1.5
9. Little Femme Osage Creek-at MK&T RR Bridge, down-stream from quarry	4	<0.001	<0.001	<0.001	< 1.5
10. Little Femme Osage Slough-670 feet southwest of quarry pool	3	0.001	<0.001	<0.001	< 1.5
11. Femme Osage Slough-920 feet southeast of quarry pool	4	0.001	<0.001	<0.001	< 1.5
12. Femme Osage Slough-2680 feet east of quarry pool at dirt road crossing	4	0.002	<0.001	<0.001	< 1.5
13. Background sample from spring-at junction of St. Rt. No. 94 & U.S. Rt. No. 40/61	4	<0.001	<0.001	<0.001	< 1.5

*DOE Standard for uncontrolled areas is 0.066 d/m/mL.

Table 12. Weldon Spring Site Pit Area Water Sampling Results

1979-1980

Ra-228

Sample No. & Description		No. of Samples	Maximum Conc. Found d/m/mL	Minimum Conc. Found d/m/mL	Avg. Conc. Found d/m/mL	Avg. Conc. Found % of Std.*
1.	Process sewer outfall	4	0.004	<0.001	<0.002	< 3.0
2.	Process sewer outfall stream at St. Rt. No. 94	3	0.001	<0.001	<0.001.	< 1.5
3.	Process sewer outfall stream-near power line crossing	1	--	--	<0.001	< 1.5
4.	Process sewer outfall stream-near MK&T railroad	1	--	--	<0.001	< 1.5
5.	Northwest stream-onsite	4	0.001	<0.001	<0.001	< 1.5
6.	Northwest stream-offsite at County Road "D"	4	<0.001	<0.001	<0.001	< 1.5
7.	St. Charles Co. Water Treatment Plant-incoming flow	4	0.003	0.001	0.002	3.0
8.	Little Femme Osage Creek-at St. Rt. No. 94, upstream from quarry	4	0.002	<0.001	<0.001	< 1.5
9.	Little Femme Osage Creek-at MK&T RR Bridge, down-stream from quarry	4	0.002	<0.001	<0.001	< 1.5
10.	Little Femme Osage Slough-670 feet southwest of quarry pool	3	0.001	0.001	0.001	1.5
11.	Femme Osage Slough-920 feet southeast of quarry pool	4	0.001	0.001	0.001	1.5
12.	Femme Osage Slough-2680 feet east of quarry pool at dirt road crossing	4	0.002	<0.001	<0.001	< 1.5
13.	Background sample from spring-at junction of St. Rt. No. 94 & U.S. Rt. No. 40/61	4	0.001	<0.001	<0.001	< 1.5

*DOE Standard for uncontrolled areas is 0.066 d/m/mL.

Table 13. River Sampling Data

Location		mg/L(1)			d/m/mL(2)		d/m/L(3)		
	pH	Cl	NO_3	U	Ra-226	Ra-228	Th-228	Th-230	Th-232
Missouri River, near Matson, Mo.	8.6	24	2.3	0.004	0.001	<0.001	(4)	(4)	(4)
Missouri River, at Howard Bend Water Plant	8.6	24	5.8	<0.002	<0.001	<0.001	<0.4	0.7	<0.4
Howard Bend Water Plant, finished water	9.8	28	3.1	<0.002	<0.001	<0.001	<0.4	<0.4	<0.4
Missouri River, at St. Charles City Water Plant	8.6	25	5.6	<0.002	<0.001	<0.001	<0.4	<0.4	<0.4
St. Charles City Water Plant, finished water	8.0	29	3.9	<0.002	<0.001	0.001	<0.4	<0.4	<0.4
Mississippi River, Ellis Island, Mo.	8.3	25	14	<0.002	<0.001	<0.001	<0.4	<0.4	<0.4
Mississippi River, intake water at Chain of Rocks Water Plant	8.4	24	5.2	<0.002	0.001	0.002	<0.4	2.0	<0.4
Chain of Rocks Water Plant, finished water	9.4	27	3.4	<0.002	<0.001	<0.001	<0.4	<0.4	<0.4

(1) Milligrams per liter, mg/L.
(2) Disintegrations per minute per milliliter, d/m/mL.
(3) Disintegrations per minute per liter, d/m/L.
(4) Insufficient sample for thorium analyses.

Table 14. Analysis of Slough Fish

Sample Description	Analysis	Results ±2 stnd. dev.
1. Four Bullhead	Gross Weight	339 gm
Four Big Mouth Buffalo	Gross Weight	916 gm
		1255 gm
Edible Portion	Wet Wt. for Analysis	534 gm
	Total Uranium	<2 ug/Kg wet wt.
	Ra-226	0.8 ± 0.2 pCi/Kg wet wt.
	Pb-210	6 ± 1 pCi/Kg wet wt.
	Th-232	47 ± 9 ug/Kg wet wt.
Bone Portion	Wet Wt. for Analysis	102 gm
	Total Uranium	84 ± 15 ug/Kg wet wt.
	Ra-226	8 ± 1 pCi/Kg wet wt.
	Pb-210	29 ± 5 pCi/Kg wet wt.
	Th-232	<100 ug/Kg wet wt.
2. Four Carp	Gross Weight	1859 gm
Edible Portion	Wet Wt. for Analysis	834 gm
	Total Uranium	<1 ug/Kg wet wt.
	Ra-226	7.6 ± 0.4 pCi/Kg wet wt.
	Pb-210	2 ± 1 pCi/Kg wet wt.
	Th-232	55 ± 15 ug/Kg wet wt.
Bone Portion	Wet Wt. for Analysis	158 gm
	Total Uranium	108 ± 15 ug/Kg wet wt.
	Ra-226	7.7 ± 0.7 pCi/Kg wet wt.
	Pb-210	26 ± 6 pCi/Kg wet wt.
	Th-232	150 ± 110 ug/Kg wet wt.
3. One Large Mouth Bass	Gross Weight	420 gm
Three Bluegill	Gross Weight	218 gm
Six Sunfish	Gross Weight	318 gm
Five White Crappie	Gross Weight	230 gm
		1186 gm
Edible Portion	Wet Wt. for Analysis	434 gm
	Total Uranium	3 ± 2 ug/Kg wet wt.
	Ra-226	8.8 ± 0.7 pCi/Kg wet wt.
	Pb-210	4 ± 2 pCi/Kg wet wt.
	Th-232	<20 ug/Kg wet wt.

Table 14. Analysis of Slough Fish (Cont'd.)

	Sample Description	Analysis	Results ±2 stnd. dev.
	Bone Portion	Wet Wt. for Analysis	91 gm
		Total Uranium	<20 ug/Kg wet wt.
		Ra-226	17 ± 2 pCi/Kg wet wt.
		Pb-210	<20 pCi/Kg wet wt.
		Th-232	<90 ug/Kg wet wt.
4.	One Carp	Gross Weight	2392 gm
	Edible Portion	Wet Wt. for Analysis	1178 gm
		Total Uranium	39 ± 4 ug/Kg wet wt.
		Ra-226	11.2 ± 0.6 pCi/Kg wet wt
		Pb-210	80 ± 8 pCi/Kg wet wt.
		Th-232	72 ± 19 ug/Kg wet wt.
	Bone Portion	Wet Wt. for Analysis	166 gm
		Total Uranium	290 ± 20 ug/Kg wet wt.
		Ra-226	23 ± 2 pCi/Kg wet wt.
		Pb-210	26 ± 6 pCi/Kg wet wt.
		Th-232	<100 ug/Kg wet wt.

Table 15. Radon-222 Concentrations

Location	Radon-222 Concentrations, pCi/L[1]			
	Period of 6/9/80 - 11/11/80		Period of 11/11/80 - 3/20/81	
	Average	% of Standard[2]	Average	% of Standard[2]
<u>Pit Area</u>				
R1. DOE fence, north of Pit 4	0.74[3]	24.7	1.29	43
R2. DOE fence, east of Pit 3	1.11[3]	37	1.26	42
R3. DOE fence, east of Pits 1&2	3.40[3]	113.3	4.70	156.7
R4. DOE fence, south of Pit 4	0.59	19.7	0.35	11.7
R5. DOE fence, west of Pit 4	0.56	18.7	0.50	16.7
<u>Quarry</u>				
R6. Tree near fence, St. Rt. No. 94 side,west end	.23	7.7	0.42	14
R7. Fence, St. Rt. No. 94, east end	0.90	30	0.39	13
R8. Fence, near upper gate	0.87	29	1.15	38.3
R9. Fence, near Well #8	0.81[3]	27	0.53	17.7
R10. Fence, near well "South"	0.78[3]	26	0.28	9.3
R11. Fence, at lower quarry gate	0.50	16.7	--[4]	--
<u>Offsite</u>				
R12. Army Reserve Site, fence behind guard office	0.20	6.7	0.13	4.3
R13. University of Missouri Research Center, post near garden area	0.08	2.7	0.10	3.3
R14. Busch Memorial Wildlife Area, fence at weather station	0.23	7.7	0.24	8

[1] Picocuries per liter (pCi/L)
[2] DOE Standard for individuals in uncontrolled areas is 3 pCi/L
[3] Filters were damaged
[4] Detector and housing destroyed by shotgun pellets

Table 16. Calculated Bone Dose From Fish Ingestion

Isotope	Intake (1) uCi/Kg	50-Year Bone Dose Commitment, mrem(2)
Uranium-234 & Uranium-238	3.7×10^{-6}	0.006
Radium-226	7.1×10^{-6}	2.1
Lead-210	23×10^{-6}	0.3
Thorium-232	5.4×10^{-6}	0.012
Total		2.4

(1) Intake is based on the average concentrations in the edible portion of all four samples listed in Table 14.

(2) Doses are calculated for the ingestion of one kilogram (2.2 lbs) of fish from the Weldon Spring Femme Osage Slough.

FIGURE 1. WELDON SPRING SITE PIT AREA

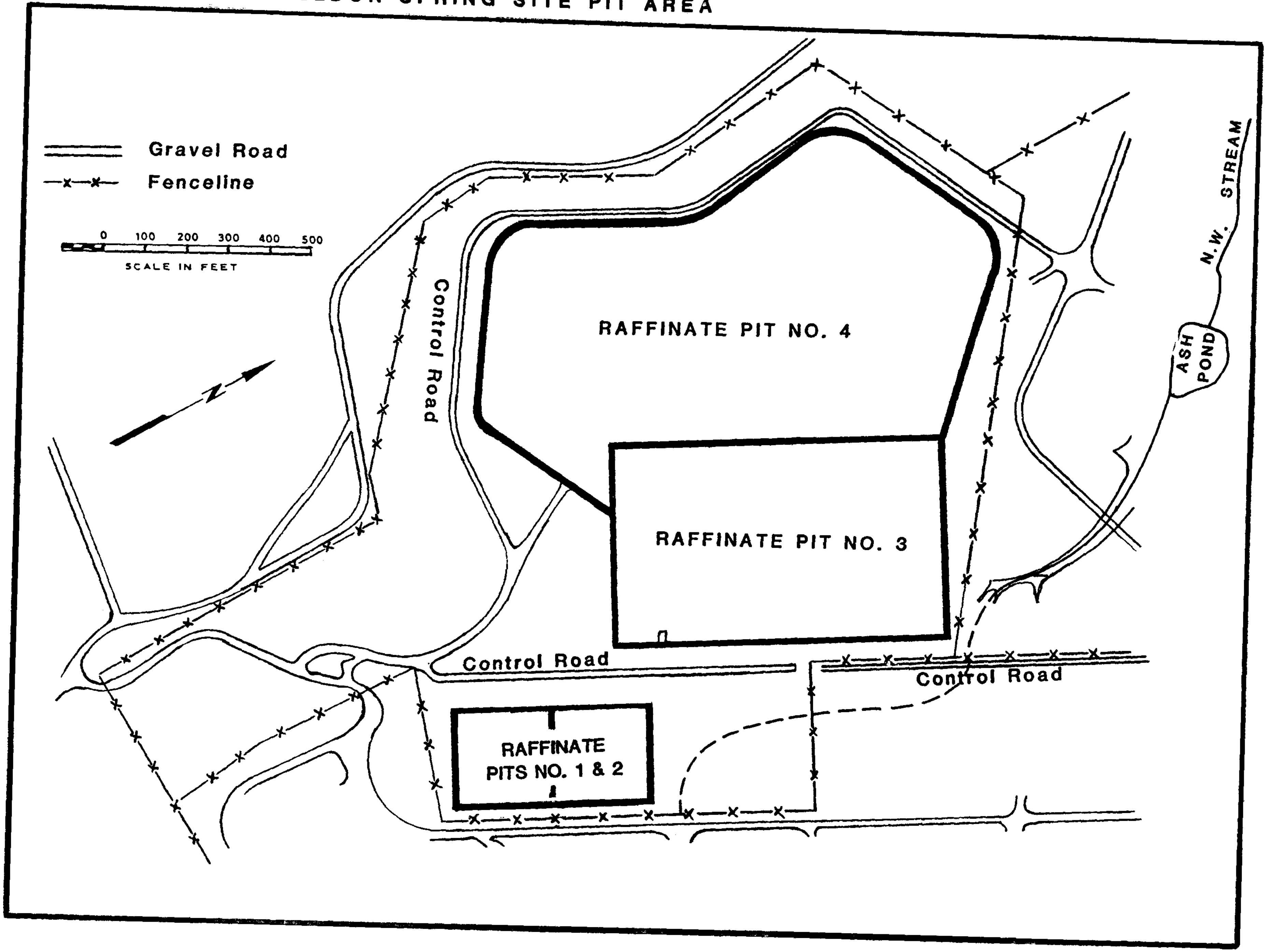

FIGURE 2. ROAD MAP, ST. LOUIS-WELDON SPRING AREA

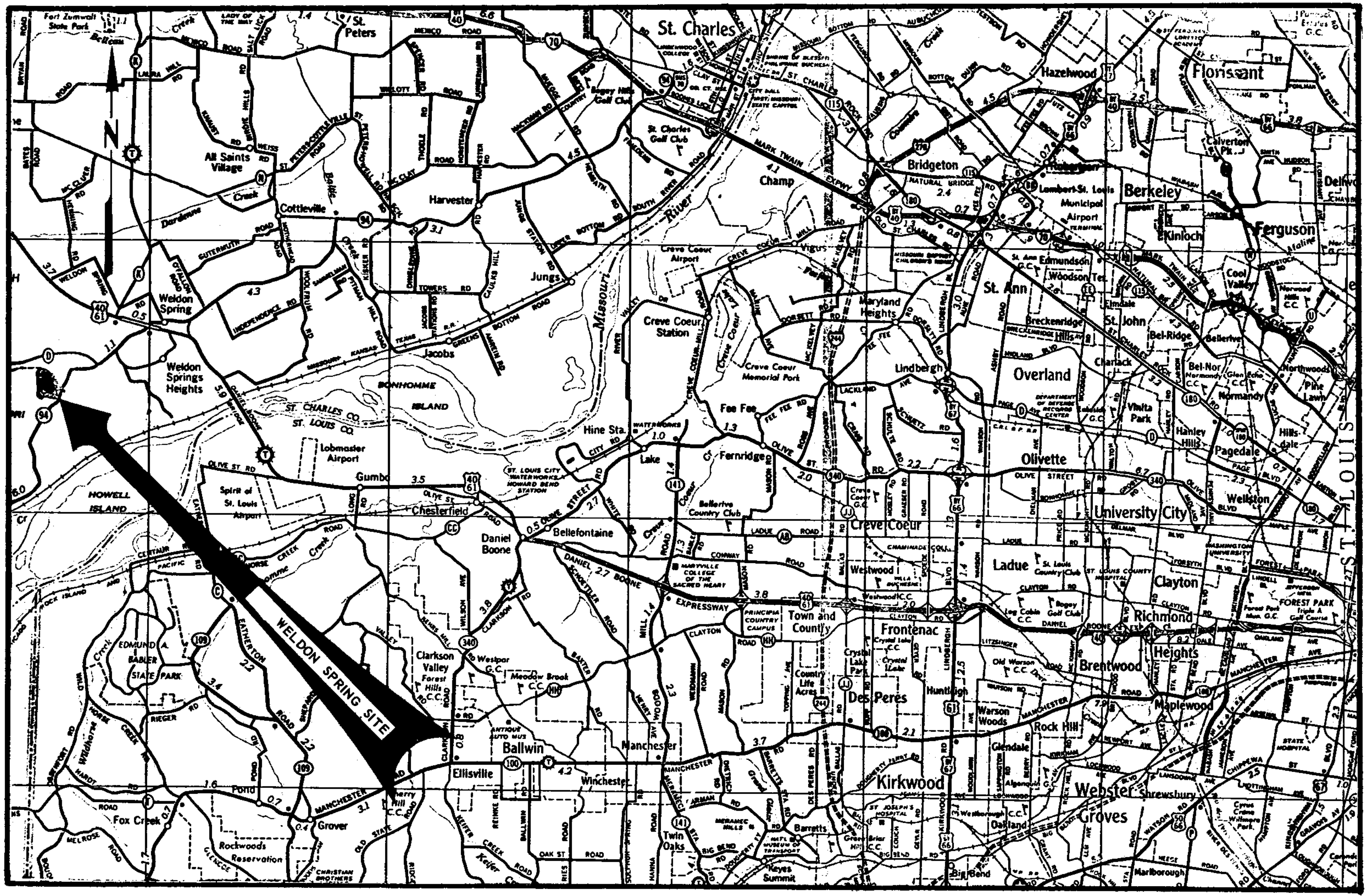

FIGURE 3. VICINITY MAP, WELDON SPRING SITE

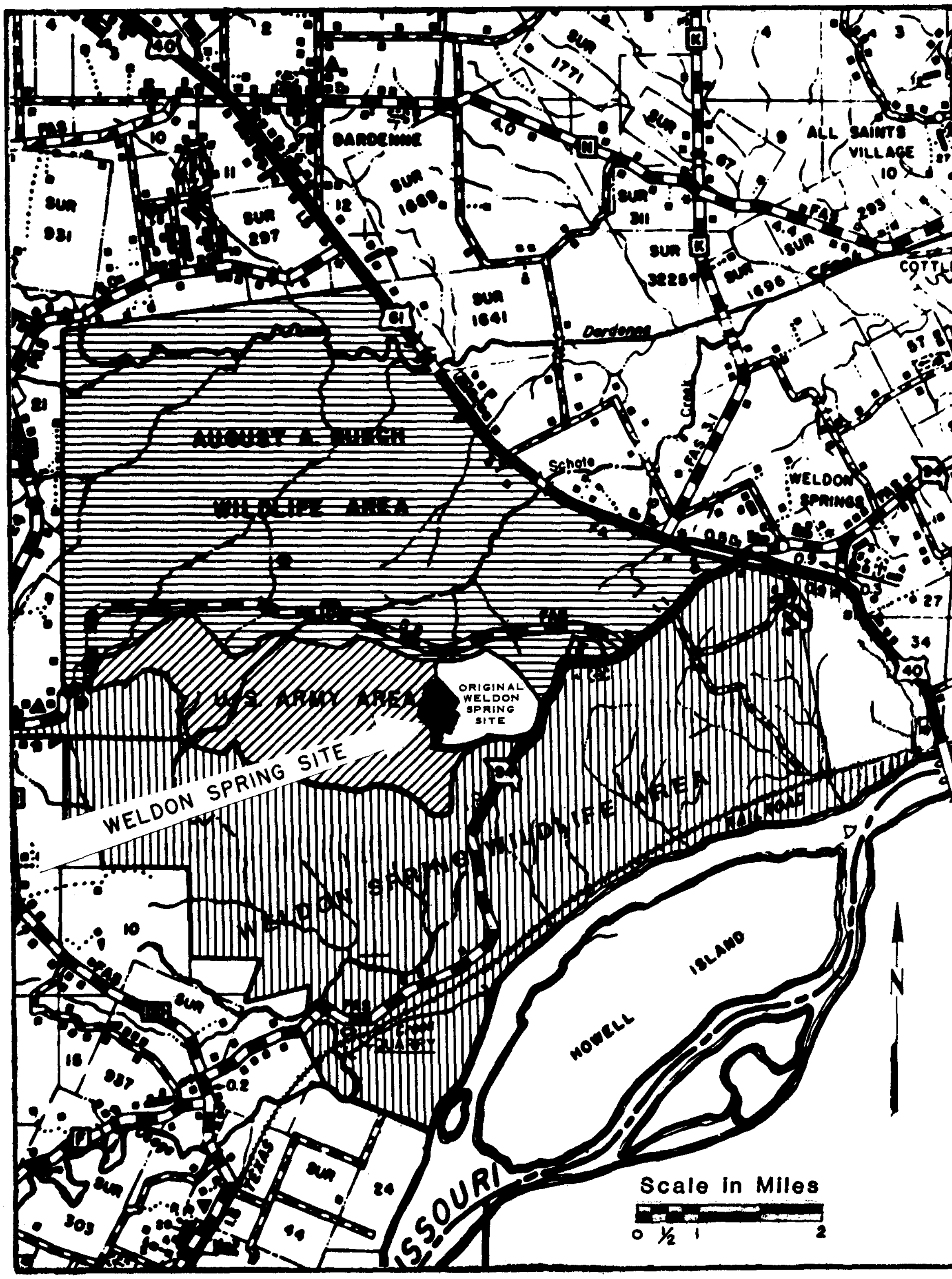

FIGURE 4. SECTION THROUGH ROCK QUARRY AT WELDON SPRING

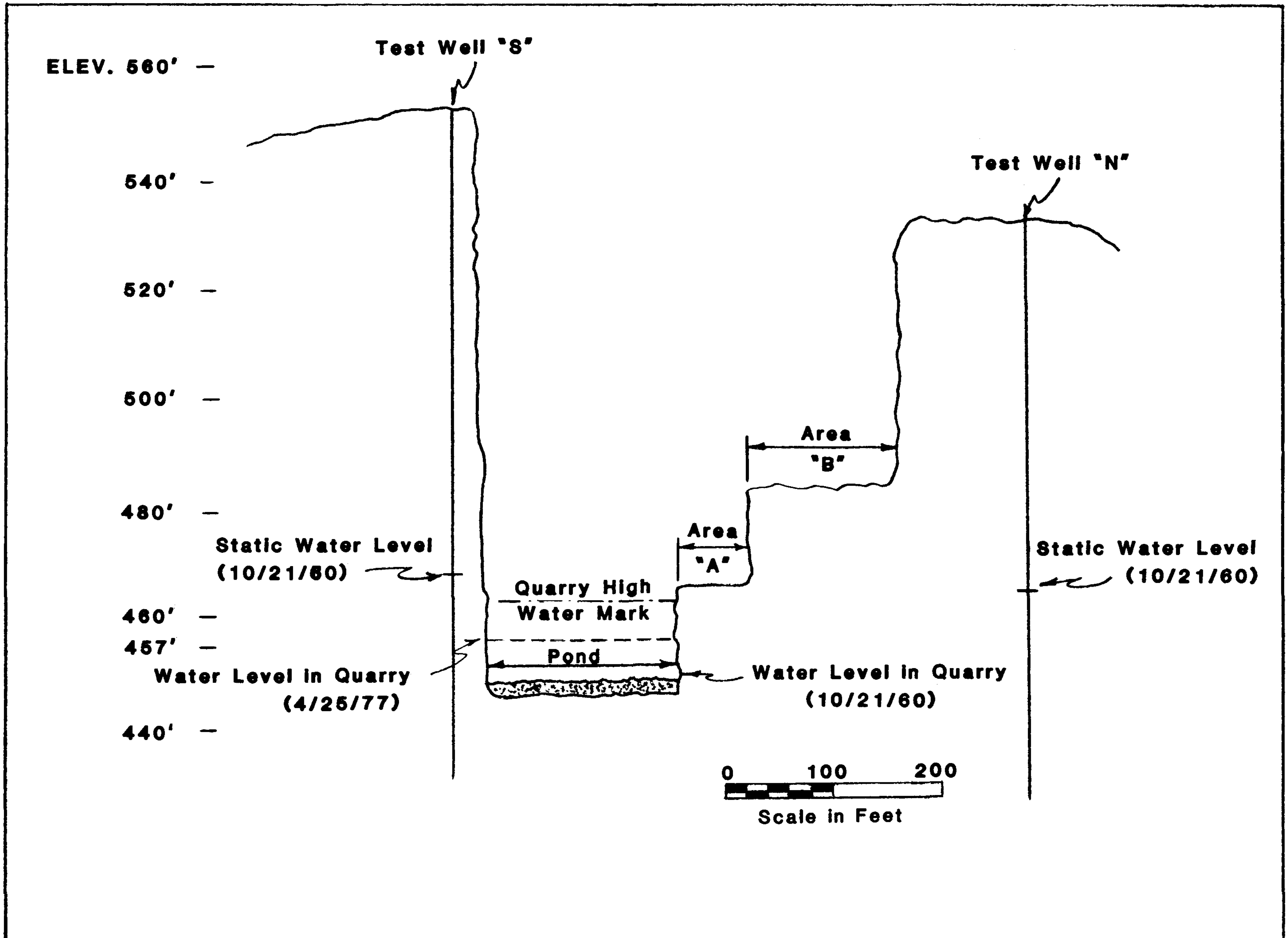

FIGURE 5. WELDON SPRING QUARRY AREA

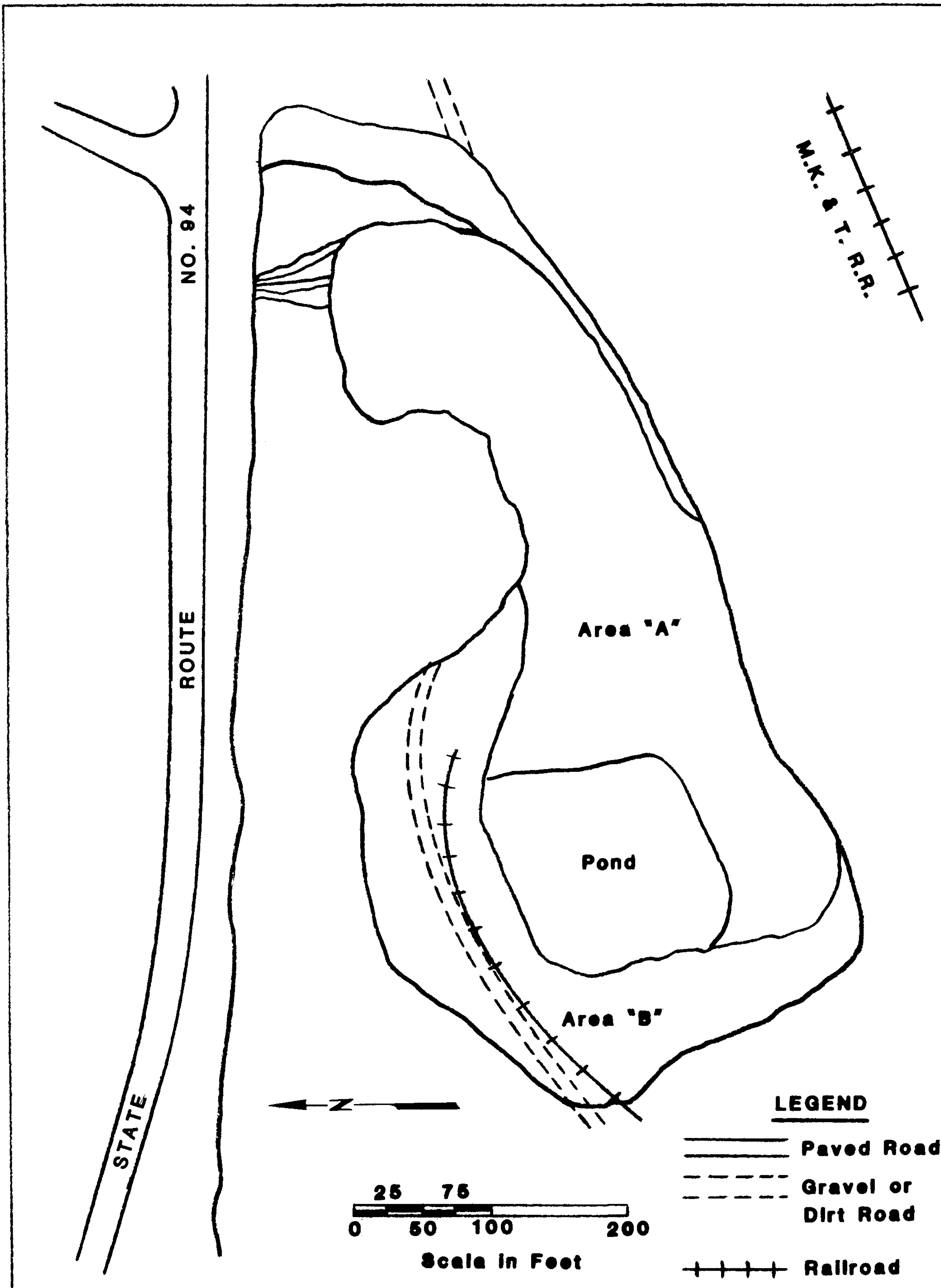

FIGURE 6. TEST WELL LOCATIONS AT WELDON SPRING QUARRY

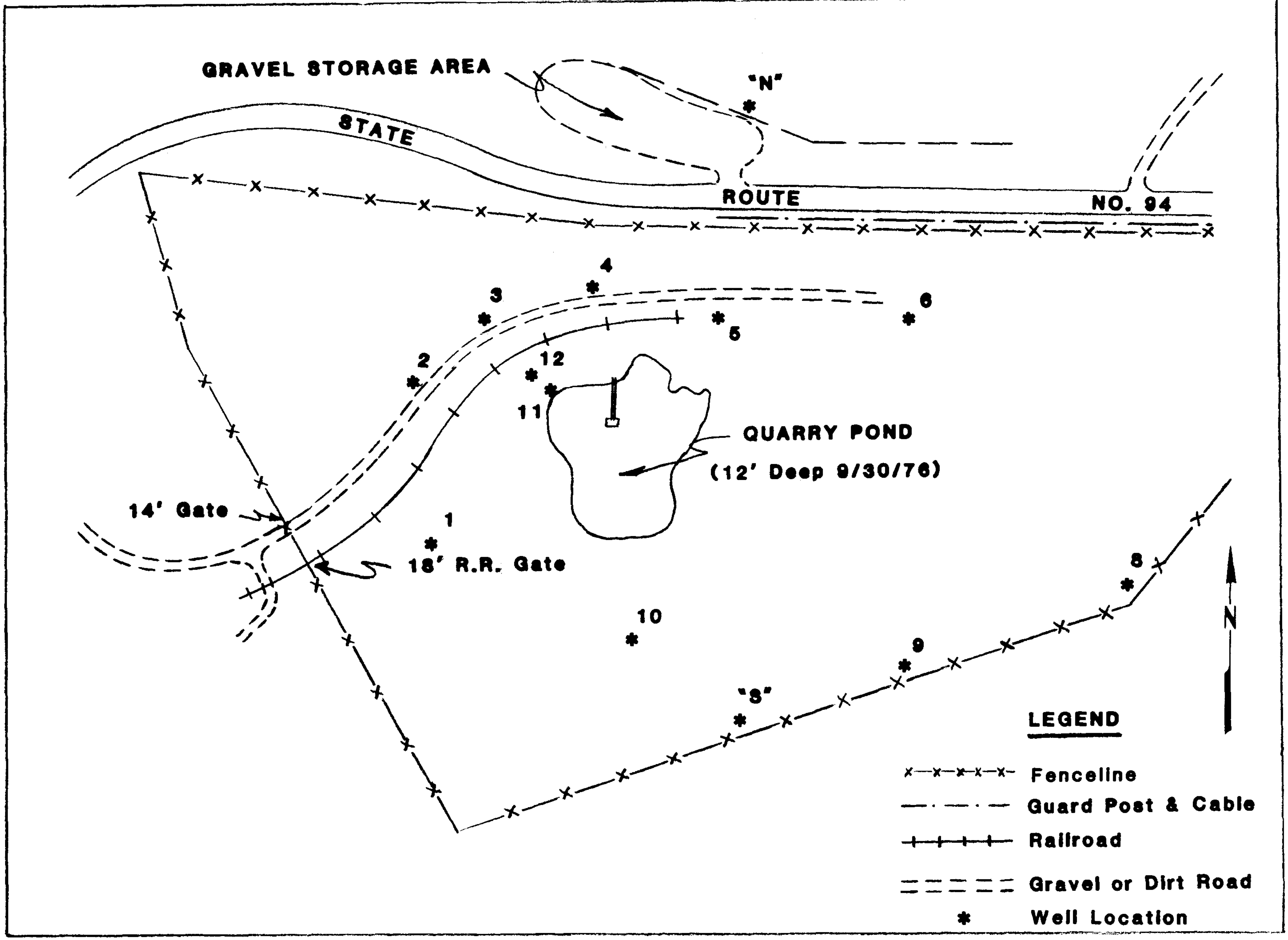

FIGURE 7.

WATER SAMPLING LOCATIONS AT WASTE PIT AREA AND PLANT SITE

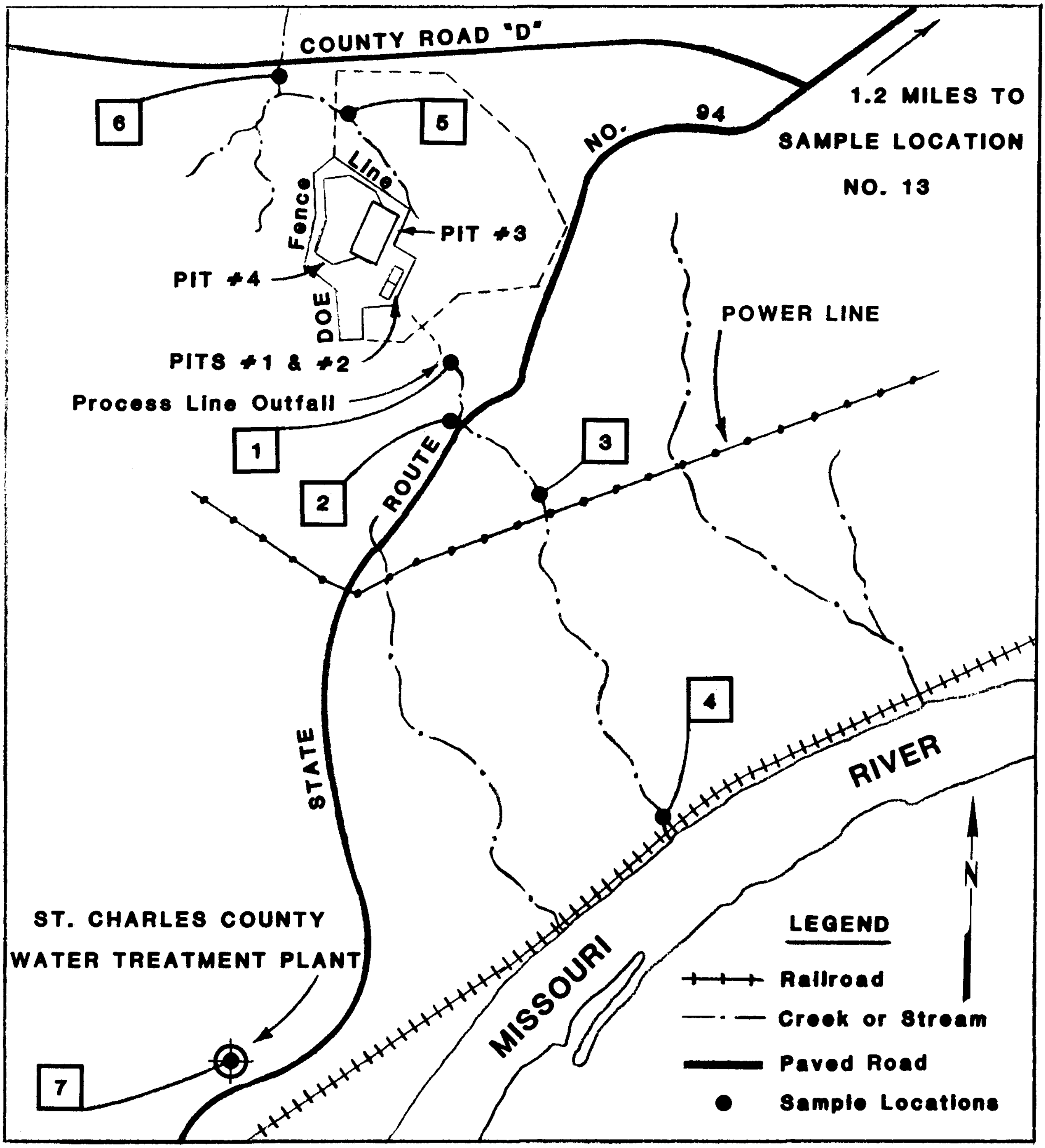

FIGURE 8. WATER SAMPLING LOCATIONS AT QUARRY AREA

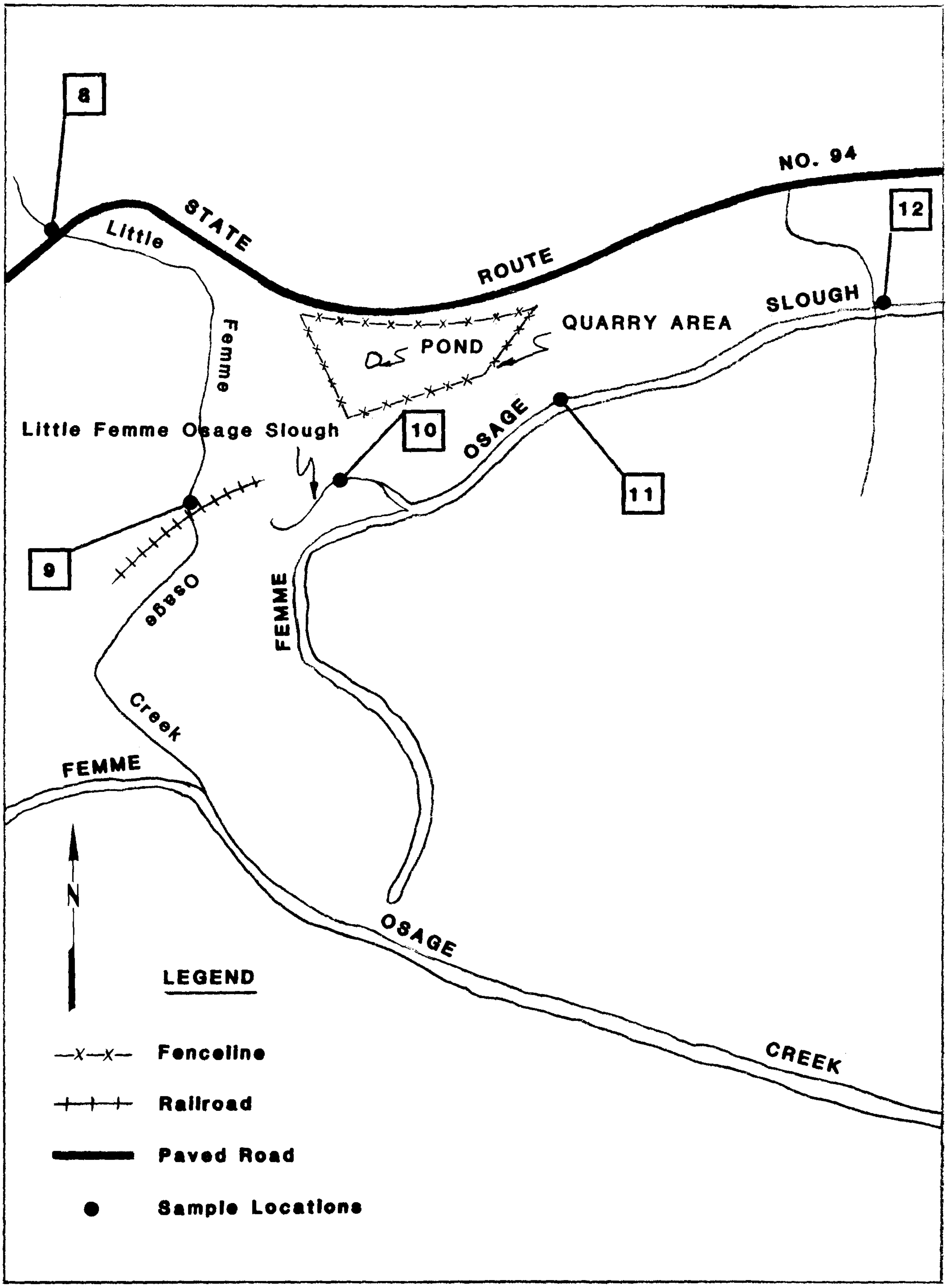

FIGURE 9.   WATER SAMPLING LOCATIONS AT QUARRY SITE AND VICINITY

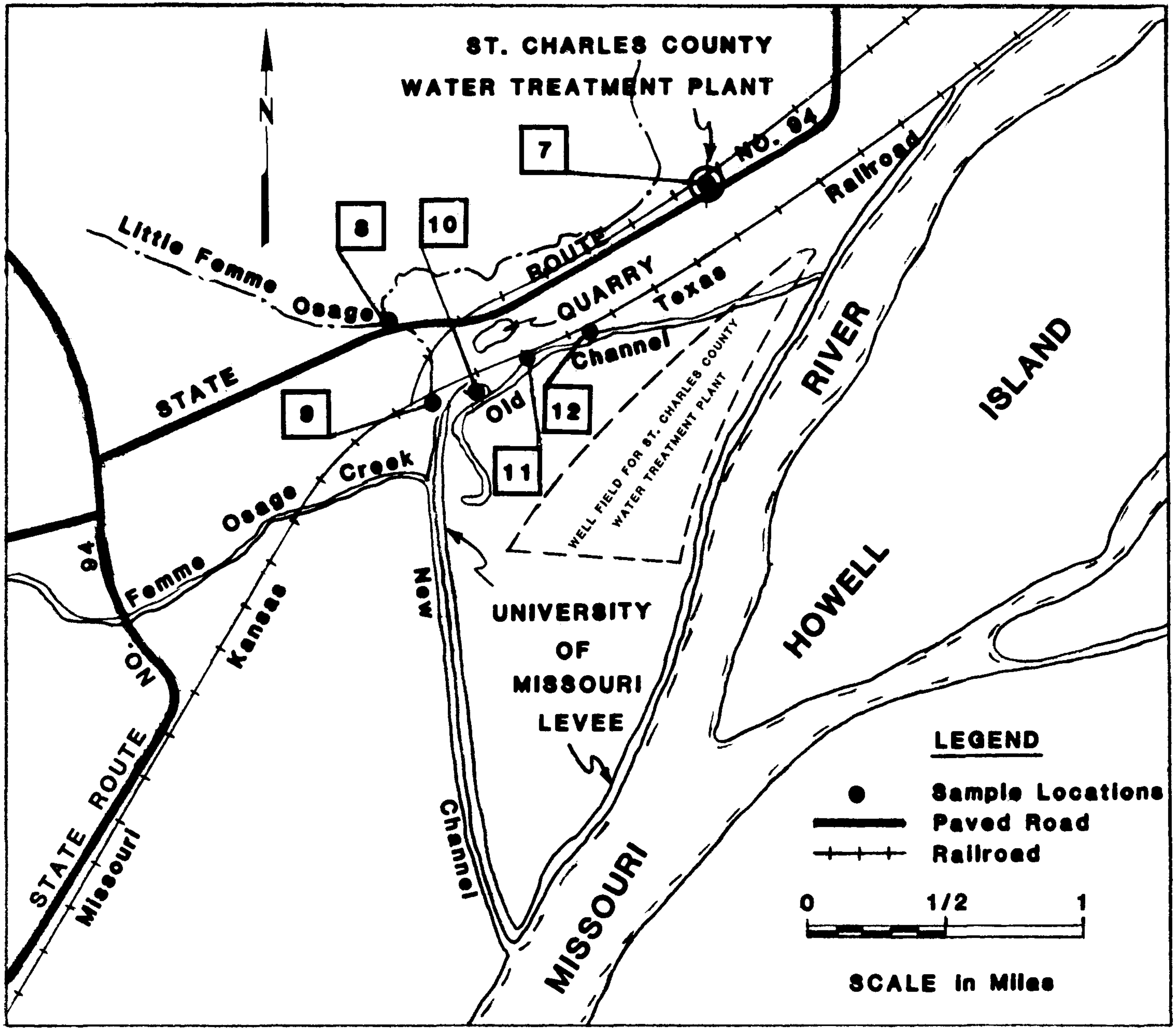

FIGURE 10.
WATER SAMPLING LOCATIONS, MISSOURI AND MISSISSIPPI RIVERS

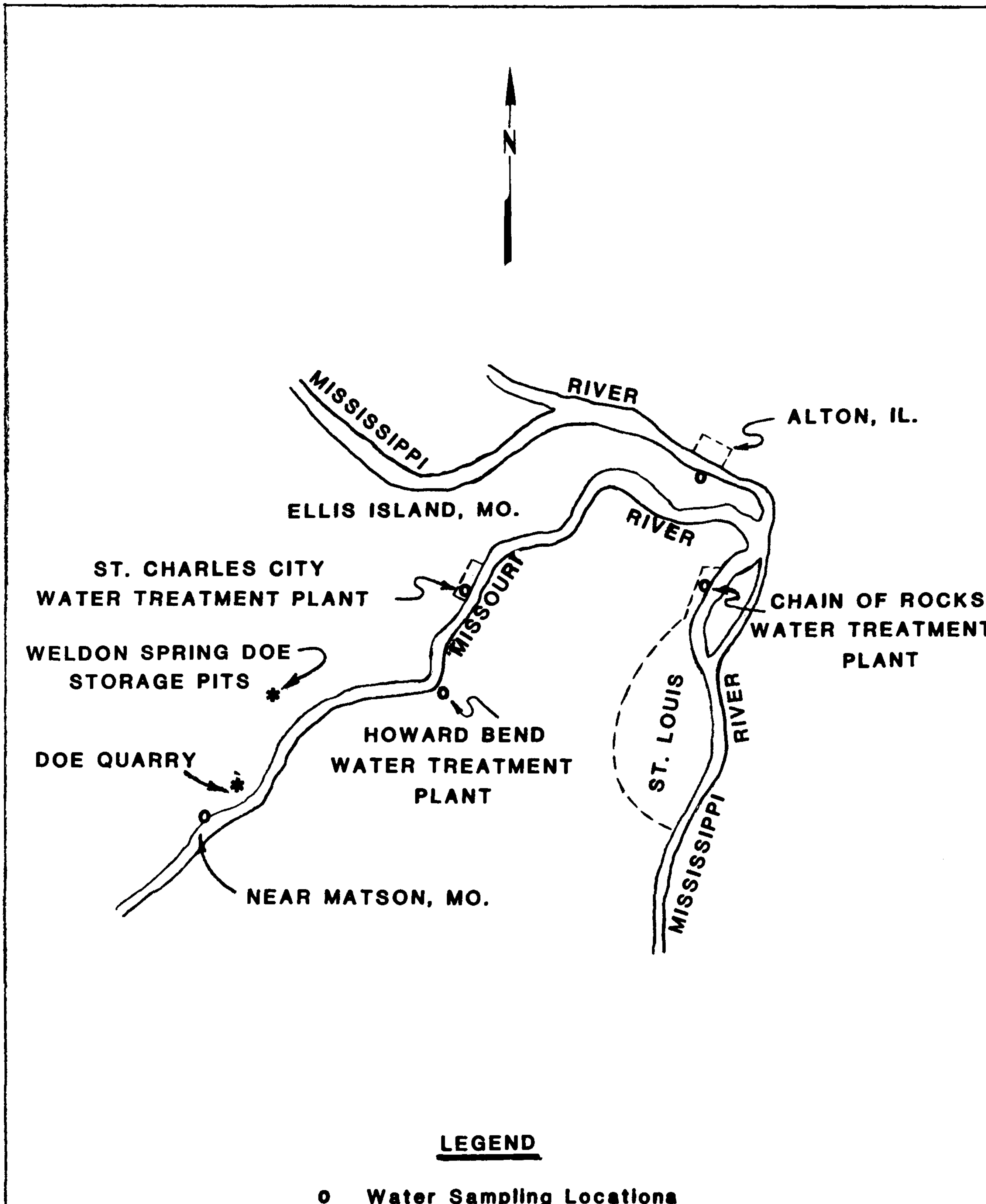

FIGURE 11. RADON-222 MONITORING LOCATIONS AT WELDON SPRING STORAGE SITE

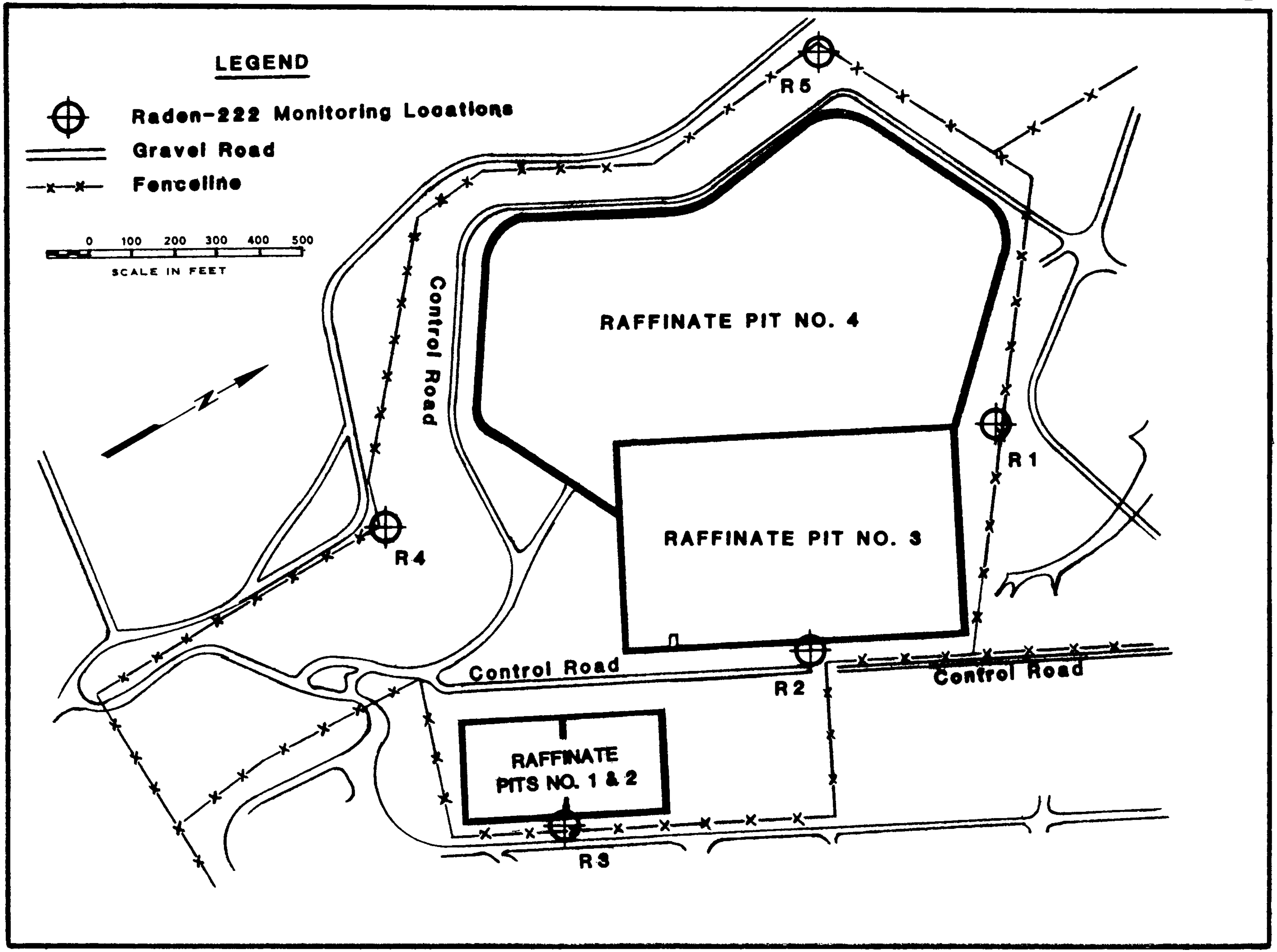

FIGURE 12. RADON-222 MONITORING LOCATIONS AT WELDON SPRING QUARRY

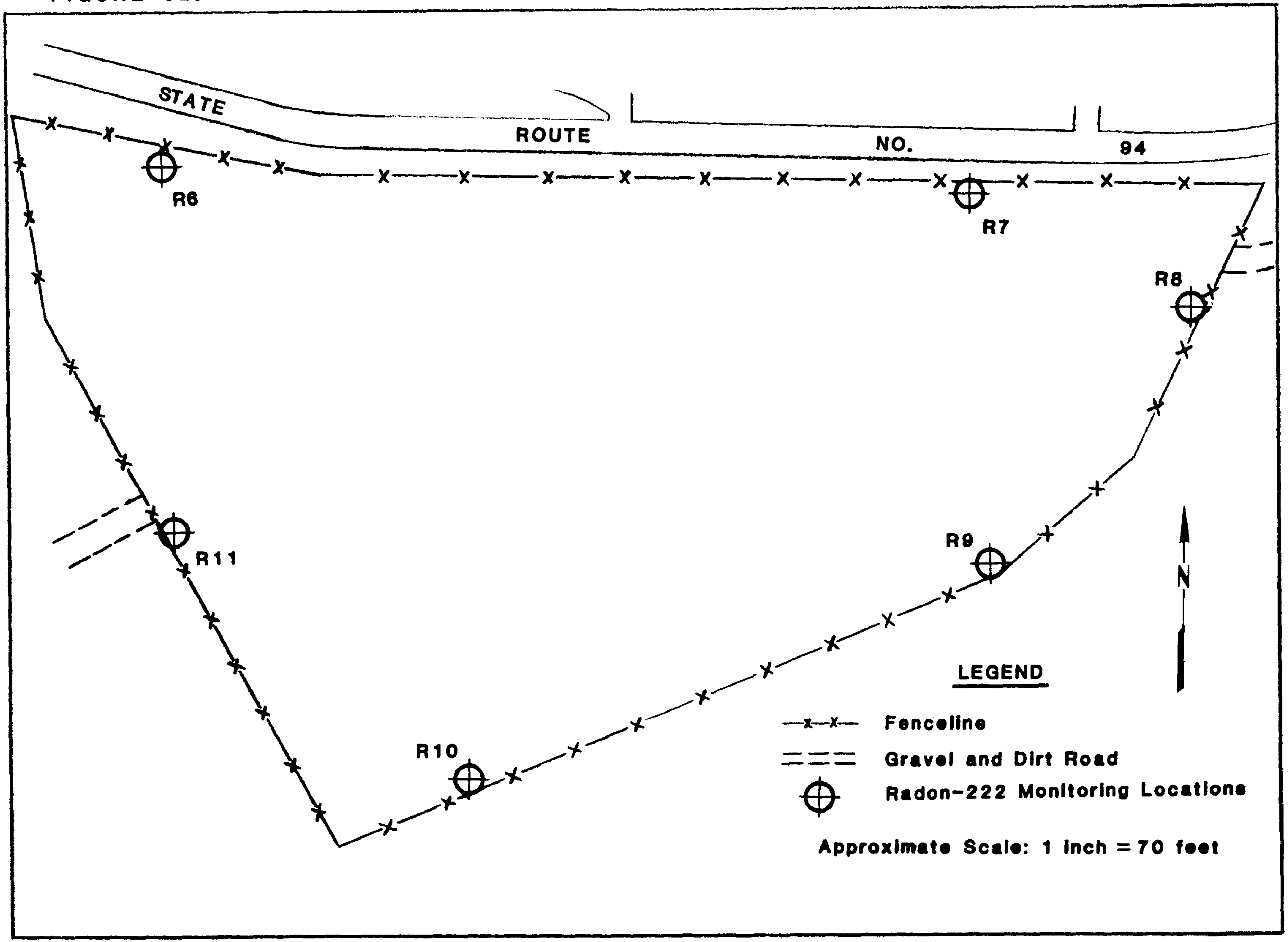

FIGURE 13. RADON-222 MONITORING LOCATIONS AT WELDON SPRING OFFSITE LOCATIONS