An Investigation of Tritium in the Gordon and Other Aquifers in Burke County, Georgia

Joseph H. Summerour, Earl A. Shapiro, Jerrry A. Lineback,
Paul F. Huddlestun, and Allan C. Hughes

GEORGIA DEPARTMENT OF NATURAL RESOURCES
Joe D. Tanner, Commissioner
ENVIRONMENTAL PROTECTION DIVISION
Harold F. Reheis, Director
GEORGIA GEOLOGIC SURVEY
William H. McLemore, State Geologist

Atlanta
1994

INFORMATION CIRCULAR 95

EXECUTIVE SUMMARY

Tritium was initially detected in the ground water of eastern Burke County, Georgia, in April, 1988 by the Environmental Radiation Program of the Georgia Environmental Protection Division (EPD) as part of a long-term monitoring program. Tritium was not detected again until 1991, when repeated sampling showed elevated tritium concentrations consistently present in ground-water samples from what was reported to be a deep public water supply well. At the direction of Governor Zell Miller, the Georgia Geologic Survey (GGS) Branch of the EPD initiated an investigation, in late 1991, to evaluate if Georgia aquifers had become polluted by tritium, the extent of that pollution, the possible threat to public health, and the pathways for tritium to enter the ground-water regime in Georgia. In March, 1992, the EPD received authorization for funding for this study from the U.S. Department of Energy (DOE).

The GGS conducted or sponsored seven sub-investigations in eastern Burke County as part of this project. These studies include:

1. tritium analysis of water samples from 109 water wells;
2. two studies of tritium abundance in the base flow of streams;
3. installation of fifteen ground-water monitoring wells at six sites, and tritium analyses of ground-water samples from those wells;
4. analysis of the subsurface geology;
5. analysis of the hydrogeology of the Upper Three Runs (water table) and Gordon aquifers;
6. geochemical evaluation of the Upper Three Run and Gordon aquifers; and
7. a seismic survey of the Savannah River channel in the study area.

The analysis of water samples from 109 water wells in eastern Burke County indicates that fifteen wells contain average tritium concentrations of 500 picoCuries or more. Nine of these fifteen wells are definitely drawing their water from the Upper Three Runs aquifer, and the remaining six wells are probably drawing their water from this source (based upon the evidence of this study). At least eight of the fifteen water wells are either ungrouted, lack casing, lack a surface pad, or have experienced failure of the casing.

The base flow studies indicate tritium pollution of the Upper Three Runs aquifer throughout all of eastern Burke County. All samples contain less than 18 percent of the of the Maximum Contaminant Level (MCL) for tritium set by the Environmental Protection Agency (EPA). The highest concentrations of tritium (up to 3,500 picoCuries per liter) occur north of Hancock Landing. Tritium levels decrease to the northwest, west, and southeast of this area.

The ground-water monitoring wells show no detectable concentrations of tritium in the uppermost confined aquifer (Gordon aquifer) in eastern Burke County in five out of six wells. The sixth Gordon monitoring well may be detecting a very local point source of tritium pollution. Although tritium is present in all of the monitoring wells sampling the Upper Three Runs aquifer, to this date, all water samples have been well below the MCL for tritium set by EPA.

The analysis of the subsurface geology indicates that there are complex facies changes within many of the sedimentary units. These facies changes complicate the flow of ground water in the study area. The Savannah River has cut through the sediments that make up the Upper Three Runs aquifer in at least the northern half of the study area. McBean Creek and several other small streams in the study area have also cut through the aquifer.

Analysis of the hydrogeology of the shallow aquifers indicates that the Upper Three Runs aquifer is compartmentalized by streams in the study area resulting in numerous small, local, ground-water flow regimes. Recharge and discharge of the Upper Three Runs aquifer is primarily restricted to these local regimes. The recharge area for the Gordon aquifer is most likely in southern Richmond and northwestern Burke Counties, outside of the study area. Within the study area, the Gordon aquifer discharges to the Savannah River. The potential direction of vertical groundwater flow is generally downward from the Upper Three Runs aquifer into the Gordon aquifer. However, the confining bed between these two aquifers retards such movement of ground water.

The Upper Three Runs aquifer consists of two hydrogeochemical layers and the Gordon aquifer consists of a single hydrogeochemical layer. Lateral geochemical variation occurs in the direction of ground-water flow. The primary conclusions of this study are as follows:

1. there is no evidence of a threat to public health due to tritium pollution of aquifers in Burke County;
2. there is widespread tritium pollution of the Upper Three Runs (water table) aquifer in eastern Burke County, but this pollution is below the concentration of tritium allowed for drinking water by EPA;
3. there is no evidence of regional tritium pollution of the Gordon aquifer in eastern Burke County; and
4. existing data are not adequate to fully resolve the issue of the pathway for tritium into the Upper Three Runs aquifer. However, the investigation indicates that some pathways are more likely than others and suggests specific pathway models for future investigation.

A series of thirteen recommendations are made including one recommendation for increasing public awareness, two recommendations concerning public health issues, seven recommendations for further technical studies of the aquifers, and three recommendations for long-term monitoring.

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

An Investigation of Tritium in the Gordon and Other Aquifers in Burke County, Georgia

INTRODUCTION

Statement of Problem

The Environmental Radiation Program of the Georgia Environmental Protection Division (EPD) has conducted routine sampling of water wells for tritium in Burke County, Georgia since 1979 (see Appendix 1, p. 70, for sampling dates and analytical results). This sampling program was initiated because of concerns over environmental releases of tritium from the nearby Savannah River Site (SRS) in South Carolina. Public water supply wells (i.e., those used by communities and trailer parks) have been of special interest in this program. As part of this regular sampling program, a water sample was collected on April 4, 1988 from one of three public water supply wells at the Delaigle Trailer Park in eastern Burke County (Figure 1, p. 3). The chemical analysis of the sample from this well (designated by EPD as Delaigle Trailer Park well #3) indicated a tritium concentration of 600 (± 100) picoCuries per liter, which is equivalent to three percent of the U.S. Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL) for tritium. [Note: The EPA MCL is based on the requirement that a person not receive a radiation dose of more than 4 millirem per year from drinking water. For comparison, the natural background dose at sea level from cosmic rays is approximately 26 millirem, and the total radiation dose from all natural sources of radiation is approximately 300 millirem (National Council on Radiation Protection and Measurements, 1987). Drinking two liters of water, containing 20,000 picoCuries per liter, every day for a year results in a radiation dose of 4 millirem]. A follow-up sampling on April 10, 1990 did not detect any tritium in the water from this well (detection limits were only 300 picoCuries per liter at that time). However, samples, collected on January 8 and July 18, 1991 measured 1200 (±200) picoCuries per liter, which is six percent of the EPA MCL.

The well data report for public water systems, submitted to the EPD by the driller of the Delaigle well, stated that this well was drilled into the Gordon aquifer to a depth of 300 feet. As reported, this well was constructed using 200 feet of six inch polyvinyl chloride (PVC) casing, which was pressure grouted from 200 feet to the surface. Below this interval, from 200 to 300 feet, the well was constructed of four inch PVC screen. This information and the results of the tritium analyses raised the following concerns:

1. a public water supply well, used by dozens of local residents, was polluted by tritium, in amounts significantly above normal background concentrations (background is approximately 39 picoCuries per liter);
2. at least one of the deep, confined, drinking water aquifers (the Gordon aquifer) in Burke County appeared to be polluted with tritium; and
3. if the Gordon aquifer were polluted with tritium, that pollution might represent the dilute leading edge of a tritium plume entering the aquifer through an undetermined pathway from the Savannah River Site in South Carolina.

To address these concerns, Georgia Governor Zell Miller directed EPD to conduct an investigation to:

1. map the extent of tritium pollution in the ground water of eastern Burke County;
2. to evaluate if there was any current or future threat to public health; and
3. to assess how the tritium entered the ground-water regime.

The Georgia Geologic Survey (GGS) Branch of EPD was assigned the responsibility to conduct the investigation. Drilling was initiated at Tritium Project cluster site TR92-1 (see p. 24 for a description of the monitoring well program) in December, 1991. In March of 1992, the U. S. Department of Energy (DOE) provided EPD with $800,000 to perform the study.

Previously, in late July, 1991, the DOE entered into an agreement with the U. S. Geological Survey (USGS) for an investigation of the conditions under which ground water from SRS in South Carolina can migrate beneath the Savannah River, into Georgia aquifers. Originally referred to as the Underflow Project, this study is now known as the Trans-River Flow Project. The USGS Trans-River Flow Project and the GGS Tritium Project have different but complimentary goals and objectives. The focus of the Trans-River Flow Project is the modeling of the deeper aquifers in Georgia and South Carolina. The focus of the tritium investigation is on a documented pollution occurrence in the shallow aquifers. However, each project generates information that contributes to the success of the other project.

Location of Study Area

Burke County is located on the eastern margin of Georgia, along the Georgia-South Carolina border (Figure 1). The northern boundary of the County is approximately 15 miles southeast of Augusta, Georgia, while the southern boundary is approximately 70 miles northwest of Savannah, Georgia. Burke County is bounded on the east by the Savannah River and to the north by McBean Creek. The DOE's Savannah River Site is located directly across the Savannah River from Burke County.

The northern boundary of Burke County lies 12 to 19 miles south of the Fall Line, which separates the Piedmont from the Coastal Plain physiographic province. Burke County is located in the Vidalia Upland District of the Coastal Plain physiographic province (Clark and Zisa, 1976). The Vidalia Upland District is moderately dissected by streams, and relief varies from 100 to 150 feet. Stream valleys are narrow except for major rivers. Major rivers usually have wide flood plains occupied by wetlands.

The study area is located in the eastern third of Burke County. The study area extends from the Savannah River on the east to Brier Creek on the west, and from the Richmond-Burke County line (McBean Creek) on the north to the Burke-Screven County line on the south.

Geology/Hydrogeology

The Cretaceous and Tertiary sedimentary rocks that underlie Burke County were deposited in the form of several alternating layers of permeable sands and limestones separated by less permeable layers of calcareous or kaolinitic clay. Ground water flows more easily through the permeable layers, which, if they yield significant quantities of water to wells and springs, are termed "aquifers" (a glossary of technical terms is provided on p. 70). The less permeable clay layers, termed "aquitards" (or confining beds), form barriers to the upward or downward movement of ground water and yield little water to wells. Aquitards have a strong influence on local and regional ground-water flow and may serve to protect high quality ground water in one aquifer from natural contamination or human induced pollution that may exist in an overlying or underlying aquifer.

In the Tritium Project study area, the entire sedimentary section from the ground surface downward to the unweathered Paleozoic igneous and metamorphic basement is included in the Southeastern Coastal Plain hydrogeologic province (Aadland and others, 1992). The hydrostratigraphic terminology used in this report (Figure 2, p. 4) was developed following the USGS guidelines.

The sandy Tobacco Road Formation and the Irwinton Sand Member of the Dry Branch Formation (Barnwell Group) make up the top 100 to 200 feet of the stratigraphic section in eastern Burke County (Figures 2 and 3). Some beds, lenses, and laminae of clay occur within the Irwinton Sand (Huddlestun and Hetrick, 1986). The calcareous sands of the Griffins Landing Member of the Dry Branch Formation underlie the Irwinton Sand Member and crop out along the bluffs of the Savannah River and in the deeper tributary streams along with the underlying Utley Limestone Member of the Clinchfield Formation. The Barnwell Group forms the local unconfined or water table aquifer and was initially referred to as the "Jacksonian" aquifer. The chrono-stratigraphic term "Jacksonian" was used by Vincent (1982) and Brooks and others (1985) to identify the water table aquifer (on the basis of its Jacksonian (Upper Eocene) age). At the USGS Trans-River Flow Miller's Pond site (Figure 1), the water table aquifer is referred to Upper Floridan (Clarke and others, in review), however Miller (1986) defines the Floridan aquifer as a carbonate aquifer; thus the term "Floridan" is inappropriate. The SRS equivalent of the "Jacksonian" aquifer is referred to as the Upper Three Runs (Aadland and others, 1992). As this is a more proper hydrostratigraphic term, hereinafter, the water table aquifer in eastern Burke County will be referred to as the Upper Three Runs aquifer.

The Lisbon Formation underlies the Barnwell and consists of two members, the McBean Member in the northern part of the study area and the Blue Bluff member in the southern part of the study area (Figure 2). The Blue Bluff member is dense, clayey, calcareous, and has a low permeability. In central and southern Burke County, the Blue Bluff member lies between the Barnwell Group sands and limestones that make up the Upper Three Runs aquifer and the underlying Gordon aquifer. In this position, the Blue Bluff member of the Lisbon Formation serves as a local aquitard (confining layer). The McBean Member, on the other hand, is a permeable calcareous sand to sandy limestone and has the potential to permit ground-water recharge (by downward leakage) from the Upper Three Runs aquifer into the Gordon aquifer.

The Gordon aquifer in Burke County is made up of two sandy units: the Bennock Millpond sand/Still Branch sand, and unnamed Congaree-equivalent sand (Huddlestun, in preparation). [Note: for this report, the Bennock Millpond sand and the Still Branch sand are informal descriptive names, with Bennock Millpond and Still Branch being the general locations where these lithologic units crop out]. The Gordon aquifer is very porous, transmissive, and yields large amounts of potable water to wells in eastern Burke County. In the central and southern part of the study area, the Gordon has a slight hydrogen sulfide (rotten egg) odor and its use as water supply is less viable.

The Gordon aquifer is underlain by an aquitard formed by the regionally extensive kaolinitic clay at the top of the Oconee Group (Figure 2). This kaolin is characteristically mottled, strongly pigmented, dense, impermeable, and varies in thickness from 10 feet to 50 feet and is stratigraphically equivalent to the Snapp Formation of South Carolina. Hereinafter, in this report, this kaolinitic clay unit will be referred to as the Snapp Formation. In South Carolina, the Snapp Formation is part of the upper portion of the Meyers Branch Confining System (Aadland and others, 1992).

The Snapp Formation is underlain by sand and kaolinitic sand which contains occasional streaks or thin beds of lignite. This unit is the "Ellenton" Formation, which is lowest Tertiary formation in the section (Figure 2). In Tritium Project monitoring well TR92-1C (described on p. 24), this sand aquifer is referred to as "sand within the Meyers Branch Confining System". For the sake of brevity, hereinafter, this aquifer will be referred to as the Meyers Branch "aquifer". Beneath the "Ellenton" Formation, in the Cretaceous part of the Oconee Group in eastern Burke County, the stratigraphic section consists of sand beds interbedded with the lenticular kaolinitic clay beds of the Steel Creek Formation, which forms the lower part of the Meyers Branch Confining System, in South Carolina (Aadland and others, 1992). Underlying the Steel Creek Formation is the Gaillard Formation, within which lies the Dublin aquifer. Generally, the Oconee Group consists of a series of fining upward sand sequences with the most permeable sands near the base of each sequence and poorly permeable to impermeable, fine-grained kaolinitic sands or kaolins in the upper part of each sequence. As these clays or kaolins are not areally extensive, the stack of Oconee Group sands is probably hydrologically interconnected and forms a single aquifer in the study area, especially in the updip areas.

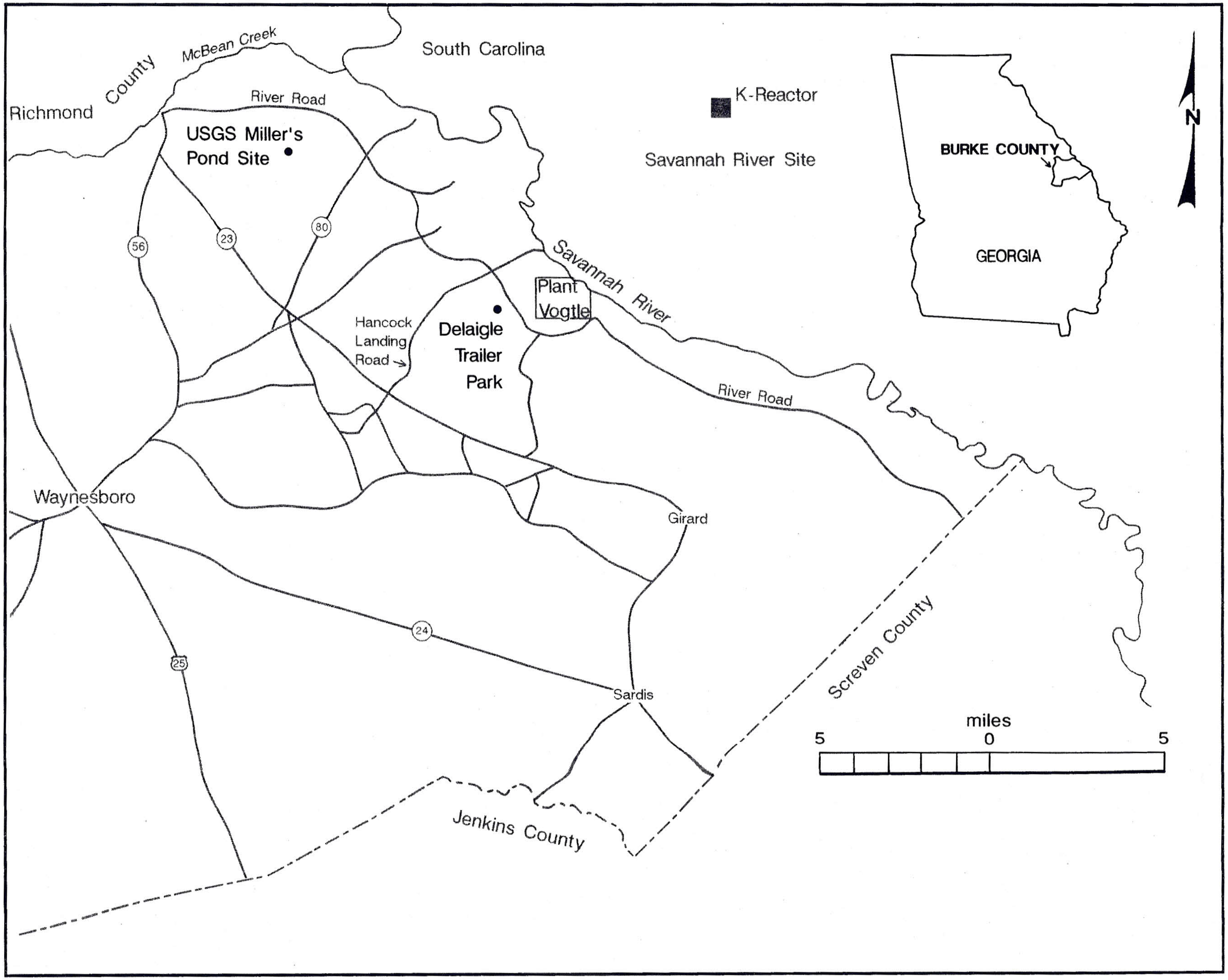


Figure 1. Index map of eastern Burke County.

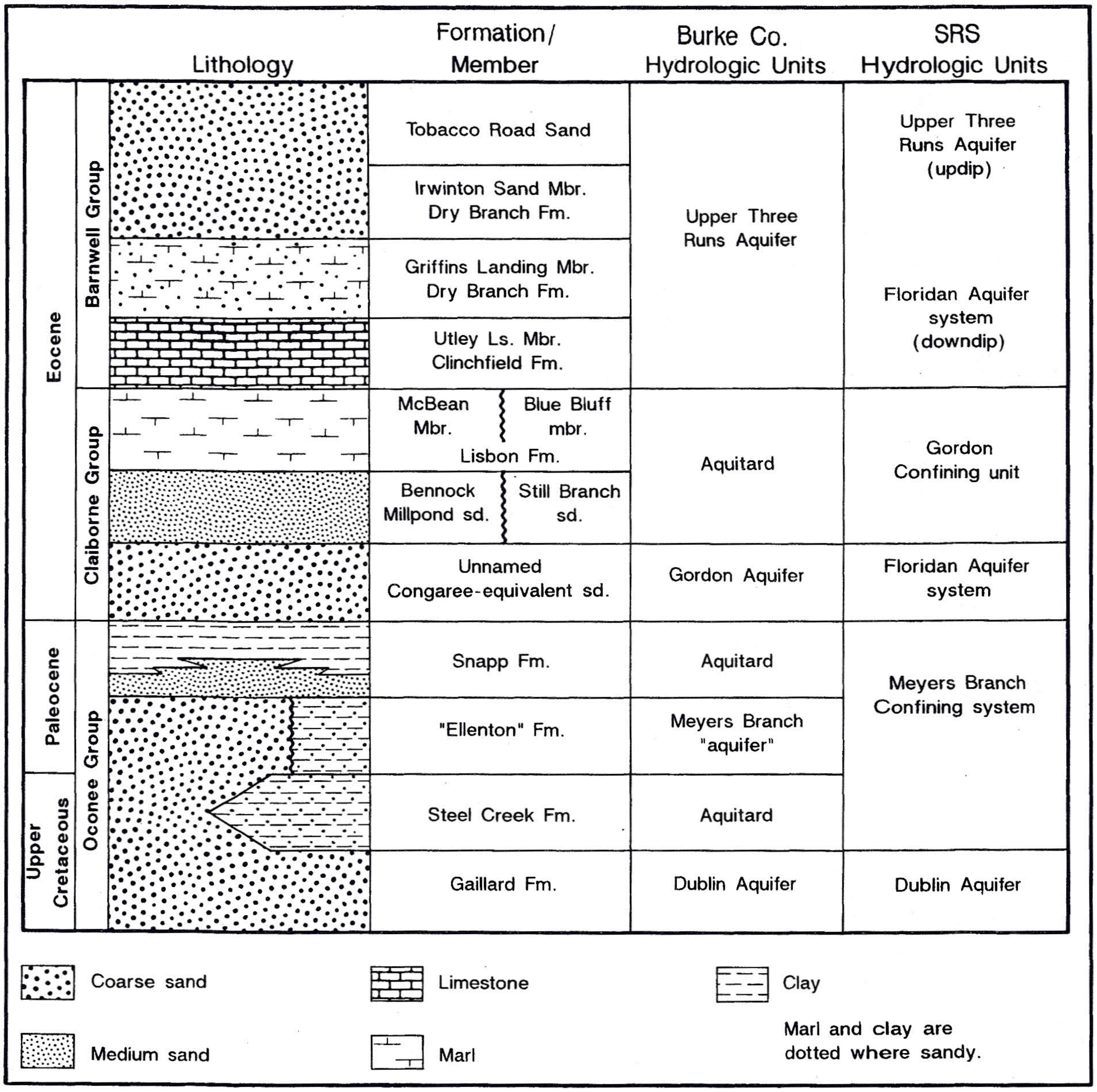


Figure 2. Stratigraphic and hydrostratigraphic units for Burke County and SRS area. SRS terminology from Aadland and others, 1992.

Regional dip on the top of the Blue Bluff member in eastern Burke County is approximately 10 feet per mile to the southeast. However, there may be local or formational deviations from this dip. No faults have been firmly documented in eastern Burke County. Faye and Prowell (1982) postulated a northeast-southwest trending fault (the Millett fault) extending from near Barnwell, South Carolina to near the town of Perkins in Jenkins County, Georgia. The town of Girard, in southern Burke County lies along this postulated fault. An investigation that included core drilling, seismic surveys, and other methods, conducted by the Bechtel Corporation in 1982 for the Georgia Power Company, found no evidence for the existence of the Millett fault. Snipes and others (1993) identified a fault (the Pen Branch fault) trending northeast-southwest across SRS in South Carolina and projected this fault into Georgia, citing elevation differences in the Utley Limestone exposed along the bluffs of the Savannah River immediately south of Plant Vogtle. Henry (unpublished data, 1994) has identified the possible extension of the Pen Branch fault in the sediments underlying the Savannah River in the vicinity of Hancock Landing. The possibility of the Pen Branch fault occurring in Burke County is suggested by variances in subsurface elevations shown in structural contour and formational thicknesses shown in isopach maps. No surface expression of the fault plane has been observed.

Weather

Burke County has a climate that is characterized by warm, humid summers and mild winters. Data collected at the National Weather Service office at Bush Airport (south

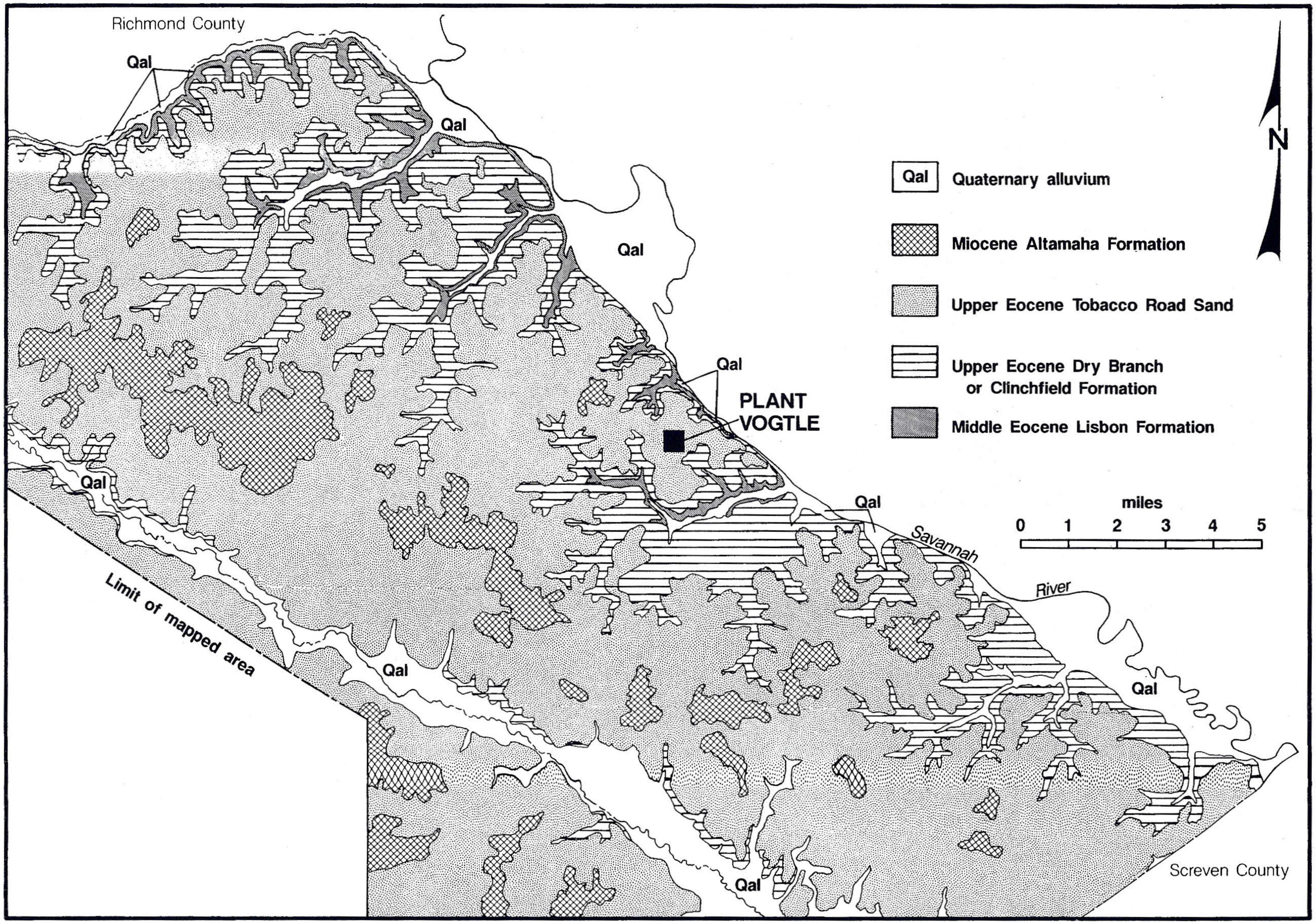


Figure 3. Geologic map of eastern Burke County (modified after Hetrick, 1992).

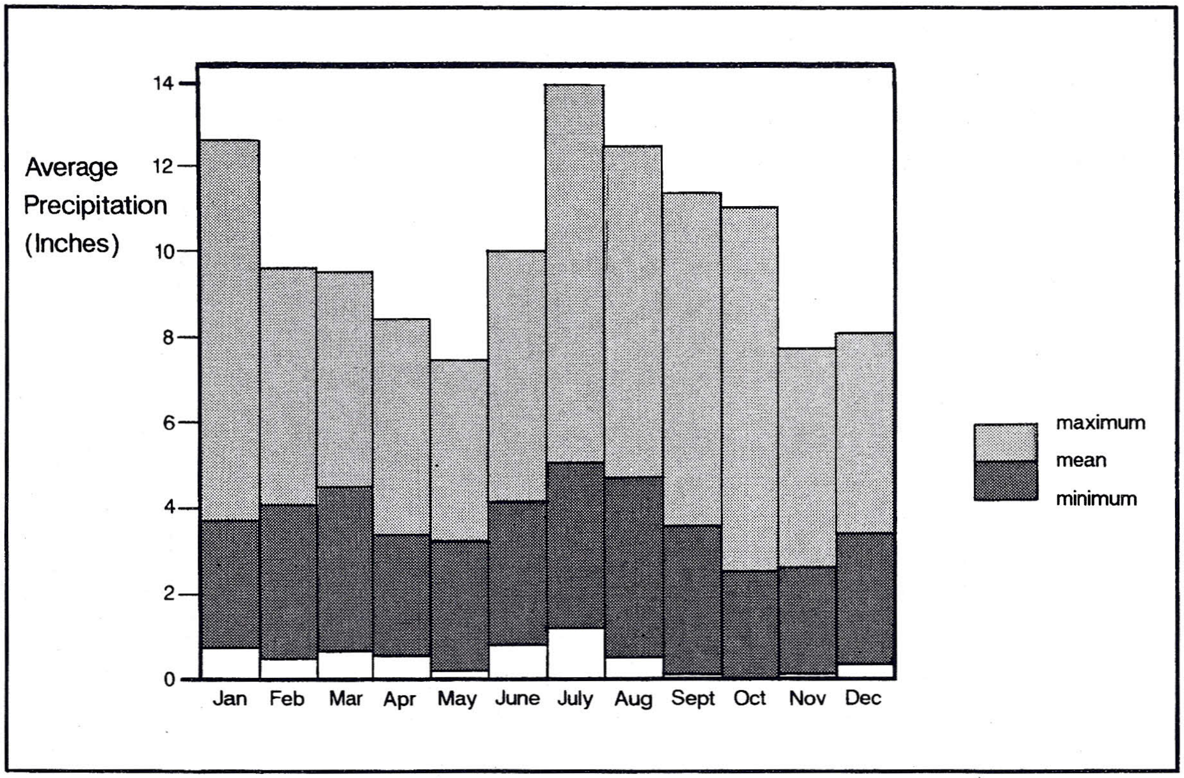


Figure 4. Mean and maximum monthly precipitation values at Bush Airport, Augusta, Georgia (from Gorday, 1985).

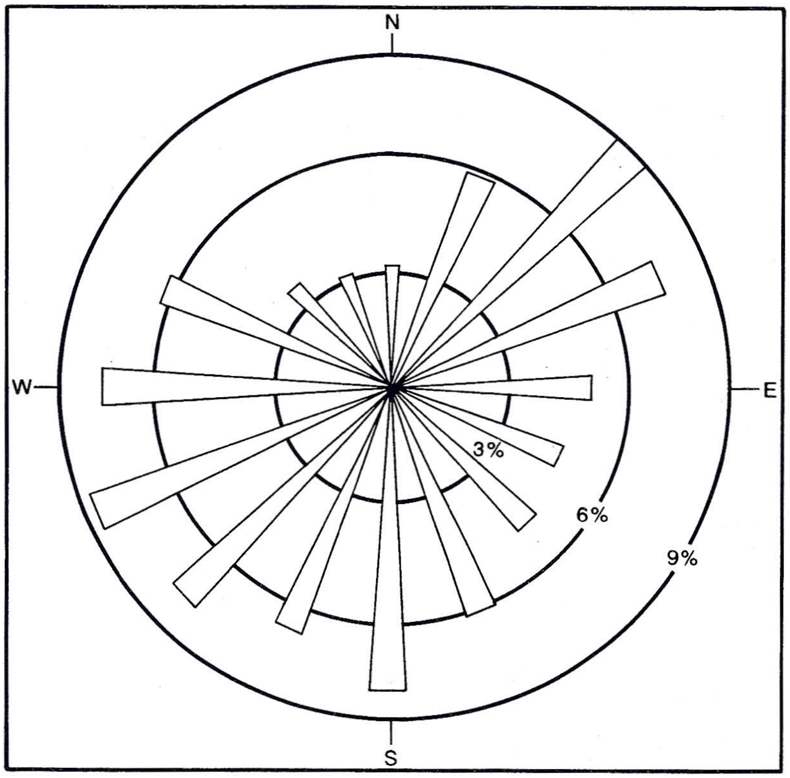


Figure 5. Wind rose plot (1987 - 1991) for the SRS-Burke County area, showing direction from which the wind blows and frequency of occurrence. (Modified from Aadland and others, 1993.)

Table 1
Daily water use for Burke County, Georgia, in 1987 and 1990.
1a. Withdrawals in million gallons per day.

Source	1987 volume (1)	% of 1987 total (1)	1990 volume (2)	% of 1990 total (2)
Ground water	8.53	13.82	6.99	9.88
Surface water	53.19	86.18	63.77	90.12
Total	61.72	100.00	70.76	100.00

1b. Withdrawals by water-use categories in million gallons per day.

Category	1987 (1)	1990 (2)
Thermo-electric generation	52.09	64.54
Irrigation	6.91	3.02
Public supply	1.48	2.11
Domestic/ Commercial	1.05	0.91
Livestock	0.19	0.18

(1) Bachtel and Boatright, 1992.
(2) Fanning and others, 1992.

of Augusta) indicate that monthly mean high temperatures range from 91°F in July to 58°F in December and January, while monthly mean low temperatures range from 39°F in December to 72°F in July (Baker, 1979).

Mean annual precipitation at Bush Airport measures approximately 44.6 inches per year (Baker, 1979). The highest monthly precipitation rates usually occur in July and August, which coincides with peak thunderstorm activity. The lowest precipitation occurs in October and November (Figure 4) (Baker, 1979). Information furnished by Plant Vogtle indicate yearly rainfall totals similar to those measured at Bush Airport. The primary wind direction, measured at the SRS in South Carolina, is from the northeast with secondary wind directions from the west and south (Figure 5).

Cultural Features

Burke County is the second largest county in Georgia with an area of 834.1 square miles (Bachtel and Boatright, 1992). As of the 1990 Census, the population of Burke County is 20,579, of which 72.3 percent is rural and 27.7 percent urban. As of 1989, the per capita income for the county was estimated at $10,380, and ranked 147th of the

Table 2

Yearly totals of SRS planned tritium atmospheric releases (1954 - 1992).

Year	Released Tritium-Ci (Curies)	Year	Released Tritium-Ci (Curies)	Year	Released Tritium-Ci (Curies)
1954	216 (1)	1967	689,000 (1)	1980	317,000 (1)
1955	36,100 (1)	1968	762,000 (1)	1981	395,000 (1)
1956	469,000 (1)	1969	469,000 (1)	1982	434,000 (1)
1957	1,200,000 (1)	1970	513,000 (1)	1983	618,000 (1)
1958	2,340,000 (1)	1971	621,000 (1)	1984	786,000 (1)
1959	1,050,000 (1)	1972	822,000 (1)	1985	667,000 (2)
1960	951,000 (1)	1973	601,000 (1)	1986	425,000 (3)
1961	886,000 (1)	1974	937,000 (1)	1987	590,000 (3)
1962	1,110,000 (1)	1975	518,000 (1)	1988	462,000 (3)
1963	1,130,000 (1)	1976	304,000 (1)	1989	310,000 (3)
1964	1,520,000 (1)	1977	381,000 (1)	1990	250,000 (3)
1965	744,000 (1)	1978	360,000 (1)	1991	200,000 (3)
1966	675,000 (1)	1979	333,000 (1)	1992	156,000 (3)

(1) Murphy and others, 1991.
(2) Arnett and others, 1992.
(3) Aadland and others, 1993.

159 counties in Georgia. The largest contributor to the economy of Burke County is the Vogtle Electric Generating Plant, operated by Georgia Power Co. As of 1991, there were 20 manufacturing plants in the county, producing apparel, furniture, lumber, and textiles. As defined by 1987 data, 38.1 percent (317.79 square miles) of Burke County land is utilized as farmland, ranking 45th of 159 counties. Of the farmland, 38 percent (120.76 square miles) is identified as harvested cropland. As of 1990, irrigated cropland accounts for 21.92 percent (26.48 square miles) of the harvested cropland (Fanning and others, 1992). The major crops of Burke county are peanuts, soybeans, corn, cotton, wheat, oats, and rye.

The production of electricity by Georgia Power's Plant Vogtle represents the county's largest user of water, with 1990 estimates of 64.54 million gallons per day, while irrigation (3.03 millon gallons per day) and public supply (2.11 millon gallons per day) rank second and third (Fanning and others, 1992). 1987 estimates (Bachtel and Boatright, 1992) indicate that 37 percent of the Burke County population is served by public water supplies. Water use data for Burke County, for 1987 and 1990, are shown in Table 1 (p. 7).

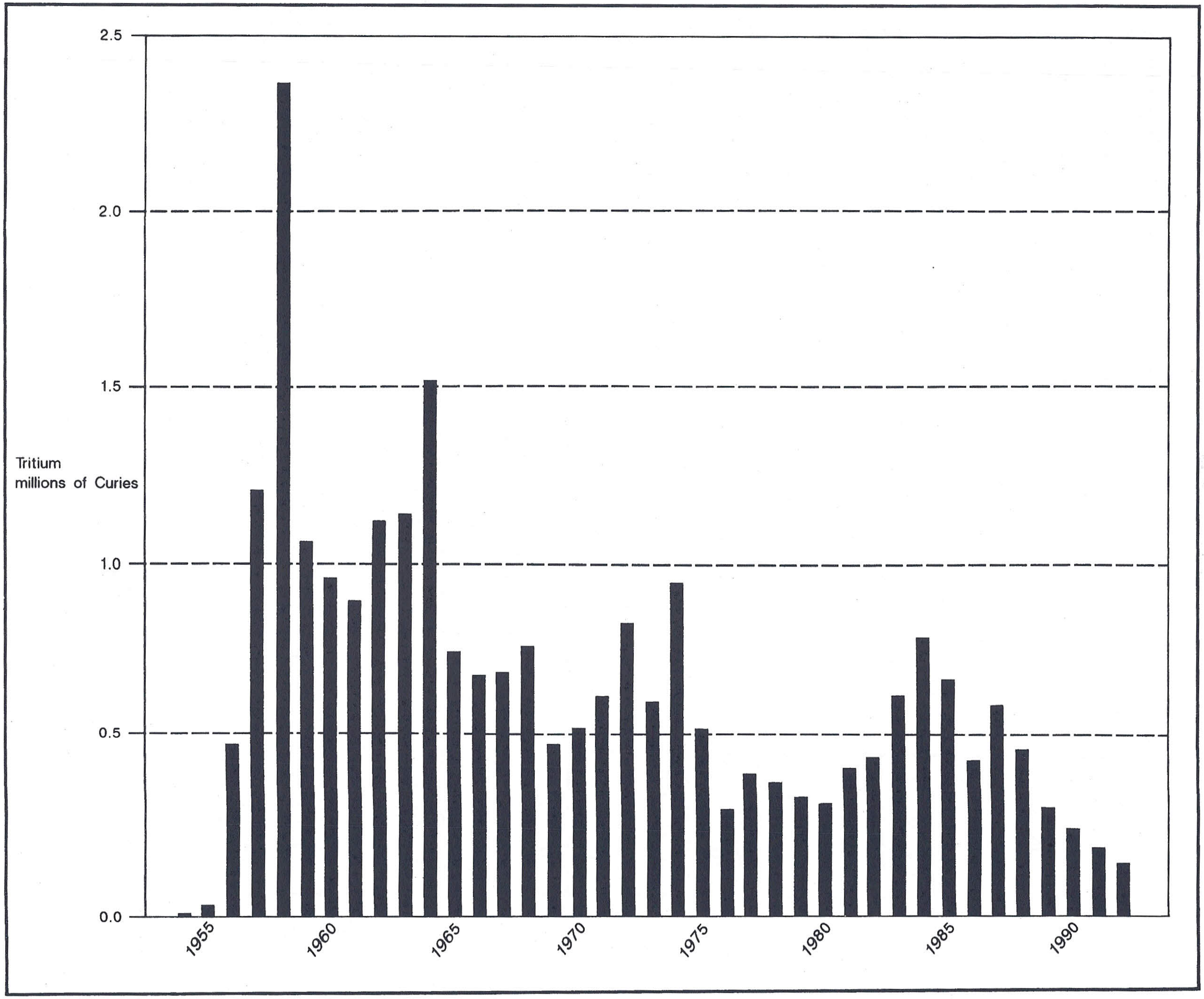


Figure 6. Bar graph showing comparisons of yearly SRS atmospheric tritium releases, 1954 - 1992. See Table 2 for sources. Values are not corrected for radioactive decay.

Table 3

Summary of significant unplanned releases from the Savannah River Site.

Date of Release	Release in Curies	Pathway	Percent Tritiated Water	Percent Elemental Tritium	Release Area
05/02/74 (1)	479,000	Atmospheric	<1	>99	Separations area
12/31/75 (1)	182,000	Atmospheric	99.4	0.6	Separations area
03/37/81 (1)	33,000	Atmospheric	99.7	0.3	Separations area
07/16/83 (1)	56,000	Atmospheric	~1	~99	Separations area
03/23/84 (1)	7,500	Atmospheric	~70	~30	Separations area
09/02/84 - 09/07/84 (1)	57,900	Atmospheric	99	1	Separations area
01/31/85 (1)	9,285	Atmospheric	54	46	Separations area
03/27/85 (1)	19,422	Atmospheric	99.9	0.1	Separations area
07/31/87 (1)	172,000	Atmospheric	2.7	97.8	Separations area
03/01/88 (1)	20,000	Atmospheric	14	86	Separations area
06/07/88 (1)	3,650	Atmospheric	4	96	Separations area
10/06/88 (1)	7,000	Atmospheric	~11	~89	Separations area
12/07/88 (1)	3,500	Atmospheric	99.5	0.5	Separations area
12/22/91 - 12/25/91 (2)	5,700	Surface water	100	0	Pen Branch
05/25/92 (3)	80	Atmospheric	Not specified (4)	Not specified (4)	Separations area
07/12/92 (3)	12,000	Atmospheric	Not specified (4)	Not specified (4)	Separations area

(1) Murphy and others, 1991.
(2) Arnett and others, 1992.
(3) Aadland and others, 1993.
(4) Primarily elemental tritium.

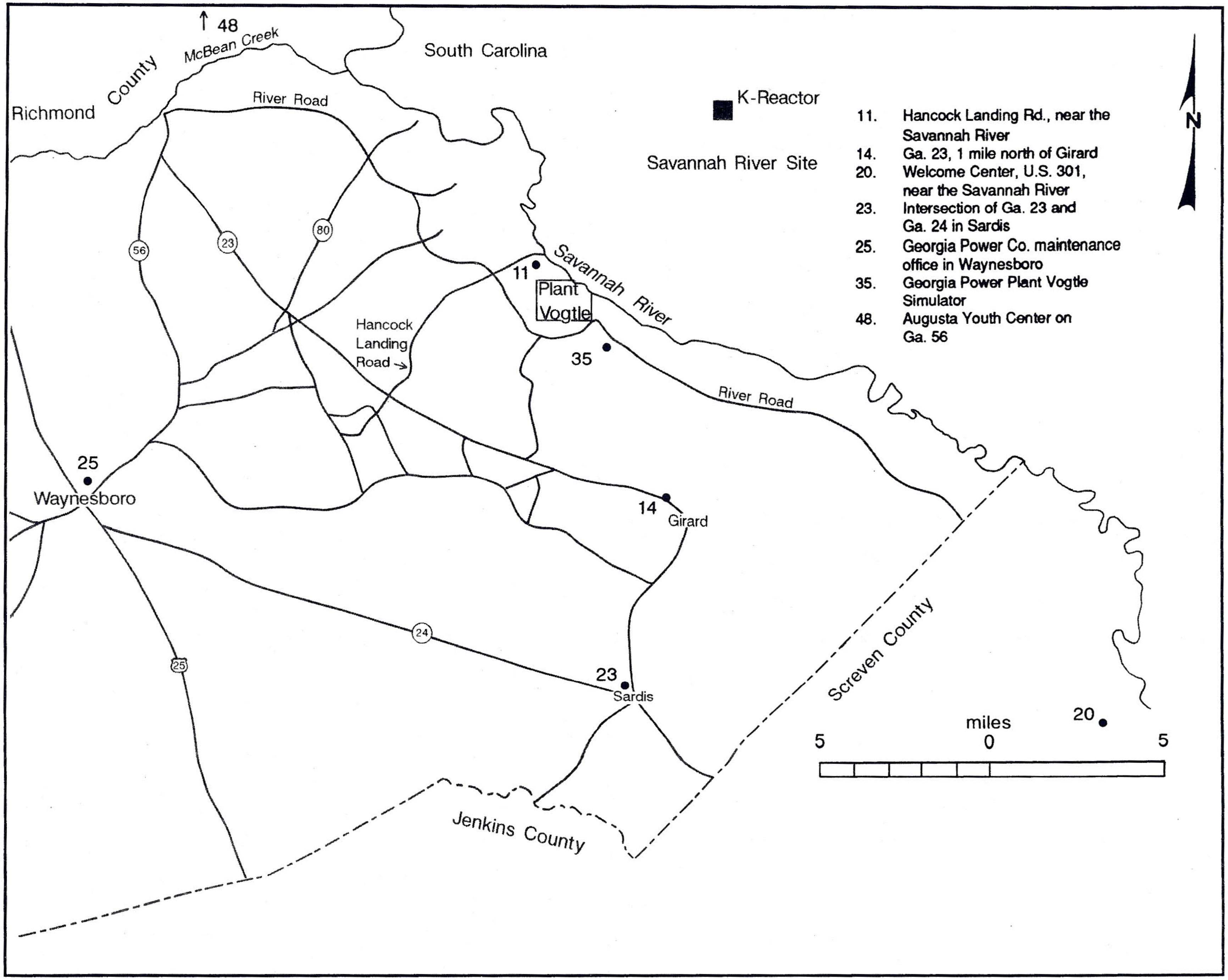


Figure 7. Locations of EPD rainfall collection sites. Site #48 is located in Augusta.

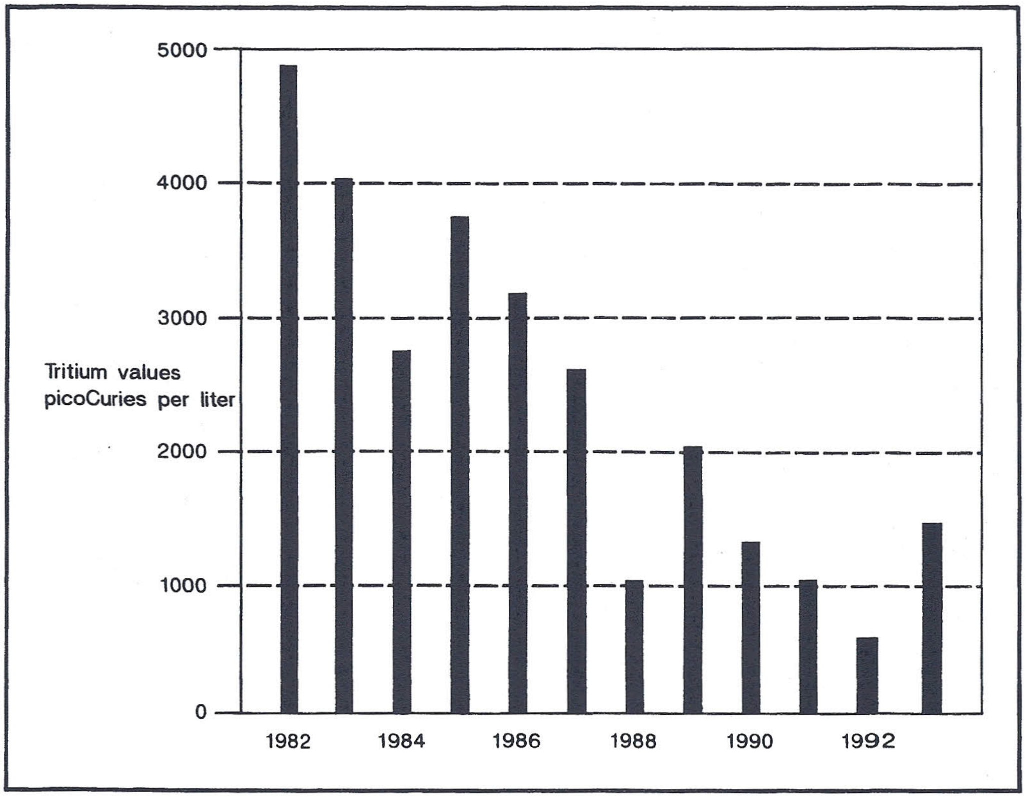


Figure 8. Bar graph showing average yearly rainfall tritium values at EPD station #11. Location is shown in Figure 7.

History of Tritium Releases from Savannah River Site

Tritium is a radioactive isotope of hydrogen with a half-life of 12.35 years (Fritz and Fontes, 1980). The unit of measurement for tritium used throughout this report is the picoCurie per liter (1 trillionth of one Curie per liter), which represents 0.037 electron releases per minute.

From the initiation of SRS operations in 1954 through 1988, approximately 25.6 million Curies (Ci) of tritium were released to the atmosphere and surface waters of the site, and approximately seven million Ci of tritium were placed into seepage basins and burial grounds (Murphy and others, 1991), with the largest yearly release (2.4 million Ci) in 1958 (Aadland and others, 1993). The yearly totals of planned atmospheric releases are listed in Table 2 (p. 10) and graphically indicated on Figure 6 (p. 9). Because radioactive decay should have removed over three fifths of this material, there are currently about 9.9 million Ci of tritium from the atmospheric and stream releases remaining in the environment and approximately 3.2 million Ci remaining in the seepage basins and burial grounds (Murphy and others, 1991). A brief table showing the radioactive decay of tritium over a 100 year period is provided in Appendix 2 (p. 77).

Tritium is released to the atmosphere as water vapor and as a gas from routine reactor operations, recovery of transuranic elements, recovery of tritium, heavy water rework, and laboratory research. Of the original 24 million Ci in atmospheric releases, 28.0 percent were from reactor areas, 71.6 percent were released from separations areas, and 0.4 percent were from other facilities (Murphy and others, 1991). Of the 1.5 million Ci released to Savannah River Site streams, 75.0 percent were derived from reactor areas, 15.5 percent were from separations facilities, and 9.5 percent were from other facilities.

In addition to releases during normal operations, there have been inadvertent (unplanned) releases of over 1 million Ci of tritium due to mechanical or human process errors. A brief summary of the most significant unplanned releases is provided in Table 3 (p. 10).

As of 1993, none of the reactors at the Savannah River Site are operating. Total (planned) atmospheric releases of tritium have steadily declined in recent years from 595,000 Ci in 1987 to approximately 156,000 Ci in 1992 (Aadland and others, 1993). This represents a decline of approximately 20 percent per year (Aadland and others, 1993). In 1992, 69.75 percent of the atmospheric releases were from the separations facilities, 29.95 percent from the reactor areas, 0.31 percent from heavy water rework, and 0.005 percent from diffuse sources including ponds and polluted land areas. Unplanned atmospheric releases during 1992 included 80 Ci from the K reactor (May 25) and 12,000 Ci from the H separations area (July 12).

Tritium in Rainfall in Burke County

The natural abundance of tritium in the terrestrial environment is extremely low. Tritium is produced natu-

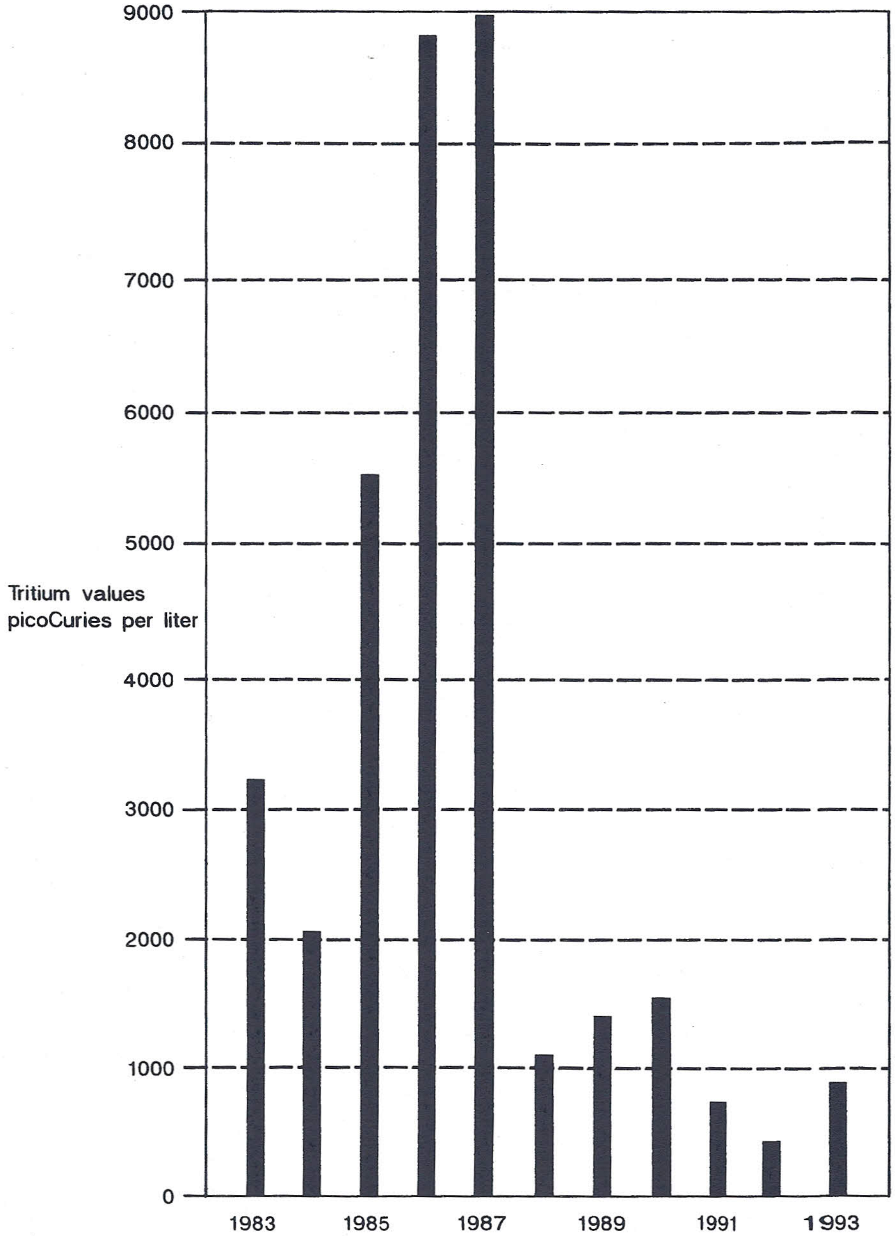


Figure 9. Bar graph showing average yearly rainfall tritium values at EPD station #35. Location is shown in Figure 7.

rally, in small quantities, in the upper atmosphere through the interaction of cosmic rays with atmospheric nitrogen. This natural production results in tritium concentrations in rainfall of 13 to 80 picoCuries per liter (Gat, 1980). Robertson and Cherry (1989) calculated from field data that natural concentrations of tritium in rainfall, in Ohio, between 1920 and 1952, were approximately 10 picoCuries per liter. However, there is significant latitudinal, seasonal, and geographical (continental versus oceanic) variation in natural levels of tritium in rainfall (Gat, 1980; Fontes, 1980). Starting in 1952, the low background concentrations of tritium in rainfall were overwhelmed by tritium produced during the atmospheric testing of nuclear weapons. This "bomb" tritium has declined since the cessation of atmospheric testing in 1963, and, as of 1978, "bomb" tritium accounts for over 16 picoCuries per liter of tritium in rainfall (Fontes, 1980) above the natural background concentrations.

Current concentrations of tritium in rainfall near Atlanta, Georgia, including both natural and "bomb" tritium are 39 picoCuries per liter (Rose, 1993). Because Atlanta is approximately 150 miles from the Tritium Project study area, SRS activities should have only minor effects on these measurements. Therefore, the concentration of tritium

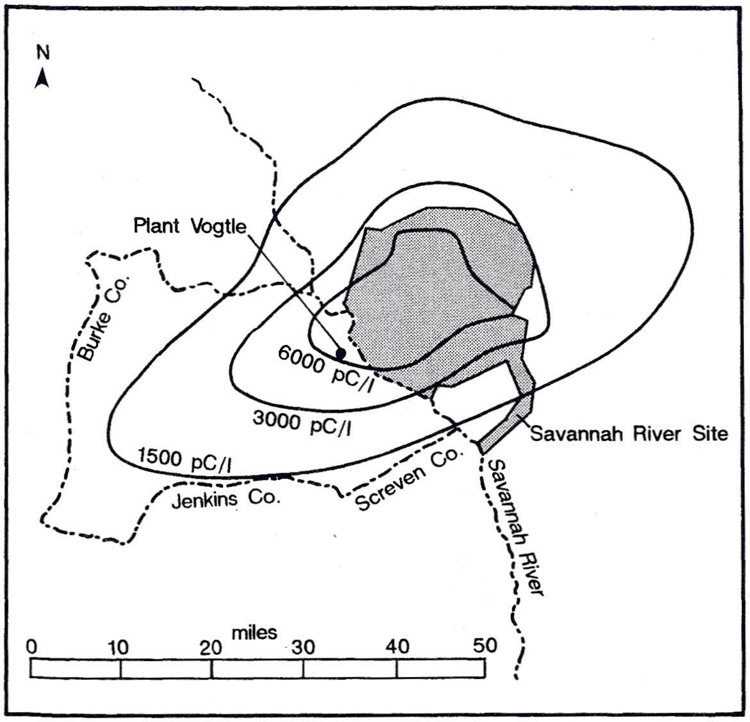


Figure 10. Directional distribution of tritium in rainfall for SRS-Burke County area, based on analyzed rainfall samples (1982 - 1986). Values are stated in picoCuries per liter. (Modified from Murphy and others, 1991.)

found in rainfall near Atlanta can be treated as background levels for comparison with measurements taken in Burke County.

Tritium concentrations in rainfall have been measured by the Environmental Radiation Program of EPD from selected sites in eastern Burke County since 1981 (Figure 7, p. 11). In addition, DOE maintains rainfall stations in Burke, Richmond, and Screven counties but also has stations in Augusta, Savannah, and Macon, Georgia. Elevated tritium concentrations have been observed at all EPD and DOE stations. Tritium values from samples collected from EPD sites on Hancock Landing Road (Station 11) and at the Plant Vogtle Simulator (Station 35) (Figure 7), both near the Savannah River, are of particular interest to the present study because these sites lie closest to the area of maximum concentration of tritium seen in Burke County ground water. Average yearly rainfall tritium values for Stations 11 and 35 are shown on Figures 8 and 9, respectively.

The highest tritium concentration measured in rainfall at the Hancock Landing Road site between 1981 and 1994 was 11,500 picoCuries per liter, from a sample collected December 24, 1984. As late as January 7, 1993, a rainfall sample collected from this site showed a tritium content of 7,000 picoCuries per liter, however, this was the first sample to measure above 5,000 picoCuries per liter since December 17, 1987 (Appendix 3, p. 78). A compilation of tritium values above 5000 picoCuries per liter (25 percent of EPA MCL) from EPD rainfall monitoring stations in eastern Burke and Screven Counties (Figure 7), including the Hancock Landing Road site, is included in Appendix 3. However, most rainfall samples collected by the EPD in Burke County contain only moderately elevated concentrations of tritium. Eighty-seven percent of the EPD samples (n = 726) from seven sites in Richmond, Burke and Screven Counties contain less than 2,500 picoCuries per liter of tritium (Appendix 4, p. 79).

Murphy and others (1991) produced a map showing the distribution of average tritium in rainwater around the Savannah River Site between 1982 and 1986 (Figure 10). This map was based on rainwater samples collected from 33 stations within a 25 mile radius around the Savannah River Site, including four stations in Georgia. The map shows that rainfall over eastern Burke County, during the period from 1982 to 1986, had average tritium concentrations exceeding 1,500 picoCuries per liter and that, near the Savannah River, the rainfall had average tritium concentrations exceeding 6,000 picoCuries per liter.

Tritium in Ground Water

The potential sources of tritium in ground water are recharge from rainfall, recharge from rivers or lakes, and transport from other aquifers. Recharge from rainfall includes both tritium in current rainfall and tritium that has

Table 4

Tritium concentrations of surface water samples collected by Georgia Power Co./Southern Nuclear Operating Co., August, 1982 - October, 1991. Locations shown in Figures 7 & 11. Analyses courtesy of Southern Nuclear Operating Co. Samples collected on 19 November 1991, 27 October 1992, and 20 October 1993 by EPD personnel. Tritium concentrations in picoCuries/liter.

Date	Blue Bluff Spring-River Mile 150.1	Plant Vogtle Spring-River Mile 150.9	Mallards Pond	Beaverdam Creek at River Road
08/03/82	3810			
08/10/82			1280	
07/05/83	1610		2540	
10/04/83	1480		2320	1910
01/03/84	1850		2290	
04/03/84		3333	2120	
07/10/84		2460	2120	
10/08/84		2490	1820	
03/05/85		3930		
05/13/85		2820	2030	
07/22/85		2000		
10/15/85		2300	2080	
01/16/86		2710	1810	
04/03/86		2580	1670	
07/14/86		2650	1850	
10/07/86		2600	1850	
01/12/87		3310	1750	
04/09/87		3100	1700	
10/22/91		2430	1660	1390
11/19/91				1300±200
10/27/92 (1)	1400±200 (2)		1400±200	1100±200
07/27/93		1800±200		800±100
10/20/93 (3)	1300±200 (2)		Dry	

(1) Collected during 1992 base flow study.
(2) Collected from nearby springs on Blue Bluff at River Mile 149.5 (approximate).
(3) Collected during 1993 base flow study.

Table 5

Tritium concentrations in ground water samples from Upper Three Runs (water table) aquifer monitoring wells on Plant Vogtle property (see Figure 11). Analyses courtesy of Southern Nuclear Operating Company. Tritium values in picoCuries per liter.

Date	129	142	800	801	802	803A	805A	806B	807A
03/05/85	1950	940	1270			1270	1940		
05/13/85	1970	1740	1190	1880		1340	1950	3510	
07/22/85	2000		920	2090		1320	2080		3770
10/15/85	2530		580	2020	2220	1750		3940	
01/15/86-01/18/86	2080		637	2430	922	1220		3360	
04/03/86-04/04/86	2110		934	1730		1160		2980	1340
10/17/86-07/18/86	2160		1090	1990	969	1370		3200	
10/07/86-10/10/86			673	1910	996	1150		2680	
01/06/87-01/12/87			766	1770		1200		2960	
04/09/87-04/13/87	2050		886	1730		1060		3020	
08/26/87-08/27/87	2090		827	1640		1290			
12/28/88			775	1480		1300		2360	
10/22/91				1530		1750		2170	

accumulated in the vadose zone from previous rainfall. Current background tritium concentrations (as measured in the shallow ground water of the north Georgia Piedmont) average 62 picoCuries per liter and range up to 109 picoCuries per liter in soil and weathered rock material (Rose, 1992). Tritium behaves as a conservative tracer of ground-water flow (Fontes, 1980; Davis and others, 1985; Allison, 1988; Rose, 1992; Rose, 1993) and has been used extensively as a tracer in ground-water studies since the 1950's. Tritium has many properties that make it an ideal tracer. It primarily occurs as tritiated water (Gat, 1980), replacing one (or both) of the hydrogens in the water molecule. It does

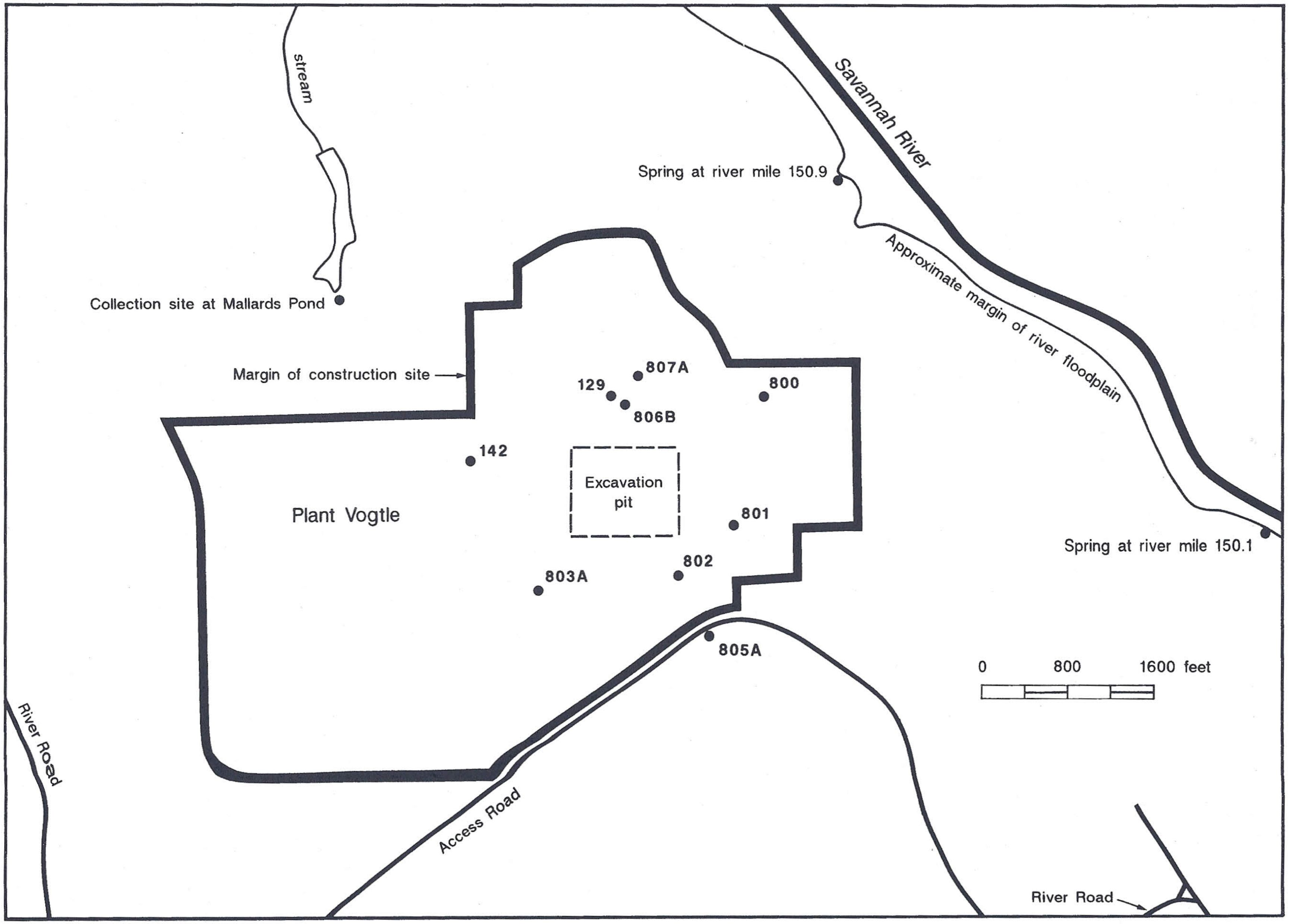


Figure 11. Map of Plant Vogtle construction site showing surface water collection sites and Upper Three Runs aquifer monitoring wells (1985 - 1991): refer to Tables 4, 5, and 6. (Modified from Georgia Power Co. Figure 2.4.12-2 - Plant Vogtle Final Safety Analysis Report.)

Table 6

Construction data for Upper Three Runs aquifer monitoring wells on Plant Vogtle property. Wells in use from 1985 - 1991. Locations shown in Figure 11. Information from Southern Nuclear Operating Company and USGS.

Plant Vogtle well #	Ground elevation (feet above M.S.L.)	Casing depth (feet below surface)	Screened interval (feet)
129	215.8	92	5
142	231.2	85	10
800	213.7	69	20
801	214.8	62.5	20
802	235.0	76.75	9
803A	218.3	57	20
805A	232.7	95	20
806B	210.0	55	10
807A	202.0	65	10

not adsorb onto the surface of rock particles, nor is it absorbed into the minerals' structure (Davis and others, 1985). Isotopic fractionation of tritium in ground water is of relatively minor importance (Fontes, 1980). Tritium is not significantly affected by reactions other than radioactive decay (Freeze and Cherry, 1979; Dincer and Davis, 1984).

The potential mechanisms of movement of tritium in ground water include advection, convection, mechanical dispersion, and molecular diffusion (Freeze and Cherry, 1979; Davis and others, 1985; Domenico and Schwartz, 1990). Advection is the bulk movement of ground water in response to local or regional hydraulic gradient. In most aquifers, advection is the dominant process of water movement. Convection (free or natural convection) is the movement of ground water due to difference in density. Although tritiated water molecules are slightly heavier than normal water molecules, the difference in density is minor. Mechanical dispersion is the mixing of ground water during the process of advection caused by local variations in velocity and path followed by water molecules. Mechanical dispersion is a major factor in the dilution and spread of a pollutant away from the advective path. Molecular diffusion is the mixing of ground water due to random molecular motions. Molecular diffusion in rapidly moving ground water is generally considered to be of minor importance compared to mechanical dispersion (Davis and others, 1985). However, Robertson and Cherry (1989) found that, when dispersion and linear ground-water velocity are low, molecular diffusion controls the mixing of tritium in ground water.

The earliest surface water samples indicating the presence of measurable tritium in eastern Burke County, were collected by Georgia Power Company and/or Southern Nuclear Operating Company (both Southern Company subsidiaries), prior to the start-up of Plant Vogtle. From August, 1982 through October, 1991, surface water samples (Table 4, p. 15) were collected from spring sites along the Savannah River bluffs at River Mile 150.1 and River Mile 150.9, from a site at the head of Mallards Pond (Figure 11, p. 17) and the River Road crossing of Beaverdam Creek (Figure 17, p. 27). Bar graphs show comparative tritium concentrations from the Plant Vogtle spring at River Mile 150.9 (Figure 12, p. 19) and Mallards Pond (Figure 13, p. 21), which were sampled on a sporadic basis from April, 1984 through July, 1993.

The initial collection of water samples from Upper Three Runs aquifer monitoring wells on Plant Vogtle property (Table 5, p. 16; Figure 11) began on March 5, 1985.

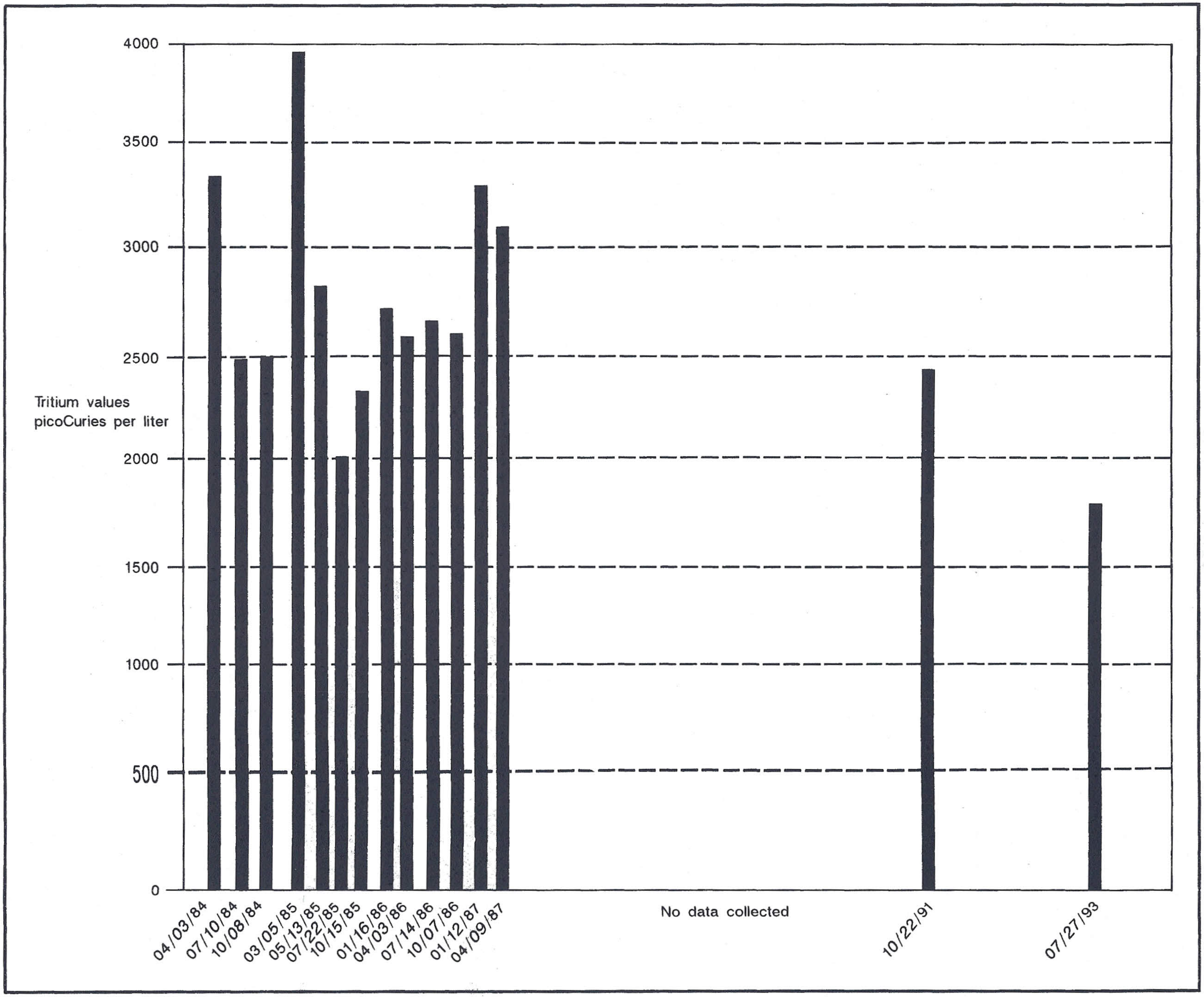


Figure 12. Bar graph showing tritium values in samples collected from Plant Vogtle spring at river mile 150.9. Values are shown in Table 4. Location is shown in Figure 11.

Table 7

Results of initial sampling of wells within the Savannah river corridor by the EPD Environmental Radiation Program, prior to the initiation of the Tritium Project. Tritium Project numbers and locations are shown in Figure 14 and listed in Appendix 1.

Tritium Project Number	EPD Station Number	Name	Date of First Sample	Results
34	1	I-20 Welcome Center, Augusta	04/13/87	Below detection
7	6	Augusta Lock & Dam	04/13/87	Below detection
39	8	Residence - Bennock Mill Rd.	10/04/88	Below detection
100	12	Plant Vogtle Visitor Center	04/13/87	Below detection
37	14	Girard Main Well	04/13/87	Below detection
87	17	Stoney Bluff Park	10/05/88	Below detection
35	20	U.S. 301 Welcome Center, Screven Co.	04/13/87	Below detection
105	25	Waynesboro Main Well	04/13/87	Below detection
107	26	Old Shell Station - Hancock Landing Rd./ River Rd.	04/13/87	Below detection
3	29	Delaigle Well #3 (aka A&A Store #3)	09/22/87	Below detection
98	35	Plant Vogtle Simulator	09/22/87	Below detection
94	37	Viola Brigham Residence	04/13/87	Below detection

From this date through October 22, 1991, samples were collected on a sporadic basis from a total of nine monitoring wells. Basic construction details for the Plant Vogtle shallow monitoring wells (depth and screened intervals) are listed in Table 6.

On April 13, 1987, the Georgia EPD Environmental Radiation Program began the periodic sampling of eight wells (Table 7; Figure 14, p. 23) along the Savannah River corridor from the Georgia Welcome Center, Interstate Highway 20, in Augusta, southward to the Georgia Welcome Center, U.S. Highway 301, near Sylvania, in northeastern Screven County. Four more wells were added later, including the Delaigle Trailer Park well #3.

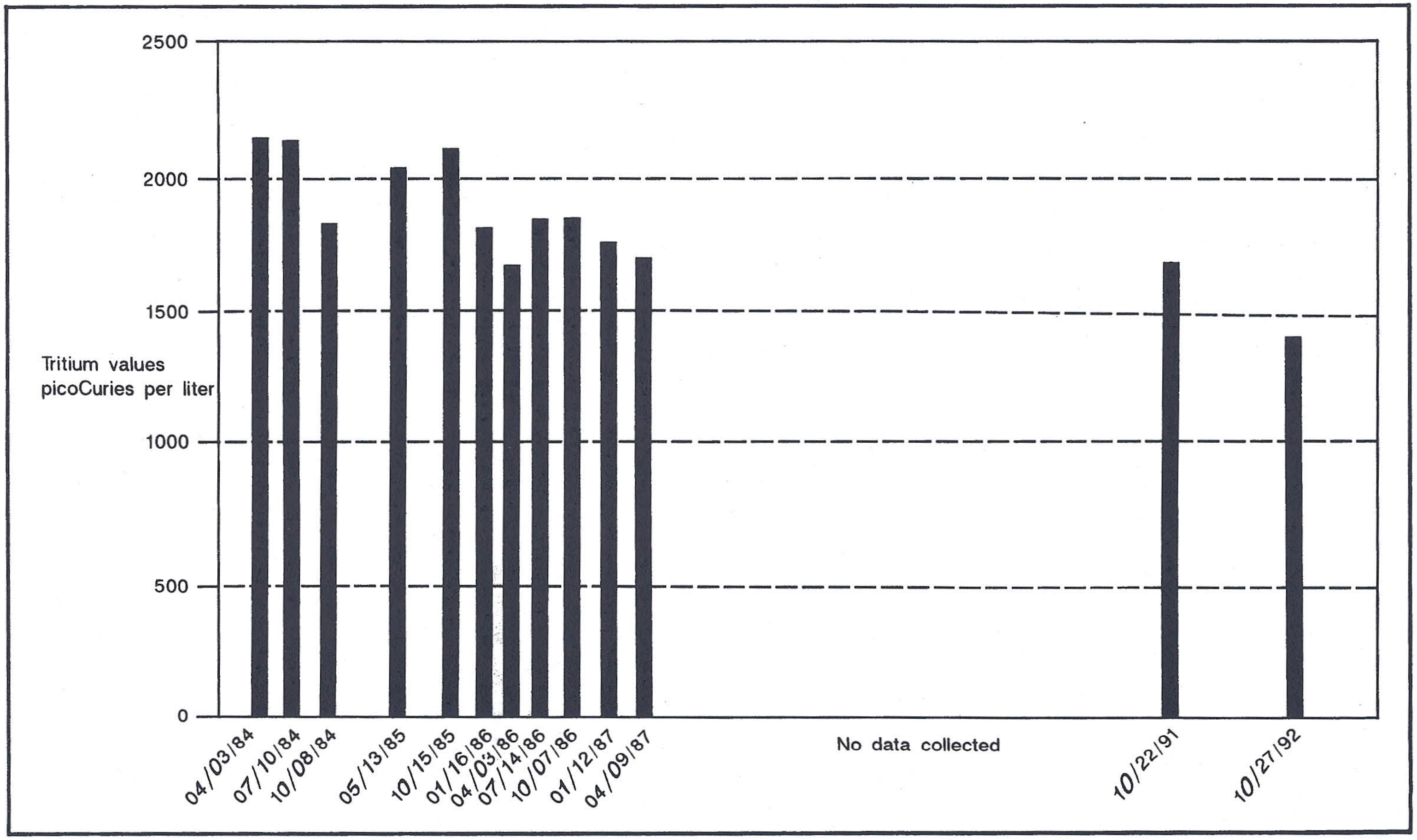


Figure 13. Bar graph showing tritium values in samples collected from Mallards Pond, Plant Vogtle Property. Values are shown in Table 4. Location is shown in Figure 11.

Acknowledgments

We wish to extend our appreciation to the Burke County property owners and residents for their invaluable assistance and cooperation with our drilling and sampling activities during the Tritium Project. For permission to install cluster sites on their properties, we wish to thank the following: Georgia Power Company, Mr. Avner Delaigle, Mr. R. W. Mobley, Mr. Earl Nally, and Thomson Oak Flooring Company. For allowing the geophysical logging of residential wells, we wish to thank the following: Mr. Avner Delaigle, Mr. Mark Jackson, Mr. Lamar Paul, Ms. Rose Johnson, Mr. Frank Wimberly, Mr. Larry Sconyer (Hug-A-Hog Plantation), Mr. Ralph Greer, Mr. George Wilson, and Ms. Marie Vann (Walnut Run Ostrich Farm). For allowing the storage of materials, we wish to thank the following: Mr. Marshall A. Miller and Mr. Avner Delaigle. For technical assistance and information, we wish to thank the following: Mr. Gerald Grainger (Southern Company), Mr. Bill Ollinger (Southern Nuclear Operating Company), Mr. Carl Carswell (Georgia Power Company, Plant Vogtle), Mr. Carlton Chambers (Georgia Power Company, Plant Vogtle Land Office), Dr. Chet Nichols (Westinghouse Savannah River Corporation); Mr. John Clarke, Mr. Fred Falls, Ms. Joan Baum, and Mr. Chris Leeth (USGS); Dr. Seth Rose, Mr. Philip James (Georgia State University); Mr. Cliff Blackman, Mr. James Gary, and Mr. Robert Rosson (Environmental Radiation Laboratory, Georgia Institute of Technology); and Dr. Vernon J. Henry (Georgia Southern University).

The Tritium Project Technical Advisory Committee includes the following persons: Mr. John Clarke (USGS), Mr. Tom Temples (DOE); Dr. Van Price, Jr. (Westinghouse Savannah River Corporation); Dr. Leland T. Long and Dr. William Chameides (Georgia Institute of Technology); Dr. Wade Nutter and Dr. James Spaulding (University of Georgia).

This project was supported, in part, through a Cooperative Agreement with DOE (Cooperative Agreement Number DE-FC09-92SR18268). This report does not constitute an endorsement by the Department of Energy of the views expressed in this report.

PROCEDURES

Study of Water Wells

Prior to the initiation of the Tritium Project, the EPD Environmental Radiation Program periodically tested twelve water wells in eastern Burke County for tritium (Figure 14, Table 7, p. 20;

Following the discovery of tritium in the Delaigle Trailer Park well #3, EPD expanded the sampling of private and public supply wells in eastern Burke County. Private water supply wells include domestic (residential), supply, commercial (business and institutional), and agricultural water wells; public water wells include both publicly owned and privately owned wells that provide water to at least 25 people or have at least 15 hookups. The wells were selected to provide a relatively uniform geographic coverage throughout the study area. Other wells were sampled at the request of property owners. By February, 1994, a total of 109 wells had been sampled (see Figures 15, 22 and 23 for locations and Appendix 1 for analytical results).

During the current study, water samples were taken at each residence from the outdoor faucet closest to the well. The water was allowed to run for approximately ten minutes prior to sampling in order to clear the water pipes of standing water. The Environmental Radiation Laboratory at the Georgia Institute of Technology analyzed the water samples for tritium. The detection limit for tritium at this laboratory is 100 picoCuries per liter. As part of the EPD's quality assurance procedures, blank samples of deionized water (with no tritium) and duplicate samples were submitted along with the well samples. Within the sample of 109 water wells, all wells that yielded tritium concentrations at or above 500 picoCuries per liter were considered radiologically anomalous or polluted. The 500 picoCuries per liter "threshold" is 2.5 percent of the EPA MCL for tritium of 20,000 picoCuries per liter, and is slightly higher than the analytical detection limit of 100 picoCuries per liter. The polluted water wells were periodically resampled during the course of the investigation.

The USGS conducted geophysical logging of nine of the anomalous water wells. The specific types of geophysical logs used depended on the availability of equipment. Geophysical logging provided information on the total depth of the well, the screened or open interval within the well (indicating the aquifer being sampled), whether the well had been properly grouted, and any damage to the well casing. Water level measurements were also taken during the geophysical logging.

Base Flow Studies

Water moving through a stream channel is derived from three sources: overland flow, interflow, and base flow (Freeze and Cherry, 1979; Domenico and Schwartz, 1990). Overland flow is rain water that moves over the land surface into stream channels. Interflow is the water derived from soils and sediments above the water table. Base flow is water derived primarily from the water table aquifer. During the Fall season in Burke County, precipitation is at its lowest level and soil moisture has been depleted by crops and other vegetation. During this time period, streamflow is typically very low and is primarily derived from base flow. Water samples collected from streams during such periods provide a reasonable sample of water in the Upper Three Runs (water table) aquifer. "Ideal" base flow conditions are identified from recorded stream flow discharge rates on streams with USGS gaging stations (Figure 16, p. 26), one of which lies within the study area. Because the true depths of most wells in eastern Burke County are uncertain and the number of springs and streams far exceeds

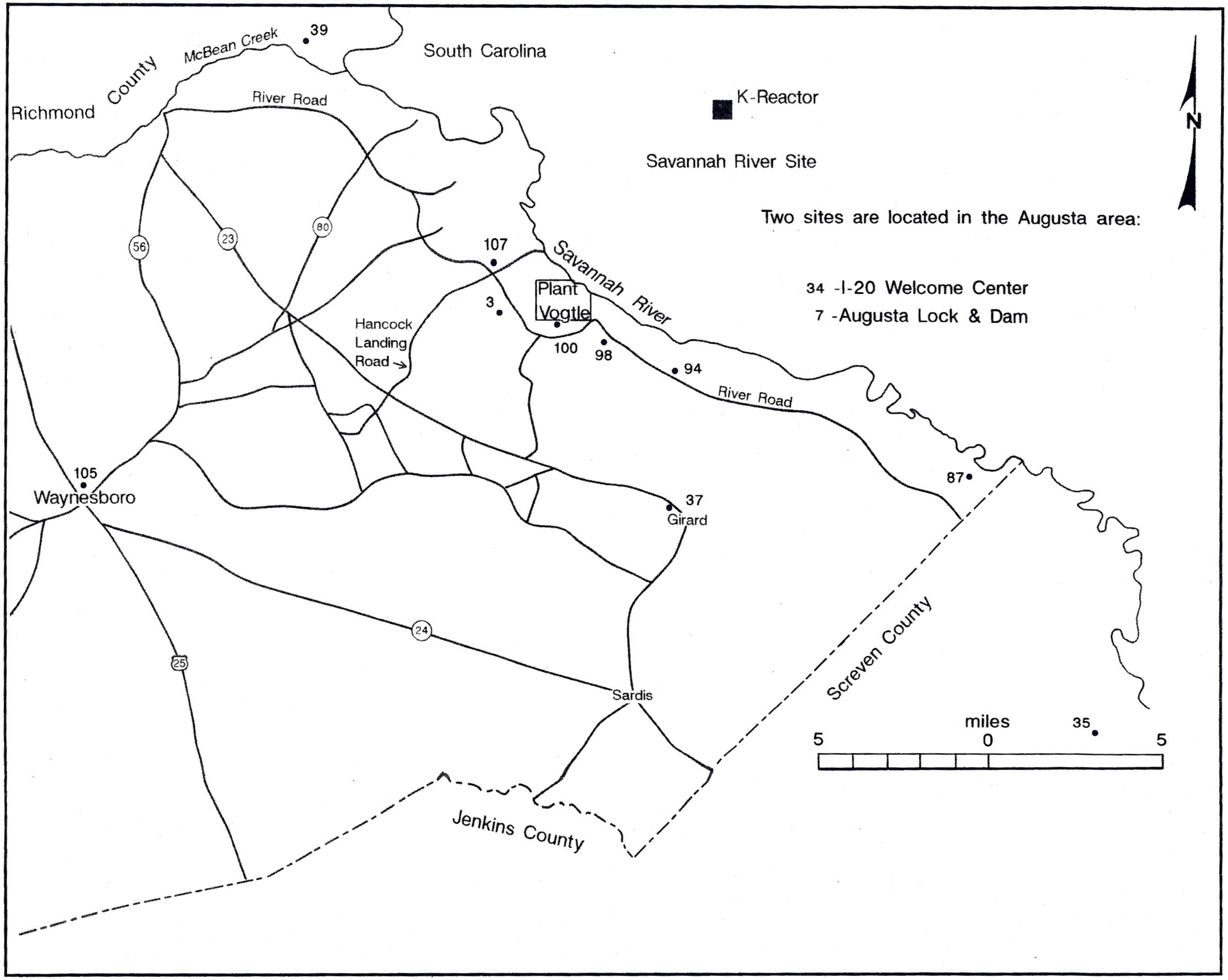


Figure 14. Index map showing wells (with Tritium Project numbers) sampled by EPD Environmental Radiation Program (1987-1991), prior to the initiation of the Tritium Project. Wells are identified in Table 7.

the number of wells in eastern Burke County, a base flow study is a good method to evaluate the areal distribution of tritium in the Upper Three Runs aquifer.

The preferred sampling locations for base flow studies are springs and small first-order streams (close to the origin of the streams). Second and third-order streams are less preferred sampling sites as these larger streams represent mixing of ground water from several sources, producing a composite sample. Areas immediately downstream from swamps, ponds, and lakes are the least preferred collection sites because tritium concentrations in these surface water bodies may be biased by recent rainfall and surface runoff. Second and third-order streams may be utilized, where more favorable sites are not available due to time, personnel, and accessibility constraints.

1991 Base Flow Study

On November 19 and 20, 1991, EPD personnel conducted a base flow study over an area covering parts of three USGS 7.5 minute quadrangles (see Figure 17, p. 27, for sampling locations). A total of 53 samples were collected, primarily from road crossings of area streams.

1992 Base Flow Study

From October 26 through 28, 1992, GGS personnel conducted the second base flow study over an area covering parts of seven USGS 7.5 minute quadrangles (Figure 18, p. 29). A total of 126 samples were collected, primarily from springs and small first-order streams, and road crossings when more preferable sites were not available. In order to achieve the proper spacing, a grid system was established for the area to be sampled. The grid spacing was not uniform over the sampling area. Because the Shell Bluff Landing 7.5 minute quadrangle map contained thirteen of the fifteen polluted domestic water wells, this area was designated as a "dense sampling zone." Within this "dense sampling zone," four samples were collected per square mile wherever possible. This "dense sampling zone" extended two to three miles into the margins of the adjacent quadrangles. A buffer, approximately four miles wide, surrounding the "dense sampling zone" was defined as a "moderate sampling zone" in which one sample per square mile was collected. The area beyond the "moderate sampling zone" buffer was defined as the "light sampling zone." Within this "light sampling zone" one water sample was collected within every four square miles.

The general boundaries of the 1992 study were the Burke-Screven County line to the southeast, the Savannah River to the east, McBean Creek to the north, the Norfolk Southern System railroad tracks west of Georgia Highway 56 to the west, and U.S. Highway 25 to the southwest.

Installation of Monitoring Wells

During the Tritium Project, GGS drilling crews installed fifteen ground-water monitoring wells in clusters at six sites in eastern Burke County (see Figure 19, p. 31, for well cluster locations) in order to obtain *in situ* samples of ground water for tritium analyses. Continuous cores were taken at each monitoring well site prior to the installation of the monitoring wells. Following the completion of drilling, the USGS geophysically logged each core hole. Correlation of the cores and geophysical logs allowed the selection of the most appropriate interval to place the screen within each monitoring well. Screened intervals were selected on the basis of high permeability of the sediment, low clay content, thickness of the high permeability zones (as interpreted from core samples and/or geophysical logs), and the projected elevation of the aquifer to be sampled. In most wells, ground-water sampling was restricted to a ten foot screened interval. See Table 8, p. 28, for aquifers, depths, and screened intervals.

The construction details for a typical monitoring well are shown in Figure 20 and "as built" construction diagrams are illustrated in Appendix 7. After drilling and installation, each well was developed using a surge block and an air compressor. The development process removes the remnants of drilling mud and formational clays, silts, and fine sands from the vicinity of the screen and otherwise corrects damage to the aquifer caused by the drilling process. After development, a concrete pad was poured around the top of each well and a locked, protective steel housing was placed over the well. A permanent submersible pump was installed in each well.

The first four cluster sites (TR92-1 through TR92-4) were placed between the locations of the polluted water wells. The locations of the two subsequent cluster sites (TR92-5 and TR92-6) were based on the results of tritium analyses from the first four cluster sites, from the polluted water wells, from base flow sampling, as well as site availability and suitability.

Seven monitoring wells at the USGS Miller's Pond cluster site (Figure 19, p. 31) were also available for periodic sampling. These wells are part of the ongoing USGS Trans-River Flow Project.

Using the calculated water volume of each well, a minimum of three well volumes were purged prior to sampling. Periodic water level measurements were also taken in each well.

Description of Cores

The rock units of eastern Burke County act as the "plumbing" through which the ground water flows. Careful examination and description of cores allow the reconstruction of that "plumbing". Staff of the GGS and the USGS examined 9,244 feet of core including material from all six cluster sites, a core from the USGS Miller's Pond site, one core drilled by Georgia Power Company at Plant Vogtle, one core drilled by the GGS in 1991 near McBean Creek (as part of another project), and eight cores drilled by the Bechtel Corporation in southern Burke County in 1982 (Figure 21, p. 33).

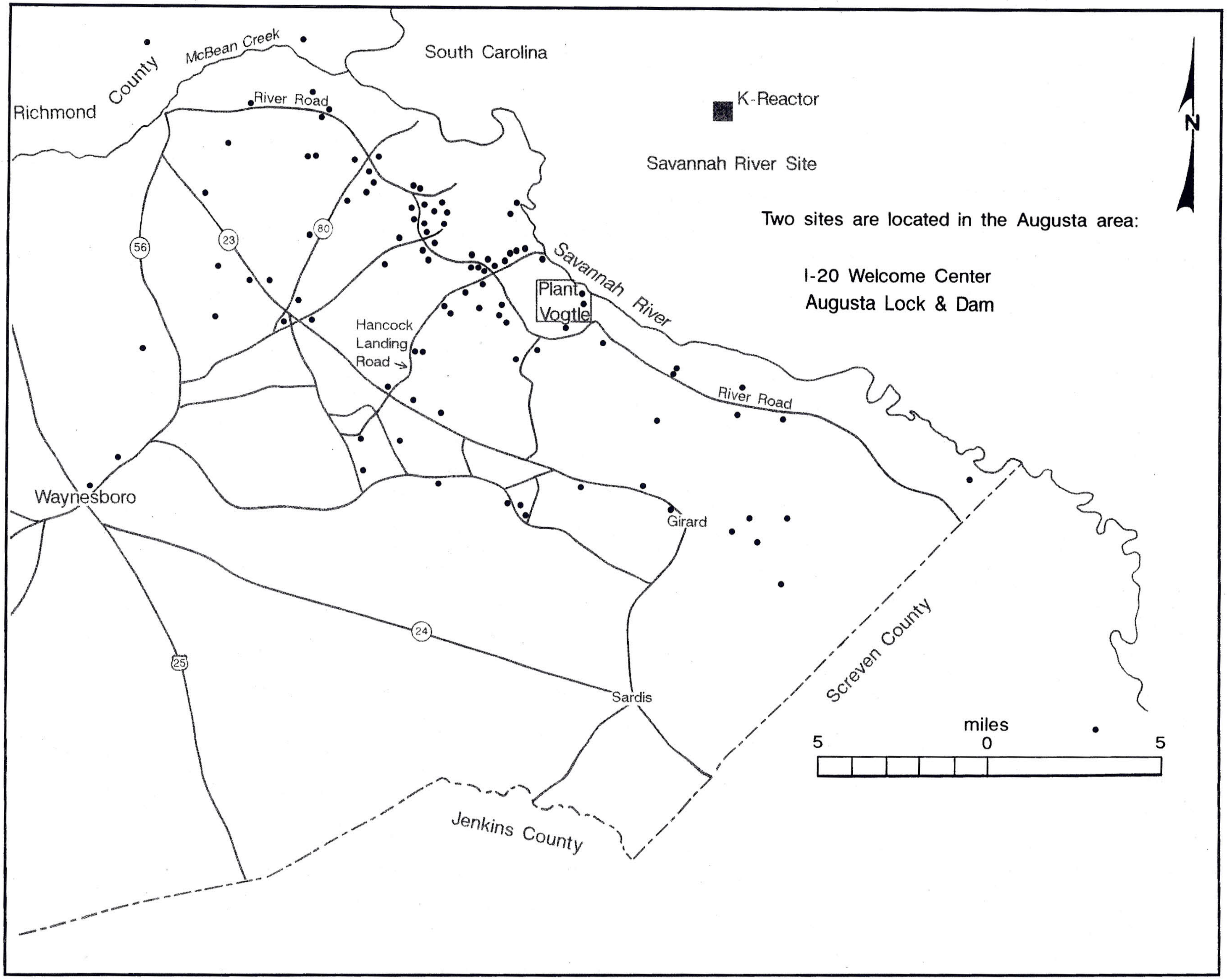
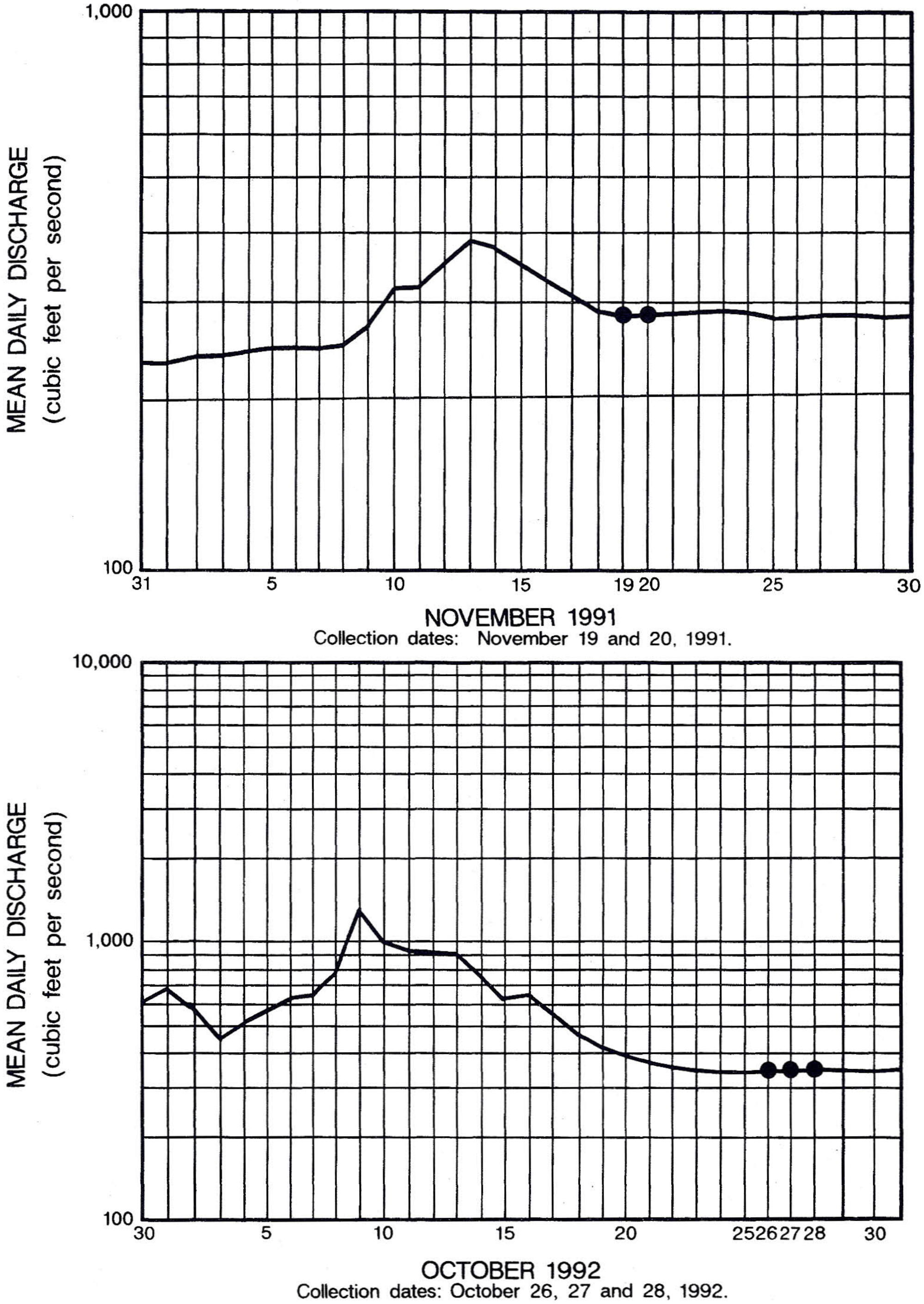


Figure 15. Index map of eastern Burke County, showing geographic spread of public and private wells sampled by EPD and GGS during the Tritium Project (mid-1991 through early-1994).



02197830 Brier Creek near Waynesboro, Georgia. Note difference in vertical scales.

Figure 16. Hydrographs showing stream discharge rates for Brier Creek (near Waynesboro) during the 1991 and 1992 base flow studies. (From USGS data.)

Seismic Survey of Savannah River Channel

During the course of the Tritium Project, two seismic surveys were conducted by Dr. Vernon J. Henry, of Georgia Southern University, and others, along the Savannah River channel, within the study area. The seismic surveys were

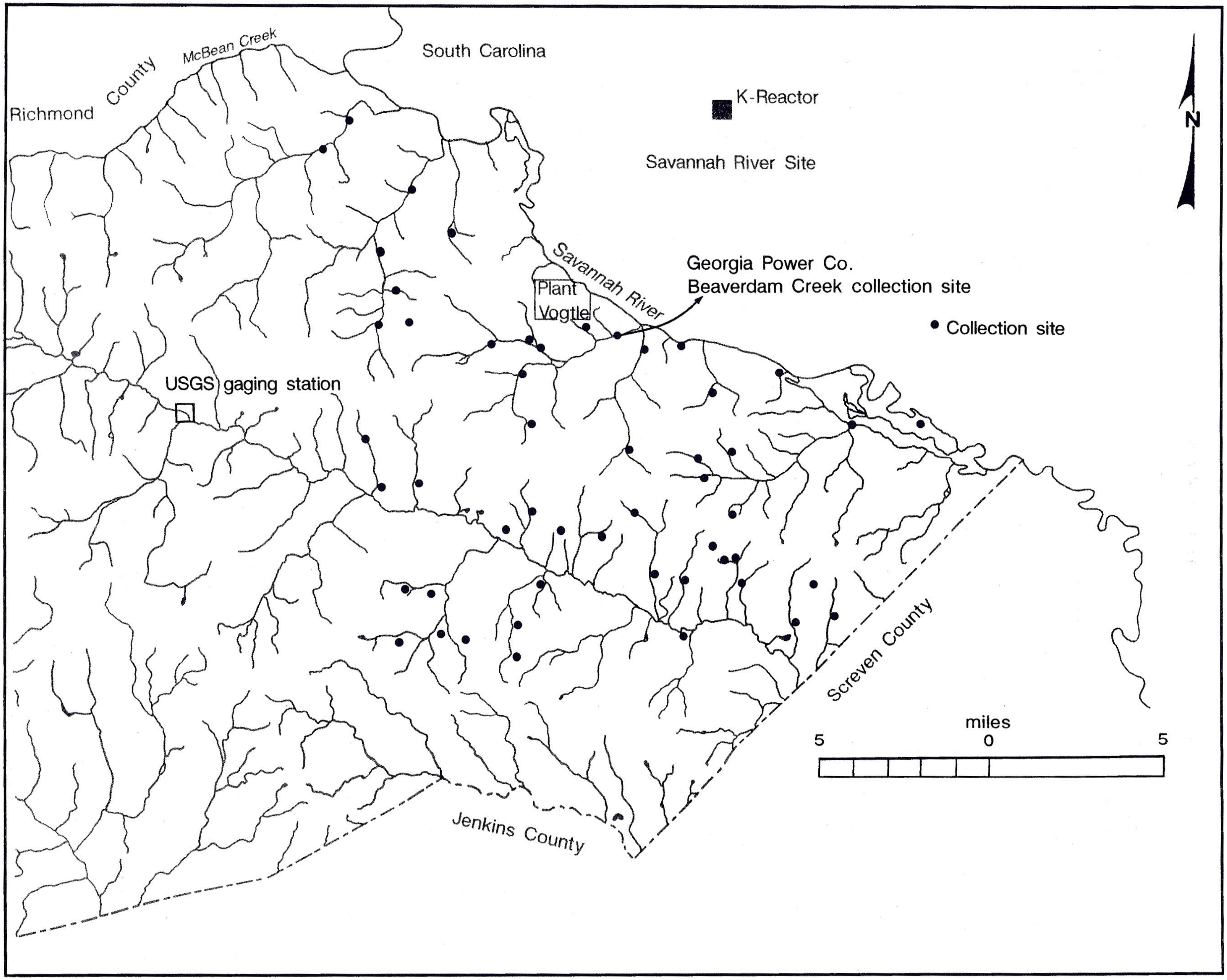


Figure 17. Locations of collection sites for the 1991 base flow study and the USGS gaging station on Brier Creek.

Table 8

Summary of Tritium Project ground water monitoring wells.

Well Number	Aquifer	Elevation - feet above M.S.L.	Depth below Surface (feet)	Screened Interval (feet)
TR92-1A	Upper Three Runs	235	105	90 - 100
TR92-1B	Gordon	235	225	210 - 220
TR92-1C	Meyers Branch	235	310	290 - 300
TR92-1D	Dublin	235	370	345 - 355
TR92-2A	Upper Three Runs	285	120	105 - 115
TR92-2B	Gordon	285	330	310 - 320
TR92-3A	Upper Three Runs	195	75	55 - 65
TR92-3B	Gordon	195	205	185 - 195
TR92-4A	Upper Three Runs	192	60	55 - 65
TR92-4A2	Upper Three Runs	192	90	75 - 85 (1)
TR92-4B	Gordon	192	190	175 - 185
TR92-5A	Upper Three Runs	235	165	145 - 155
TR92-5B	Gordon	235	305	275 - 285
TR92-5C	Gordon	235	315	200 - 300 (2)
TR92-6A	Upper Three Runs	240	141	dry hole (3)
TR92-6B	Gordon	240	250	180 - 200 (4)

(1) Redrilled to greater depth to produce more water.
(2) Designed to duplicate driller's records for Delaigle Trailer Park well #3.
(3) Screened in impermeable part of Utley Limestone.
(4) Designed to also meet the needs of the USGS Trans-River Flow Project.

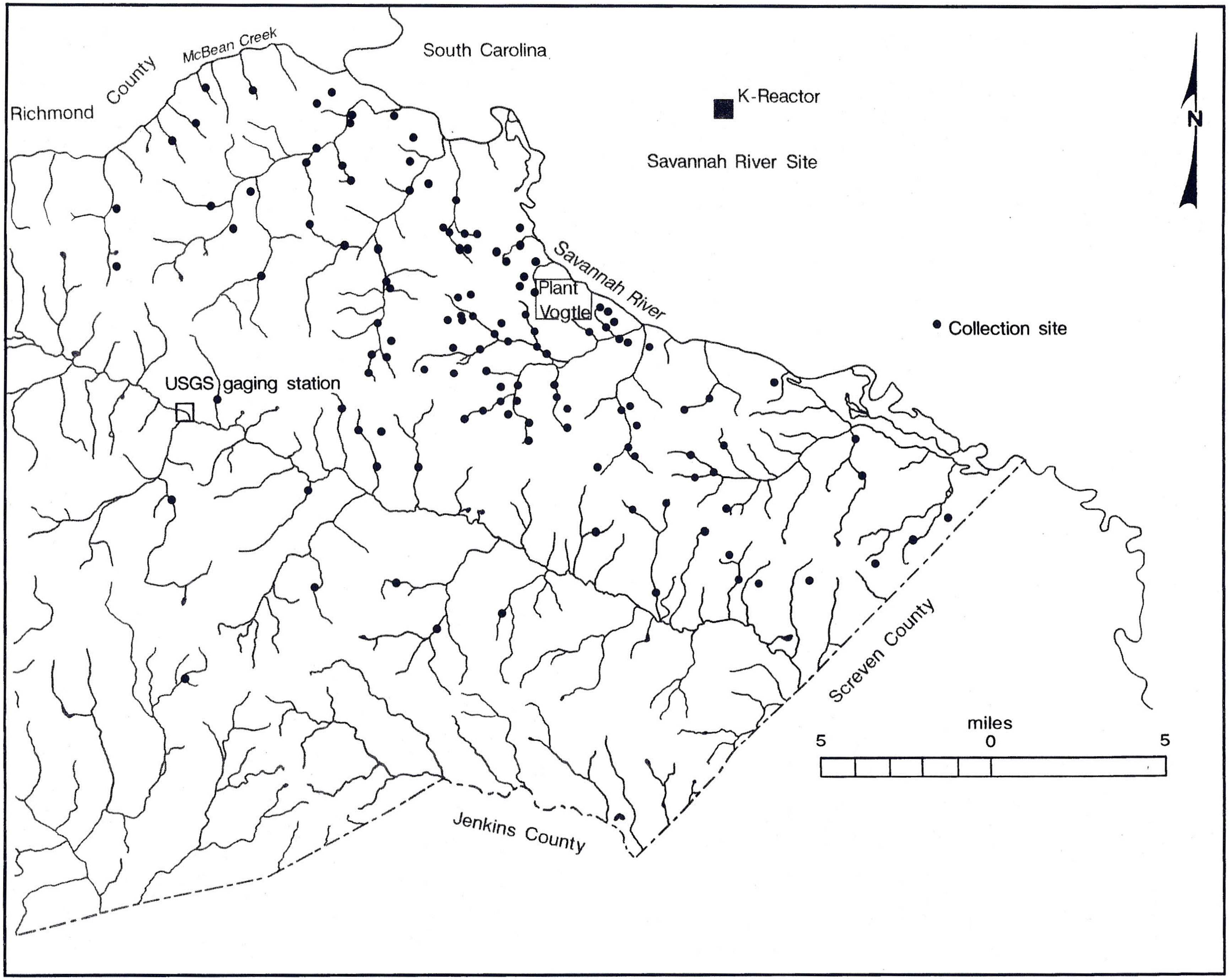


Figure 18. Locations of collection sites for the 1992 base flow study.

conducted to address the following objectives: 1) evaluation of possible breaching of the shallow aquifers (Upper Three Runs and Gordon) by the Savannah River; 2) evaluation of the thickness of the Savannah River alluvium; 3) correlation of seismic sequences with the upper Cretaceous/lower Tertiary stratigraphic units identified in regional water wells and Tritium Project cores; and 4) possible identification of the Pen Branch fault.

A high resolution seismic survey was conducted during October 10 - 13, 1992 between the Richmond-Burke County line and the Burke-Screven County line, a distance of 70 river miles. This study was performed using a boat-drawn EG&G Model 225 UNIBOOM system, with data recorded on both a magnetic tape and a graphic (analog) recorder. The data were used to estimate the thickness of river channel alluvium, to assess breaching of shallow aquifers, and to correlate the stratigraphic units, where possible. The information from the seismic study were compared with stratigraphic data derived from eighteen auger holes drilled along the adjacent river floodplain in Georgia and South Carolina by the USGS (Leeth and Nagle, in preparation).

A medium resolution seismic survey was conducted during August 23-27, 1993 between Hancock Landing and the Georgia Power Boat Ramp, approximately one mile down-river from Plant Vogtle. This survey was carried out using a boat-drawn Bolt 600B air gun with one cubic inch and ten cubic inch chambers.

Ground-Water Geochemistry

As rainwater falls and seeps into the soil, its chemistry is initially affected by the gases and dust-sized particulate matter in the atmosphere and then by the particulate matter and gases within the soil. As the water percolates downward, its chemistry is further altered by chemical reactions with the sediments. Because the chemical composition of the sediments of each aquifer is often different, the ground water contained within each aquifer may also be chemically different.

Dr. Seth Rose and Philip James, of Georgia State University, performed a study of ground-water geochemistry to define and interpret geochemical variation within the Upper Three Runs and Gordon aquifers in eastern Burke County (Rose and James, 1993). The goal of the study was to characterize the geochemistry of each aquifer and to suggest the pathways for water movement within the aquifers. The Rose and James (1993) study included seventy-five water samples from a variety of sources including private and public water supply wells (56 samples), ground-water monitoring wells (10 samples), springs (4 samples), and first-order streams during periods dominated by base flow (5 samples). Each sample was measured for alkalinity, pH, and specific conductance within 48 hours of collection. Samples were analyzed for ionic concentrations of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), silicon (Si), manganese (Mn), iron (Fe), aluminum (Al), boron (B), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr), and molybdenum (Mo) using inductively coupled plasma spectrometry, and for chloride (Cl), sulfate (SO_4), nitrate (NO_3), fluoride (F), and phosphate (PO_4) using ion chromatography. Calcite saturation indices were calculated for all samples. The University of Georgia Cooperative Extension Service performed all chemical analyses, except for tritium analyses, which were performed by the Environmental Radiation Laboratory at the Georgia Institute of Technology.

Aquifer Testing

The four monitoring wells at site TR92-1 (Figure 19, p. 51) were subjected to pumping tests by a group of researchers from Clemson University, Department of Earth Sciences (Moore and others, 1992). This aquifer testing was carried out as part of the previously mentioned USGS Trans-River Flow Project. The purpose of the testing was to obtain transmissivity data on each aquifer and to estimate the degree of interconnection (leakage) between the aquifers. The aquifer testing was accomplished by pumping each well in turn, beginning with the shallowest (TR92-1A), while using the other wells as observation wells. Pumping was conducted using temporarily installed multi-stage submersible pump, to allow for aquifer testing at varying flow rates. While the pumping was underway, pressure transducers installed in the observation wells were used to record any drawdown of the water level, which would indicate aquifer interconnection.

RESULTS

Tritium in Water Wells

As of early 1994, 109 private and public water supply wells had been sampled during the Tritium Project (Figures 22, p. 35, and 23, p. 37). Tritium Project numbers (#1 through #109) were assigned to every sampled well and the subsequent tritium analysis results are shown in Appendix 1. Using the previously identified "threshold" value of 500 picoCuries per liter, as of early 1994, a total of fifteen wells had been identified as polluted (Table 9, p. 34). The first ten polluted wells, identified between July, 1991 and October, 1992, were selected for USGS geophysical logging, to establish the accurate depths of the wells. Property owners granted permission for geophysical logging of nine of these first ten polluted wells. One property owner, however, declined permission for geophysical logging because of the age and condition of his well. The results of the geophysical logging, which took place in September, 1992 and February, 1993, are shown in Table 10. The geophysical logging of the nine wells demonstrate that eight of the nine wells are drawing their water from the Upper Three Runs aquifer. The logging results of the ninth well (Delaigle Trailer Park well #3) were inconclusive, but a downhole video camera study of the well in April, 1993, showed that the 6 inch PVC casing was shattered from 154 feet below the top of the

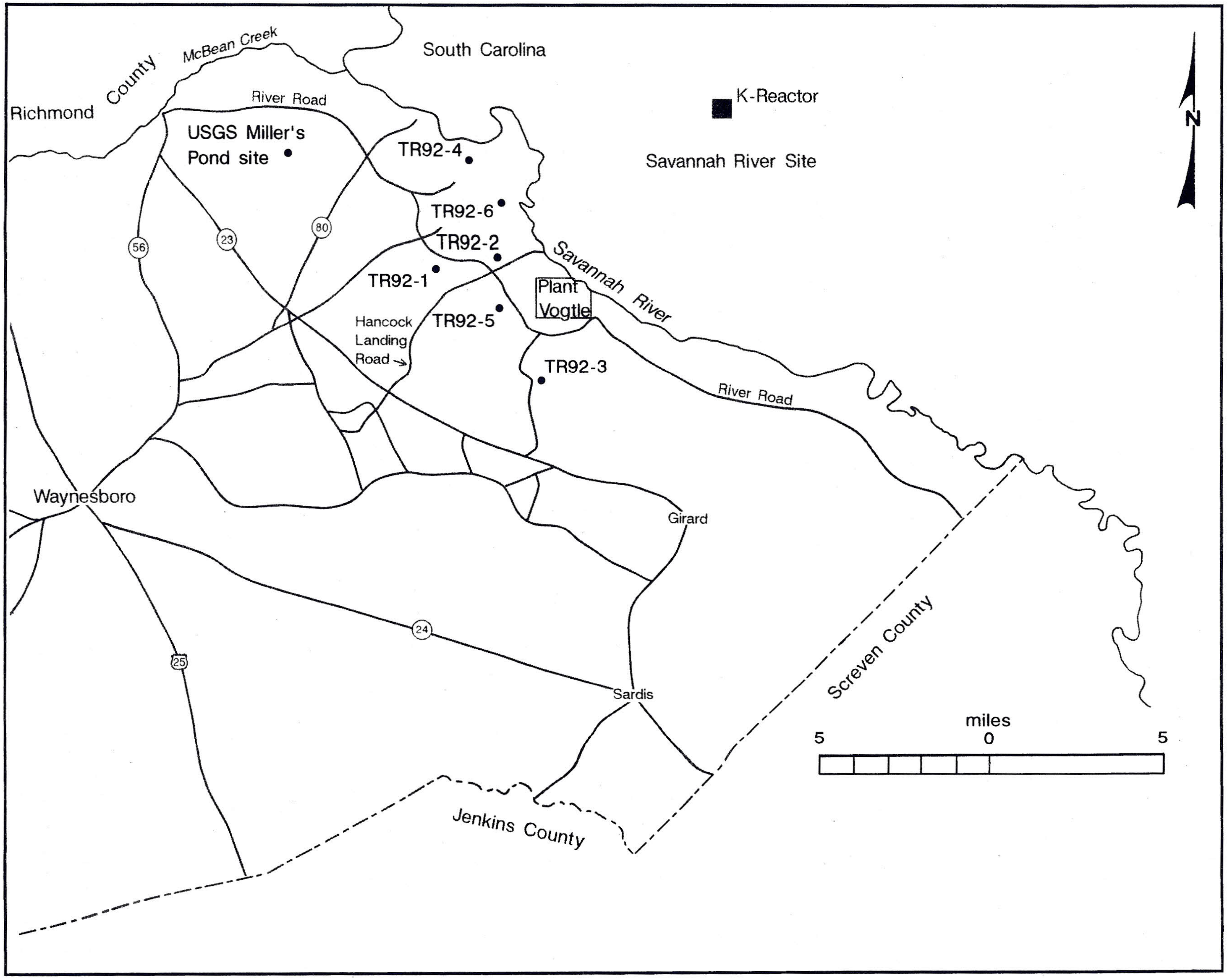


Figure 19. Locations of Tritium Project well cluster sites and the USGS Trans-River Flow Project Miller's Pond site.

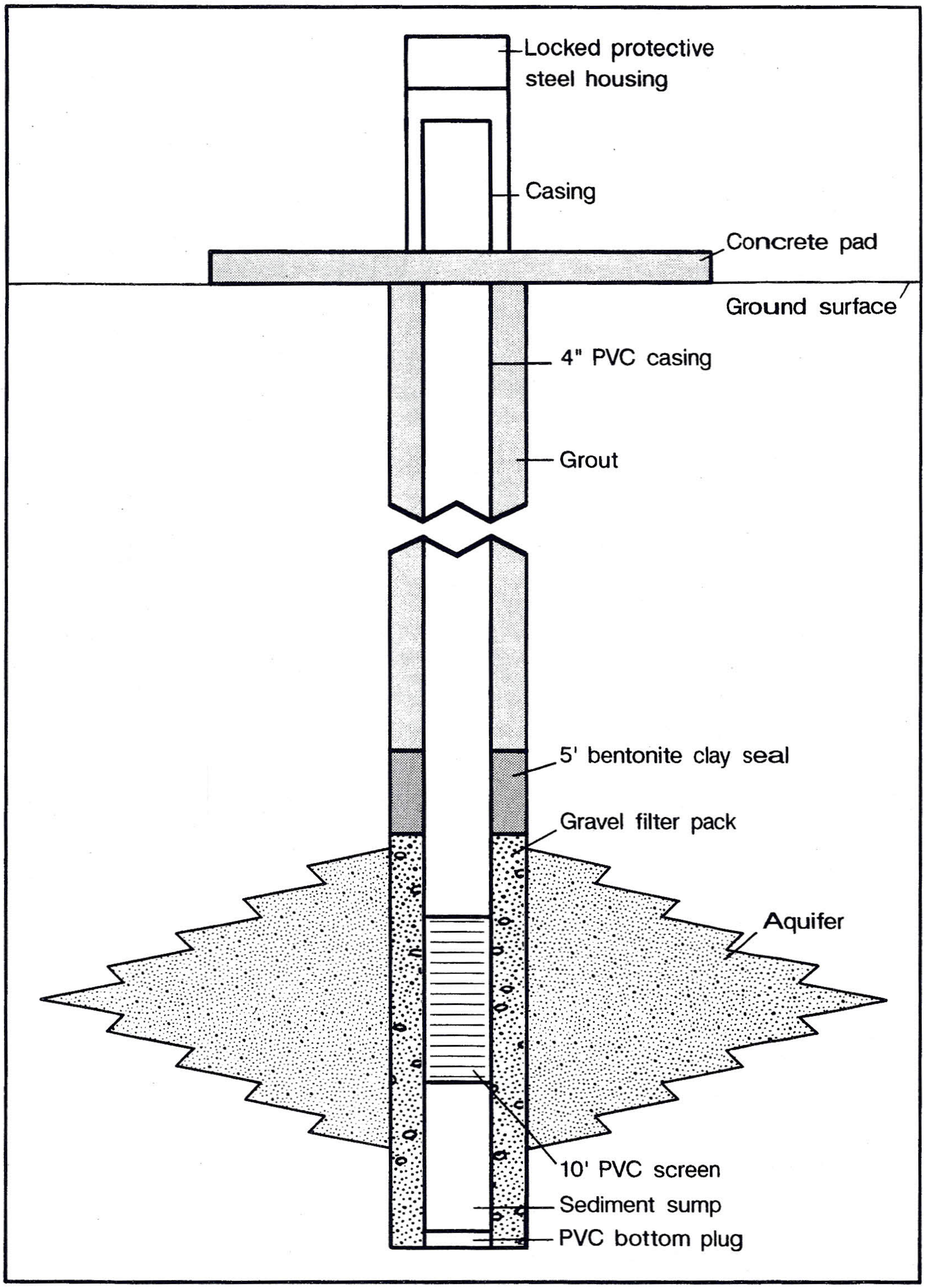


Figure 20. Details of a typical ground water monitoring well constructed for the Tritium Project.

casing downward for at least three feet (Figure 24, p. 38). The total shattered interval is unknown, because below 157 feet, the well is filled with sand, limestone fragments, and PVC fragments. The ground water entering the well from the 154 to 157 foot interval is probably from the Utley Limestone Member of the Clinchfield Formation. The Utley Limestone is included in the Upper Three Runs aquifer.

Six of the nine geophysically logged wells lack grouting or casing (in the case of the two cistern type wells). Only three of the wells have a concrete pad at the surface protecting the wells from leakage around the well casing.

Prior to geophysical logging, the GGS obtained "reported" depths for six of the first ten polluted wells from either the well driller or the home owner (Table 10). In all

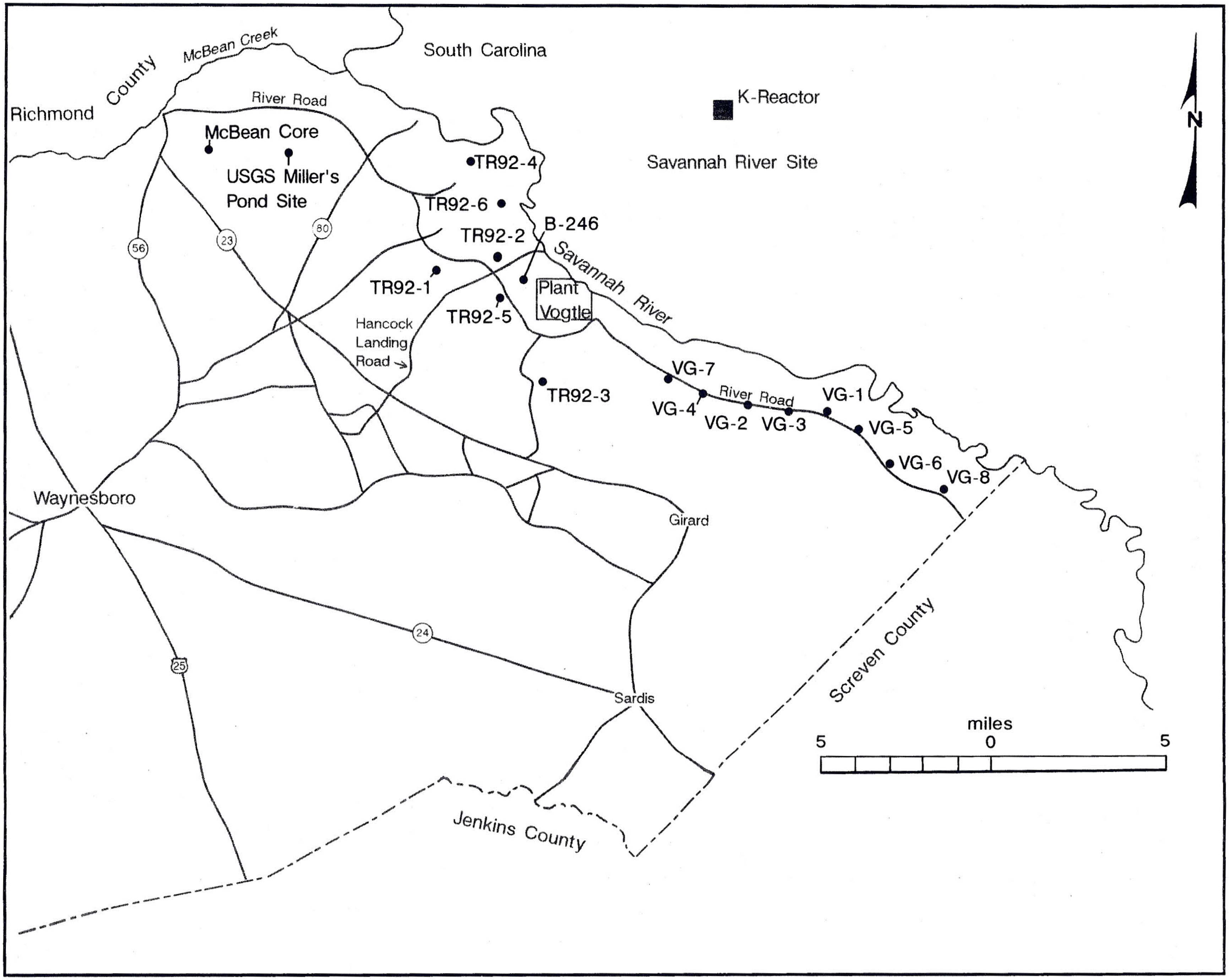


Figure 21. Index map of eastern Burke County, showing locations of cores used to develop the geologic framework. Core B-246 was drilled by Georgia Power in the early 1970's. "VG" cores were drilled by the Bechtel Corporation in 1982. All other cores were drilled by GGS.

Table 9

Water wells with elevated concentrations of tritium (≥500 picoCuries per liter) in eastern Burke County. 109 wells were sampled. Well locations are shown in Figures 22 and 23.

Name	**Tritium Project Well Number**	**Date of Initial Sample**	**Tritium-picoCuries/liter**
Arthur Jackson Residence	6	10/08/91	1300 ± 200
Delaigle Trailer Park Well #3	3	07/07/91	1200 ± 200
Ralph Greer Residence	79	11/20/91	1000 ± 100
Hug-a-Hog Plantation	46	10/17/91	1000 ± 100
George Wilson Residence	36	02/10/92	600 ± 100
Lamar Paul Residence	59	08/21/92	900 ± 100
Walnut Run Ostrich Farm	77	08/14/92	700 ± 100
Ricky Greer Residence	80	02/10/92	500 ± 100
Rose Johnson Residence	84	10/08/91	500 ± 100
Frank Wimberly Residence	33	10/01/92	1000 ± 100
Julian Morris Residence	56	07/07/92	500 ± 100
Bill Sturgeon Residence	9	02/02/93	1200 ± 200
Mary Johnson Residence	65	05/18/93	1600 ± 200
Alma Crook Residence	108	02/03/94	2000 ± 200
Earl Mills Residence	109	02/03/94	800 ± 100

cases the measured depth of the well is significantly shallower than the reported depth. The discrepancy may be due to gradual filling of the wells with sediment, failure of the well (as in the Delaigle well), or improper "reporting" of depths. For whatever reason, the discrepancy indicates that "reported" depths of wells in Burke County are not usable for hydrogeologic analysis.

The five additional polluted wells were located (after the USGS logging) by re-examination of EPD records (#56) and additional sampling (#9, #65, #108, and #109) (Figure 23, p. 37). Four of these five polluted wells are "reported" to have been drilled into the Upper Three Runs aquifer by the owners (#56 and #108) or by the driller of the other two wells (#9 and #65) (who orally stated that the wells were

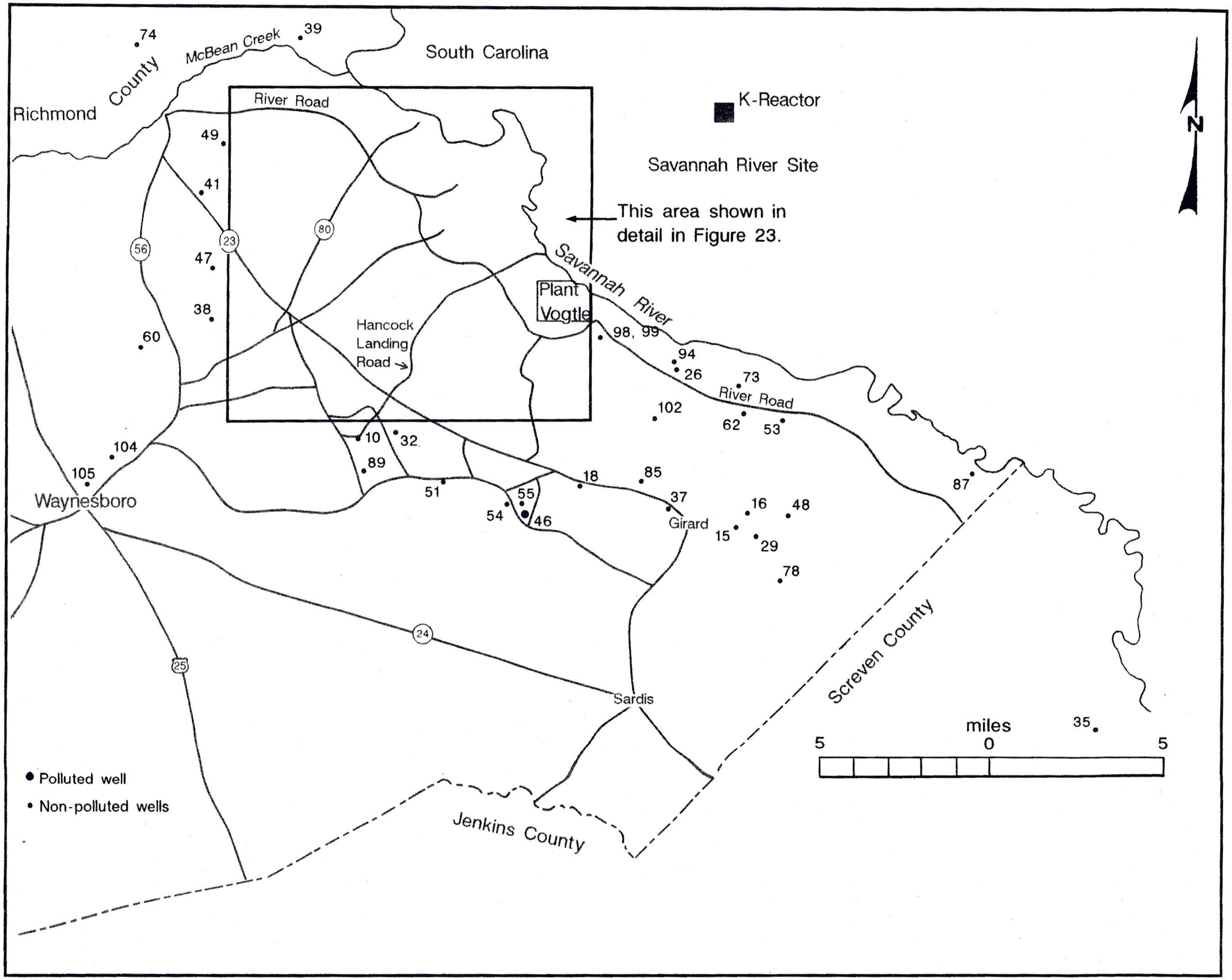


Figure 22. Index map of eastern Burke County, showing locations of wells sampled by EPD personnel, before and during the Tritium Project (April, 1987 - present). Polluted well is at Hug-a-Hog Plantation.

Table 10

Results of geophysical logging of anomalous water wells, and surface inspection of well sites. Well locations shown in Figures 22 and 23. All wells are in Three Runs Aquifer.

Name	Well Number	Well Construction	Screened/Open Interval (feet below surface)	Original Reported Depth (feet)
Arthur Jackson Residence (1)	6	no grout, no surface pad	100 - 138.9	220 (6)
Delaigle Trailer Park Well #3 (1)	3	grouted, surface pad, damaged casing	154 - 157 + (5)	300 (6)
Ralph Greer Residence (2)	79	no grout, no surface pad	87 - 118.1	180 (6)
Hug-a-Hog Plantation	46	36" cistern, no casing	0 - 27	not reported
George Wilson Residence (2)	36	grouted, surface pad	149 - 168.9	220 (6)
Lamar Paul Residence (4)	59	grouted (?), no surface pad	90 - 114	140 (6)
Walnut Run Ostrich Farm (3)	77	no grout, no surface pad	99 - 114	220 (6)
Ricky Greer Residence (7)	80	unknown	unknown	not reported
Rose Johnson Residence	84	no grout, no surface pad	105 - 112	not reported
Frank Wimberly Residence	33	36" cistern, no casing, surface pad	0 - 80.8	not reported

(1) Geophysically logged on 04 September 1992.
(2) Geophysically logged on 11 September 1992.
(3) Geophysically logged on 02 February 1993.
(4) Geophysically logged on 03 February 1993.
(5) Casing shattered from 154' to 157'+ below surface. Damage revealed through downhole video-camera examination.
(6) Oral communication from well driller or property owner.
(7) Owner declined offer to perform geophysical logging of well because of concern about condition of old pump. The piston-type pump used can lift water <100'.

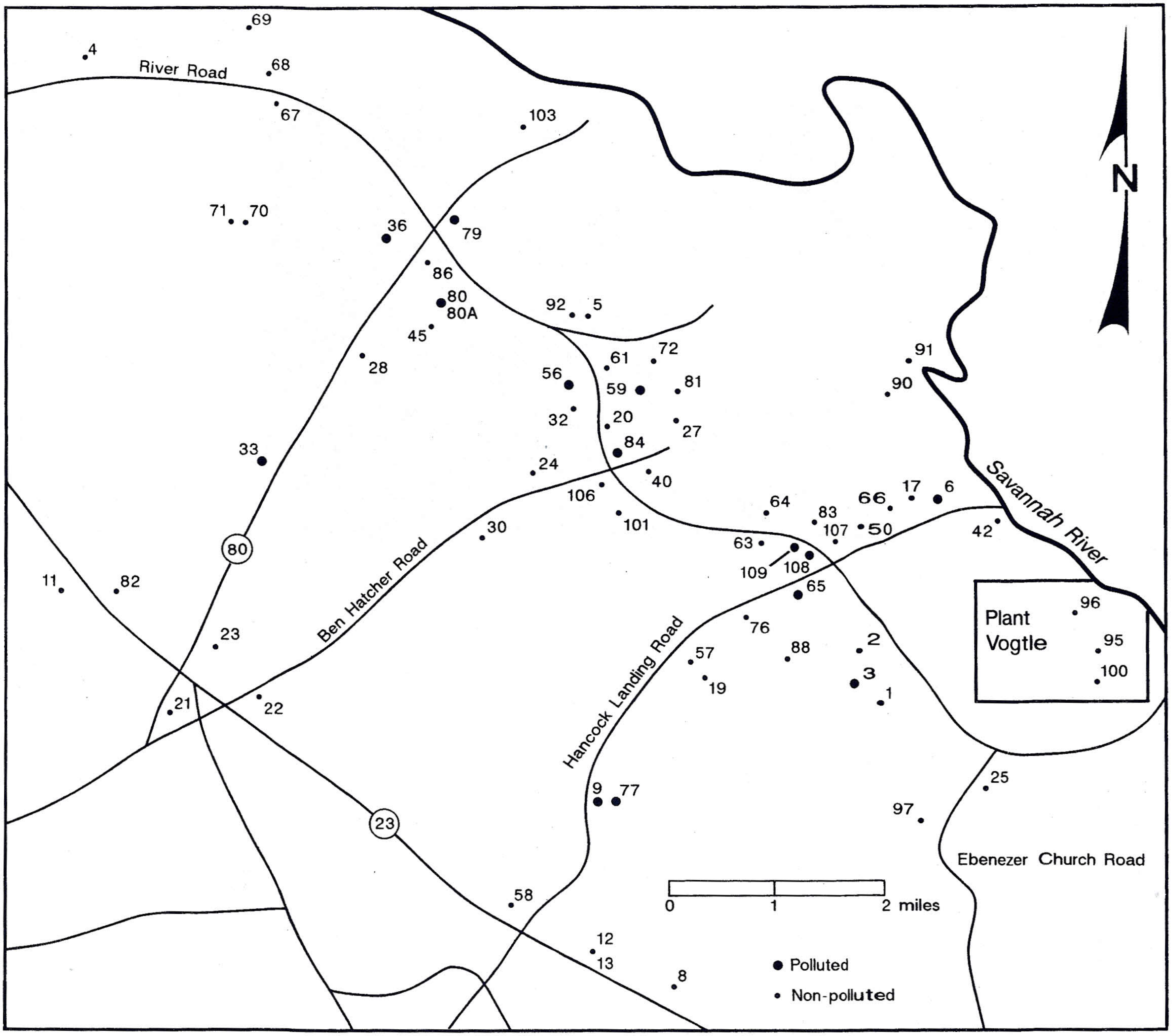


Figure 23. Detailed map of the central portion of the Tritium Project study area. Numbers identify wells sampled by EPD personnel before and during the Tritium Project (1987 - present). Polluted wells average average >500 picoCuries per liter.

"drilled above the (Utley) limestone"). The other polluted well (#109) was "reported" by the owner to be a "deeper" well. As with the nine logged wells, these five orally reported depths are considered unreliable. Sampling dates and results for subsequent testing of all fifteen polluted water wells are listed in Appendix 5 (p. 80).

Beyond the nine wells measured by geophysical logging, the well depths of the remaining 100 (unlogged) wells are unknown (or unreliable). Other than variances in well depth (Upper Three Runs aquifer vs. Gordon aquifer), the significance of the interspersal of polluted wells within the non-polluted wells is uncertain, as 100 percent of the local wells have not yet been sampled.

Tritium in Base Flow

1991 Base Flow Study

The tritium concentrations of the 53 samples collected during the 1991 base flow study ranged from 400 (± 100) to 1900 (± 200) picoCuries per liter. The areal distribution of

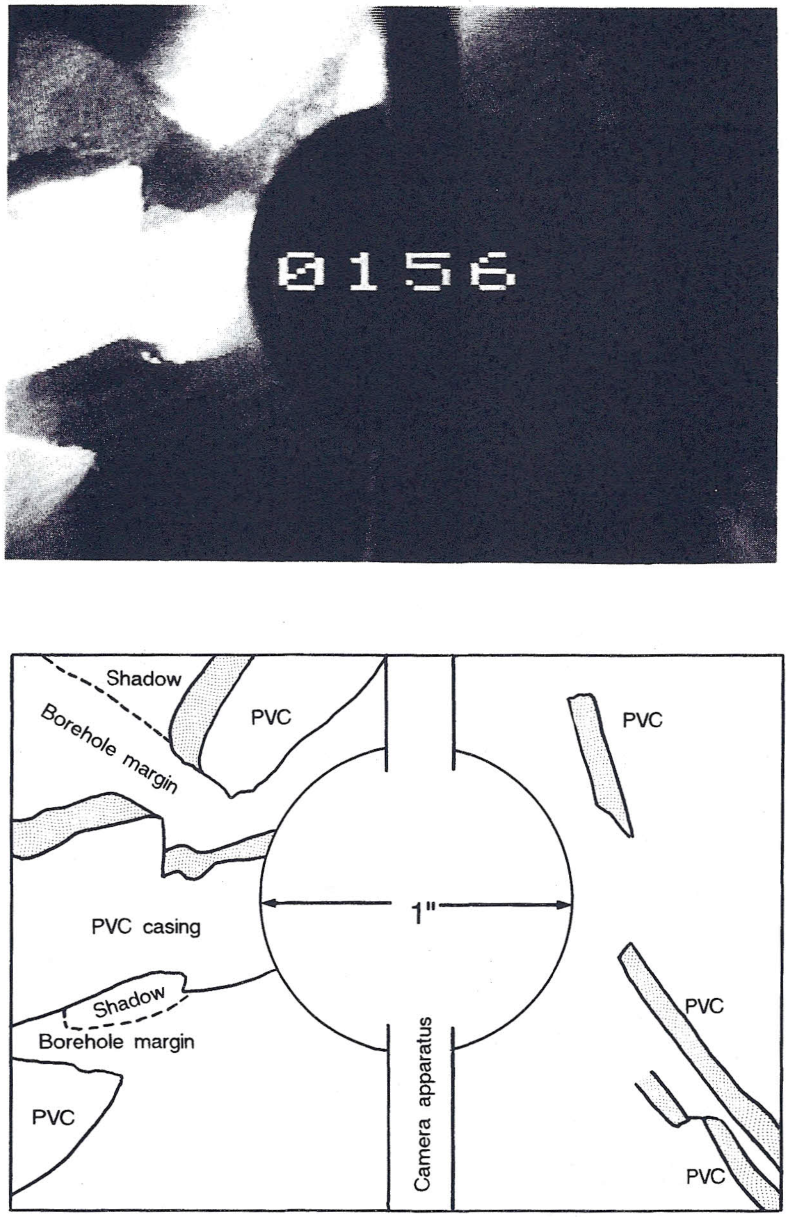


Figure 24. Photograph of the shattered portion of the Delaigle Trailer Park Well #3.

tritium concentrations based on the 1991 base flow study is shown in Figure 25 (p. 39). As the water present in streams under base flow conditions is derived almost entirely from Upper Three Runs aquifer discharge, tritium concentrations in the streams should approximate the tritium concentrations in the aquifer. As shown on the isopleth map (Figure 25, p. 39), the area with the highest concentrations of tritium lies near the Savannah River, just north of Hancock Landing Road and east of River Road. From this area, tritium concentrations decrease to the northwest, west, and southeast.

1992 Base Flow Study

The tritium values of 126 samples collected during the

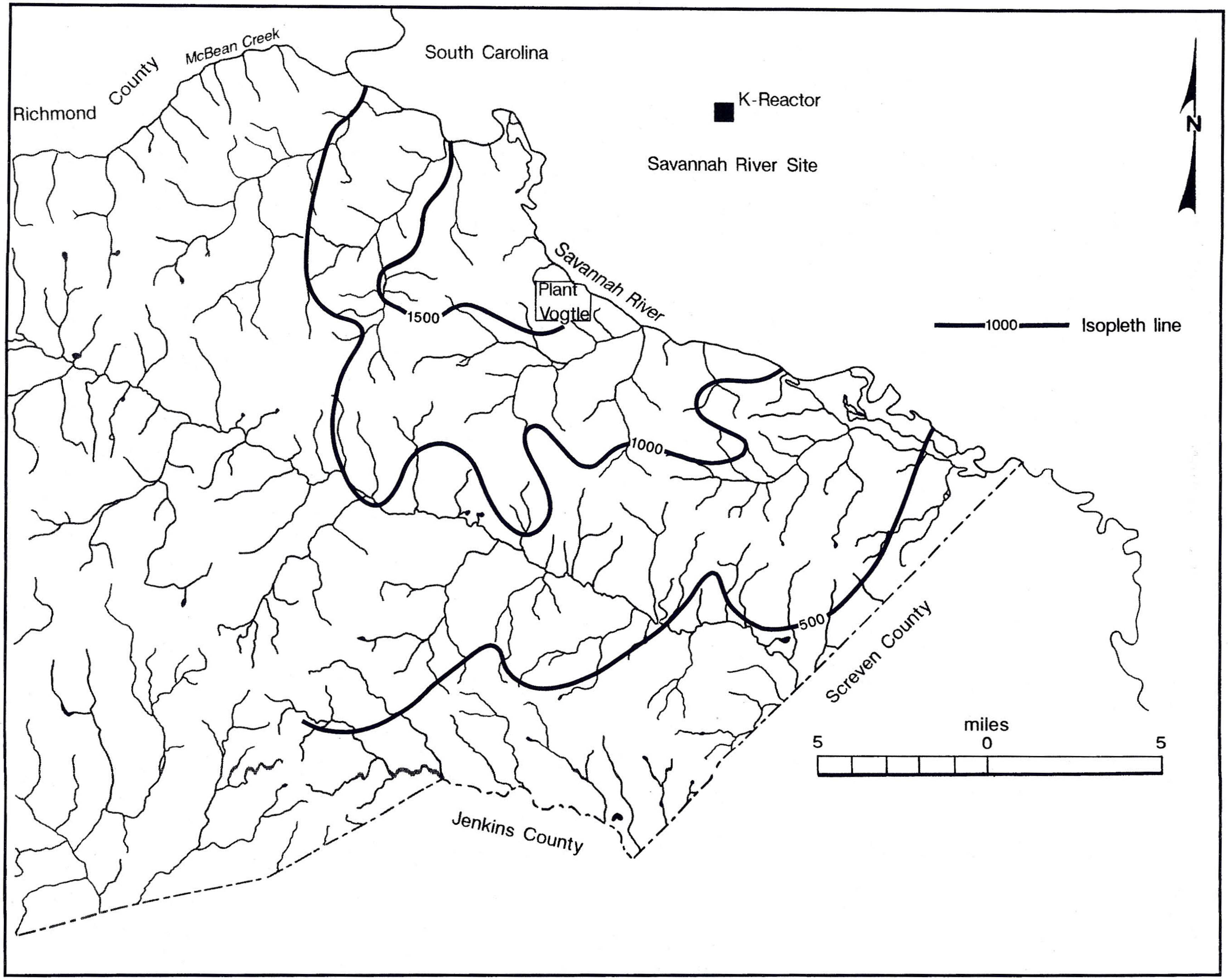


Figure 25. Isopleth map based on surface water tritium values of the 1991 base flow study, eastern Burke County. Values are in picoCuries per liter.

Table 11

Comparison of tritium concentrations estimated from 1992 base flow study with measurements from public and private supply wells. Well locations are shown in Figures 22 and 23.

Tritium Project Well Numbers	Expected Tritium Concentrations (based on 1992 Base Flow Study)	Measured Tritium Concentrations (picoCuries/liter)	Date Measured
3	1500	1200	08/06/92
6	2100	1000	12/30/92
9	1200	1200	02/02/93
33	1000	1000	10/01/92
36	1100	700	09/03/92
46	700	900	08/14/92
56	1500	500	07/07/92
59	1600	800	09/04/92
65	1600	1600	05/18/93
77	1200	700	12/30/92
79	1200	800	09/03/92
80	1300	600	03/04/92
84	1600	500	01/15/93
108	1700	2000	02/03/94
109	1700	800	02/03/94

1992 base flow study ranged from <100 (below detection limits) to 2200 (±200) picoCuries per liter. The areal distribution of tritium concentrations based on the 1992 base flow study is shown in Figure 26 (p. 41). As with the 1991 base flow study, the area with the highest tritium values lies just north of Hancock Landing Road and just east of River Road. Subsequent sampling within this area of peak tritium concentration showed a tritium concentration of 3,500 picoCuries per liter (±200) from a spring along the bluffs of the Savannah River near drilling site TR92-6 (see Figure 19 for location of this cluster site).

Comparison of 1991 and 1992 Results

In general, the distribution of tritium in 1992 was similar to the 1991 distribution. Detailed comparisons of the 1991 and 1992 studies are not appropriate because of the differences in the number of samples used in the two studies. However, the data suggest that in 1992 there was a slight contraction of the 500 and 1000 picoCurie per liter isopleths on the southeastern side of the area of pollution. Whether this represents a long-term trend towards reduction in tritium pollution or is the result of year to year fluctuations is unknown.

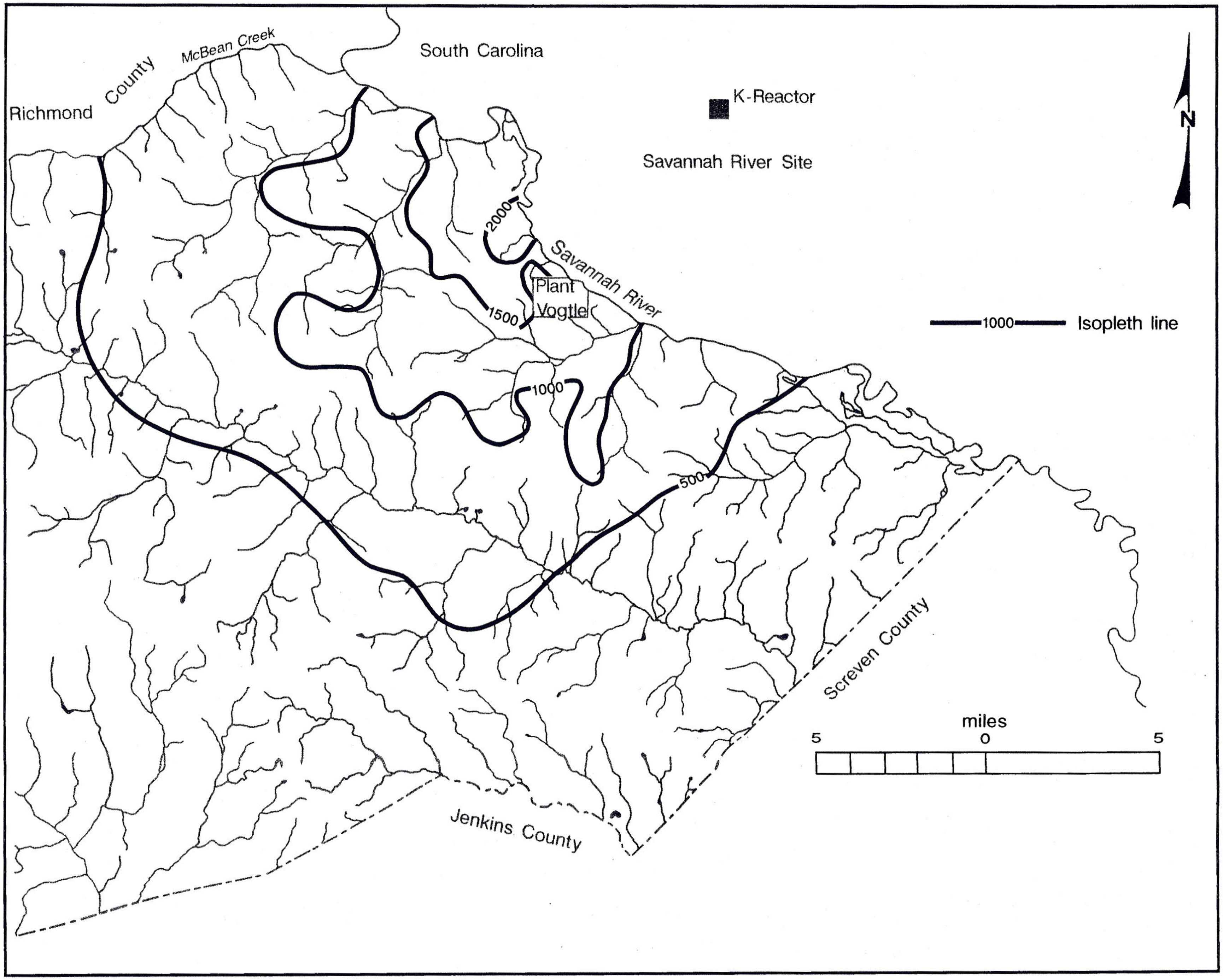


Figure 26. Isopleth map based on surface water tritium values of the 1992 base flow study, eastern Burke County. Values are in picoCuries per liter.

Comparison of 1992 Base Flow Results with Water Well Data

The results from the 1992 base flow study are generally corroborated by tritium concentrations observed in water supply wells (Table 11; Figure 27, p. 43), based on the geographic location of each polluted water supply well. Thus, a water supply well located half way between the 500 and 1,000 picoCurie per liter isopleths would have a predicted tritium concentration of 750 picoCuries per liter. One water well sample has a tritium concentration higher than the predicted tritium concentrations from the 1992 base flow samples. Three of the fifteen water wells have tritium concentrations that match the predicted base flow concentrations, five wells have tritium concentrations between 100 and 500 picoCuries per liter (one contour interval) of the predicted base flow concentrations, and six wells have tritium concentrations between 600 and 1,100 picoCuries per liter (two contour intervals) of predicted base flow concentrations. The fact that these public and private water supply wells generally have lower concentrations of tritium than the base flow samples may be due to these water wells drawing their water from various depths in the aquifer, whereas the base flow samples generally are derived from the uppermost part of the aquifer. The five water supply wells that have tritium concentrations 600 picoCuries per liter or more below the predicted concentrations lie along a line between Hancock Landing and the intersection of River Road and Georgia Highway 80. This zone of significantly lower than expected tritium concentrations may be due to the presence of discontinuous clay layers within the Upper Three Runs aquifer, which differentially retard the downward movement of tritium-polluted ground water, or to effects from faulting which has been postulated for that area.

Tritium in Monitoring Wells

The average tritium concentrations for samples from each of the fifteen ground-water monitoring wells at the six cluster sites are shown in Table 12 (p. 44). The results of all monitoring well tritium analyses are presented in Appendix 6 (p. 84).

After development and purging of the seven Gordon aquifer monitoring wells, only one Gordon aquifer monitoring well (TR92-5C) showed consistent detectable concentrations of tritium (above 100 picoCuries per liter). This result has been confirmed by repeated sampling at all six cluster sites.

Gordon aquifer monitoring well TR92-5B showed low concentrations of tritium (500 to 600 picoCuries per liter) when initially sampled, on June 15, 1993. The well was later resampled after extensive purging of the well prior to sampling. These later samples had tritium concentrations below the detection limits. The initial positive results for this well were probably due to tritium introduced into the Gordon aquifer from the overlying polluted Upper Three Runs aquifer, during drilling. This tritium was flushed out after thorough purging of the well. Monitoring well TR92-5C, screened between 200 and 300 feet, consistently shows low concentrations of tritium (300 to 400 picoCuries per liter) even after extensive purging. This well is located 50 feet from the radiologically anomalous Delaigle Trailer Park well #3. The Delaigle well is screened between the depths of 200 and 300 feet (according to the driller's report), but the casing has been shattered at a depth of 154 feet (Figure 24, p. 38). It is likely that the Delaigle Trailer Park well #3 is acting as a conduit allowing tritium polluted water from the Upper Three Runs aquifer to enter the Gordon aquifer, and that monitoring well TR92-5C is detecting this pollution. Monitoring well TR92-5B, which is also screened in the Gordon aquifer, is located 94 feet from the Delaigle Trailer Park well #3 and does not show detectable concentrations of tritium. This suggests that the area of pollution within the Gordon aquifer is relatively small.

After development and purging of the six Upper Three Runs aquifer monitoring wells (excluding TR92-6A, which was dry), all of the samples from the Upper Three Runs aquifer have detectable concentrations of tritium, with values ranging from 200 to 1700 picoCuries per liter (Appendix 6), well below the EPA MCL of 20,000 picoCuries per liter. Tritium concentrations in the Upper Three Runs aquifer monitoring wells TR92-2A, TR92-3A, TR92-4A, TR92-4A2, TR92-5A, and TW-4 (USGS Miller's Pond site) are consistent with the tritium concentrations measured in the 1992 base flow studies (Figure 28, p. 45; Table 13, p. 46). Tritium concentrations detected in the Upper Three Runs well TR92-1A, however, are significantly lower than concentrations expected based on the results of the base flow studies. Results from the 1991 and 1992 base flow studies suggest that tritium concentrations in the Upper Three Runs aquifer in the vicinity of cluster site TR92-1 should be within the range of 1200 to 1800 picoCuries per liter. Repeated sampling of TR92-1A, however, resulted in a maximum tritium concentration of 300 picoCuries per liter (Appendix 6). Examination of the core samples from this cluster site indicates that monitoring well TR92-1A is screened in a zone that is separated from the upper part of the Upper Three Runs aquifer by a thin clay layer. This clay layer may serve as a partial confining unit that retards the tritium polluted water in the upper part of the aquifer from freely entering the strata sampled by the well. In addition to the information supplied by the GGS Tritium Project monitoring wells, seven USGS Trans-River Flow Project monitoring wells at Miller's Pond were sampled for tritium. The depths and aquifers sampled for each well at the Miller's Pond Cluster Site are shown in Table 14 (p. 48). Of the samples tested, only the Upper Three Runs aquifer well (TW-4) had detectable tritium concentrations (700 picoCuries per liter ± 100).

Geology

Seventeen cores (see Figure 21, p. 33, for core locations) were examined and used to reconstruct a three dimensional geologic framework for eastern Burke County. Figure 29 (p. 47) shows an approximate north-south slice

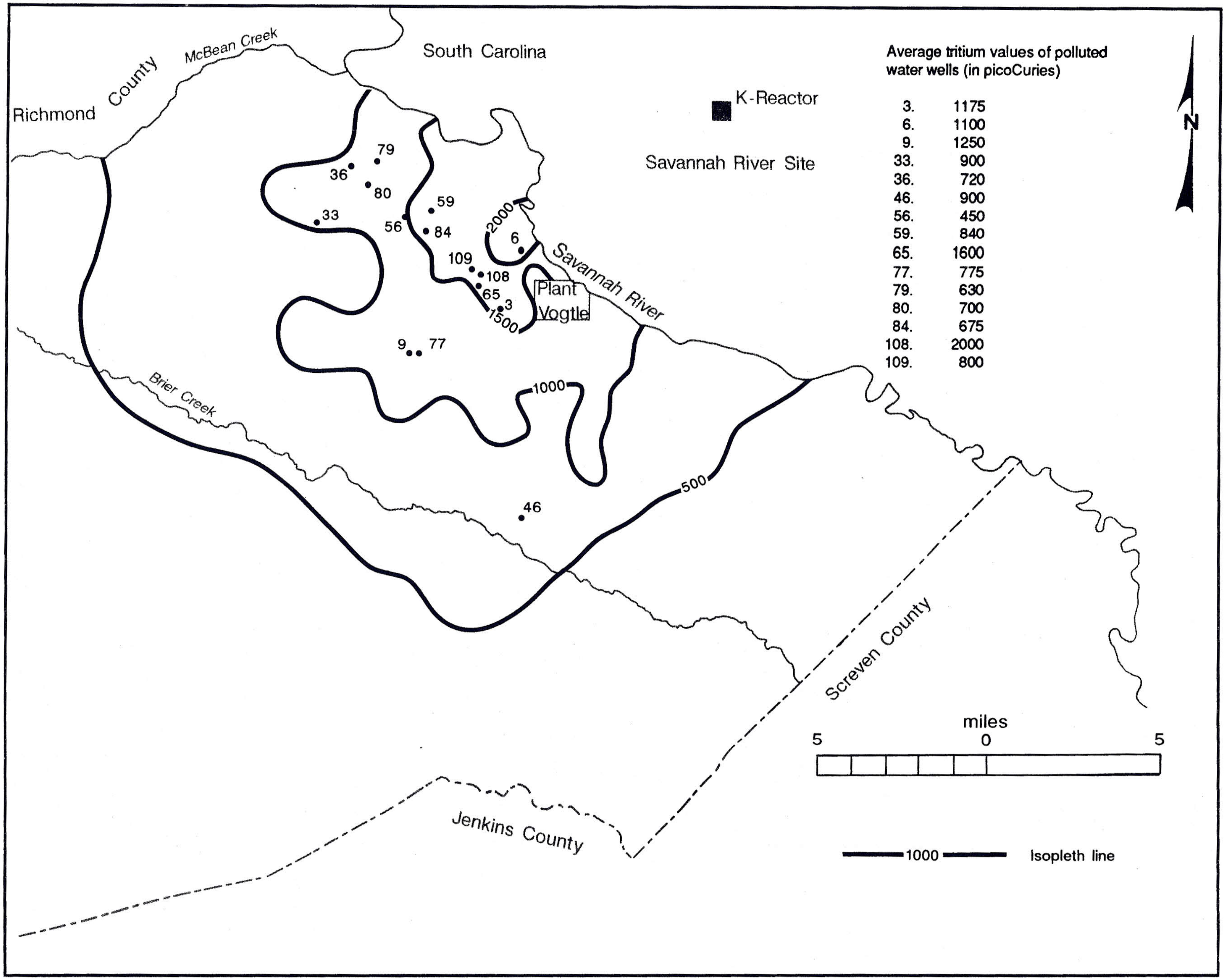


Figure 27. Index map showing polluted wells in relation to 1992 base flow isopleths. Wells are identified by number in Appendix 1. Values are in picoCuries per liter.

Table 12

Results of tritium analyses of water samples from Tritium Project ground-water monitoring wells.

Well Number	Aquifer	Tritium (picoCuries/liter)	Sampling Date
TR92-1A	Upper Three Runs	200	11/17/92
TR92-1B	Gordon	below detection	11/17/92
TR92-1C (1)	Meyers Branch	below detection	12/14/92
TR92-1D	Dublin	below detection	12/14/92
TR92-2A	Upper Three Runs	1400	03/02/93
TR92-2B	Gordon	below detection	02/18/93
TR92-3A	Upper Three Runs	1200	03/02/93
TR92-3B	Gordon	below dectection	01/05/93
TR92-4A	Upper Three Runs	1600	03/02/93
TR92-4A2 (2)	Upper Three Runs	1600	02/03/94
TR92-4B	Gordon	below detection	01/06/93
TR92-5A	Upper Three Runs	1000	09/01/93
TR92-5B	Gordon	below detection	06/24/93
TR92-5C (3)	Gordon	400	09/01/93
TR92-6A (4)	Upper Three Runs	dry hole	
TR92-6B	Gordon	below detection	09/01/93

(1) Sand within Meyers Branch Confining System.
(2) Redrilled slightly deeper for better water production.
(3) 100' screened interval, to duplicate reported construction of Delaigle Trailer Park well #3.
(4) Well is screened in an impermeable portion of the Utley Limestone.

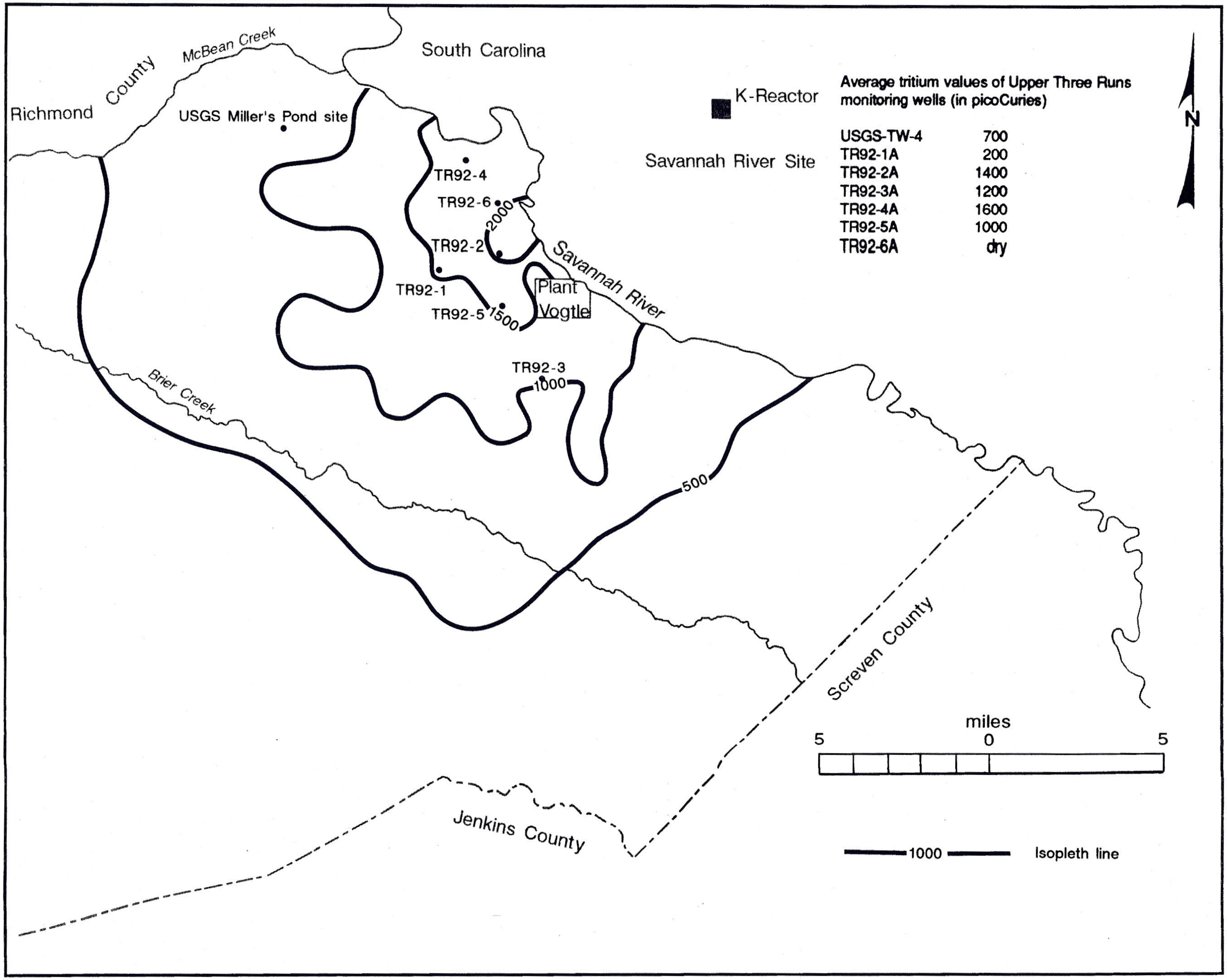


Figure 28. Index map showing cluster sites in relation to 1992 base flow isopleths. Values are in picoCuries per liter.

Table 13

Comparison of tritium concentrations predicted from 1992 base flow study with measurements from Tritium Project ground-water monitoring wells.

Well	Estimated Tritium Concentrations Based on 1992 Base Flow Study (picoCuries/liter)	Measured Tritium Concentrations (picoCuries/liter)	Date Measured
TR92-1A	1500	200	11/17/92
TR92-2A	2000	1700	02/18/93
TR92-3A	1100	1200	03/02/93
TR92-4A	1700	1600	03/02/93
TR92-5A	1500	1000	08/26/93
TR92-6A	2000	dry	-------
TW-4 (Miller's Pond)	900	700	01/15/93

through the study area that includes five of the six cluster sites.

The sediments of the Upper Eocene Barnwell Group (consisting of the Tobacco Road Formation, the Irwinton Sand Member and the Griffin's Landing Member of the Dry Branch Formation, and the Utley Limestone Member of the Clinchfield Formation) make up the upper part of the stratigraphic section (Figure 29).

The Tobacco Road Sand is a deeply weathered, highly pigmented, massively-bedded, moderately to poorly sorted, burrowed and bioturbated, medium to coarse-grained sand, containing minor amounts of clays, chert, calcite, glauconite, and other minor constituents (Huddlestun, in preparation). The Irwinton Sand Member of the Dry Branch Formation is generally a well sorted, variously bedded, fine to medium grained sand. Smectitic clay beds, lenses, and laminae of varying thickness and lateral extent occur throughout the Irwinton Sand, resulting in locally perched water tables. Down dip from and underlying the Irwinton Sand is the Griffin's Landing Member of the Dry Branch Formation. The Griffin's Landing Member is a moderately sorted, massive to vaguely bedded calcareous sand, with local occurrences of thin limestone beds, calcareous beds or lenses, oyster shell beds and bioherms, and chert and silica-cemented sandstones (Huddlestun, in preparation). The basal unit of the Barnwell Group is the Utley Limestone Member of the Clinchfield Formation. Occurring primarily in eastern Burke County, the Utley Limestone is typically a moldic, fossiliferous sandy limestone that is variably glauconitic, with occasional beds of calcareous sands. The Utley Limestone is highly variable in thickness, perhaps due to dissolution, ranging in thickness from 0 (where missing) to 13 feet, at the type locality at Mallards Pond, near Plant Vogtle (Figure 11, p. 17). In summary, approximately the upper 95 percent of the Barnwell Group is composed of sandy units; the lower 5 percent is a limestone. There appears to be little change of facies within the Barnwell Group across the study area except that the top of the Griffin's Landing Member grades both upward and laterally into the Irwinton Sand.

Recent geological mapping by Hetrick (1992) shows that, within the study area, the Savannah River has cut through the sediments of the Barnwell Group at least as far south as Beaverdam Creek, downstream from Plant Vogtle.

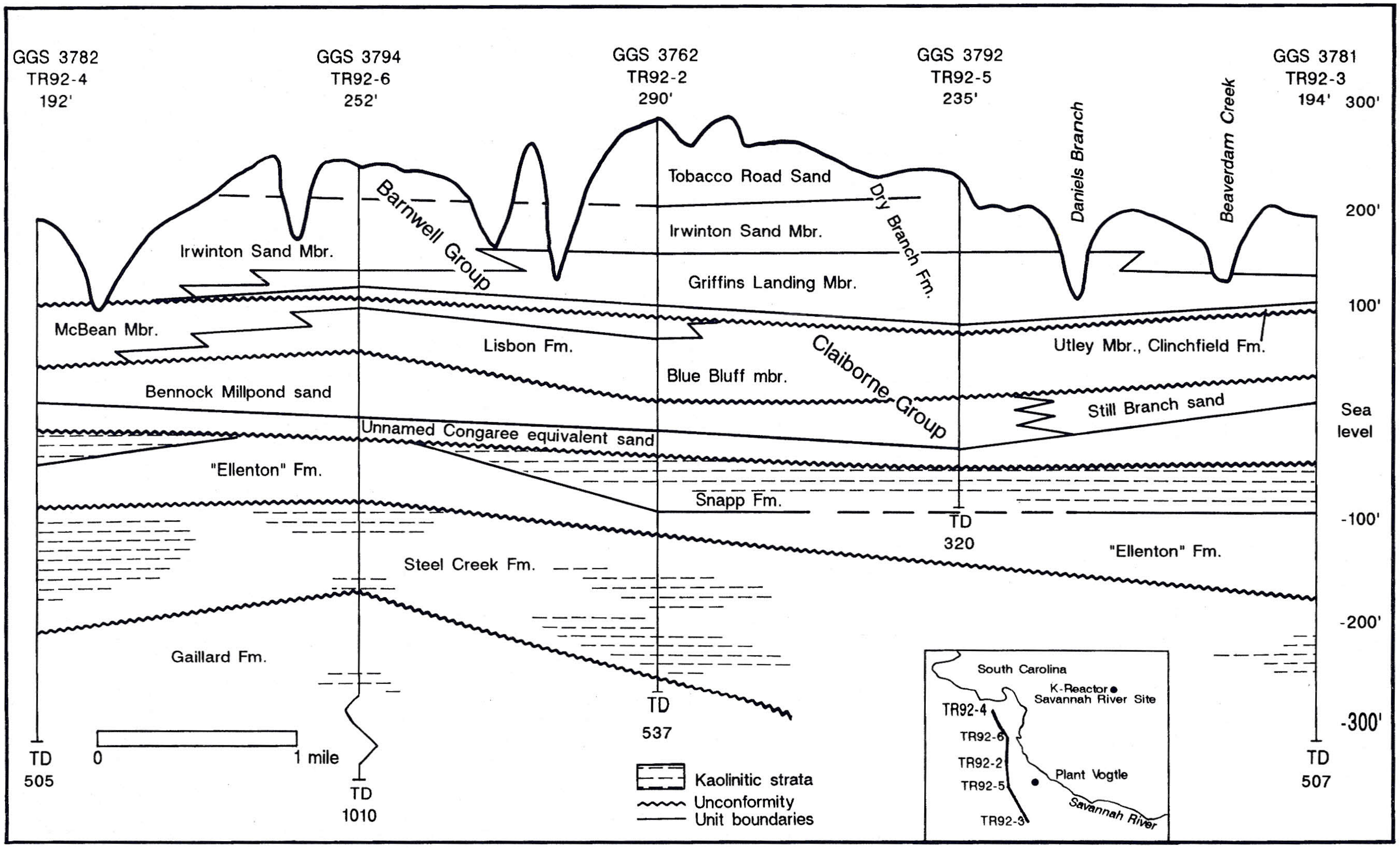


Figure 29. North-south stratigraphic cross-section in east-central Burke County, Georgia.

Table 14

USGS Trans-River Flow Project monitoring wells at Miller's Pond Site in Burke County, Georgia. All data provided by USGS.

Well Number	Screened Interval (feet below surface)	Tritium (picoCuries/ liter)	Aquifer
TW-4	80 - 199	700 ± 100	Upper Three Runs
TW-5A	211-251	below detection	Upper Dublin
TW-6	299 - 325	below detection	upper Lower Dublin
TW-7	450 - 475	below detection	lower Lower Dublin
TW-3	518 - 548	below detection	Allendale confining unit
TW-2	595 - 625	below detection	upper Midville
TW-1	705 - 735	below detection	lower Lower Midville

This incision by the Savannah River probably extends further to the south, but the contact between the Barnwell Group and the Lisbon Formation is covered by Quaternary alluvium. Geologic mapping also shows that McBean Creek has cut through the Barnwell Group sediments in the study area as have several smaller tributaries to the Savannah River including Boggy Gut Creek, Newberry Creek, Beaverdam Creek, and several small unnamed creeks.

The Lisbon Formation occurs throughout the study area, with the McBean Member in the northern part and the Blue Bluff member underlying the remainder of the area. The McBean Member is typically a fine grained sandy limestone that is variably calcarenitic, argillaceous, micaceous, and carbonaceous (Huddlestun, in preparation), with some glauconite in the lower part. In the McBean core, the McBean Member of the Lisbon Formation is a hard to mildly indurated, friable and brittle limestone that is massively-bedded and occasionally fossiliferous, with occasional beds of soft, sandy limestone.

In the northern and central parts of the study area, the McBean grades laterally through an "undifferentiated Lisbon" consisting of a soft, sandy limestone, overlying an unconsolidated calcareous, argillaceous, glauconitic, bioclastic, phosphatic sand, as seen in core from the TR92-4 site, and into the Blue Bluff member (Huddlestun, in preparation). The Blue Bluff Member of the Lisbon Formation ranges in composition from a bioturbated to thinly-bedded, silty to finely sandy, calcareous clay to a very argillaceous limestone, with minor lenses of sand. The Blue Bluff member ranges in thickness from 39 feet in areas where it intertongues with the updip McBean Member to 64 feet in core from the TR92-3 site and 84.5 feet in the Georgia Power core VG-1, near Girard (Huddlestun, in preparation). Because of its thickness and argillaceous nature, the Blue Bluff member (where present) appears to serve as a local aquitard.

Underlying the Lisbon Formation in the northern part of the study area are the sediments of the Claiborne Group, with the uppermost portion consisting of the Bennock Millpond sand (informal name) and, in the southern part of the study area, its downdip equivalent, the Still Branch sand (informal name) (Figure 29, p. 47; The Bennock Millpond sand broadly consists of three distinctive sand lithofacies: 1) a fossiliferous, calcareous, fine sand; 2) a massive to thinly bedded, noncalcareous, fine to very fine sand; and 3) a noncalcareous, bioturbated sand. The Bennock Millpond sand appears to be correlative with the Warley Hill Formation of South Carolina. Downdip, in the vicinity of Hancock Landing, the Bennock Millpond sand intertongues with and grades laterally into the Still Branch sand. The Still Branch sand consists of a calcareous, massively bedded, fine to medium grained sand, with an upper part which is a moldic, fossiliferous sandy limestone/calcareous sandstone. Where permeability permits, the Bennock Millpond and Still Branch

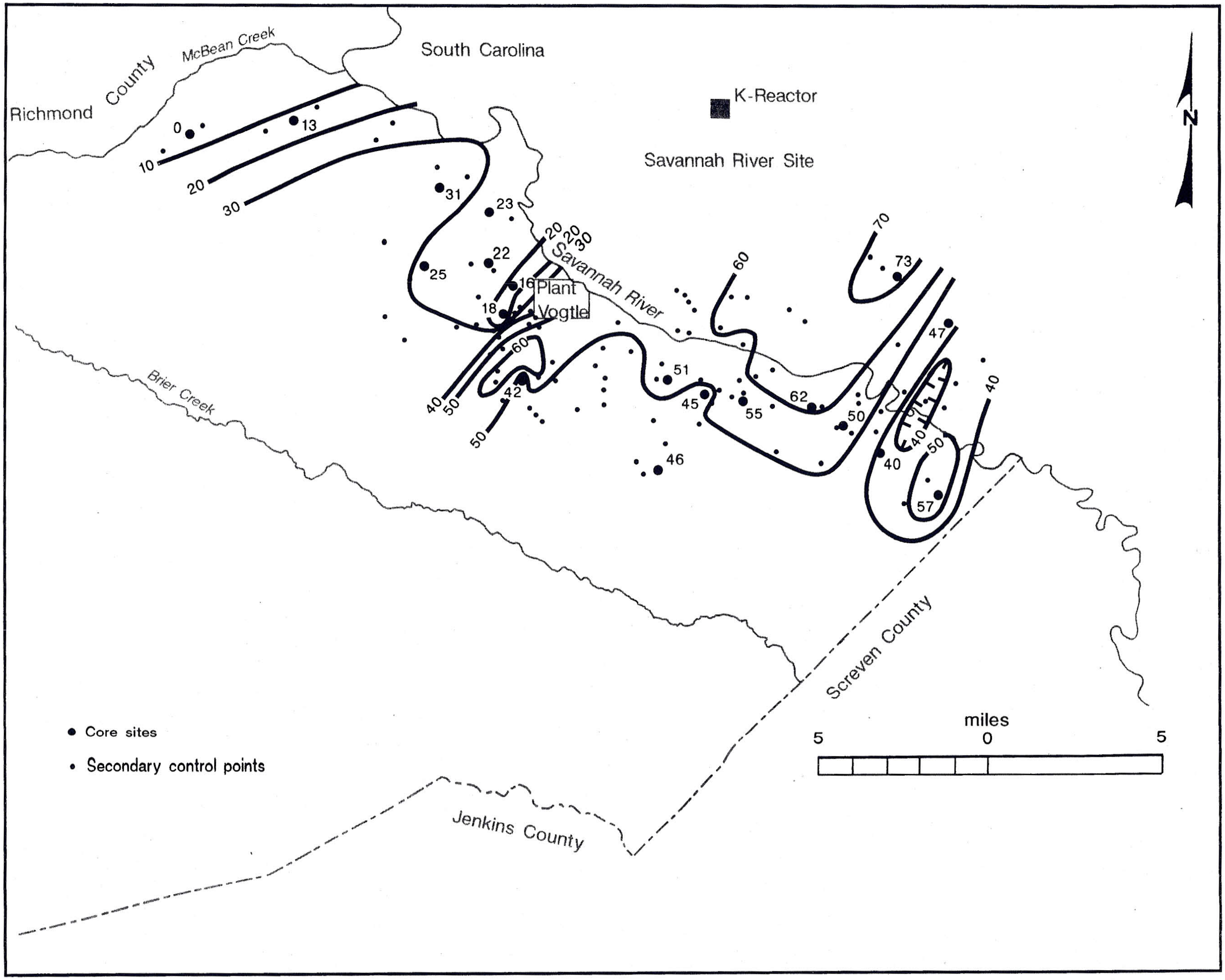


Figure 30. Isopach (thickness distribution) map of the Unnamed Congaree-equivalent sand. Thicknesses are in feet.

sands compose the upper portion of the Gordon aquifer.

Underlying both the Bennock Millpond and Still Branch sands is an unnamed Congaree-equivalent sand. This Congaree-equivalent sand is soft, barely cohesive to loose, noncalcareous sand, with scattered thin beds of clay, with no appreciable facies changes throughout the study area. These characteristics permit this unit to serve as the main portion of the Gordon aquifer in the study area. The thickness of this sand unit varies from absent in the McBean core to 62 feet in Georgia Power core VG-1 (Figure 30, p. 49). This sand appears to grade laterally (eastward) into the Congaree Formation in South Carolina (Huddlestun, in preparation).

Beneath the Claiborne Group lies the Oconee Group, consisting of the Lower Paleocene Snapp Formation (Figure 31, p. 51) and the "Ellenton" Formation and the Upper Cretaceous Steel Creek and Gaillard Formations (Figure 32, p. 53). The Snapp Formation marks the uppermost occurrence of kaolinitic clays in the study area. The kaolinitic beds of the Snapp Formation mark the top of a fining upward sequence, with a basal sand unit (Huddlestun, in preparation). The Snapp Formation kaolin is massively bedded and structureless, variably silty, finely micaceous, occasionally pyritic, and generally hackly with an irregular fracture. The Snapp Formation is absent in the core at site TR92-6, possibly permitting some vertical leakage between the Gordon aquifer and the underlying aquifer.

Gradationally underlying the Snapp Formation is the "Ellenton" Formation. Within the study area, the sands of the "Ellenton" Formation are fine to medium-grained and moderately to well-sorted, with the bedding ranging from massively structureless to rudely bedded and faintly bioturbated, with some interlaminated thin clay beds. Most commonly, the sands of the "Ellenton" are loose to barely cohesive and soft (Huddlestun, in preparation), characteristics which define this unit as the lower portions of the Gordon aquifer in Georgia and the sand within the Meyers Branch Confining System in South Carolina (Aadland and others, 1992). Disconformably underlying the "Ellenton" is the Upper Cretaceous Steel Creek Formation, which consists of interbedded, mottled, varicolored, fining upward kaolin and sand units. The quartz sands of the Steel Creek are variably cohesive to loose (depending on the kaolin content), massively bedded and structureless (Huddlestun, in preparation). The kaolin beds are generally silty to sandy, micaceous, massively bedded, structureless, and contain varying amounts of heavy minerals. As with the overlying Snapp Formation, this kaolin is dense, with a hackly, irregular fracture.

The deepest unit encountered by a Tritium Project monitoring well (TR92-1D) is the Upper Cretaceous Gaillard Formation, which conformably underlies the Steel Creek Formation. The sands of the Gaillard Formation are similar to those of the Steel Creek, except there are fewer clay beds present. The Gaillard Formation is defined as the Dublin aquifer within the study area, as well as in South Carolina (Aadland and others, 1992).

Structurally, the study area can be characterized as a region of gently dipping sediments, with a regional dip (between the Richmond-Burke County line and the Burke-Screven County line) on the top of the Blue Bluff member of 10 feet per mile to the southeast (Figure 33, p. 55). The Pen Branch fault, as defined at SRS, cannot be detected within the spacing of the current series of cores. There are, however, two minor structural features of uncertain significance near cluster site TR92-3 south of Beaverdam Creek. The Hancock Landing structural high appears to influence mainly the deeper rock units (Paleocene and Cretaceous formations) (Figure 34, p. 57) whereas the Beaverdam Creek structural high influences only the shallower rock units (Eocene formations) (Figure 33).

Seismic Survey of the Savannah River Channel

The information provided by the high resolution seismic survey and the auger boring suggests the breachment of the Lisbon Formation (aquitard) by the paleo-river channel and the incision of the underlying Gordon aquifer between the Point Comfort area and Hancock Landing (Figure 33) (Henry, unpublished data, 1994 and Leeth and Nagle, in preparation). North of McBean Creek, the Dublin aquifer has also been breached by the paleo-river channel.

The medium resolution seismic survey suggests the presence of a high angle reverse fault or related drape fold approximately 1000 feet down-river from Hancock Landing. This structural feature extends upward to within approximately 200 feet of the paleo-river channel base and terminates in Paleocene or early Eocene deposits (Henry, unpublished data, 1994).

Within SRS, the location of the Pen Branch Fault is well defined by drill core and seismic reflection data (Snipes and others, 1993). If projected to the Savannah River from its known location (Snipes and others, 1993), the Pen Branch Fault possibly could intersect the river in the vicinity of the structural feature described by Henry (unpublished data, 1994).

Hydrogeology

Upper Three Runs Aquifer

The Upper Three Runs aquifer in the study area is formed by the permeable sands and limestones of the Barnwell Group. A general map of the approximate water table surface has been constructed (Figure 35) using the elevation of the springheads (point of origin) of perennial streams (as interpreted from USGS 1:24,000 topographic maps) supplemented by water level information from monitoring wells. As perennial steams mark the intersection between the land surface and the Upper Three Runs aquifer, the springhead of a perennial stream approximates the elevation of the water table. Because there are many more springheads than monitoring wells in the study area, the use of springheads improves the resolution of a water table map.

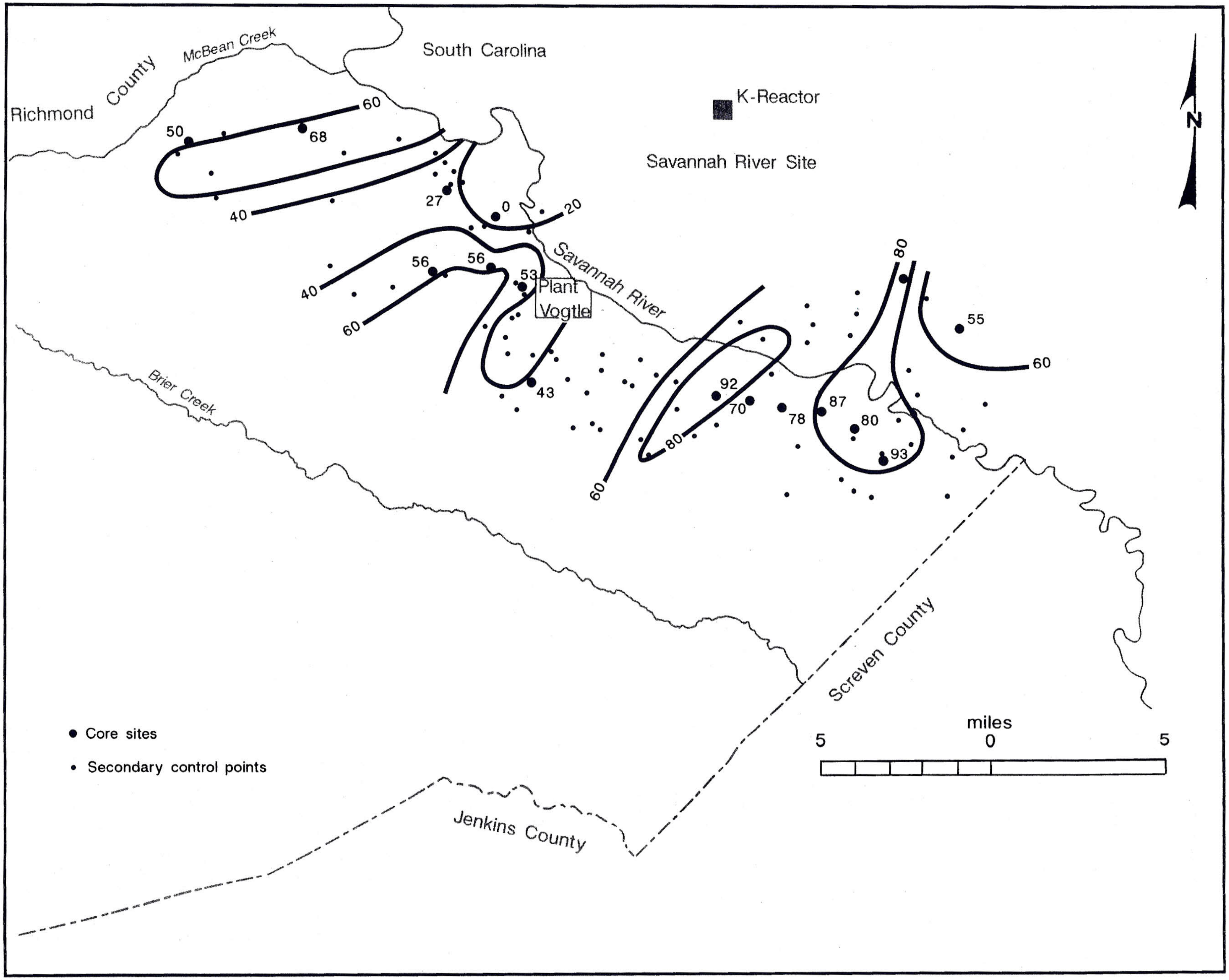


Figure 31. Isopach (thickness distribution) map of the Snapp Formation. Thicknesses are in feet.

Table 15

Ground-water levels in the Upper Three Runs and Gordon aquifers. Water levels are in feet above mean sea level.

Cluster Site	Land Surface Elevation	Upper Three Runs Aquifer	Gordon Aquifer	Potential Vertical Flow
Miller's Pond Site (1)	230	165.19 (6)	122.70 (2, 6)	Downwards
TR92-1	235	186.16 (4)	150.58 (3)	Downwards
TR92-2	285	208.95 (4)	108.50 (4)	Downwards
TR92-3	195	136.64 (4)	146.66 (4)	Upwards (3)
TR92-4	192	128.00 (5)	116.76 (4)	Downwards
TR92-5	235	156.03 (4)	140.74 (4)	Downwards
TR92-6	240	dry hole	91.00 (4)	unknown

(1) USGS Trans-River Project site.
(2) The Gordon aquifer is missing at Miller's Pond. Instead, the upper Dublin aquifer occurs immediatedly below the Blue Bluff member aquitard.
(3) See text (Section 3.6.3) for discussion.
(4) Water levels measured 09/10/93.
(5) Water levels measured 09/14/93.
(6) Water levels measured 09/13/93. Data from USGS.

As the major streams in eastern Burke County are incised completely through the Barnwell sediments that constitute the Upper Three Runs aquifer, ground-water flow in the Upper Three Runs aquifer is compartmentalized and local (Figure 35). A major, northwest-southeast trending compartment is formed between the Savannah River, Brier Creek, and McBean Creek. Sub-compartments are formed by the major tributaries to the principal streams. Dissection of the land surface by streams tributary to the Savannah River has divided the eastern side of the study area into several small, local, ground-water flow regimes. Dissection of the land surface by streams tributary to Brier Creek is much less marked, resulting in less compartmentalization of ground-water flow. Consequently, some down gradient flow to the southeast is possible, parallel to Brier Creek. However, most water in the Upper Three Runs aquifer in eastern Burke County appears to discharge directly to local streams.

As expected, there is a close relationship between the elevation of the land surface and the elevation of the water table (Figure 36, p. 60). With the possible exception of monitoring wells in very close proximity to the Savannah River (TR92-6A), land surface elevation appears to be the dominant factor in determining the depth to the water table and proximity to a perennial stream a secondary factor. Each upland area in eastern Burke County serves as a recharge area for local ground-water flow in the Upper Three Runs aquifer. Since flow regimes in the Upper Three Runs aquifer are local, the chemistry of the ground water discharging from each individual recharge area should closely reflect local conditions. Recharge to the downdip portion of the Upper Three Runs aquifer probably takes place primarily in the area near Girard.

The Upper Three Runs aquifer in eastern Burke County is an anisotropic multi-layered unconfined aquifer. The upper layer of the aquifer is composed of the sands of the Tobacco Road Formation and the Irwinton Sand Member of the Dry Branch Formation.

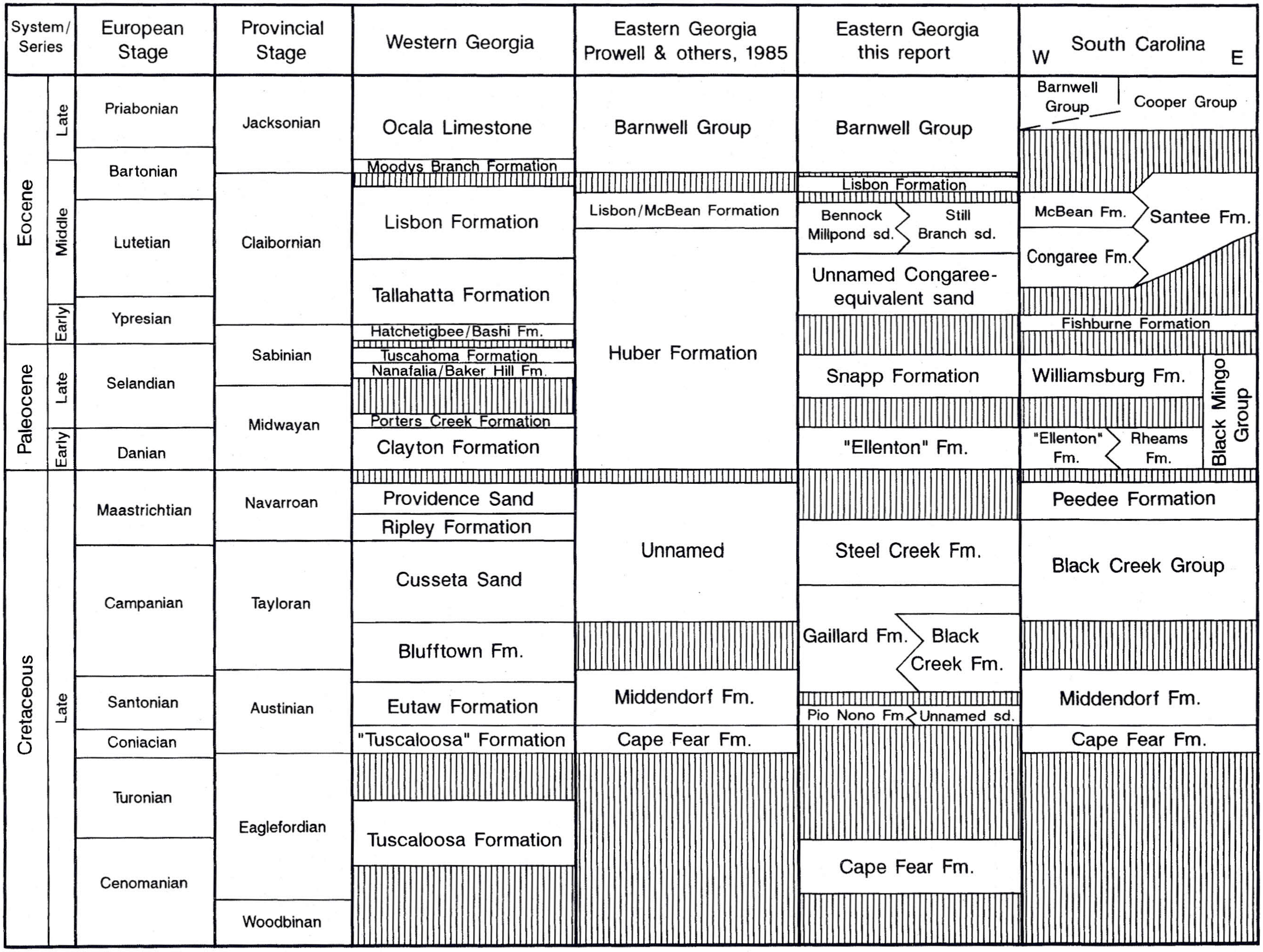


Figure 32. Correlation chart for the Tritium Project study area and adjacent regions. Shaded areas indicate missing stratigraphic intervals. (Modified from Prowell and others, 1985.)

Table 16

Transmissivity values of the aquifers at Tritium Project cluster site TR92-1. Data based on Clemson University aquifer tests. Location is shown in Figure 19.

Aquifer	Transmissivity
Upper Three Runs (water table)	479 ft^2/d
Gordon	112 ft^2/d
Meyers Branch "aquifer"	637 ft^2/d
Dublin	92 ft^2/d

Discontinuous clay beds and lenses in the Irwinton Sand Member create vertical and possibly lateral differences in the hydraulic conductivity of this layer. The lower layer of the Upper Three Runs aquifer is composed of the limestones of the Utley Member of the Clinchfield Formation. During drilling operations for the installation of ground-water monitoring wells, voids were encountered within the Utley. This suggests that at least some of the ground-water flow in the Utley may be through solution channels.

Gordon Aquifer

A potentiometric surface map of the Gordon aquifer within the Tritium Project study area has been constructed (Figure 37, p. 61) based on water level information from the six monitoring wells (Table 15). In contrast to the localized recharge and flow patterns of the Upper Three Runs aquifer, recharge and flow through the Gordon aquifer is regional in nature. As indicated by published potentiometric maps (Brooks and others, 1985), the regional flow of the Gordon aquifer is to the southeast, except where locally influenced by the incisement of local streams. In the case of northern Burke County, the incisement by the upper waters of McBean Creek and Brier Creek (Brooks and others, 1985; Hetrick, 1992) locally influences the potentiometric contour lines. East of Brier Creek, as indicated by the potentiometric map shown in Brooks and others (1985), as well as Figures 37 and 38 (pages 61 and 63) of this report, and from unpublished USGS data, the direction of local flow for the Gordon aquifer (in the study area) is to the northeast, towards the Savannah River, indicating that the river forms a regional discharge zone for the Gordon. Because the calcareous clays of the upper aquitard (Blue Bluff member of the Lisbon Formation) of the Gordon aquifer extend throughout most of the study area, the major recharge area for the Gordon aquifer in eastern Burke County is probably in southern Richmond County and northwestern Burke County (inferred from the potentiometric surface map of the Gordon aquifer in Brooks and others, 1985). The beds that make up the Gordon aquifer only crop out along stream channels in Richmond County and do not crop out at all in northwestern Burke County (Hetrick, 1992). Recharge of the Gordon aquifer in southern Richmond and northern Burke Counties is probably by downward vertical leakage through the relatively permeable McBean Member of the Lisbon Formation which overlies the Gordon aquifer in those areas.

Vertical Hydraulic Gradient

At all but one of the monitoring well cluster sites in Burke County, the head in the Upper Three Runs aquifer is higher than the head in the Gordon Aquifer (Table 15, p. 52). As a result of this difference in potential energy, there is the potential for ground water to move downwards from the tritium polluted Upper Three Runs aquifer into the tritium-free (i.e., below the limits of detection) Gordon aquifer. Because the Blue Bluff member aquitard, which lies between the Upper Three Runs and the Gordon aquifers, underlies most of the study area, such downward movement appears to be retarded. As no confining bed provides a perfect barrier against vertical transport, it is likely that some vertical transport may eventually occur. However, if the rate of flow is slower than the decay rate for tritium, tritium may never reach the upper Gordon aquifer in any significant quantity.

As previously shown in Table 15, the cluster site water levels in the Upper Three Runs aquifer are higher than the water levels in the Gordon aquifer, except for TR92-3. This reversal in water levels (or hydraulic heads) may be due to: topographic effects and/or structural effects.

The low water level in well TR92-3A may be due to the previously discussed relationship between topography and water levels in the Upper Three Runs aquifer (p. 50), as site TR92-3 is at a relatively low elevation (195 feet above mean sea level). In this case, the confined Gordon aquifer would be unaffected by surface topography.

The relatively high water level in well TR92-3B may be related to a minor structural high in the Barnwell, Lisbon (Figure 33, p. 55), and Congaree-equivalent sediments, which may locally affect the hydraulic head of the Gordon aquifer. The possibility exists that the head reversal may due to both topographic and structural effects.

In the northern part of the study area, where the Blue Bluff member of the Lisbon Formation is replaced by the more permeable McBean Member, there is the potential for vertical transport of both water and tritium from the Upper Three Runs aquifer into the Gordon. However, tritium has not been detected in the Gordon aquifer at the cluster sites at which the McBean Member has replaced the Blue Bluff member. This suggests that there are sufficient clay and fine grained sands in the Barnwell Group sediments and the

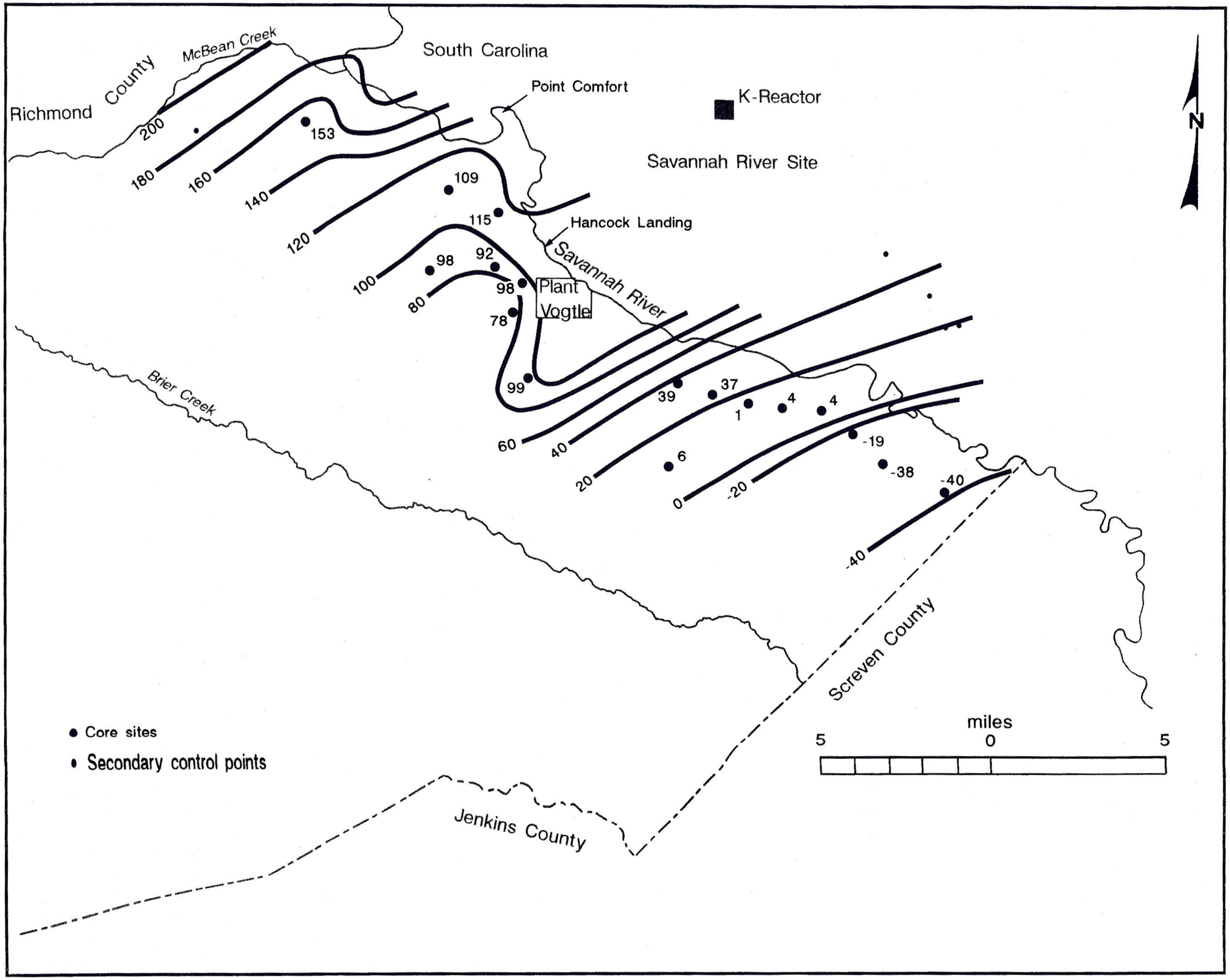


Figure 33. Structural contour map on the top of the Lisbon Formation. Elevations are in feet relative to mean sea level.

Table 17

Ground-water geochemistry of the Upper Three runs and Gordon aquifers. The values given are medians for that parameter from all samples within the gydrogeochemical unit. Data from Rose and James (1993, umpublished).

Chemical Parameter	Unit 1: upper Upper Three Runs Aquifer	Unit 2: lower Upper Three Runs Aquifer	Unit 3: Gordon Aquifer
pH	7.3	7.7	7.8
TDS (1)	100 mg/L	226 mg/L	242 mg/L
Na	1.2 mg/L	1.7 mg/L	2.7 mg/L
Ca	19.4 mg/L	44.7 mg/L	44.9 mg/L
Mg	0.4 mg/L	1.2 mg/L	1.2 mg/L
HCO_3	55.4 mg/L	132.9 mg/L	136.3 mg.L
SO_4	1.3 mg/L	4.4 mg/L	10.3 mg/L
K	0.2 mg/L	0.3 mg/L	0.4 mg/L
Si	15.6 mg/L	32.4 mg/L	34.0 mg/L
Cl	4.0 mg/L	4.1 mg/L	2.8 mg/L

(1) TDS is Total Dissolved Solids.

McBean Member of the Lisbon to minimize vertical transport.

Results of Aquifer Tests

The aquifer pumping tests carried out on the four monitoring wells at site TR92-1 (see Figure 19, p. 31) by Clemson University (Moore and others, 1992) showed transmissivity values between 92 ft^2/d and 637 ft^2/d (Table 16). These data show that, at site TR92-1, the Upper Three Runs aquifer and the Meyers Branch "aquifer" have much higher transmissivity values than the Gordon and Dublin aquifers. These variations are most likely due to the grain size and clay content of the sediments forming the aquifers. No drawdown was observed in any of the observation wells during the pumping tests, indicating that the three lower aquifers are confined with respect to the Upper Three Runs aquifer and to each other.

Ground-Water Geochemistry

Vertical Geochemical Variation

Based primarily on ground-water geochemistry, but also considering differences in hydrostatic head and lithologic information from cores, the upper three hundred feet of the ground-water system in eastern Burke County can be divided into three hydrogeochemical units (Rose and James, 1993) (Table 16, p. 54). This results in a partition of the Upper Three Runs aquifer into two hydrogeochemically different units. Hydrogeochemical Unit 1 consists of ground water within the sands and clays of the Tobacco Road and Dry Branch Formations. These two formations make up 90 to 95 percent of the Upper Three Runs aquifer. The ground

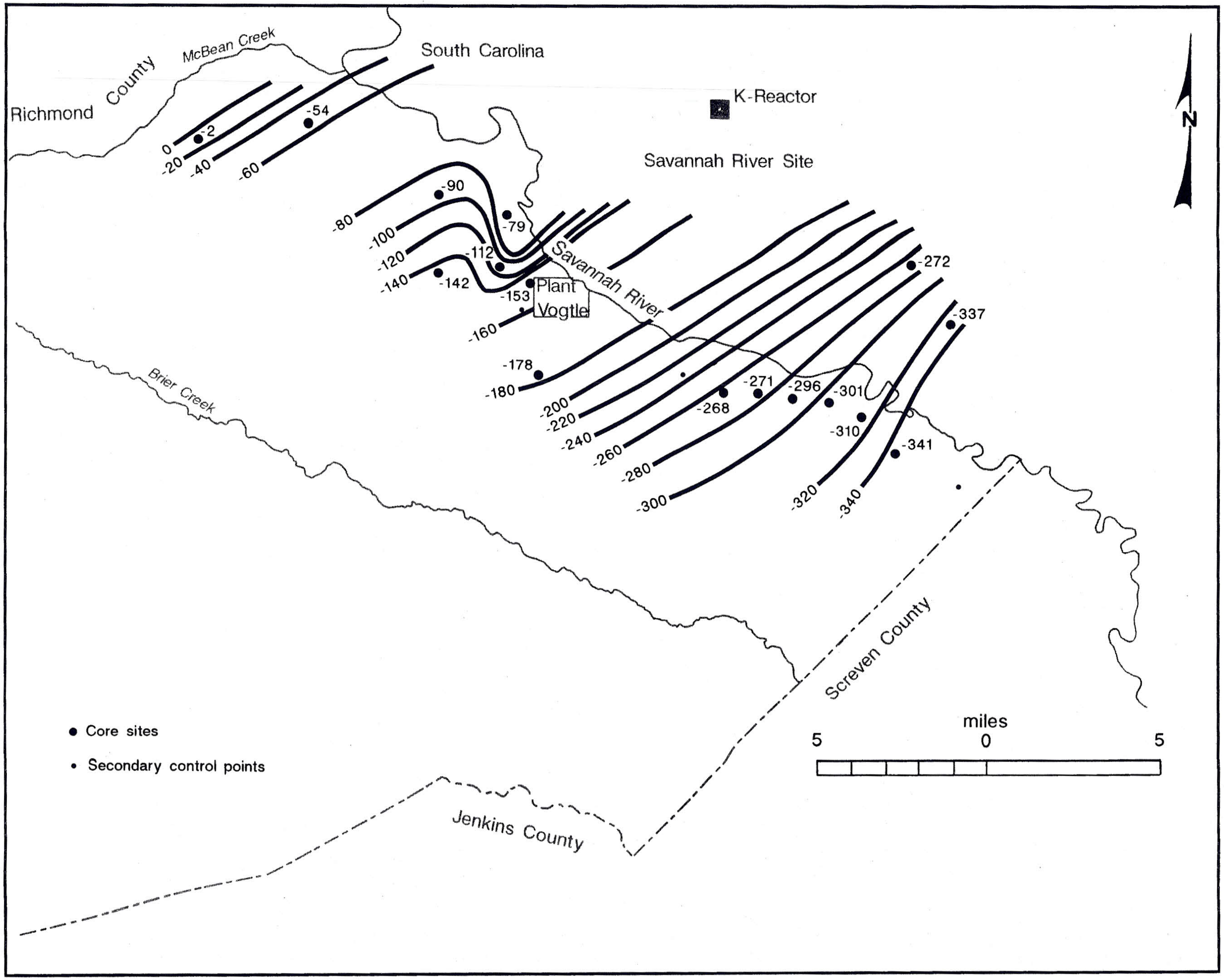


Figure 34. Structural contour map on the top of the Steel Creek Formation. Elevations are in feet relative to mean sea level.

water within Unit 1 has approximately neutral pH and is low in dissolved solids (Table 17). Hydrogeochemical Unit 2 consists of ground water within the Utley Limestone Member of the Clinchfield Formation and carbonate rich portions of the Griffins Landing Member of the Dry Branch Formation. The portions of the Griffins Landing Member that are dominated by sand and clay are part of Hydrogeochemical Unit 1. Hydrogeochemical Unit 2 is equivalent to the lowermost part of the Upper Three Runs aquifer. The ground water within Unit 2 is characterized by significantly higher concentrations of total dissolved solids, Na, Ca, Mg, HCO_3, and SO_4 than Unit 1.

Hydrogeochemical Unit 3 consists of the sandy Bennock Millpond and Still Branch sands and the unnamed Congaree-equivalent sands that lie beneath the Lisbon Formation (the Gordon aquifer). Except for a higher concentration of sodium and possibly sulfate, the ground water of Unit 3 is chemically similar to the water of Unit 2.

All three hydrogeochemical units are chemically characterized as a calcium-bicarbonate water type. Analysis of the data shows that 80 to 90 percent of the ionic content of these waters has evolved from the dissolution of calcite (Rose and James, 1993).

Lateral Geochemical Variation

Rose and James (1993) document lateral chemical gradients for total dissolved solids, calcium, bicarbonate, magnesium, sodium, sulfate, dissolved silica, and calcite saturation indices in Hydrogeochemical Unit 2 within the study area. Such lateral chemical gradients confirm the general direction of flow within the aquifer. Figure 39 (p. 65) is modified from their figure and shows the lateral variability in total dissolved solids for Unit 2 (the total dissolved solids are dominated by calcium and bicarbonate). The contour line pattern shown in Figure 39 has a general resemblance to the water table surface map for the Upper Three Runs aquifer (Figure 35, p. 59). The upland recharge areas east of Brier Creek have high concentrations of total dissolved solids. Dissolved solids decrease towards Brier Creek and, particularly, towards the Savannah River. This trend, however, is inconsistent with chemical trends normally expected within an aquifer. Under normal ground-water conditions, total dissolved solids should increase in the direction of ground-water flow (Freeze and Cherry, 1979). For example Brooks and others (1985) show increasing down-gradient concentrations of total dissolved solids in the Gordon aquifer within the Georgia Coastal Plain. The observed decrease in total dissolved solids along the projected flow path of the Upper Three Runs aquifer may be due to the precipitation of calcite or the vertical mixing of ground waters (Rose and James, 1993).

CONCLUSIONS

As presented in the introduction of this report there were three goals for the Tritium Project. These goals were to:

1. map the extent of tritium pollution in the ground water of eastern Burke County;
2. evaluate if there was any current or future threat to public health;
3. assess how the tritium entered the ground-water regime.

Extent of Pollution

Stratigraphic Extent of Pollution

At the present time, there is no evidence that the Gordon aquifer in eastern Burke County is regionally polluted by tritium. None of the polluted water wells are withdrawing water from the Gordon aquifer, and the few water wells in eastern Burke County that are in the Gordon have no detectable concentrations of tritium. Five of the six ground-water monitoring wells installed into the Gordon aquifer as part of this project contain no detectable concentrations of tritium. The sixth monitoring well may be detecting tritium that has entered the Gordon aquifer through a nearby water well in which the casing has shattered.

There is definite, low concentration, tritium pollution of the Upper Three Runs aquifer in eastern Burke County. Nine of the ten geophysically logged water wells that have elevated concentrations of tritium are drawing their water from the Upper Three Runs aquifer, and there is good circumstantial evidence that the tenth well is also in the Upper Three Runs aquifer. Of the five tritium polluted water wells that were identified after geophysical logging was completed (#9, #56, #65, #108, and #109, see Figure 23), there is good circumstantial evidence that all five wells are in the Upper Three Runs aquifer. All of the ground-water monitoring wells screened in the Upper Three Runs aquifer contain detectable concentrations of tritium. Analysis of 1992 base flow studies detected tritium in 177 out of 179 samples (99 percent).

An unresolved question regarding the sampling of water wells in Burke County concerns the 94 water wells that did not contain anomalous concentrations of tritium. Many of these wells are interspersed among the anomalous wells. The majority of these low-tritium (less than 500 picoCuries per liter) wells are also probably drawing water from the Upper Three Runs aquifer, however, the lack of records concerning the depths of the wells prevents a clear identification of the aquifer. A possible explanation for the lack of tritium in these wells is the known heterogeneity of the sediments that constitute the Upper Three Runs aquifer. Variable clay content, discontinuous clay beds, and clay lenses cause local perched water tables, variable rates of vertical and lateral ground-water movement, and complex flow paths. An alternative explanation is that the high-tritium wells are the result of faulty well construction such as lack of grout, failure of the casing, or lack of a cement pad. This second explanation, however, is not supported by the distribution of tritium in the Upper Three Runs aquifer as observed in the base flow study (Figures 25 and 26). The widespread nature of the tritium pollution, its concentric distribution pattern, and the occurrence of tritium up-gradient from the anomalous wells, all argue against the anoma-

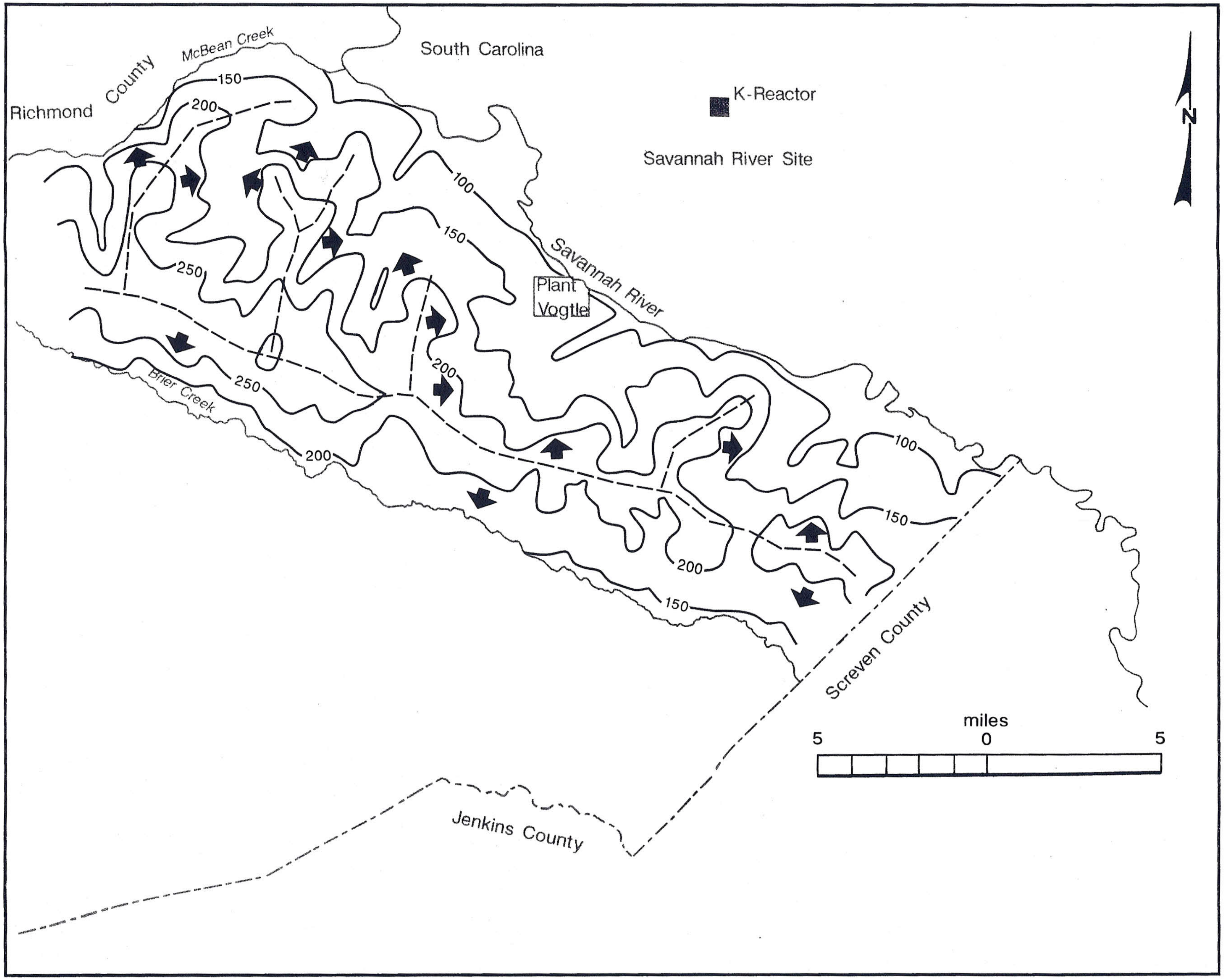


Figure 35. Water table surface map of the Upper Three Runs aquifer in eastern Burke County. Contours are in feet above mean sea level. Dashed lines represent ground-water "divides".

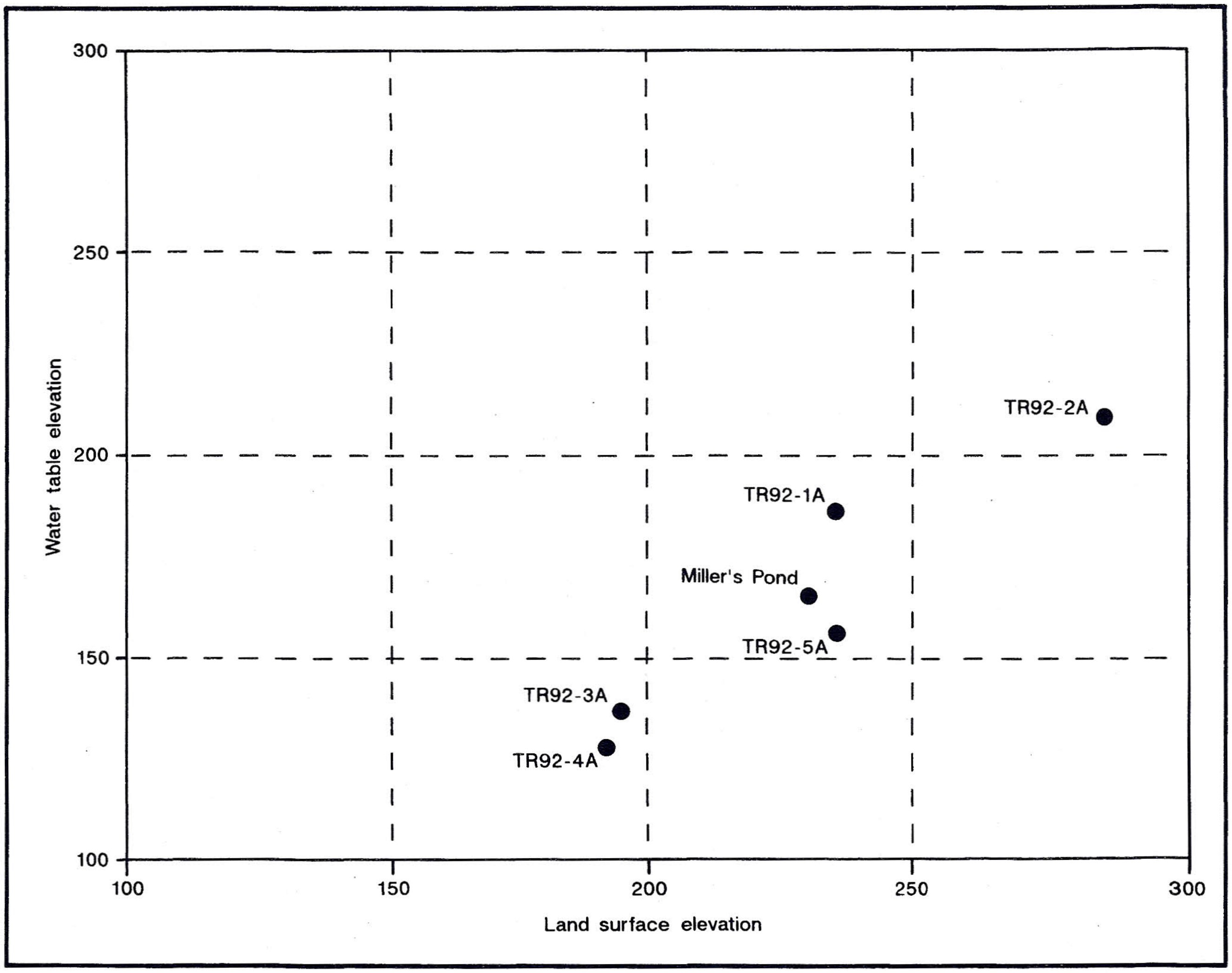


Figure 36. Relationship of water table and land surface elevations for the Upper Three Runs aquifer in eastern Burke County. Elevations are in feet above mean sea level.

lous wells acting as point sources for regional pollution of the Upper Three Runs aquifer. The question of low-tritium wells dispersed among the high-tritium wells can only be resolved by additional studies of the construction of the low-tritium wells, and detailed studies of the Upper Three Runs aquifer.

Geographic Extent of Pollution

Tritium pollution of the Upper Three Runs aquifer is widespread throughout eastern Burke County. The base flow studies show that the pollution extends from the Savannah River on the northeast to beyond Brier Creek on the southwest, and from at least McBean Creek on the northwest to at least the Burke-Screven county line on the southeast.

Surface water samples taken after the 1992 Base Flow Study from sites in Louisville (23 miles WSW from Waynesboro) and Wrens (23 miles WNW from Waynesboro) (both in Jefferson County) and Butler Creek (Richmond County, south of Augusta) (21 miles north of Waynesboro) measured below detection limits for tritium (<100 picoCuries per liter). Other surface water samples collected in the vicinity of the McBean community, in southern Richmond County, measured from 400 to 500 picoCuries per liter. Samples taken from southeast Burke County, near the Screven County line also measure near the detection limits. From this information, it appears that the tritium pollution of the Upper Three Runs aquifer does not extend far beyond the boundaries of Burke County.

Public Health

There is no evidence of a threat to public health at the present time. All analyses of water samples from the Upper Three Runs aquifer show that the concentrations of tritium are significantly lower than the EPA MCL for tritium (which is 20,000 picoCuries per liter). The highest observed tritium concentration was 3,500 picoCuries per liter, which is 17.5 percent of the EPA MCL. More than half of the samples from the 1992 base flow study have tritium concentrations less than 4.5 percent of the EPA MCL.

Future threats to public health are a function of the

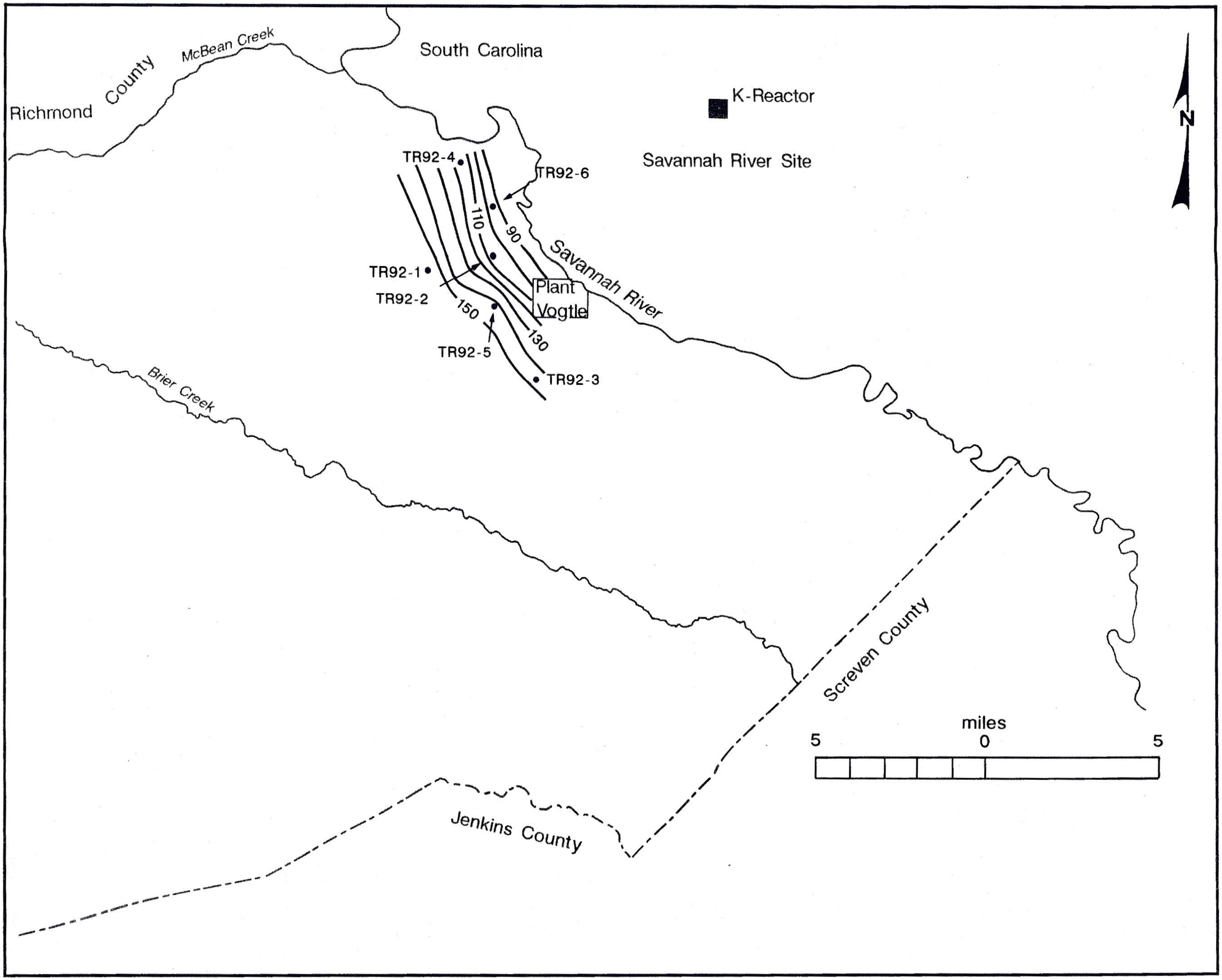


Figure 37. Local potentiometric surface map of the Gordon aquifer, as defined by data from Tritium Project monitoring wells. Elevations are in feet above mean sea level.

pathway for tritium into the Upper Three Runs aquifer and future production of tritium at the Savannah River Site. No reactors have been operating at the Savannah River Site since 1988. As a result, the amount of tritium released to the environment declined by approximately two thirds between 1987 and 1991 (Arnett and others, 1992).

Pathway into the Aquifer

Existing data are not adequate to resolve the issue of the pathway for tritium into the Upper Three Runs aquifer. However, the data generated by the investigation place major constraints on reasonable transport models, greatly reduce the likelihood of some models. The method of multiple working hypotheses was used in evaluating the pathway for tritium into the Upper Three Runs aquifer. This scientific method requires the development of a large number of falsifiable alternative hypotheses (a falsifiable hypothesis is one that can be tested and has the potential to be proven wrong). These hypotheses are tested against the data, and hypotheses that are inconsistent with the data are eliminated. Repeated testing of an hypothesis provides greater and greater confidence in a specific model. There are several models for the transport of tritium into the Upper Three Runs aquifer. The tritium might enter the aquifer laterally, it might enter from below, or it might enter the aquifer from above.

Direct Lateral Transport

The model of direct lateral transport postulates that tritium has polluted the Upper Three Runs aquifer in South Carolina, and that tritiated water from the South Carolina aquifer has moved as a plume directly into the Upper Three Runs aquifer of Georgia.

We know that the first part of this model is correct; that the Upper Three Runs aquifer at the Savannah River Site has been polluted with tritium (Murphy and others, 1991; Arnett and others, 1992). However, the geometry of the Upper Three Runs aquifer deposits in Georgia and the direction of ground-water flow within that aquifer indicate that direct lateral transport of tritium from the Savannah River site is unlikely. Because the Savannah River has cut completely through the sediments that make up the Upper Three Runs aquifer, there is no subsurface path that would allow a plume of tritiated water within the Upper Three Runs aquifer at the Savannah River Site to move directly into Georgia. In addition, the direction of ground-water flow in the Upper Three Runs aquifer in Burke County is to the east (towards the Savannah River) rather than to the west.

Indirect Lateral Transport

The model of indirect lateral transport postulates that tritium from the Savannah River Site in South Carolina has polluted the water of the Savannah River and the ground water in the alluvium of the river. The model then postulates that the tritium-laden water from the Savannah River and its alluvial fill recharge the unconfined aquifer in Georgia.

We know that the water of the Savannah River has received tritium from the Savannah River Site. However, existing data from Burke County do not support the other components of the model. The sediments that make up the Upper Three Runs aquifer in Burke County are topographically higher than the floodplain of the Savannah River in the area of pollution. Therefore, the waters of the Savannah River have no direct connection with that aquifer. This model is also inconsistent with the observation that the hydrostatic head in the Upper Three Runs aquifer is higher than the level of the Savannah River in the area of pollution. This suggests that ground water in the Upper Three Runs aquifer is discharging to the river rather than being recharged by the river. The conclusion that the Upper Three Runs aquifer is discharging to the Savannah River is supported by the map of the water table surface (Figure 35) and the occurrence of a line of springs along the bluffs of the Savannah River, near the base of the Upper Three Runs aquifer and above the flood plain of the river.

Upwards Transport

The model of upwards transport postulates that tritium from the Savannah River Site in South Carolina has polluted deeper, confined aquifers in South Carolina, and that tritium-laden water has moved under the Savannah River into Georgia. The model then postulates that the tritium polluted water in the confined aquifer moves upwards, through breaches in the confining bed, into the Upper Three Runs aquifer.

Upwards transport of tritium into the Upper Three Runs aquifer from underlying aquifers may be possible but is not supported by the existing data. First, no tritium has been detected in the aquifers below the Upper Three Runs aquifer in eastern Burke County. Second, the hydrostatic head in the Upper Three Runs aquifer in eastern Burke County is generally higher than the head in the shallowest of the confined aquifers (the Gordon aquifer) directly below it. This means that there is the tendency for water to move downwards from the Upper Three Runs aquifer into the confined aquifer rather than upwards into the Upper Three Runs aquifer. Third, current data for the Gordon aquifer in eastern Burke County indicate that the direction of ground-water flow within the aquifer is to the east rather than to the west. Therefore, any tritium leaking upwards into the Upper Three Runs aquifer should be carried towards the Savannah River rather than into the interior of Burke County.

However, the model can not be totally rejected. Tritium has been detected in the Congaree Formation at the Savannah River Site (Cummins and others, 1991; Murphy and others, 1991; Arnett and others, 1992). The number of sites in Burke County for sampling the Gordon aquifer for tritium is small. There is at least one area in Burke County (Site TR92-3) in which the hydrostatic head is reversed so that, at that site, it may be possible for ground water to move from the Gordon aquifer into the Upper Three Runs aquifer. There are areas in Burke County in which the confining bed that separates the Upper Three Runs and Gordon aquifers is

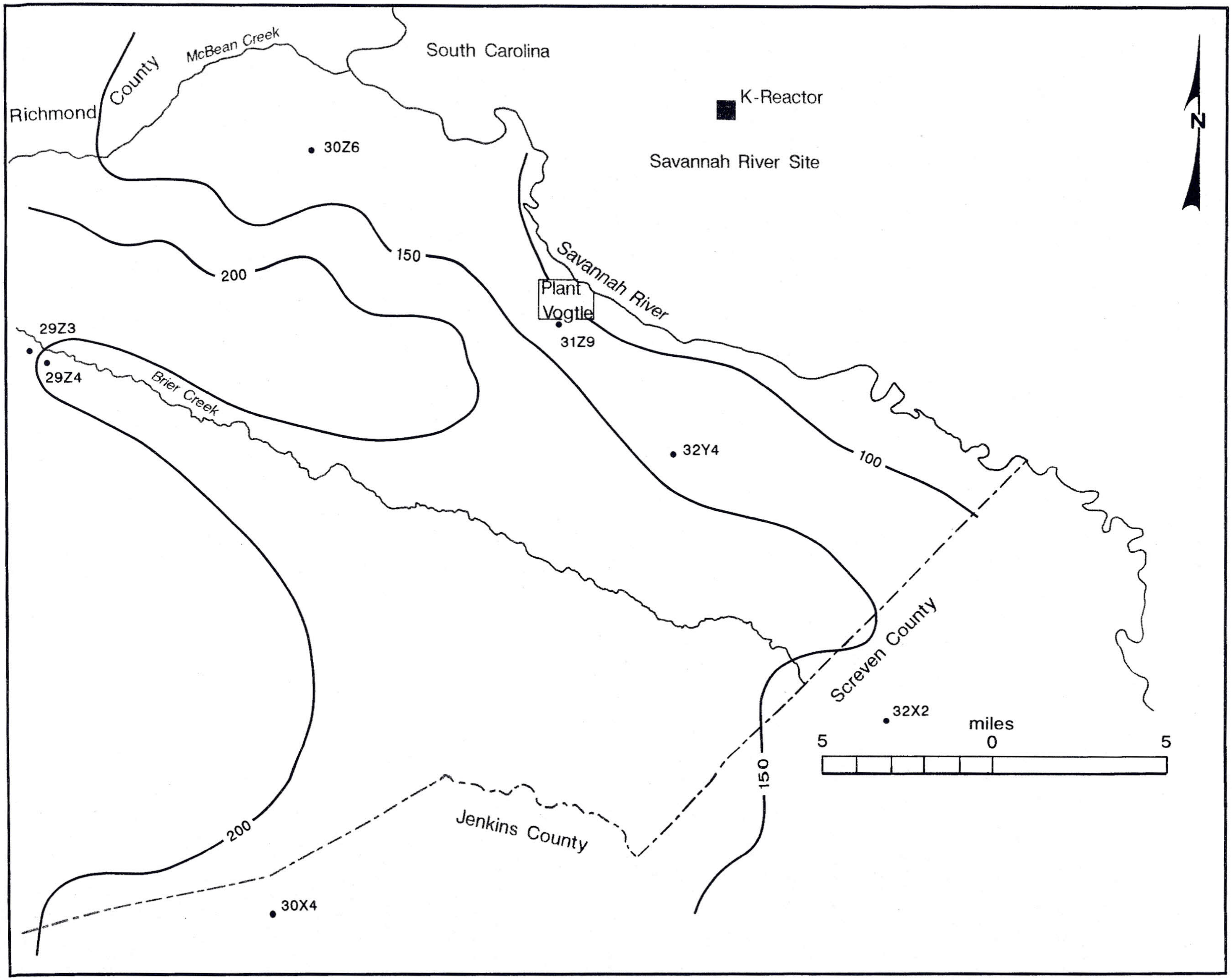


Figure 38. Potentiometric surface map of the Gordon aquifer, as defined by data from a larger regional study (modified from Brooks and others, 1985). Elevations are in feet above mean sea level. Wells are identified in Appendix 8.

missing. Moreover, the data for the direction of ground-water flow in the Gordon aquifer are sparse, thus the eastward direction of ground-water flow may have some exceptions.

Downwards Transport

The model of downwards transport postulates that tritium from the Savannah River Site in South Carolina has polluted rainwater in Georgia. The model postulates that this tritium-polluted rainwater percolates downwards and recharges the Upper Three Runs aquifer in eastern Burke County. Downwards transport includes recharge of the aquifer from both tritium in current rainfall and tritium that has accumulated in the vadose zone from previous rainfall.

Tritium pollution of the Upper Three Runs aquifer through recharge by tritiated rainwater is the most viable hypothesis, although not fully tested. We have good records showing that rainfall in Burke County is polluted with tritium. The map published by the Westinghouse Savannah River Company (Murphy and others, 1991) (Figure 10), illustrating the distribution of tritium in rainwater in Georgia shows a pattern which is in reasonable agreement with the geographic distribution of tritium observed in the base flow studies.

However, although the existing data are consistent with the rainfall model, they do not prove that this is the actual pathway for tritium into the Upper Three Runs aquifer in eastern Burke County. Even though rainfall data demonstrate that rainwater in Georgia contains elevated concentrations of tritium, the data are too sparse to map the distribution of tritiated rainfall in Georgia. The Westinghouse map (Murphy and others, 1991) was based on only four data points in Georgia. There is also no information on tritium in the unsaturated zone in Burke County, and no information on the vertical distribution of tritium in the unconfined aquifer.

Point Source Pollution

A variant of the downwards transport model postulates that tritium-polluted rainwater has entered the Upper Three Runs aquifer through poorly constructed wells. This is a point source model for the pollution. This model would predict plumes of tritiated water moving in the direction of ground-water flow from the point source wells.

We know that at least eight of the fifteen water wells showing anomalous concentrations of tritium are either ungrouted, lack casing, lack a surface pad, or have experienced failure of the casing (Table 9). However, the pattern of distribution of the tritium in the Upper Three Runs aquifer (Figures 25 and 26) does not support a point source origin for the tritium. The tritium is widespread throughout eastern Burke County. The distribution pattern is approximately concentric around the Hancock Landing area. There are significant tritium occurrences up-gradient from the anomalous wells. The distribution of tritium shows no relationship to the water table surface (Figure 35) and, therefore, is inconsistent with the directions of flow in the Upper Three Runs aquifer. Because of the overall inconsistency of the data with the predictions of the model, the point source model for regional pollution of the Upper Three Runs aquifer is highly unlikely.

Other Pathways

The method of multiple working hypotheses can only test models that have been proposed. The possibility that the tritium observed in the Upper Three Runs aquifer has entered the aquifer by some pathway other than those that have been considered can not be dismissed.

Trans-River Flow (Underflow)

The discussion of potential pathways for tritium into the Upper Three Runs aquifer in Burke County (Section 4.1.4) only considers the observed pollution of that one aquifer. The potential for the pollution of deeper confined aquifers through direct transport of tritium underneath the Savannah River remains a separate unresolved issue. This issue is being addressed by another investigation, the Trans-River Flow Project (initially known as the Underflow Project), presently being carried out by the USGS. The Trans-River Flow Project will include the construction of several ground-water monitoring well clusters in Burke and Screven Counties, performance of aquifer tests at selected well clusters, study of ground-water quality, development of potentiometric surface maps, investigation of streamflow conditions in the Savannah River, development of a conceptual model of the hydrologic flow system, and testing of the conceptual model using a digital ground-water flow model.

RECOMMENDATIONS

Based on the results of the investigations conducted by EPD on the occurrence of tritium in the ground water of Burke County, thirteen recommendations are made. The recommendations fall into four broad categories: public awareness, public health, technical studies, and long-term monitoring.

Public Awareness

Recommendation 1. We recommend that the Department of Natural Resources (DNR) issue a press release in Burke County to explain the situation to the public in the affected area. Such a press release should: 1) provide the public with technically correct information about the occurrence of tritium in their ground water; and 2) provide the public with information that their health is not being threatened.

Public Health

Recommendation 2. We recommend that EPD, through the Water Well Standards Advisory Council, issue an advisory notice to all well drillers working in Burke

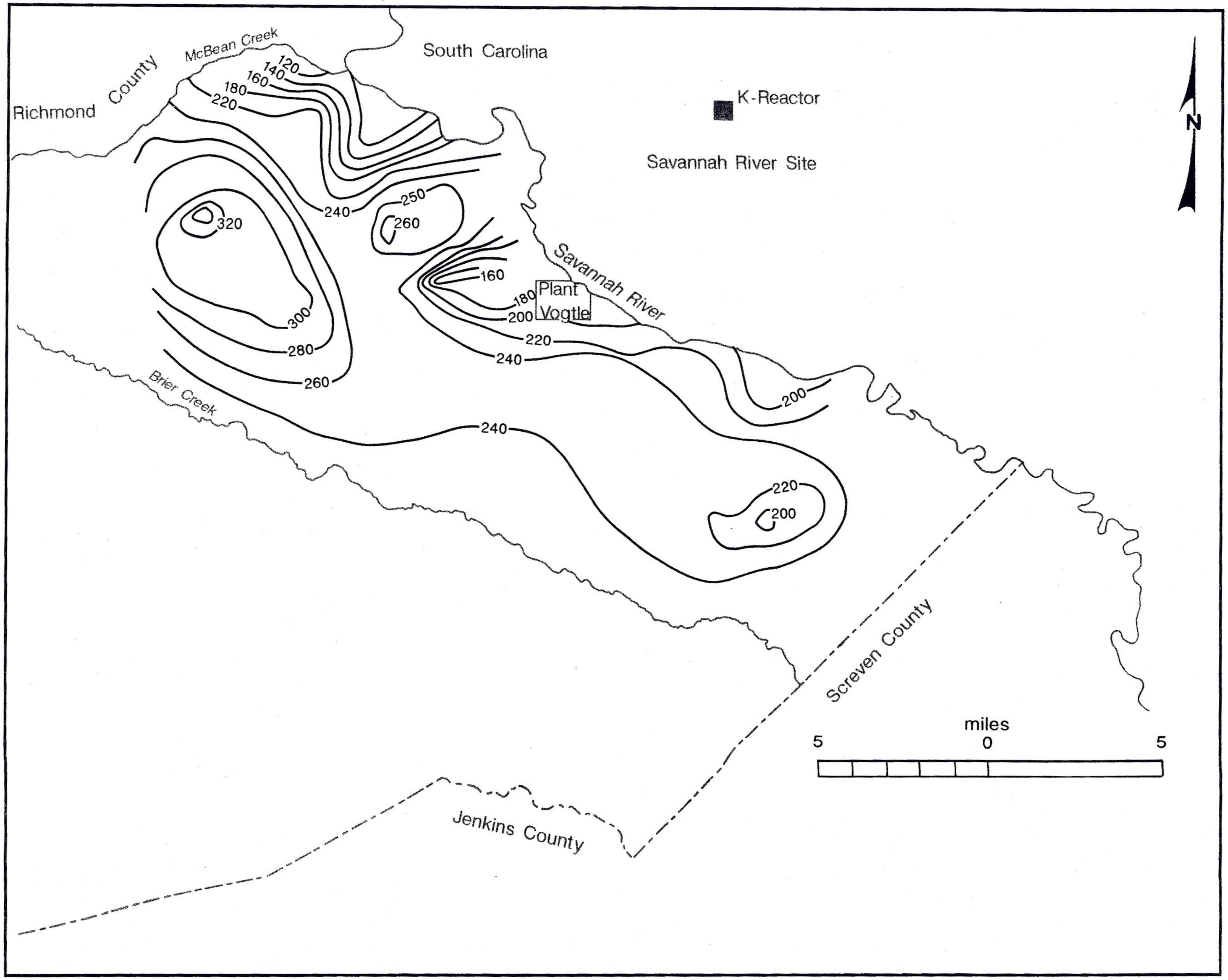


Figure 39. Lateral variability of total dissolved solids in Hydrochemical Unit 2 in eastern Burke County. Values are in milligrams per liter. (Modified from Rose and James, 1993.)

County, that, until further notice, DNR recommends that all new domestic water supply wells within the area of tritium pollution be drilled down to the Gordon aquifer and that all wells be grouted through the entire interval of the Upper Three Runs aquifer. This recommendation will result in some additional cost to well owners in that wells would be drilled approximately 70 to 100 feet deeper than current practice in eastern Burke County. Slight additional costs would also be incurred by grouting the 100 to 200 foot thickness of the Upper Three Runs aquifer. Because the concentrations of tritium in the Upper Three Runs aquifer are well below the EPA Maximum Contaminant Level (MCL), the advisory would only be a recommendation, and would leave the matter up to the landowner contracting for the construction of the well. The EPD should issue a similar advisory to the Public Health Division of the Georgia Department of Human Resources.

Recommendation 3. We recommend that EPD issue no new permits, within the area of Burke and surrounding counties affected by tritium pollution of ground water, for public water supply wells that draw their water from the Upper Three Runs aquifer.

Technical Studies

Recommendation 4. We recommend that the DOE conduct or fund additional studies of the Upper Three Runs aquifer in eastern Burke County. Specifically we recommend that studies be conducted to evaluate the following characteristics of the Upper Three Runs aquifer:

(1) The vertical distribution of tritium should be evaluated within the water table aquifer. This will provide information on which parts of the aquifer are polluted as well as on the pathway of the tritium into the aquifer.

(2) The lateral or geographic extent to the tritium distribution in the Upper Three Runs aquifer should be defined. Current studies have not firmly established the lateral limits of the pollution. At least one additional base flow study be conducted covering a larger area than the two previous base flow studies.

(3) The hydraulic properties of the Upper Three Runs aquifer should be established through aquifer tests. The hydraulic properties will allow the Department of Natural Resources to predict the horizontal and vertical flow rates within the aquifer and the effects of pumping on the aquifer.

Recommendation 5. We recommend that the DOE conduct or fund additional studies of the confining bed at the base of the Upper Three Runs aquifer in eastern Burke County. Specifically we recommend that measurements be made to assess the vertical hydraulic conductivity of the confining bed as well as the potential for leakage of tritiated ground water from the Upper Three Runs aquifer into the upper Gordon aquifer.

Recommendation 6. We recommend that DOE conduct or fund additional studies of water supply wells in eastern Burke County. Specifically we recommend that all of the domestic water wells, public drinking water supply and municipal water supply wells that are used for monitoring tritium in eastern Burke County be logged geophysically to determine well depth, aquifer, and well construction. Our current study has demonstrated that drillers' records are inadequate for this purpose.

Recommendation 7. We recommend that DOE conduct or fund additional studies of tritium transport in the Upper Three Runs aquifer in eastern Burke County. Specifically we recommend that studies be conducted to test several models of tritium transport into the Upper Three Runs aquifer including pollution through recharge by tritiated rainwater and pollution through upwards transport. Specific investigations include: analysis of the vertical distribution of tritium in the Upper Three Runs aquifer (covered in recommendation 5); age dating of the water in the Upper Three Runs aquifer; evaluation of tritium accumulation in the vadose zone; and evaluation of the effect of faults on tritium transport.

Recommendation 8. We recommend that DOE provide funding to accelerate the drilling program for the USGS Trans-River Flow Project and bring that study to conclusion.

Recommendation 9. We recommend that DOE provide funding to fully evaluate the tritium pollution of the Delaigle Trailer Park well #3. This public water supply well was the original well that alerted EPD to the general problem of tritium pollution of ground water in Burke County. Serious questions remain about the construction of this well.

Recommendation 10. We recommend that the DOE conduct or fund high resolution tritium analyses of the ground-water monitoring wells in eastern Burke County. The tritium analyses in the present study had a detection limit of 100 picoCuries per liter. It is possible that tritium has begun to leak into the Gordon aquifer but that present analytical methods can not detect the pollution. There are analytical methods that have detection limits for tritium of 1 picoCurie per liter or less. Such high resolution analysis would provide a relatively inexpensive early warning of possible contamination of the confined aquifer.

Long-Term Monitoring

Recommendation 11. We recommend that DOE establish or fund a long-term monitoring network for periodic sampling of ground water from both the Upper Three Runs aquifer and the upper Gordon aquifer in eastern Burke County. This network should be made up of wells constructed specifically as ground-water monitoring wells. Monitoring wells already constructed as part of the current study should form the base for the network. Four to twelve additional monitoring wells may be required.

Recommendation 12. We recommend that annual base flow studies be incorporated as part of a long-term monitoring program. The current investigation has clearly demonstrated that base flow studies are the best available method for evaluating the extent of pollution in the Upper Three Runs aquifer in Burke County. Annual base flow studies will show whether the area of pollution is expanding or contracting.

Recommendation 13. We recommend that the DOE establish or fund a long-term monitoring network for monthly sampling of tritium in rainwater in Georgia. The hypothesis that the pathway for tritium into the Upper Three Runs aquifer is through recharge by tritiated rainwater can not be adequately evaluated with the current number of monitoring stations in Georgia. The proposed monitoring network must contain a sufficient number of stations to allow reasonable mapping of tritium distribution.

REFERENCES

Aadland, R. K., Thayer, P. A., and Smits, A. D., 1992, Hydrostratigraphy of the Savannah River Site Region, South Carolina and Georgia: in Fallaw, Wallace and Price, Van, editors; Geological Investigations of the Central Savannah River Area, South Carolina and Georgia; Carolina Geological Society, p. B-X-1-6.

Aadland, R. K., and others, 1993, Savannah River Site Environmental Report for 1992, 396 p.

Allison, G. B., 1988, A review of the physical, chemical and isotopic techniques available for estimating groundwater recharge: in Simmers, I., editor, Estimation of Natural Groundwater Recharge: Dordrecht, D. Reidel Publishing Company, p. 49-72.

Arnett, M. W., Karapatakis, L. K., Mamatey, A. R., and Todd, J. L., 1992, Savannah River Site Environmental Report for 1991 (U): U.S. Department of Energy, WSRC-TR-92-186, 562 p. plus Appendices.

Bachtel, D. C. and Boatright, S. R., 1992, The Georgia County Guide (11th Edition): Athens, Georgia, The University of Georgia, College of Agricultural and Environmental Sciences and Department of Housing and Consumer Sciences, Cooperative Extension Service, 203 p.

Baker, Michael, Jr., Inc., 1979, Fort Gordon, Georgia terrain analysis: Unpublished report for the U.S. Army, Nov. 1979, 58 p.

Brooks, R., Clarke, J. S., and Faye, R. E., 1985, Hydrogeology of the Gordon aquifer system of east-central Georgia: Georgia Geologic Survey Information Circular 75, 41 p.

Carter. R. F., and Stiles, H. R., 1983, Average annual rainfall and runoff in Georgia, 1941-70: Georgia Geologic Survey Hydrologic Atlas 9, 1 sheet.

Clark, W. Z., Jr., and Zisa, A. C., 1976, Physiographic map of Georgia: Georgia Geologic Survey, scale 1:2,000,000, 1 sheet.

Cummins, C. L., Martin, D. K., Todd, J. L., and Exploration Resources, Inc., 1991, Savannah River Site Environmental Report (U), Volume II Groundwater Monitoring: Westinghouse Savannah River Company report WSRC-IM-91-28, 64 p., plus appendices.

Davis, S. N., Campbell, D. J., Bentley, H. W., and Flynn, T. J., 1985, Ground-water Tracers: Ada, Oklahoma, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 200 p.

Dincer, T., and Davis, G. H., 1984, Application of environmental isotope tracers to modeling in hydrology: Journal of Hydrology, v. 68, p 95-113.

Domenico, P. A., and Schwartz, F. W., 1990, Physical and Chemical Hydrogeology: New York, John Wiley & Sons, 824 p.

Fanning, J. L., Doonan, G. A., and Montgomery, L. T., 1992, Water use in Georgia by county for 1990: Georgia Geologic Survey Information Circular 90, 98 p.

Faure, Gunter, 1986, Principles of isotope geology: New York, John Wiley and Sons.

Faye, R. E. and Prowell, D. C., 1982, Effects of Late Cretaceous and Cenozoic faulting on the geology and hydrogeology of the Coastal Plain near the Savannah River, Georgia and South Carolina: U.S. Geological Survey Open-File Report 82-156, 73 p.

Fontes, J. Ch., 1980, Environmental isotopes in groundwater hydrology: in Fritz, P. and Fontes, J. Ch., editors, Handbook of Isotope Geochemistry; Volume 1, The Terrestrial Environment, A: Amsterdam, Elsevier Scientific Publishing Company, p. 75-140.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.

Fritz and Fontes, 1980, Introduction: in Fritz, P. and Fontes, J. Ch., editors, Handbook of Isotope Geochemistry; Volume 1, The Terrestrial Environment, A: Amsterdam, Elsevier Scientific Publishing Company, p. 1-19.

Gat, J. R., 1980, The isotopes of hydrogen and oxygen in precipitation: in Fritz, P. and Fontes, J. Ch., editors, Handbook of Isotope Geochemistry; Volume 1, The Terrestrial Environment, A: Amsterdam, Elsevier Scientific Publishing Company, p. 21-47.

Gorday, L. L., 1985, The hydrogeology of the Coastal Plain strata of Richmond and northern Burke Counties, Georgia: Georgia Geologic Survey Information Circular 61, 43 p.

Henry, Vernon J., 1994 Summary of results of a seismic survey of the Savannah River adjacent to the Savannah River Plant Site, Burke County, Ga.; unpublished progress report to the Georgia Geologic Survey Tritium Project, February, 1994, 3 pages.

Hetrick, J. H., 1992, A geologic atlas of the Wrens-Augusta area: Georgia Geologic Survey Geologic Atlas 8.

Huddlestun, Paul F., in preparation, Stratigraphy of eastern Burke County (manuscript in progress), Georgia Geologic Survey Open File Report.

Huddlestun, P. F. and Hetrick, J. H., 1979, The stratigraphy of the Barnwell Group of Georgia: Georgia Geologic Survey Open File Report 80-1, 89 p.

Huddlestun, P. F. and Hetrick, J. H., 1986, Upper Eocene stratigraphy of central and eastern Georgia: Georgia Geologic Survey Bulletin 95, 78 p.

Leeth, D. C. and Nagle, D. N., 1994 Geomorphology and geologic characterization of the Savannah River Floodplain, Georgia and South Carolina; Geologic Society of America Abstracts with Programs, vol. 26, #4.

Moore, J., James, A., Daggett, J., and Price, S., 1992, Aquifer Test Report, Tritium Site TR92-1, Georgia, August 11-12, 1992: Clemson University Department of Earth Sciences Draft Report, 93 p.

Murphy, C. E., Jr., Bauer, L. R., Hayes, D. W., Marter, W. L., Ziegler, C. C., Stephenson, D. E., Hoel, D. D., and Hamby, D. M., 1991, Tritium in the Savannah River Site environment (U): Westinghouse Savannah River Company report WSRC-RP-90-424-1, 133 p., plus appendices.

National Council on Radiation Protection an Measurements, 1987, Ionizing radiation exposure of the population of the United States: NCRP Report 93, 87 pp.

Robertson, W. D., and Cherry, J. A., 1989, Tritium as an indicator of recharge and dispersion in a groundwater system in central Ohio: Water Resources Research, v. 25, no. 6, p 1097-1109.

Rose, S., 1992, Tritium in groundwater of the Georgia Piedmont: implications for recharge and flow paths: Hydrological Processes, v. 6, p. 67-78.

Rose, S., 1993, Environmental tritium systematics of baseflow in Piedmont Province watersheds, Georgia (USA): Journal of Hydrology, v. 143, p. 191-216.

Rose, S. and James, P., 1993, Geochemical description of ground water in the Gordon and other aquifers in Burke County, Georgia; Preliminary draft report: Unpublished report submitted to the Georgia Geologic Survey, 62 p.

Snipes, D. S., Fallaw, W. C., and Price, V., Jr., and Cumbest, R. J., 1993, The Pen Branch fault: Documentation of Late Cretaceous and Tertiary faulting in the Coastal Plain of South Carolina: Southeastern Geology, vol. 33, #4, pg. 195-218.

GLOSSARY

"Aquifer"-a permeable body of rock or sediment with the ability to store and transmit ground water. The permeability is due to the presence of fractures and minute passageways between grains. Examples in the study area are sand and/or gravel bodies and fractured limestones.

"Confined aquifer"-an aquifer which is bounded above and below by confining beds. Recharge is by rainfall onto distant exposed portions of the aquifer, or downward leakage through the overlying confining bed.

"Confining bed"-an impermeable body of rock or sediment which prevents the flow of ground water. The impermeability is due to the density of the rock. Examples in the study area are clays and dense limestones.

"Discharge"-methods by which water leaves the aquifer.

"picoCurie"- the quantity of a radioactive element which releases 0.037 electrons per second.

"Potentiometric surface"-water in confined aquifers is under hydraulic pressure. When a well penetrates the upper confining bed, the potentiometric head is the distance above the aquifer that the water level reaches (because of the pressure). Contour maps constructed from water level measurements give indications of the direction of groundwater flow.

"Recharge"-methods by which water enters the aquifer.

"Unconfined aquifer"-an aquifer which is exposed to the ground surface. Recharge is by rainfall and sometimes by surface stream leakage. Other terms for this type of aquifer include: "Water Table aquifer," "Surficial aquifer," "Shallow aquifer," and "Upper Three Runs aquifer" (in this report).

"Water table"-the level at which subsurface rock or sediment becomes saturated with water. Measurements are taken in wells or at spring sites, where the water table intersects the ground surface. The water table generally follows the surface topography.

Appendix 1

Identification of wells sampled before and during the Tritium Project by EPD personnel

Owner/Resident	Date	Lab #	Tritium-pC/liter
1. A & A Store #1	10/30/91	S-5397	300 ± 100
	12/06/91	S-5466	100 ± 100
2. A & A Store #2	09/04/92	S-5937	200 ± 100
	01/05/93	S-6298	<100
3. A & A Store #3	09/22/87	SR-3272	<200
(aka Delaigle Trailer	04/04/88	SR-3577	600 ± 100
Park well #3)	04/10/90	SR-4852	<300
	01/08/91	SR-5382	1200 ± 200
	07/18/91	SR-5688	1200 ± 200
	09/04/91	SR-5799	1500 ± 200
	10/08/91	SR-5838	1400 ± 200
	10/30/91	SR-5943	1200 ± 200
	11/06/91	SR-5954	800 ± 100
	12/06/91	SR-6048	1400 ± 200
	01/14/92	S-5482	1200 ± 200
	02/10/92	S-5548	1300 ± 200
	03/04/92	SR-6213	1100 ± 200
	07/07/92	SR-6419	1300 ± 200
	08/06/92	S-5905	1200 ± 200
	01/28/93	S-6326	1200 ± 200
	04/07/93	S-6356	1000 ± 100
	05/18/93	S-6389	1200 ± 200
	08/26/93	S-6455	1100 ± 200
4. Albert Patrick Residence	11/05/91	S-5509	<100
5. Allen Chapel Church	10/17/91	S-5504	<100
6. Arthur Jackson	10/08/91	S-5493	1300 ± 200
Residence	11/05/91	S-5507	1100 ± 200
	12/06/91	S-5464	1100 ± 200
	02/10/92	S-5547	1000 ± 100
	03/04/92	S-5673	1100 ± 200
	07/07/92	SR-6417	1200 ± 200
	12/30/92	S-6289	1000 ± 100
	07/15/93	S-6420	1100 ± 200
7. Augusta Lock and Dam	04/13/87	SR-3008	<200
	09/22/87	SR-3262	<300
	04/04/88	SR-3568	<300
	10/04/88	SR-3845	<300
	04/11/89	SR-4203	<300
	10/10/89	SR-4474	<300
	04/10/90	SR-4844	<300
	01/08/91	SR-5377	<100
	07/18/91	SR-5683	100 ± 100
	10/08/91	SR-5857	100 ± 100
	07/07/92	SR-6387	<100
8. Avner Delaigle	10/30/91	S-5398	100 ± 100
Residence	08/06/92	S-5906	<100

Owner/Resident	Date	Lab #	Tritium-pC/liter
9. Bill Sturgeon Residence	02/02/93	S-6334	1200 ± 200
	05/18/93	S-6384	1300 ± 200
10. Botsford Springs Church	10/17/91	S-5501	<100
	09/04/92	S-5911	<100
11. Burke County EMA #2	10/17/91	S-5500	<100
	09/04/92	S-5933	<100
12. Burke County EMA #11-4"	10/17/91	S-5496	<100
	08/06/92	S-5909	100 ± 100
13. Burke County EMA #11-6"	08/06/92	S-5901	<100
14. Charles Beazley Residence	01/14/92	S-5475	300 ± 100
15. Christine Williams Residence	10/01/92	S-5976	<100
16. Clyde Dixon Residence	10/01/92	S-5972	<100
17. Clarence Overton Residence	01/14/92	S-5514	<100
	07/07/92	SR-6418	200 ± 100
	10/20/93	S-6683	<100
18. Dale Heath Residence	08/06/92	S-5908	100 ± 100
19. Daniel Grove Church	10/17/92	S-5497	<100
	11/10/92	S-6240	<100
20. Dave Rogers Residence	08/21/92	S-5916	<100
21. Derossie Delaigle Residence Residence	08/06/92	S-5907	<100
22. E. J. Weis, Sr. Residence	09/11/92	S-5944	200 ± 100
23. E. J. Weis, Jr. Residence	09/11/92	S-5945	200 ± 100
24. Earl Bush Residence	08/06/92	S-5904	100 ± 100
25. Ebenezer Church	10/17/91	S-5495	<100
26. Emma Moton Residence	07/07/92	SR-6422	200 ± 100
27. Ethel Wesby Residence	01/28/93	S-6328	<100
28. Eugene Carter Residence	09/03/92	S-5939	100 ± 100
29. Eula Hopkins Residence	10/01/92	S-5971	100 ± 100
30. Fairfield Church	10/17/91	S-5499	<100
31. Flakes Auto	10/08/91	SR-5846	<100
	02/10/92	S-5545	100 ± 100
	08/21/92	S-5915	<100

Owner/Resident	Date	Lab #	Tritium-pC/liter
32. Flakes Residence	10/30/91	S-5399	<100
33. Frank Wimberly Residence	10/01/92	S-5974	1000 ± 100
	01/06/93	S-6296	800 ± 100
34. Ga. Welcome Ctr.	04/13/87	SR-3007	<200
I-20 Augusta	09/22/87	SR-3261	<300
	04/04/88	SR-3567	<300
	10/04/88	SR-3844	<300
	04/12/89	SR-4202	<300
	10/10/89	SR-4475	<300
	04/10/90	SR-4843	<300
	01/08/91	SR-5376	<100
	07/18/91	SR-5682	100 ± 100
	10/08/91	SR-5856	100 ± 100
	07/07/92	SR-6386	200 ± 100
35. Ga. Welcome Ctr.	04/13/87	SR-3011	<200
I-20 Augusta	09/22/87	SR-3266	<300
	10/05/88	SR-3851	<300
	04/12/89	SR-4207	<300
	10/10/89	SR-4470	<300
	04/10/90	SR-4850	<300
	01/08/91	SR-5380	<100
	0 7/18/91	SR-5687	<100
	10/08/91	SR-5859	100 ± 100
	07/07/92	SR-6390	<100
36. George Wilson Residence	02/10/92	S-5544	600 ± 100
	03/04/92	S-5670	700 ± 100
	07/07/92	S-5880	1100 ± 200
	09/03/92	S-5940	700 ± 100
	01/06/93	S-6293	500 ± 100
37. Girard Mall	04/13/87	SR-3010	<200
	09/22/87	SR-3263	<300
	04/04/88	SR-3571	<300
	04/11/89	SR-4205	<300
	10/10/89	SR-4471	<300
	04/10/90	SR-4848	<300
	01/08/91	SR-5378	<100
	07/18/91	SR-5685	100 ± 100
	10/08/91	SR-5860	100 ± 100
	07/07/92	SR-6388	<100
38. Glen Saxon Residence	10/01/92	SR-5969	100 ± 100
39. Glenn Stroud Residence	07/07/92	SR-6405	<100
40. Gobbie Grove Church	09/11/92	S-5948	<100
(aka Eva Grubbs Residence)	01/05/93	S-6297	<100
41. Greg Hawkins	09/04/92	S-5935	400 ± 100
42. Hancock Landing	04/10/90	SR-4846	<300
Lodge	10/08/91	SR-5848	100 ± 100

Owner/Resident	Date	Lab #	Tritium-pC/liter
43. Harry Williams Residence	01/14/92	S-5519	200 ± 100
44. Hatcher Farm Well	11/20/91	S-5407	300 ± 100
	07/07/92	SR-6412	100 100
45. Hatcher Farm Irrigation well	02/10/92	S-5541	<100
	07/07/92	SR-6412	100 ± 100
46. Hug-a-Hog Plantation	10/17/91	S-5494	1000 ± 100
	11/05/91	S-5508	900 ± 100
	08/14/92	S-5897	900 ± 100
	01/06/93	S-6294	800 ± 100
47. Jeanette Powell Residence	10/01/92	S-5970	<100
48. Jeff Chandler Residence	08/21/92	S-5919	<100
49. Jerry Collins Residence	09/04/92	S-5936	100 ± 100
50. Jim Garrison Residence	10/27/92	S-6236	<100
51. Job Springs Church	10/17/91	S-5503	100 ± 100
52. John Sturdivant Residence	02/10/92	S-5550	<100
53. Jones Residence on River Rd.	01/14/92	S-5517	<100
54. J. C. Mallard Residence	08/14/92	S-5898	100 ± 100
55. Chris Mallard Residence	08/14/92	S-5899	200 ± 100
56. Julian Morris Residence	02/12/92	S-5617	400 ± 100
	07/07/92	SR-6414	500 ± 100
	02/03/94	S-6709	400 ± 100
57. Kennedy Store	10/17/91	S-5498	<100
	08/21/92	S-5913	<100
58. Kwik Way Store	02/10/92	S-5549	<100
	08/21/92	S-5912	<100
59. Lamar Paul Residence	08/21/92	S-5918	900 ± 100
	09/04/92	S-5934	800 ± 100
	01/06/93	S-6295	900 ± 100
	02/03/93	S-6332	800 ± 100
	07/15/93	S-6421	800 ± 100
60. Leonard Williams Residence	08/06/92	S-5902	200 ± 100
61. Lewis Sullivan Trailer	08/06/92	S-5903	<100
62. Lonnie Griffin Residence	10/01/92	S-5978	<100
63. Lucy Rouse Residence	11/17/92	S-6260	<100

Owner/Resident	Date	Lab #	Tritium-pC/liter
64. Margaret Williams Residence	11/17/92	S-6261	<100
65. Mary Johnson Residence	05/18/93	S-6386	1600 ± 200
	02/03/94	S-6708	1600 ± 200
66. Mattie Stevens Residence	02/20/93	S-5941	<100
67. M. A. Miller Residence	07/02/92	S-5847	<100
68. M. A. Miller Trailer	07/02/92	S-5848	100 ± 100
69. M. A. Miller flowing well east of River Rd.	09/03/92	S-5941	<100
70. M. A. Miller flowing well, downstream from dam	07/02/92	S-5844	100 ± 100
71. M. A. Miller flowing well, upstream from dam	10/22/91	S-5392	100 ± 100
	07/02/92	S-5845	<100
72. Mary Fincher Residence	08/21/92	S-5917	<100
73. Mayonnaise Residence	02/10/92	S-5551	100 ± 100
74. McBean Fire Station	01/17/92	S-5477	<100
75. McCoy Residence	01/15/92	SR-6110	200 ± 100
76. Bill Rucker Residence	02/08/94	S-6716	<100
77. Walnut Run Ostrich Farm	08/14/92	S-5900	700 ± 100
	12/30/92	S-6290	700 ± 100
	02/02/93	S-6333	600 ± 100
	05/18/93	S-6385	900 ± 100
78. Percy Dixon Residence	10/01/92	S-5973	100 ± 100
79. Ralph Greer Residence	02/10/92	S-5543	600 ± 100
	03/04/92	S-5669	600 ± 100
	07/07/92	SR-6407	700 ± 100
	09/03/92	S-5938	800 ± 100
	01/06/93	S-6292	500 ± 100
	07/15/93	S-6422	600 ± 100
80. Ricky Greer (trailer)- out of service mid-'92	11/20/91	S-5408	1000 ± 100
	02/10/92	S-5542	500 ± 100
	03/04/92	S-5671	600 ± 100
80A. Ricky Greer Hog Pen faucet	02/03/93	S-6336	<100
81. Rickey Johnson Residence	09/11/92	S-5947	100 ± 100
82. Robert Lynch	09/03/92	S-5930	200 ± 100

Owner/Resident	Date	Lab #	Tritium-pC/liter
83. Roman Powell Residence	10/28/92	S-6239	<100
84. Rose Johnson Residence	10/08/91	S-5492	500 ± 100
(aka Willie Brown Residence	11/05/91	S-5506	400 ± 100
Gobbie Grove Church)	02/10/92	S-5546	400 ± 100
	03/04/92	S-5672	500 ± 100
	07/07/92	SR-6415	600 ± 100
	08/21/92	S-5914	500 ± 100
	01/28/93	S-6327	400 ± 100
	02/03/93	S-6335	400 ± 100
85. Sharon Jackson Residence	10/01/92	S-5975	100 ± 100
86. Shell Bluff Store	10/08/91	S-5490	<100
	01/14/92	S-5520	<100
	07/07/92	SR-6406	100 100
	09/03/92	S-5942	100 ± 100
87. Stoney Bluff Park	10/05/88	SR-3850	<300
	04/12/89	SR-4206	<300
	04/10/90	SR-4849	<300
	01/08/91	SR-5379	<100
	07/18/91	SR-5686	<100
	10/08/91	SR-5858	<100
	07/07/92	SR-6389	<100
88. Thomas J. Rouse Residence	09/16/92	S-5949	<100
89. Thompson Bridge Church	10/17/91	S-5502	<100
90. Thomson Oak Flooring	10/26/92	S-6237	100 ± 100
(Big T Hunting Lodge)	01/28/93	S-6325	100 ± 100
91. Thomson Oak Flooring	05/18/93	S-6387	<100
(flowing well - Cox Point)			
92. Tommy Greer Residence	01/14/92	S-5476	<100
	02/10/92	S-5540	<100
	07/07/92	SR-6411	100 ± 100
93. Unknown Yellow House	07/07/92	SR-6413	400 ± 100
	07/07/92	SR-6413	400 ± 100
94. Viola Brigham Residence	04/13/87	SR-3014	<200
	09/22/87	SR-3274	<300
	10/04/88	SR-3858	<300
	04/11/89	SR-4211	<300
	10/10/89	SR-4489	<300
	04/10/90	SR-4854	<300
	01/08/91	SR-5384	<100
	07/18/91	SR-5690	<100
	10/08/91	S-5485	<100
	01/14/92	S-5518	<100
	07/07/92	SR-6423	100 ± 100
	10/01/92	S-5977	<100

Owner/Resident	Date	Lab #	Tritium-pC/liter
95. Vogtle Construction well	10/08/91	S-5489	<100
96. Vogtle Make Up well	10/08/91	S-5486	<100
97. Vogtle Rec. Ctr. well	10/08/91	S-5488	<100
98. Vogtle Simulator	09/22/87	SR-3273	<200
	04/08/88	SR-3579	<300
	10/04/88	SR-3856	<300
	04/11/89	SR-4210	<300
	10/10/89	SR-4488	<300
	04/10/90	SR-4853	<300
	01/08/91	SR-5383	<100
	07/18/91	SR-5689	100 ± 100
	10/08/91	S-5484	<100
	01/14/92	S-5521	<100
	07/07/92	SR-6421	200 ± 100
99. Vogtle Training Center	10/08/91	S-5487	<100
100. Vogtle Visitor Center	07/07/92	SR-6420	100 ± 100
101. Walter Grubbs Residence	09/03/92	S-5931	200 ± 100
102. William Cox Residence	08/06/92	S-5910	<100
103. Wanda Siller Residence	07/07/92	SR-6408	<100
104. Waynesboro Filter Plant	02/12/92	S-5616	<100
105. Waynesboro Main Well	04/13/87	SR-3012	<200
	09/22/87	SR-3269	300 ± 100
	04/04/88	SR-3575	<300
	10/05/88	SR-3853	<300
	04/11/89	SR-4208	<300
	10/11/89	SR-4469	<300
	04/10/90	SR-4851	<300
	01/09/91	SR-5381	<100
	07/18/91	SR-5680	<100
	10/08/91	SR-5861	<100
	02/12/92	S-5515	<100
	05/01/92	SR-6289	<100
106. William Edwards Residence	07/07/92	SR-6416	200 ± 100
	09/04/92	S-5977	100 ± 100
107. Shell Station-River Road/ Hancock Landing Road (closed in 1989)	04/13/87	SR-3013	<200
	09/22/87	SR-3270	<200
	04/04/88	SR-3576	<300
	10/04/88	SR-3855	<300
	04/11/89	SR-4209	<300
	10/10/89	SR-4487	<300
108. Alma Crook Residence	02/03/94	S-6706	2000 ± 200
109. Earl Mills	02/03/94	S-6707	800 ± 100

Appendix 2

Radioactive decay of tritium

Tritium is a radioactive isotope of hydrogen with a half-life of 12.35 years (i.e. after 12.35 years, 50 percent of the original amount of tritium remains). Below is a short table to illustrate the breakdown of tritium over an approximate 100 year time period.

Time Elapsed:	Amount of Tritium Remaining
Release date:	100.00%
12.35 years:	50.00%
24.70 years:	25.99%
37.05 years:	12.50%
49.40 years:	6.25%
61.75 years:	3.12%
74.10 years:	1.56%
86.45 years:	0.78%
98.80 years:	0.39%

Appendix 3

Tritium in rainfall samples collected in Burke and Screven counties

EPD Station Number	Sample Number	Collection Date	Tritium (picoCuries/ liter)	EPD Station Number	Sample Number	Collection Date	Tritium (picoCuries/ liter)
11	1115	07/12/83	8,900	20	2519	04/17/86	7,500
11	1348	12/28/83	7,600	20	4692	01/23/90	5,700
11	1810	12/24/84	11,500	25	857	12/02/82	31,700
11	1863	01/24/86	10,400	25	923	01/27/83	6,300
11	1918	02/27/85	6,800	25	1102	06/16/86	6,700
11	1972	03/28/85	13,7000	25	1813	12/18/84	9,500
11	2387	01/23/86	9,000	25	1970	03/28/85	5,300
11	2728	09/25/86	10,900	35	1353	12/28/83	8,000
11	2884	12/12/86	7,700	35	1811	12/18/84	5,400
11	2959	02/26/87	10,700	35	1859	01/24/85	9,900
11	3419	12/17/87	5,200	35	1967	03/28/85	8,900
11	6682	01/07/93	7,000	35	2683	08/27/86	11,000
14	1969	03/28/85	5,200	35	2961	02/26/87	9,400
14	2386	01/23/86	13,000	35	4803	03/15/90	5,300
14	2822	12/12/86	12,300	35	5389	01/08/91	5,700
20	858	12/02/82	6,000				

The table shows rainfall tritium concentrations >5000 picoCuries per liter, from a total of 25 EOD rainfall collection stations in the study area. Locations are shown in Figure 7.

Station 11: Hancock Landing Road, near the Savannah River
Station 14: Georgia Highway 23, 1 mile north of Girard
Station 20: Welcome Center, U.S. Highway 301 at the Savannah River
Station 25: Georgia Power company Maintenance Office in Waynesboro
Station 35: Georgia Power Plant Vogtle Simulator

Appendix 4

Tritium in rainfall categorized by tritium concentration

This table categorizes rainfall tritium samples into three concentration classes. All samples are from collection sites in Bruke and Screven counties in Georgia. Of the 25 EPD rainfall collection sites in the area, the seven presented have the longest and most consistent collection history. Values are in picoCuries per liter. Rainfall collection sites are shown in Figure 7.

Collection Site Number	Total Number of Samples	Number (%) of Samples <2500 picoCuries per liter	Number (%) of Samples 2500 - 4999 picoCuries per liter	Number (%) of Samples >5000 picoCuries per liter
11	110	80 (72.2)	17 (15.4)	13 (11.8)
14	59	52 (88.1)	4 (6.8)	3 (5.1)
20	116	110 (94.8)	3 (2.6)	3 (2.6)
23	38	34 (89.5)	4 (10.5)	0
25	144	132 (88.5)	12 (8.2)	5 (3.3)
35	1114	84 (75.7)	19 (17.1)	8 (7.2)
48	148	142 (95.9)	6 (4.1)	0

Site 11: Hancock Landing Road, near the Savannah River
Site 14: Georgia Highway 23, 1 mile north of Girard
Site 20: Welcome Center on U.S. Highway 301 at the Savannah River
Site 23: Intersection of Georgia Highways 23 and 24 in Sardis
Site 25: Georgia Power Company Maintenance Office in Waynesboro
Site 35: Georgia Power Plant Vogtle Simulator
Site 48: Augusta Youth Center on Georgia Highway 56

Appendix 5

Results of analyses from fifteen tritium polluted residential and public water wells

The locations of the anomalous water wells are shown in Figures 22 and 23. All tritium values are in picoCuries per liter.

Site 6: Arthur Jackson Residence
Latitude: 33°09'40"
Longitude: 81°46'32"

Collection Date	Lab ID Number	Tritium Content
10/08/91	S-5493	1300 ± 200
11/05/91	S-5507	1100 ± 200
12/06/91	S-5464	1100 ± 200
02/10/92	S-5547	1100 ± 200
03/04/92	S-5673	1100 ± 200
07/07/92	SR-6417	1200 ± 200
12/30/92	S-5905	1200 ± 200
07/15/93	S-6420	1100 ± 200

Site 36: George Wilson Residence
Latitude: 33°12'32"
Longitude: 81°50'56"

Collection Date	Lab ID Number	Tritium Content
02/10/92	S-5544	600 ± 100
03/04/92	S-5670	700 ± 100
07/07/92	S-5880	1100 ± 200
09/03/92	S-5490	700 ± 100
01/06/93	S-6293	500 ± 100

Site 3: Delaigle Trailer Park well #3
Latitude: 33°08'09"
Longitude: 81°47'03"

Collection Date	Lab ID Number	Tritium Content
09/22/87	SR-3272	<200
04/04/88	SR-3577	600 ± 100
04/10/90	SR-4852	<300
01/08/91	SR-5382	1200 ± 200
07/18/91	SR-5688	1200 ± 200
09/04/91	SR-5799	1500 ± 200
10/08/91	S-5483	1400 ± 200
10/30/91	S-5396	1200 ± 200
11/05/91	S-5505	800 ± 100
12/06/91	S-5465	1400 ± 200
01/14/92	S-5516	1200 ± 200
02/10/92	S-5548	1300 ± 200
03/04/92	SR-6213	1100 ± 200
07/07/92	SR-6419	1300 ± 200
08/06/92	S-5905	1200 ± 200
01/28/93	S-6326	1200 ± 200
04/07/93	S-6356	1000 ± 100
05/18/93	S-6389	1200 ± 200
08/26/93	S-6455	1100 ± 200

Site 79: Ralph Greer Residence
Latitude: 33°12'37"
Longitude: 81°12'37"

Collection Date	Lab ID Number	Tritium Content
12/20/91	S-5408	100 ± 100
12/06/91	S-5463	<100(?)
02/10/92	S-5543	600 ± 100
03/04/93	S-5669	600 ± 100
07/07/92	SR-6407	700 ± 100
09/03/92	S-5938	800 ± 100
01/06/93	S-6292	500 ± 100
07/15/93	S-6422	600 ± 100

Site 84: Rose Johnson Residence
Latitude: 33°10'23"
Longitude: 81°53'00"
(first 2 samples recorded as Gobbie Grove Church)

Collection Date	Lab ID Number	Tritium Content
10/08/91	S-5492	500 ± 100
11/05/91	S-5506	500 ± 100
02/10/92	S-5546	400 ± 100
03/04/92	S-5672	500 ± 100
07/07/92	SR-6415	600 ± 100
08/21/92	S-5914	500 ± 100
01/28/93	S-6327	400 ± 100
02/03/93	S-6335	400 ± 100

Site 46: Hug-a-Hog Plantation
Latitude: 33°03'10"
Longitude: 81°47'39"

Collection Date	Lab ID Number	Tritium Content
10/17/91	S-5494	1000 ± 100
11/05/91	S-5508	900 ± 100
08/14/92	S-5897	900 ± 100
01/06/93	S-6294	800 ± 100

Site 77: Walnut Run Ostrich Farm
Latitude: 33°07'57"
Longitude: 81°50'48"

Collection Date	Lab ID Number	Tritium Content
08/14/92	S-5900	700 ± 100
12/30/92	S-6290	700 ± 100
02/04/93	S-6333	600 ± 100
05/18/9.	S-6385	600 ± 100

Site 59: Lamar Paul Residence
Latitude: 33°11'09"
Longitude: 81°49'20"

Collection Date	Lab ID Number	Tritium Content
08/21/92	S-5918	900 ± 100
09/04/92	S-5934	800 ± 100
01/06/93	S-6295	900 ± 100
02/04/93	S-6332	800 ± 100
07/15/93	S-6241	800 ± 100

Site 56: Julian Morris Residence
Latitude: 33°11'05"
Longitude: 81°49'15"

Collection Date	Lab ID Number	Tritium Content
02/12/92	S-5617	100 ± 100
07/07/92	SR-6414	500 ± 100
02/03/94	S-6709	400 ± 100

Site 65: Mary Johnson Residence
Latitude: 33°07'57"
Longitude: 81°50'22"

Collection Date	Lab ID Number	Tritium Content
05/18/93	S-6386	1600 ± 200
02/03/94	S-6708	1600 ± 200

Site 80: Ricky Greer Residence
Latitutde: 33°12'24"
Longitude: 81°50'48"
(Well out of service as of mid-1992)

Collection Date	Lab ID Number	Tritium Content
02/10/92	S-5542	500 ± 100
03/04/92	S-5671	600 ± 100

Site 109: Earl Mills Residence
Latitude: 33°09'26"
Longitude: 81°47'38"

Collection Date	Lab ID Number	Tritium Content
02/03/94	S-6706	800 ± 100

Site 9: Bill Sturgeon Residence
Latitude: 33°07'57"
Longitude: 81"50'22"

Collection Date	Lab ID Number	Tritium Content
02/02/93	S-6334	1200 ± 200
05/18/93	S-6384	1300 ± 200

Site 108: Alma Crook Residence
Latitude: 33°09'24"
Longitude: 81°47'38"

Collection Date	Lab ID Number	Tritium Content
02/03/94	S-6707	2000 ± 200

Site 33: Frank Wimberly Residence
Latitude: 33°10'34"
Longitude: 81°53'00"

Collection Date	Lab ID Number	Tritium Content
10/01/92	S-5974	1000 ± 100
01/06/93	S-6296	800 ± 100

Appendix 6

Results of Tritium Analyses from Ground-Water Monitoring Wells

The locations of the ground-water monitoring wells are shown in Figure 19. All tritium values are in picoCuries per liter.

Site TR92-1

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-1A Upper Three Runs	06/25/92	S-5389	<100
TR92-1A Upper Three Runs	07/16/92	S-5853	200 ± 100
TR92-1A Upper Three Runs	08/14/92	S-5895	300 ± 100
TR92-1A Upper Three Runs	08/14/92	S-5896	200 ± 100
TR92-1A Upper Three Runs	11/17/92	S-6258	200 ± 100
TR92-1A Upper Three Runs	02/08/94	S-6714	300 ± 100
TR92-1B Gordon	06/25/92	S-5840	<100
TR92-1B Gordon	07/08/92	S-5851	<100
TR92-1B Gordon	11/17/92	S-6259	<100
TR92-1B Gordon	02/08/94	S-6715	<100
TR92-1C Meyers Branch "aquifer" (1)	06/25/92	S-5841	<100
TR92-1C Meyers Branch "aquifer"	07/16/92	S-5854	<100
TR92-1C Meyers Branch "aquifer"	12/14/92	S-6284	<100
TR92-1D Dublin	06/25/92	S-5842	<100
TR92-1D Dublin	07/07/92	S-5852	<100
TR92-1D Dublin	12/14/92	S-6285	<100

(1) Same as "Sand within Meyers Branch Confining System".

Site TR92-2

Well Designation and aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-2A Upper Three Runs	02/18/93	S-6345	1700 ± 200
TR92-2A Upper Three Runs	03/02/93	S-6348	1400 ± 200
TR92-2A Upper Three Runs	03/02/93	S-6349	1400 ± 200
TR92-2A Upper Three Runs	07/15/93	S-6418	1400 ± 200
TR92-2A Upper Three Runs	02/03/94	S-6712	1400 ± 200
TR92-2B Gordon	01/06/93	S-6286	<100
TR92-2B Gordon	02/18/93	S-6346	<100
TR92-2B Gordon	07/15/93	S-6419	100 ± 100

Site TR92-3

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-3A Upper Three Runs	03/02/93	S-6350	1200 ± 200
TR92-3B Gordon	01/05/93	S-6287	<100
TR92-3B Gordon	09/01/93	S-6462	<100

Site TR92-4

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-4A Upper Three Runs	03/02/93	S-6351	1600 ± 200
TR92-4A-2 Upper Three Runs (1)	02/03/64	S-6713	1600 ± 200
TR92-4B Gordon	01/06/93	S-6288	<100
TR92-4B Gordon	08/26/93	S-6454	<100

(1) Second well drilled for better water production.

Site TR92-5

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-5A Upper Three Runs	08/26/93	S-6450	1000 ± 100
TR92-5A Upper Three Runs	09/01/93	S-6456	800 ± 100
TR92-5A Upper Three Runs	09/01/93	S-6457	1000 ± 100
TR92-5A Upper Three Runs	02/03/94	S-6710	1000 ± 100
TR92-5B Gordon	06/15/93	S-6395	500 ± 100 (1)
TR92-5B Gordon	06/15/93	S-6396	600 ± 100 (1)
TR92-5B Gordon	06/24/93	S-6399	<100
TR92-5B Gordon	06/24/93	S-6400	100 ± 100
TR92-5B Gordon	06/24/93	S-6401	<100
TR92-5B Gordon	07/15/93	S-6415	<100
TR92-5B Gordon	07/15/93	S-6416	<100
TR92-5C (2)	08/26/93	S-6452	300 ± 100
TR92-5C	09/01/93	S-6458	400 ± 100
TR92-5C	09/01/93	S-6459	300 ± 100
TR92-5C	09/01/93	S-6460	400 ± 100
TR92-5C	09/07/93	S-6478	300 ± 100
TR92-5C	09/07/93	S-6479	300 ± 100
TR92-5C	02/03/94	S-6711	300 ± 100

(1) Positive results due to tritium introduced during drilling. Samples taken after adequate purging had no detectable tritium.
(2) Constructed to duplicate Delaigle Trailer Park well #3.

Site TR92-6

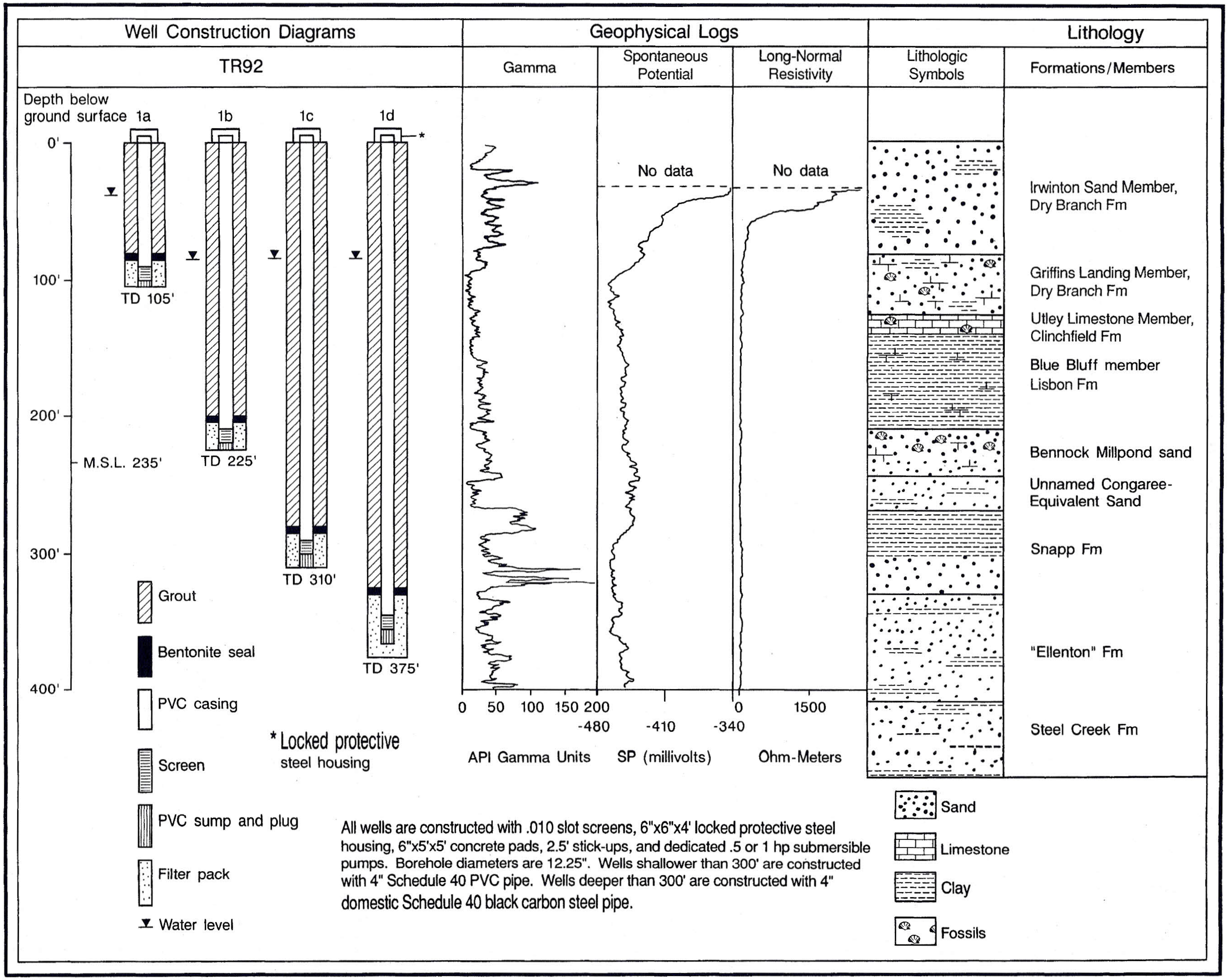
Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-6A Upper Three Runs	09/01/93	S-6463	dry hole
TR92-6B Gordon	08/26/93	S-6453	<100
TR92-6B Gordon	09/01/93	S-6461	<100
TR92-6B	09/03/93	S-6473	<100

Miller's Pond Site (USGS Trans-River Flow Project)

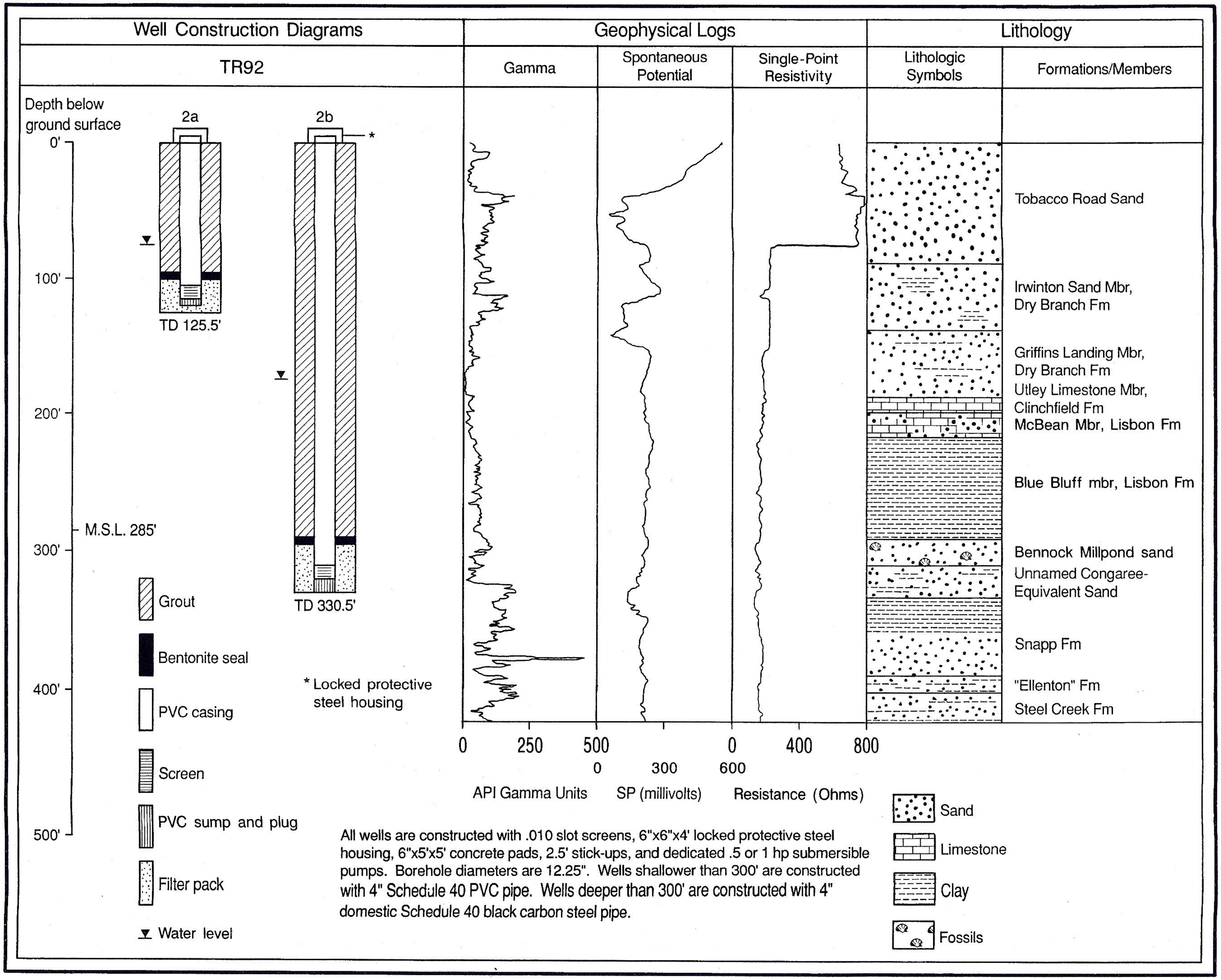
Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TW-1 Lower Midville	12/14/92	S-6282	<100
TR-2 Upper Midville	11/03/92	S-6283	<100
TW-3 Allendale Confining Bed	01/08/93	S-6329	<100
TW-4 Upper Three Runs	01/15/93	S-6330	700 ± 100
TW-5A Upper Dublin	02/11/93	S-6344	<100
TW-6 Lower Dublin	01/23/93	S-6331	<100
TW-7 Lower Dublin	03/03/93	S-6353	<100

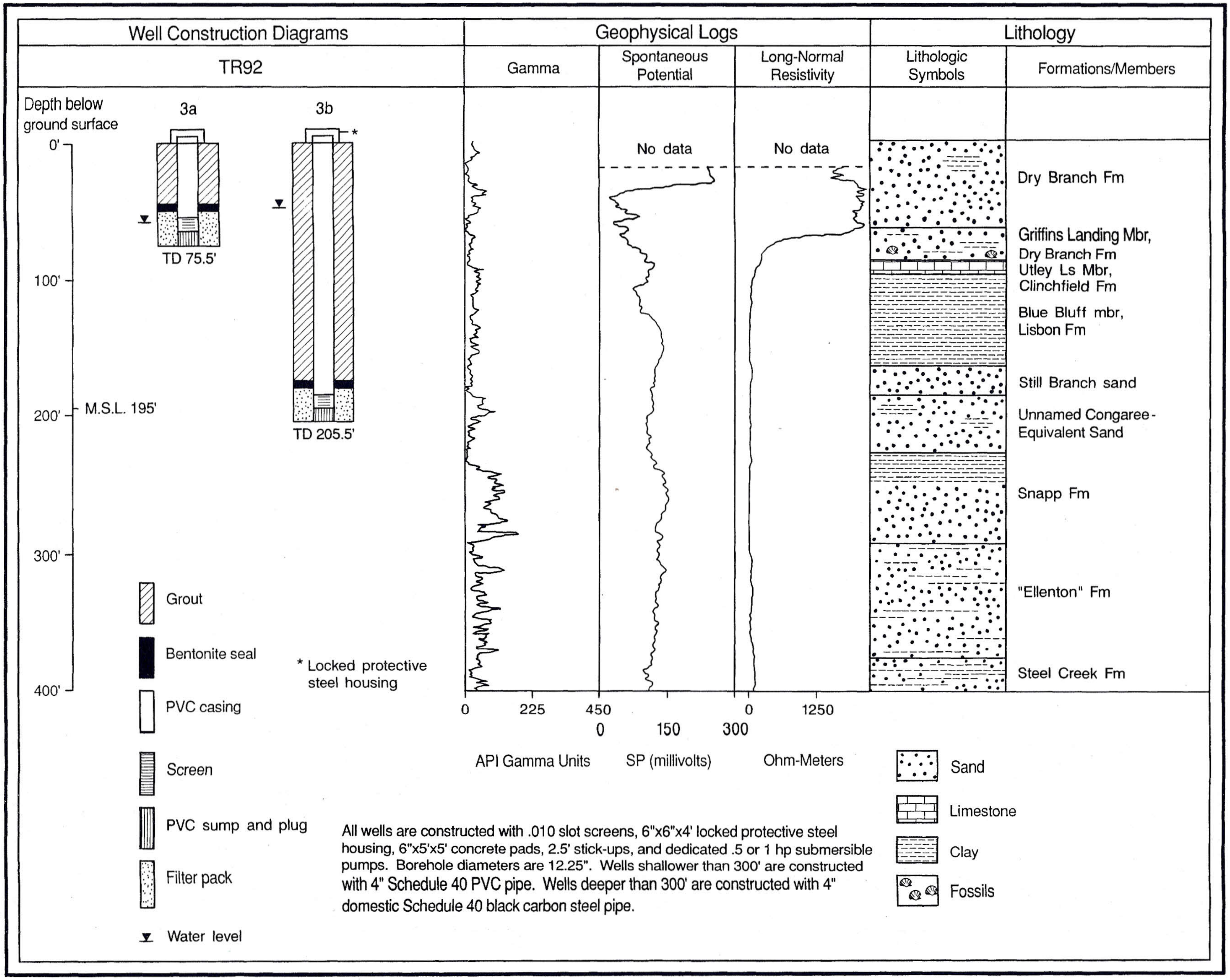
Appendix 7
Tritium Project cluster site data

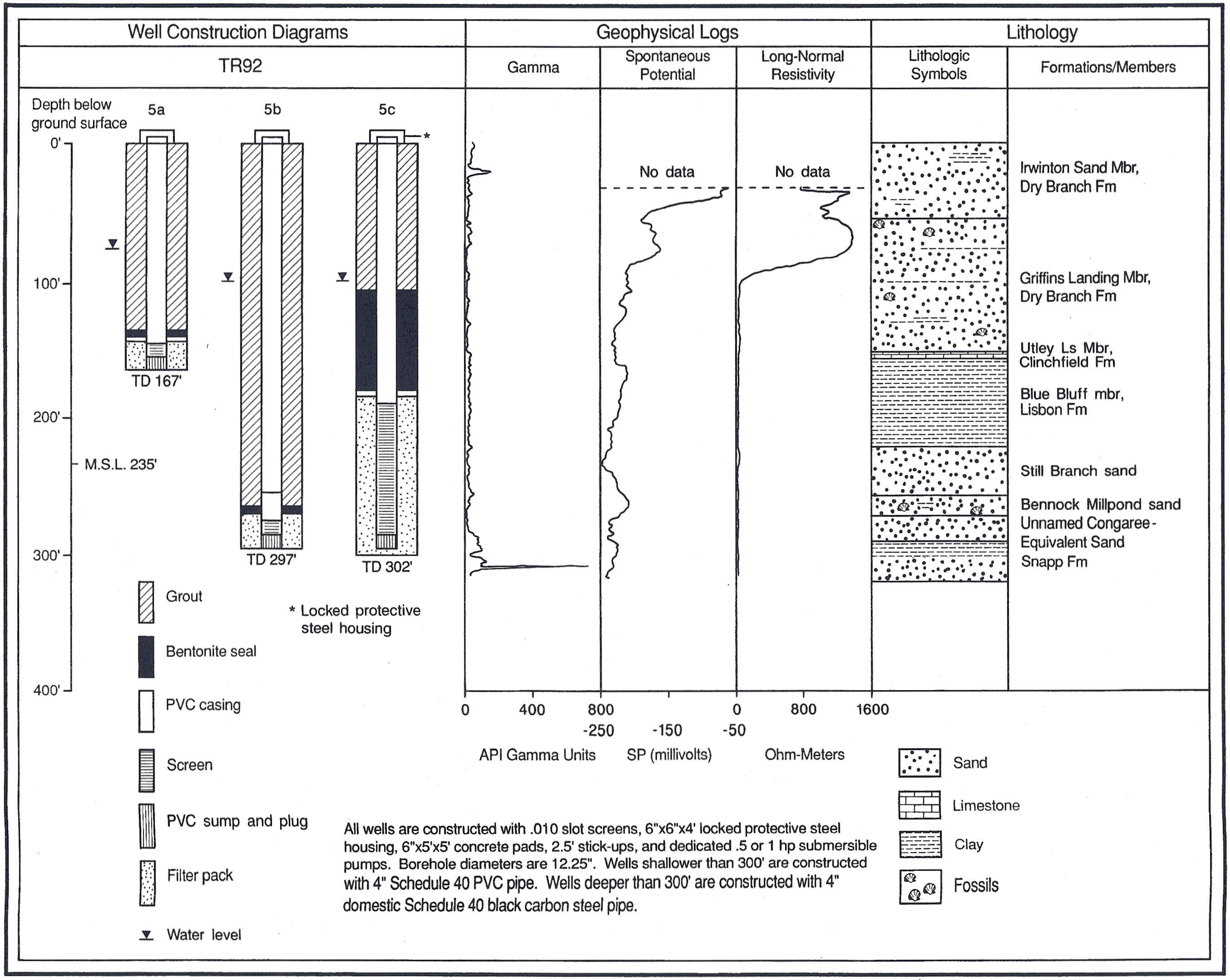
The following six pages include the pertinent data for each Tritium Project cluster site:
1) Site elevation
2) Well construction data and diagrams
3) Geophysical data
4) Lithologic data
5) Water levels

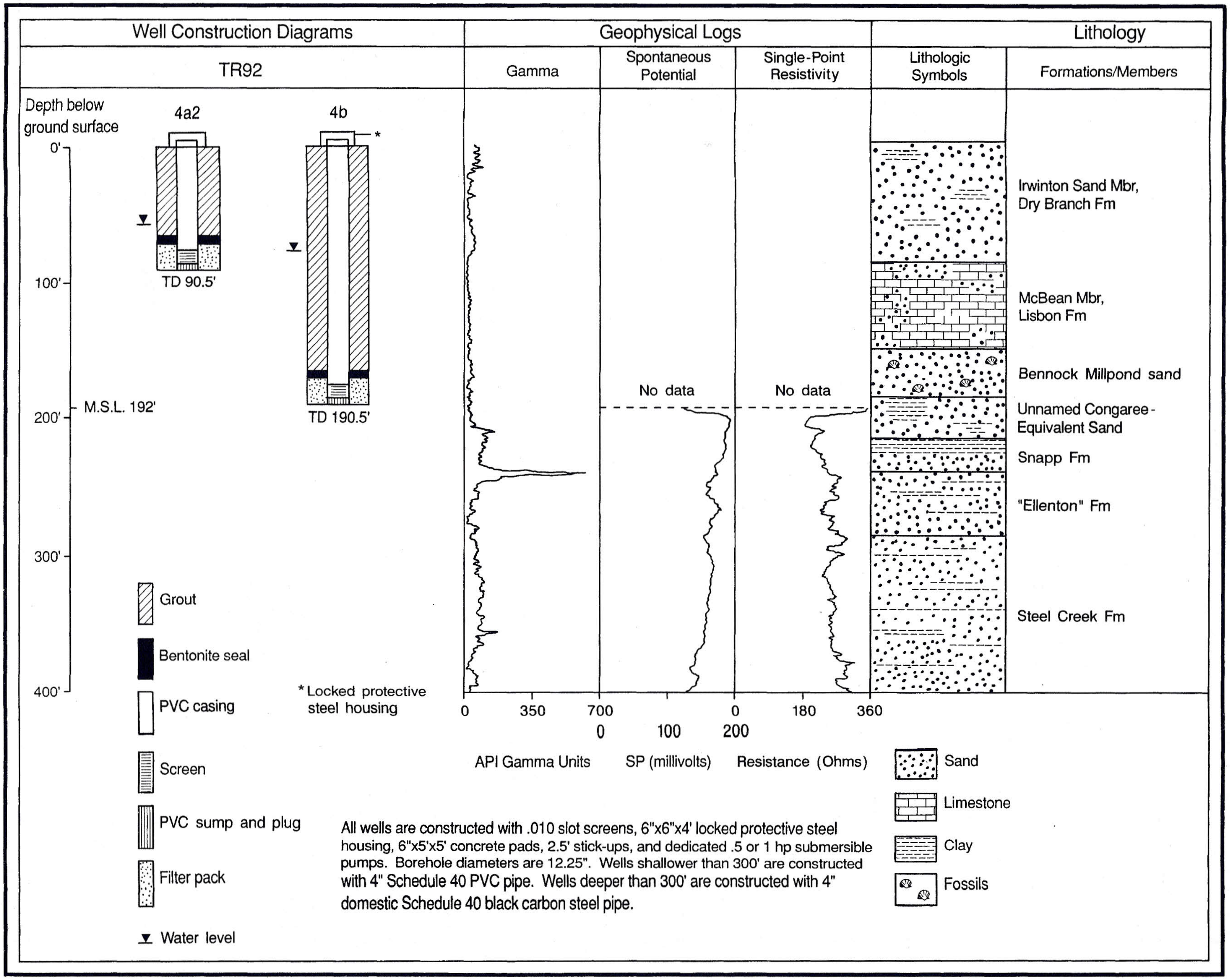


All wells are constructed with .010 slot screens, 6"x6"x4' locked protective steel housing, 6"x5'x5' concrete pads, 2.5' stick-ups, and dedicated .5 or 1 hp submersible pumps. Borehole diameters are 12.25". Wells shallower than 300' are constructed with 4" Schedule 40 PVC pipe. Wells deeper than 300' are constructed with 4" domestic Schedule 40 black carbon steel pipe.

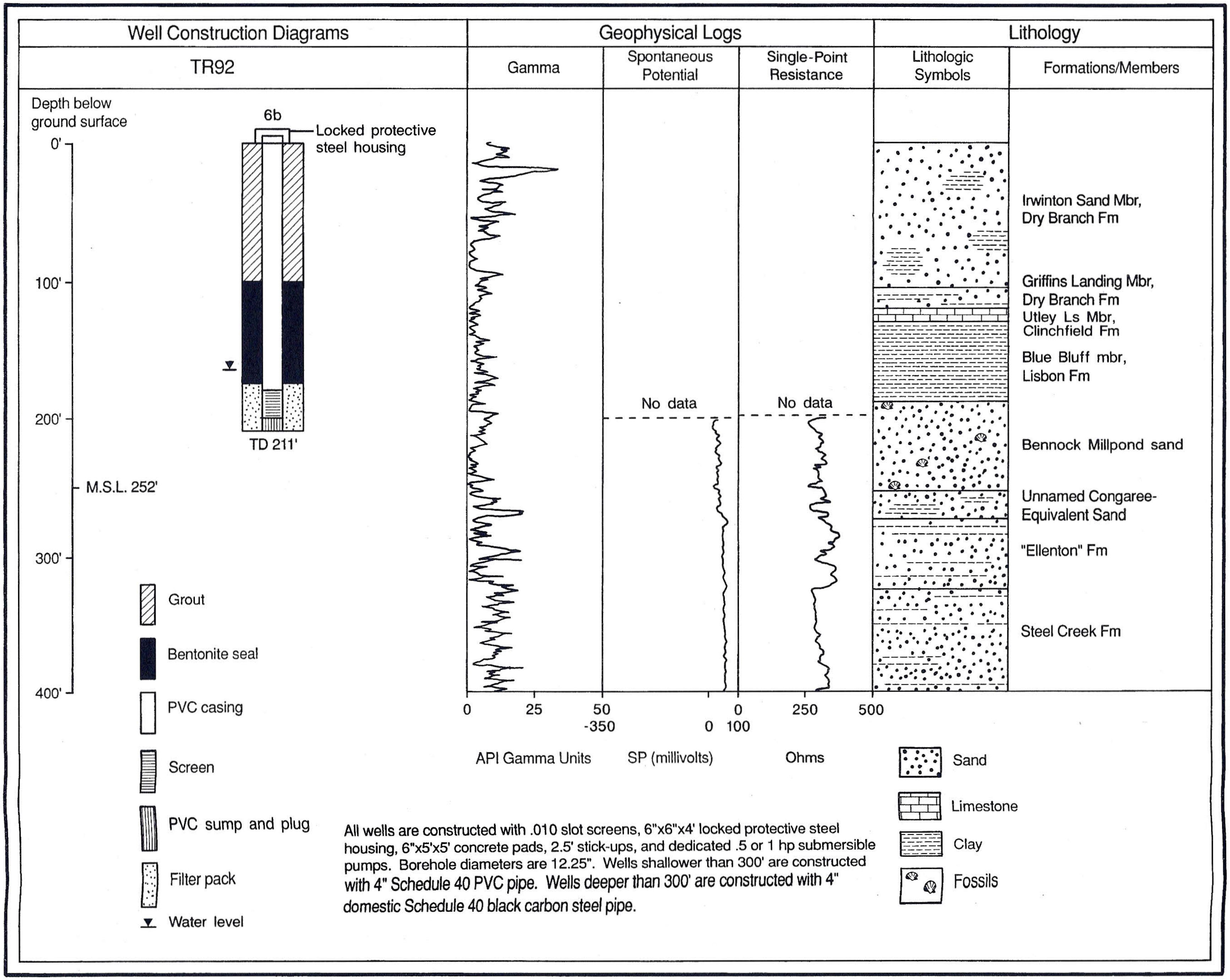

Well Construction Diagrams
Geophysical Logs
Lithology
TR92
Gamma
Spontaneous Potential
Single-Point Resistivity
Lithologic Symbols
Formations/Members
Depth below ground surface
0'
100'
200'
300'
400'
500'
M.S.L. 285'
2a
2b
TD 125.5'
TD 330.5'
Grout
Bentonite seal
PVC casing
Screen
PVC sump and plug
Filter pack
Water level
* Locked protective steel housing
0
250
500
0
300
600
0
400
800
API Gamma Units
SP (millivolts)
Resistance (Ohms)
Tobacco Road Sand
Irwinton Sand Mbr, Dry Branch Fm
Griffins Landing Mbr, Dry Branch Fm
Utley Limestone Mbr, Clinchfield Fm
McBean Mbr, Lisbon Fm
Blue Bluff mbr, Lisbon Fm
Bennock Millpond sand
Unnamed Congaree-Equivalent Sand
Snapp Fm
"Ellenton" Fm
Steel Creek Fm
Sand
Limestone
Clay
Fossils
All wells are constructed with .010 slot screens, 6"x6"x4' locked protective steel housing, 6"x5'x5' concrete pads, 2.5' stick-ups, and dedicated .5 or 1 hp submersible pumps. Borehole diameters are 12.25". Wells shallower than 300' are constructed with 4" Schedule 40 PVC pipe. Wells deeper than 300' are constructed with 4" domestic Schedule 40 black carbon steel pipe.


Well Construction Diagrams
TR92
Depth below ground surface
3a
3b
*
0'
100'
200'
300'
400'
M.S.L. 195'
TD 75.5'
TD 205.5'
Grout
Bentonite seal
PVC casing
Screen
PVC sump and plug
Filter pack
Water level
* Locked protective steel housing
Geophysical Logs
Gamma
Spontaneous Potential
Long-Normal Resistivity
No data
No data
0
225
450
0
150
300
0
1250
API Gamma Units
SP (millivolts)
Ohm-Meters
Lithology
Lithologic Symbols
Formations/Members
Dry Branch Fm
Griffins Landing Mbr, Dry Branch Fm
Utley Ls Mbr, Clinchfield Fm
Blue Bluff mbr, Lisbon Fm
Still Branch sand
Unnamed Congaree-Equivalent Sand
Snapp Fm
"Ellenton" Fm
Steel Creek Fm
Sand
Limestone
Clay
Fossils
All wells are constructed with .010 slot screens, 6"x6"x4' locked protective steel housing, 6"x5'x5' concrete pads, 2.5' stick-ups, and dedicated .5 or 1 hp submersible pumps. Borehole diameters are 12.25". Wells shallower than 300' are constructed with 4" Schedule 40 PVC pipe. Wells deeper than 300' are constructed with 4" domestic Schedule 40 black carbon steel pipe.


Well Construction Diagrams
TR92
Depth below ground surface
5a
5b
5c
0'
100'
200'
300'
400'
M.S.L. 235'
TD 167'
TD 297'
TD 302'
Grout
Bentonite seal
PVC casing
Screen
PVC sump and plug
Filter pack
Water level
* Locked protective steel housing
Geophysical Logs
Gamma
Spontaneous Potential
Long-Normal Resistivity
No data
No data
0
400
800
-250
-150
-50
0
800
1600
API Gamma Units
SP (millivolts)
Ohm-Meters
Lithology
Lithologic Symbols
Formations/Members
Irwinton Sand Mbr, Dry Branch Fm
Griffins Landing Mbr, Dry Branch Fm
Utley Ls Mbr, Clinchfield Fm
Blue Bluff mbr, Lisbon Fm
Still Branch sand
Bennock Millpond sand
Unnamed Congaree-Equivalent Sand
Snapp Fm
Sand
Limestone
Clay
Fossils
All wells are constructed with .010 slot screens, 6"x6"x4' locked protective steel housing, 6"x5'x5' concrete pads, 2.5' stick-ups, and dedicated .5 or 1 hp submersible pumps. Borehole diameters are 12.25". Wells shallower than 300' are constructed with 4" Schedule 40 PVC pipe. Wells deeper than 300' are constructed with 4" domestic Schedule 40 black carbon steel pipe.



Well Construction Diagrams
Geophysical Logs
Lithology
TR92
Gamma
Spontaneous Potential
Single-Point Resistivity
Lithologic Symbols
Formations/Members
Depth below ground surface
0'
100'
200'
300'
400'
M.S.L. 192'
4a2
4b
TD 90.5'
TD 190.5'
No data
No data
0
350
700
0
100
200
0
180
360
API Gamma Units
SP (millivolts)
Resistance (Ohms)
Irwinton Sand Mbr, Dry Branch Fm
McBean Mbr, Lisbon Fm
Bennock Millpond sand
Unnamed Congaree-Equivalent Sand
Snapp Fm
"Ellenton" Fm
Steel Creek Fm
Grout
Bentonite seal
PVC casing
Screen
PVC sump and plug
Filter pack
Water level
* Locked protective steel housing
Sand
Limestone
Clay
Fossils
All wells are constructed with .010 slot screens, 6"x6"x4' locked protective steel housing, 6"x5'x5' concrete pads, 2.5' stick-ups, and dedicated .5 or 1 hp submersible pumps. Borehole diameters are 12.25". Wells shallower than 300' are constructed with 4" Schedule 40 PVC pipe. Wells deeper than 300' are constructed with 4" domestic Schedule 40 black carbon steel pipe.



All wells are constructed with .010 slot screens, 6"x6"x4' locked protective steel housing, 6"x5'x5' concrete pads, 2.5' stick-ups, and dedicated .5 or 1 hp submersible pumps. Borehole diameters are 12.25". Wells shallower than 300' are constructed with 4" Schedule 40 PVC pipe. Wells deeper than 300' are constructed with 4" domestic Schedule 40 black carbon steel pipe.

Appendix 8

Identification of wells used in construction of Gordon aquifer potentiometric map shown in Brooks and others, 1985. Well locations are shown in Figure 38.

Well Number	Owner	Well depth (feet)	Depth of casing (feet)
29Z3	F. P. Saxon	170	-----
29Z4	W.T. Stone	225	127
30X4	Perkins	446	400
30Z6	Miller's Pond	92	42
31Z9	Plant Vogtle Construction well #8	251	220
32Y4	William Cox #2	415	360
32X23	Millhaven Company	375	-----