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

Joseph H. Summerour, Earl A. Shapiro, and Paul F. Huddlestun

Work Performed in Cooperation with U.S. Department of Energy
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GEORGIA DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION
GEORGIA GEOLOGIC SURVEY

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EXECUTIVE SUMMARY

Tritium was consistently detected in a public water supply well in eastern Burke County in 1991. This polluted well is less than two miles from the western margin of the Savannah River Site in South Carolina. In response to this discovery, Georgia Governor Zell Miller directed the Georgia Geologic Survey to evaluate any possible threat to public health due to tritium pollution of Georgia aquifers. In 1992, the Georgia Geologic Survey received funding from the United States Department of Energy for this work. The Georgia Geologic Survey conducted a series of seven sub-investigations in eastern Burke County, hereafter referred to as Phase I. In September, 1993, the Georgia Geologic Survey submitted a preliminary report to Governor Zell Miller. In September, 1994, the Georgia Geologic Survey published the final report as Information Circular 95. This report concluded that:

"1. There is no evidence of a public health threat due to tritium pollution of aquifers in Burke County.

2. There is widespread tritium pollution of the water table aquifer in eastern Burke County, but this pollution is well below the levels of tritium allowed for drinking water by the United States Environmental Protection Agency.

3. There is no evidence of regional tritium pollution of the Gordon aquifer in eastern Burke County.

4. Existing data are not adequate to resolve fully the issue of the tritium pathway into the water table aquifer. However, the investigation shows that some pathways are more likely than others and suggests specific pathway models for future investigation."

The 1993 preliminary report and 1994 final report also made recommendations for additional studies of tritium in Georgia aquifers and for long-term monitoring of tritium in ground water and rainwater. The Department of Energy provided additionally funding to the Georgia Geologic Survey to meet some of these recommendations.

Between 1993 and 1997 the Georgia Geologic Survey conducted additional studies of tritium in Burke County. Four of these Phase II sub-investigations (1, 5, 6, and 7) were continuations of Phase I studies. The other sub-investigations (2, 3, and 4) were new to Phase II. The Phase II sub-investigations, conducted in eastern Burke County, were as follows:

1. Continued monitoring of tritium in the unconfined aquifer;
2. High-resolution tritium analyses of ground water in confined aquifers;
3. An investigation of the vertical distribution of tritium in the vadose zone;
4. An investigation of the vertical distribution of tritium in the unconfined aquifer;
5. A seismic survey across the projected location of the Pen Branch fault;
6. An investigation of well construction in the public water supply well in which tritium was first discovered in Burke County ground water;
7. A revision of the lithostratigraphy and hydrostratigraphy of Burke County.

Continued monitoring evaluates time trends for tritium in the unconfined aquifer using data from domestic water wells, ground-water monitoring wells, and annual baseflow studies. Tritium-polluted domestic water wells show a statistically significant decline between 1991-1993 and 1994-1996. Tritium concentrations in ground-water monitoring wells during 1994 to 1996 generally fell within the range of variation seen during the 1991 to 1993 period. Baseflow studies show a statistically significant decline from 1991 to 1995. The continued monitoring of domestic wells, monitoring wells and annual baseflow studies suggest that tritium concentrations in the unconfined aquifer are declining. This decline in tritium is probably due to a combination of radioactive decay, dilution by untritiated ground-water, and recharge dilution by untritiated (or low tritium) rainwater.

High-resolution tritium analyses show very low, but measurable levels of tritium in all of the confined aquifers. Because the age of the water in these aquifers (11,000 to 32,000 years) is very old when compared to the half-life of tritium (12.35 years), there should be no tritium present within the confined aquifers. There is no meaningful pattern shown by these tritium concentrations. The tritium in these deep aquifers is either due to leakage from other aquifers or to contamination from drilling and sampling. There is insufficient evidence to distinguish between these alternatives.

Tritium is not uniformly distributed with depth either in the unsaturated (vadose) zone or in the unconfined aquifer. Within the vadose zone, surficial materials (0 to -1.5 feet) have tritium values of 388 picoCuries per liter. There is a slight decrease in tritium concentration (238 picoCuries per liter) at a depth of -4 to -5 feet. Tritium concentrations then increase steadily downward to 869 picoCuries per liter at a depth of -14.5 to -15 feet. Tritium concentrations then decrease to 600 picoCuries per liter just below the water table. Within the unconfined aquifer, the uppermost sand unit (the Tobacco Road Sand) shows steadily increasing tritium concentrations of 1,200 picoCuries per liter at a depth of -44 to -49 feet. Tritium levels then decrease to 800 picoCuries per liter near the base of the Tobacco Road Sand. Within the underlying Dry Branch (Irwinton Sand Member and Griffins Landing Member) Formation, tritium concentrations gradually decrease to 400 picoCuries per liter, near the middle of the Griffins Landing Member. Tritium concentrations then rapidly drop to below the detection limit. Vertical tritium variations observed in the unsaturated zone and the upper part of the unconfined aquifer may represent a historical record of tritium influx into the aquifer.

A seismic reflection survey across the projected location of the Pen Branch fault identified a series of thirteen major faults along approximately 4,550 feet of a 7,620 foot seismic line. The entire series of faults is considered to represent the extension of the Pen Branch fault zone into Georgia, from South Carolina. All thirteen faults affect the basement and project upwards into the overlying Cretaceous-age sediments. None of these faults appear to have disturbed the Gordon aquitard, which isolates the unconfined aquifer from underlying confined aquifers. The seismic profile also shows other numerous small faults within the Cretaceous and Tertiary Coastal Plain sediments. These small faults do not break the basement but some may break the Gordon aquitard (Lisbon Formation) and other aquitards in the section. The effect of the Pen Branch fault zone and the other minor faults on ground-water flow patterns remains unresolved. Besides faults, the seismic profile is interpreted to show four large-scale channel features. The largest channel feature is more than 3,000 feet wide and may be up to 700 feet deep. Two smaller, secondary channels lie within the largest channel feature. A fourth, possibly composite channel lies immediately south of the major channel. The seismic profile suggests that the largest channel cuts through the top of the Gaillard Formation and, therefore, cuts through most of the confining units that should be present. A core site, located above the deepest part of the large channel, showed the normal sequence of sediments including all of the confining units. The disparity between the seismic line and the core data remains unresolved. The existence of the channel features (and their effects on local groundwater flow patterns) remains unresolved.

Well construction of the public water supply well in which tritium was first discovered in Burke County aquifers (DeLaigle Well #3) was confirmed to a depth of 193 feet. The well was plugged to prevent leakage of tritiated ground water into the confined Gordon aquifer.

The lithostratigraphic and hydrostratigraphic framework defined in Phase I was modified and enhanced by additional data from core samples. A revision of the Late Cretaceous and Early Tertiary lithostratigraphy was published as part of the United States Geological Survey Trans-River Flow Project (Georgia Geologic Survey Bulletin 127).

The preponderance of evidence indicates that the primary pathway for tritium into the Upper Three Runs aquifer is through recharge of the aquifer by tritiated rainfall. This conclusion is supported by:

1. The verified presence of tritium in rainfall;

2. The areal distribution of tritium in the Upper Three Runs aquifer;

3. A 100-mile long tritium "plume" extending from Burke County southwestward to the vicinity of Dodge and Telfair Counties;

4. The consistency of tritium concentrations within the upper five feet of the vadose zone with tritium concentrations in recent rainfall;

5. The consistency of average (median) tritium concentrations throughout the vadose zone with tritium concentrations in rainfall between 1982 and 1992;

6. The consistency of tritium concentrations at the base of the vadose zone with tritium concentrations at the top of the unconfined aquifer.

A possible secondary pathway for tritium is suggested by the presence of very low levels of tritium in all confined aquifers in Burke County. This secondary pathway may be related to the Pen Branch fault zone or the subsurface channel features.

In this report, an additional seven recommendations are made including five recommendations for further technical studies of the aquifers, and two recommendations for long-term monitoring.

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INTRODUCTION

Statement of Problem

Since 1979, the Environmental Protection Division, Georgia Department of Natural Resources, has monitored radiation near Georgia nuclear facilities and out-of-state facilities that are next to Georgia's borders. This monitoring, conducted by the Environmental Radiation Program, includes routine radiation analyses of soil, vegetation, fish, milk, rainfall, groundwater, and air samples. One out-of-state facility that has been of particular concern has been the Savannah River Site, in Aiken and Barnwell Counties, South Carolina. Since the late 1980's, the Environmental Radiation Program has conducted routine sampling of water supply wells in the Savannah River corridor south of Augusta, near the Savannah River Site. Water samples collected on April 4, 1988 from a public water supply well in eastern Burke County, Georgia showed tritium values of 600 picoCuries per liter (+/- 100) (Summerour, and others, 1994). This well, in the DeLaigle Mobile Home Park, is hereafter termed DeLaigle Well #3 (Figure 1). This DeLaigle Well #3 sample measured three percent of the Environmental Protection Agency's Maximum Contaminant Level for tritium of 20,000 picoCuries per liter. Analysis of a follow-up sample from this well, on April 10, 1990, measured no tritium above the detection limit of 300 picoCuries per liter. Analyses of subsequent samples from this well, collected on January 8 and July 18, 1991, measured 1,200 picoCuries per liter +/- 200. Repeated sampling of this well between September 4, and December 6, 1991 (five samples) showed a range of tritium values between 800 and 1,500 picoCuries per liter. Well construction records on file with the Water Resources Branch indicated that this well was 300 feet deep, with the upper 200 feet of casing pressure grouted with cement. The presence of tritium in a deep, grouted well suggested a pathway other than vertical infiltration. If the Gordon aquifer was, in fact, polluted with tritium, the Environmental Protection Division could not dismiss the possibility that this aquifer and other underground sources of public drinking water in Burke County might be at risk. Governor Zell Miller directed the Georgia Geologic Survey to investigate any possible threat to public health, due to tritium in eastern Burke County. This investigation is hereafter referred to as the Tritium Project Phase I (or simply Phase I) (Summerour, and others, 1994). In March 1992, the U.S. Department of Energy contracted with the Georgia Geologic Survey Branch, Environmental Protection Division to conduct the investigation (Cooperative Agreement Number DE-FG-09-92SR12868).

In July 1991, the United States Department of Energy reached an agreement with the United States Geological Survey for an investigation of the possibility of ground-water flow from the Savannah River Site (under the Savannah River) into Georgia aquifers. That study, referred to as the Trans-River Flow Project (initially known as the Under-Flow Project) focused on the flow characteristics of deeper aquifers in Georgia and South Carolina. In contrast, the Tritium Project focused on tritium occurrences in the two shallowest aquifers.

Tritium Project Phase I Summary

In October and November 1991, after the discovery of measurable tritium in the DeLaigle

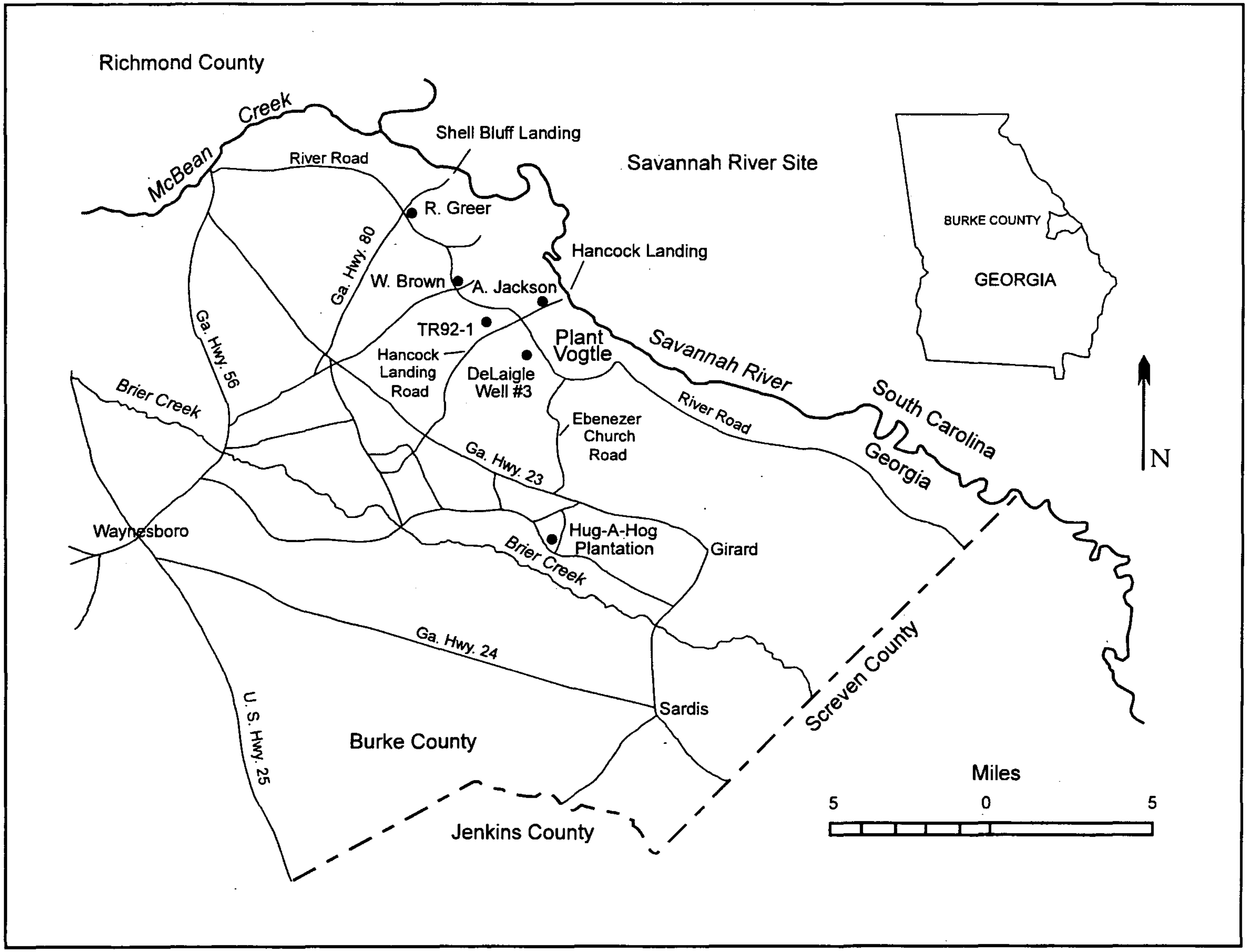

Figure 1. Index map of eastern Burke County, Georgia. Domestic water wells shown (e.g., R. Greer, Hug-A-Hog Plantation) are those that measured >500 picoCuries per liter during initial sampling in October and November, 1991. Also shown is Tritium Project well cluster site TR92-1. Modified from Summerour (1997).

Well #3, the Environmental Radiation Program sampled additional domestic wells in the area. This increased sampling resulted in the discovery of four more wells with detectible levels of tritium, lying south (Hug-A-Hog Plantation), northeast (Allen Jackson residence), and northwest (Willie Brown residence and Ralph Greer residence) of the DeLaigle Well #3 (Figure 1). Initially, all five of these wells (including the DeLaigle Well #3) were thought to be drawing water from the confined Gordon aquifer. The Georgia Geologic Survey staff selected a site between the DeLaigle Well #3, the Arthur Jackson well, and the Willie Brown well for the first cluster of monitoring wells (hereafter known as Tritium Project cluster well site TR92-1) (Figure 1). Core drilling at site TR92-1 began in December 1991. Based on the results of detailed examination of the core samples, four monitoring wells were installed in the four shallowest aquifers at site TR92-1. In descending order, these aquifers are the unconfined Upper Three Runs aquifer, and the confined Gordon, Millers Pond, and Dublin aquifers (Summerour, and others, 1994).

Environmental Protection Division personnel conducted a two-day collection of water samples from eastern Burke County streams, in November 1991. This procedure (hereafter referred to as the 1991 baseflow study) sampled 51 sites spread over five 7.5 minute quadrangles. Analyses of the samples provided initial information on the geographic distribution of tritium in the unconfined (surficial) aquifer in eastern Burke County.

During Tritium Project Phase I, seven sub-investigations were conducted:

1. Georgia Geologic Survey personnel continued and expanded the sampling of domestic and public water wells in eastern Burke County. Based on the results from 109 sampled wells, ten wells with average tritium values of 500 picoCuries per liter (or more) were designated as "polluted" or "anomalous" (including DeLaigle Well #3). The United States Geological Survey conducted geophysical logging on nine of the polluted wells, to evaluate their true depths. This logging showed that all nine wells were actually drawing water from the unconfined Upper Three Runs aquifer, rather than the confined Gordon aquifer. In DeLaigle Well #3, geophysical logging encountered an obstruction at -151 feet (below ground surface). Examination of this well by downhole video camera confirmed casing damage from at least -154 to -156 feet, within the lower part of the Upper Three Runs aquifer.

2. Baseflow studies were conducted in November 1991 and October 1992 to measure tritium abundance in local springs and creeks. These baseflow studies allowed the Environmental Protection Division to come to three conclusions concerning the distribution of tritium in Burke County ground water: (A) the unconfined aquifer is polluted with tritium throughout all of eastern Burke County; (B) the distribution of tritium in the unconfined aquifer follows a roughly concentric pattern approximately centered on an area approximately 1.5 miles northwest of Hancock Landing (Figure 1); and (C) all tritium values measured during these two baseflow studies were 2,200 picoCuries per liter (11 percent of Safe Drinking Water Act Maximum Contaminant Levels) or less.

3. Fifteen ground-water monitoring wells were installed at six cluster sites (Figure 2) in eastern Burke County. These wells included six Upper Three Runs aquifer wells (two were dry), six Gordon aquifer wells, one Millers Pond aquifer well, one Dublin aquifer well, and one well screened within the Gordon aquitard and Gordon aquifer. One of these cluster sites (TR92-5) was installed within the DeLaigle Mobile Home Park. At this site, monitoring well TR92-5C, was constructed to the reported specifications of the DeLaigle Well #3, approximately 50 feet from the damaged well. The 100 feet of screen interval of well TR92-5C included part of the Gordon aquifer and part of

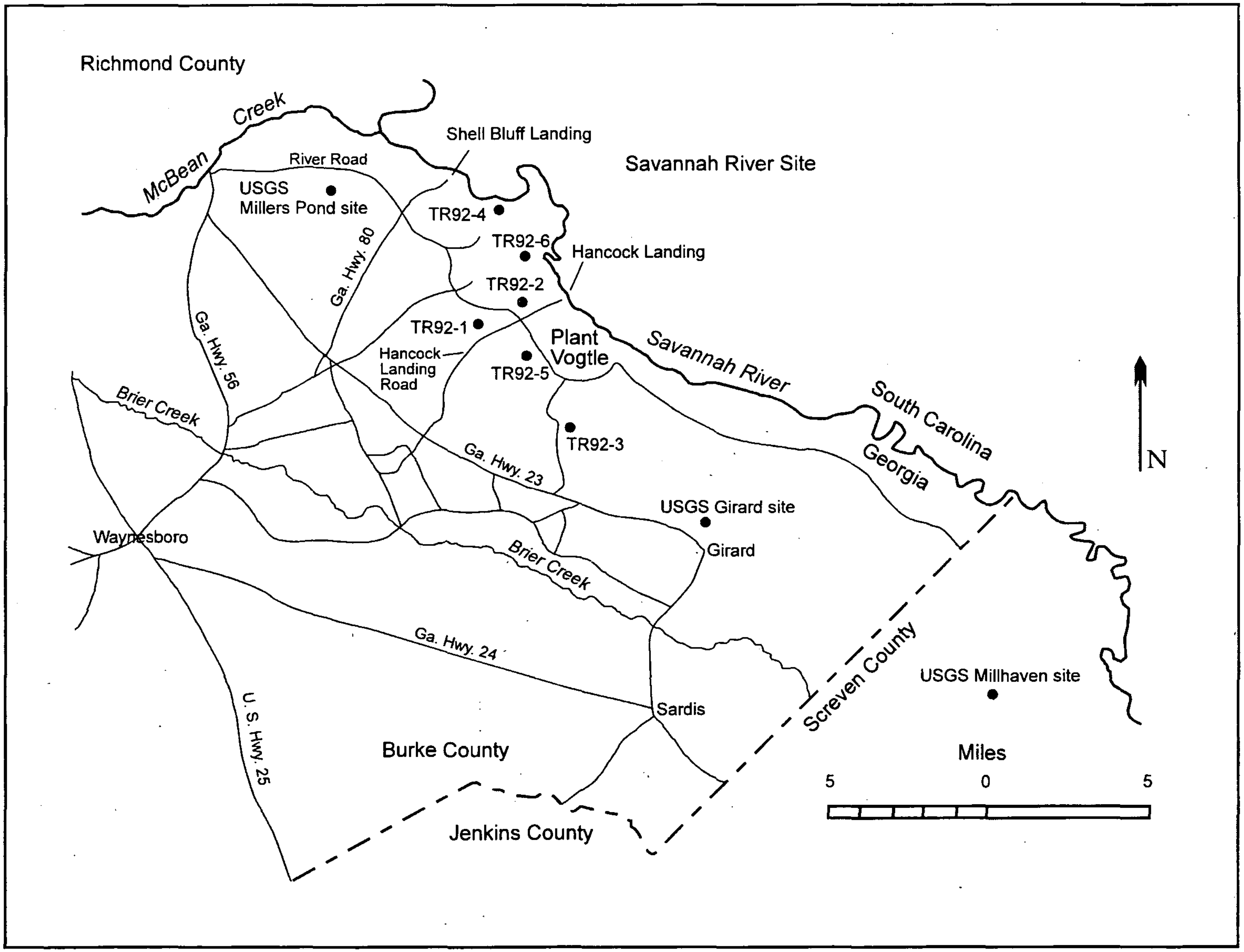

Figure 2. Locations of Tritium Project well cluster sites and United States Geological Survey Trans-River Flow Project well cluster sites. Modified from Summerour, and others (1994).

the overlying Gordon aquitard. Except monitoring well TR92-5C, no confined aquifer wells showed detectible levels of tritium. Repeated sampling of well TR92-5C yielded tritium values of 300 to 400 picoCuries per liter. These elevated tritium concentrations (in this specific well) are attributed to leakage from the nearby damaged DeLaigle Well #3.

4. Core sample analyses, field mapping, and literature from geologic investigations in Georgia and South Carolina were used to define the local lithostratigraphic and hydrostratigraphic frameworks. Core samples were collected from six Tritium Project well cluster sites (TR92-1 through TR92-6) and two Trans-River Flow Project core sites (Millers Pond and Girard). Older core data came from one site drilled by Georgia Power Co. (B-246) in the late 1960's, ten sites drilled by Bechtel Corporation (VG-1 through VG-8 and VSC-3 and VSC-4) in 1982, and Georgia Geologic Survey core GGS 3757 (hereafter referred to as the McBean core), drilled in 1991 (Hetrick, 1992).

5. Data from aquifer tests, from the Savannah River Site and Trans-River Flow Project, conducted by Clemson University were used to describe the hydrologic characteristics of the unconfined Upper Three Runs aquifer, the Gordon aquitard, and the confined Gordon aquifer (Moore, and others, 1992; Clarke, and others, 1994).

6. The geochemical characteristics of the Upper Three Runs and Gordon aquifers were described using data from analyses of water samples from public, private, and monitoring wells (Rose and James, 1993).

7. A seismic reflection survey of the Savannah River channel in the study area was conducted by Dr. Vernon J. Henry of Georgia Southern University (Henry, 1995). The seismic survey covered 70 miles of the Savannah River and extended from the Richmond-Burke County line to the Burke-Screven County line. This seismic survey evaluated the extension of the Pen Branch fault into the channel of the Savannah River. The seismic survey also investigated the thickness of river alluvium, the possible breaching of aquitards, and the correlation of seismic stratigraphic sequences with the local lithostratigraphy.

A preliminary draft report was submitted to Governor Zell Miller in September, 1993. The final results of the Tritium Project Phase I study were published as Georgia Geologic Survey Information Circular 95.

Purpose and Scope: Tritium Project Phase II

Work performed during the Phase I investigation was reviewed by a seven-person Technical Advisory Committee, composed of earth scientists representing the following disciplines: geology, hydrogeology, geochemistry, geophysics, and climatology. Members of the Technical Advisory Committee represented several universities and federal agencies. At the conclusion of the Phase I work, the Technical Advisory Committee made recommendations for additional studies. These recommendations were the basis for the Phase II work and included the following sub-investigations:

1. Continue sampling of domestic water supply wells, monitoring wells, springs and creeks (additional baseflow studies) to establish a multi-year trend.

2. Sample and analyze ground water for the presence of low concentrations of tritium (less than 100 picoCuries per liter) in the confined aquifers of Burke County. Such high-resolution analyses could further test the hypothesis of an upward pathway for tritium into the Upper Three Runs aquifer.

3. Investigate vertical distribution of tritium in the unconfined Upper Three Runs aquifer and test the hypothesis of a downward pathway for tritium into the Upper Three Runs aquifer.

4. Measure tritium values in the vadose zone at site TR92-1 to test further the hypothesis of an airborne pathway into the Upper Three Runs aquifer.

5. Perform a seismic survey between sites TR92-1 and TR92-5, to investigate the extension of the Pen Branch fault zone from South Carolina into Georgia. If present in Burke County, the Pen Branch fault zone might provide a vertical pathway for the movement of tritiated ground water into otherwise confined aquifers.

6. Evaluate the construction of DeLaigle Well #3 by drilling out the well and examining the cuttings.

7. Expand the assessment of the local geologic and hydrostratigraphic framework utilizing existing data and literature, Phase I data, Trans-River Flow Project data, and any newly developed Phase II data.

Location of Study Area

The Tritium Project study area is in eastern Burke County, Georgia. Burke County is situated along the Georgia-South Carolina border (Figure 1). Adjacent counties are Richmond County (north), Jefferson County (west), Emanuel and Jenkins Counties (south), and Screven County (southeast). The northern boundary of Burke County, McBean Creek, is approximately 15 miles southeast of Augusta, Georgia and the southeastern boundary of the county is approximately 70 miles northwest of Savannah, Georgia. The U.S. Department of Energy Savannah River Site is in Aiken and Barnwell Counties, South Carolina, directly across the Savannah River from Burke County.

Although the overall project centered on eastern Burke County, individual sub-investigations encompassed slightly larger or smaller areas. The 1993 and 1994 base flow studies covered the largest area, extending into adjacent counties to the west (Jefferson), north (Richmond), and south (Jenkins) (Summerour, 1997). Domestic and public water supply wells were tested by the Environmental Radiation Program in southern Richmond County and Burke County, east of Waynesboro. The cluster well sites are within five miles west and northwest of Georgia Power Company Plant Vogtle, near River Road, except TR92-3, which is approximately 1.5 miles south of Plant Vogtle off Ebenezer Church Road (Figure 2).

Physiographic Setting

The Tritium Project study area is in the Louisville Plateau District of the Coastal Plain physiographic province. The Louisville Plateau District has a geomorphic relief of 100 to 150 feet and is moderately dissected by a well-developed dendritic stream pattern (Atkins, and others, 1996). In the study area, the Savannah River bluffs commonly have a geomorphic relief of 100 feet or more. The stream valleys are generally narrow, except for large creeks that have wide flood plains occupied by wetlands. Brier Creek, roughly parallel to the Savannah River, has a flood plain that is approximately one-quarter to three-quarters of a mile wide. McBean Creek, which is the northern border of Burke County, has a flood plain that is approximately one-quarter to one-half mile wide. Possible Carolina Bays, near Georgia Highway 23, are shown on the McBean, Idlewood, and Alexander quadrangles. Possible sinkholes are sporadically present throughout the study area, including several on the Thomson Oak Flooring Company property (near cluster site TR92-6), north of Hancock Landing Road and east of River Road (Figure 2).

Climate

The climate of Burke County is characterized by warm, humid summers and mild winters. Monthly mean high temperatures range from 91^0 F (July) to 58^0 F (December & January) and monthly mean low temperatures range from 72^0 F (July) to 39^0 F (December) (Baker, 1979). Mean annual precipitation at Bush Airport, south of Augusta, is approximately 44.6 inches per year (Baker, 1979). The highest mean monthly precipitation is in July and August (four to five inches) and the lowest mean monthly precipitation is in October and November (approximately three inches) (Baker, 1979). The primary wind direction, measured at the Savannah River Site, is from the northeast with secondary wind directions from the west and the south (Arnett, and others, 1993). During thunderstorm events, individual storm cells commonly move from southwest to northeast (W. F. Falls, written communication, 1997). Additional weather data are presented in Summerour, and others (1994).

Cultural Features

Burke County is the second largest county in Georgia with an area of approximately 834 square miles. The 1990 population of Burke County was 20,759 (Bachtel and Boatright, 1992). Georgia Power's Plant Vogtle is the largest contributor to the county economy. Other economic contributors are manufacturing plants (apparel, furniture, lumber, and textiles), timber production and farming. Farmland uses approximately 38 percent of the county, producing peanuts, soybeans, corn, cotton, wheat, oats, and rye (Bachtel and Boatright, 1992).

Plant Vogtle, a nuclear power facility, is the largest user of water in the county, consuming approximately 65 million gallons per day (1990 estimates). Irrigation (3 million gallons per day) and public supply (2 million gallons per day), rank second and third in usage, respectively (Fanning, and others, 1992).

Characteristics of Tritium

Naturally occurring stable isotopes of hydrogen include Protium ($^1{}_1$H), and Deuterium ($^2{}_1$H) (Murphy, and others, 1993). Tritium ($^3{}_1$H) is a radioactive isotope of hydrogen with a half-life of 12.35 years (Fritz and Fontes, 1980; Murphy, and others, 1993). The mode of decay is by the emission of a weak beta particle with an average energy emission of 5.7 KeV and a maximum energy emission of 18.6 KeV. With the emission of the beta particle, tritium converts to helium. The unit of measurement for tritium used in this report is the picoCurie (one trillionth of one Curie) per liter of water. The picoCurie represents 0.037 electron releases per minute.

Upper atmospheric interaction of cosmic rays and nitrogen produce natural (background) tritium concentrations of 13 to 80 picoCuries per liter (Gat, 1980). Tritium from post-World War II nuclear weapons testing overwhelmed the background tritium values by 1952. Following the 1963 cessation of most atmospheric nuclear testing, atmospheric tritium values had declined to approximately 16 picoCuries above background by 1978 (Fontes, 1980). Current rainfall and surface water tritium values for most of Georgia range from approximately 30 to 60 picoCuries per liter (S. Rose, personal communication, 1997).

A worldwide network of rainfall collection stations was established in the late 1950s and early 1960s to monitor tritium resulting from atmospheric nuclear testing (Michel, 1989). Using data from this network of stations, Michel (1989) estimated cumulative tritium deposition values throughout the United States from 1953 to 1983. A contour map based on these values is shown in Figure 3. This contour map shows a rough north-south gradient with lower tritium values extending from the general vicinity of Los Angeles, California to Brownsville, Texas (due to the oceanic origin for most West Coast storms) (Michel, 1989). Higher tritium input values in the north and northeast portions of the United States are attributed to the effects of storm systems that form over the North American continent (Michel, 1989).

Deposition of tritium in rainfall is the result of two processes: rainout and washout. Rainout is the incorporation of tritium in precipitation, following the condensation of tritiated water vapor during cloud formation (Murphy, and others, 1993). Washout occurs when falling rain passes through air containing tritium. Near the Savannah River Site, washout is the more important process for tritium deposition (Murphy, and others, 1993).

History of Tritium Releases from Savannah River Site

From the initiation of operations in 1954 through 1988, approximately 26 million Curies (Ci) of tritium were released from Savannah River Site facilities to the atmosphere and surface waters of the site. These routine (planned) releases were from reactor operations, recovery of tritium, recovery of transuranic elements, heavy water rework, and laboratory research (Arnett, and others, 1993). The two largest sources atmospheric tritium are the separations areas (69 percent); and the reactor facilities (28 percent). All other sources of tritium constitute less than three percent of routine (planned) releases (Murphy, and others, 1993). These other sources included evaporation of small amounts of tritiated water from on-site holding ponds.

The reactor facilities release tritium to the atmosphere from heavy water moderator evaporation during occasional purges of the blanket gas system. Other moderator evaporation sources include reactor control rods, guide tubes, pipe flanges and connections. Airborne tritium is removed from reactor buildings through a filtered ventilation system on the exhaust stacks (Murphy, and others, 1993). Most of the tritium routinely released by the Savannah River Site is in tritiated water vapor (also referred to as tritium oxide).

Yearly routine atmospheric releases from 1954 through 1994 are shown in Table 1 and Figure 4. During this period, approximately seven million additional Curies were placed into seepage basins and burial grounds (Arnett, and others, 1992). Radioactive decay should have removed more than three fifths of the released tritium, leaving approximately 9.9 million Curies in the atmosphere and approximately 3.2 million Curies in the seepage basins and burial grounds (Murphy, and others, 1991). From 1987 through 1992, tritium releases from the Savannah River Site declined approximately 20 percent per year (Table 1, Figure 4). A minor increase in tritium releases, during 1993, is attributed to increased loading and unloading of tritium reservoirs in the tritium processing facilities (Arnett, and others, 1995).

During the period 1974-1992, inadvertent (unplanned) releases contributed an additional estimated 1.068 million Curies of tritium during Savannah River Site plant operations (Murphy, and others, 1991; Arnett, and others, 1992 and 1993). This is in addition to the 26 million Curies of routine (planned) releases of tritium from 1954 through 1994.

Tritium in Rainfall in Burke County

Since 1981, the Georgia Environmental Protection Division's Environmental Radiation Program has measured tritium concentrations in rainfall, at selected sites in eastern Burke County, Richmond County, and northern Screven County (Figure 5) (Summerour, and others, 1994). In addition, the United States Department of Energy maintains rainfall stations in Burke, Richmond, and Screven Counties with remote locations in Augusta, Savannah, and Macon, Georgia. All of the Environmental Protection Division sample sites have occasionally recorded tritium concentrations in rain water above detection levels. However, most of these elevated tritium values are well below the Maximum Contaminant Level (Summerour, and others, 1994).

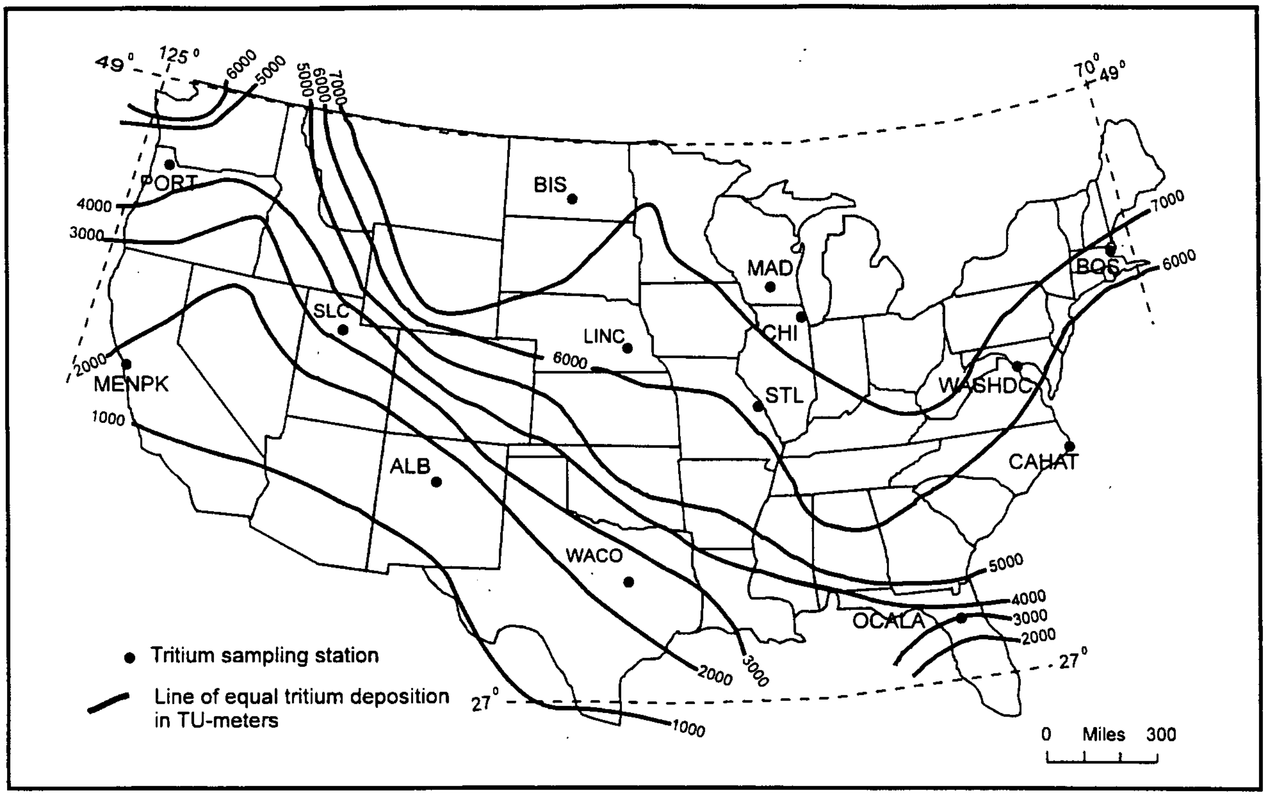

Figure 3. Contour map showing cumulative tritium deposition values (1953-1983). Tritium is measured in Tritium Units (TU). One Tritium Unit equals approximately 3.38 picoCuries per liter. Station abbreviations-PORT-Portland, OR; MENPK-Menlo Park, CA; SLC-Salt Lake City, UT; ALB-Albuquerque, NM; BIS-Bismarck, ND; LINC-Lincoln, NE; WACO-Waco, TX; STL-St. Louis, MO; MAD-Madison, WI; CHI-Chicago, IL; WASHDC-Washington, DC; BOS-Boston, MA; CAHAT-Cape Hatteras, NC; OCALA-Ocala, FL. Modified from Michel (1989).

From October 1993 to September 1997 (Phase II), the Environmental Protection Division's rainfall stations recorded a decline in the amount of tritium measured in Burke County rainfall compared with March 1992 to September 1993 (Phase I). This decline in tritium is consistent with both the world-wide atmospheric decline in tritium and the reduction of tritium releases from the Savannah River Site.

Murphy, and others (1991) produced a map of average rainfall tritium distribution values in the Burke County-Savannah River Site area from 1982 through 1986 (Figure 6). This map is the result of computer modeling that combines tritium measurements at 33 stations with prevailing wind data. The Murphy, and others (1991) map is consistent with the field measurements of tritium in rainfall made by the Environmental Protection Division.

Previous Work

Early studies of Burke County tritium include the Environmental Protection Division collection of rainwater tritium data since 1981 and Georgia Power Company's measurements of tritium, in wells and surface waters near Plant Vogtle, since 1982. Neither of these data sets were published before the Phase I report. In 1993, a United States Geological Survey project conducted an assessment of water quality (including tritium values) in 37 shallow wells in southern Georgia and northern Florida (Crandall and Berndt, 1996).

Table 1. Yearly totals of Savannah River Site atmospheric routine (planned) tritium releases (1954-1994) with decay corrected to 1996 values. Decayed values are shown on the right.

Year	Released tritium-Ci (Curies)	Year	Released tritium-Ci (Curies)	Year	Released tritium-Ci (Curies)
1954	216[1]/20	1968	762,000[1]/158,344	1982	434,000[1]/197,839
1955	36,100[1]/3,617	1969	496,000[1]/109,018	1983	618,000[1]/297,976
1956	469,000[1]/49,703	1970	513,000[1]/119,263	1984	786,000[1]/400,853
1957	1,200,000[1]/134,512	1971	621,000[1]/152,703	1985	667,000[2]/359,797
1958	2,340,000[1]/277,438	1972	822,000[1]/213,795	1986	425,000[3]/242,488
1959	1,050,000[1]/131,677	1973	601,000[1]/165,337	1987	590,000[3]/356,060
1960	951,000[1]/126,145	1974	937,000[1]/272,650	1988	462,000[3]/294,905
1961	886,000[1]/120,097	1975	518,000[1]/159,428	1989	310,000[3]/209,301
1962	1,110,000[1]/164,722	1976	304,000[1]/98,964	1990	250,000[3]/178,534
1963	1,130,000[1]/177,369	1977	381,000[1]/131,190	1991	200,000[3]/151,071
1964	1,520,000[1]/252,355	1978	360,000[1]/131,112	1992	156,000[3]/121,636
1965	744,000[1]/130,651	1979	333,000[1]/128,279	1993	191,000[4]/161,408
1966	675,000[1]/125,375	1980	317,000[1]/129,164	1994	160,000[4]/143,015
1967	689,000[1]/135,362	1981	395,000[1]/170,235		

(1.) Murphy, and others (1993) (2.) Arnett, and others (1992) (3.) Arnett, and others (1993) (4.) Arnett, and others (1995)

Acknowledgments

We wish to extend our appreciation to the Burke County residents and property owners for their invaluable assistance and cooperation with our drilling and well sampling activities during the Tritium Project. For permission to conduct the Tritium Project Phase I and Phase II sub- investigations and maintain existing facilities, we would like to thank the following: the Georgia Power Company, the Rouse family, Mr. Avner DeLaigle, Mr. R.W. Mobley, Mr. Earl Nally, the Thomson Oak Flooring Company, Mr. John Harley, the trustees for Ms. Molly Bazemore, Mr. Wiley Flanagan, and especially Mr. Marshall Miller. We would also like to thank John Clarke, David C. Leeth, William F. Falls, Lucy Edwards, Christy Crandall (United States Geological Survey); Mike Waddell, William Domoracki, Frank Keith (University of South Carolina); Mike Neary (University of Georgia Center for Applied Isotope Studies); Seth Rose (Georgia State University); Tom Temples (United States Department of Energy); David Snipes and Rex Hodges (Clemson University); and Van Price, Jr. for technical advice and assistance.

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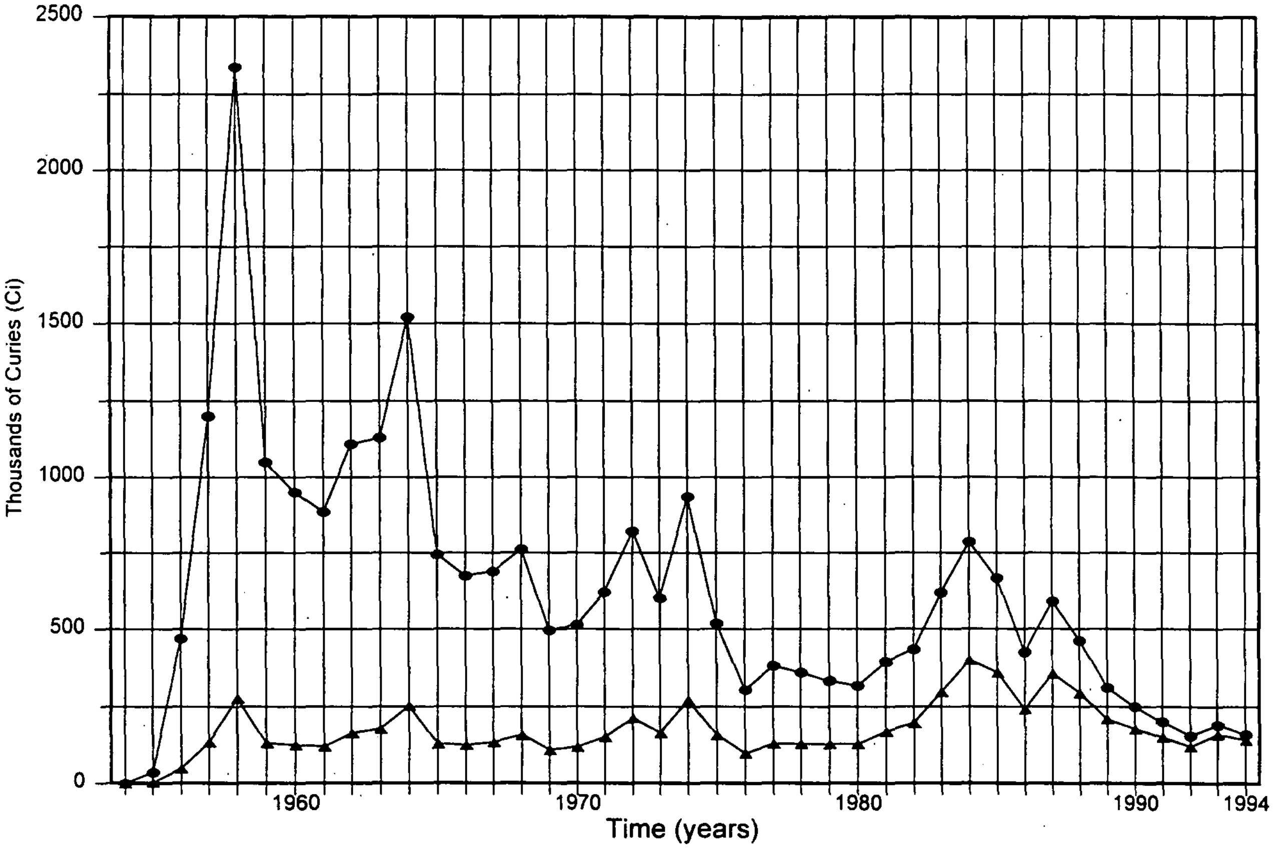


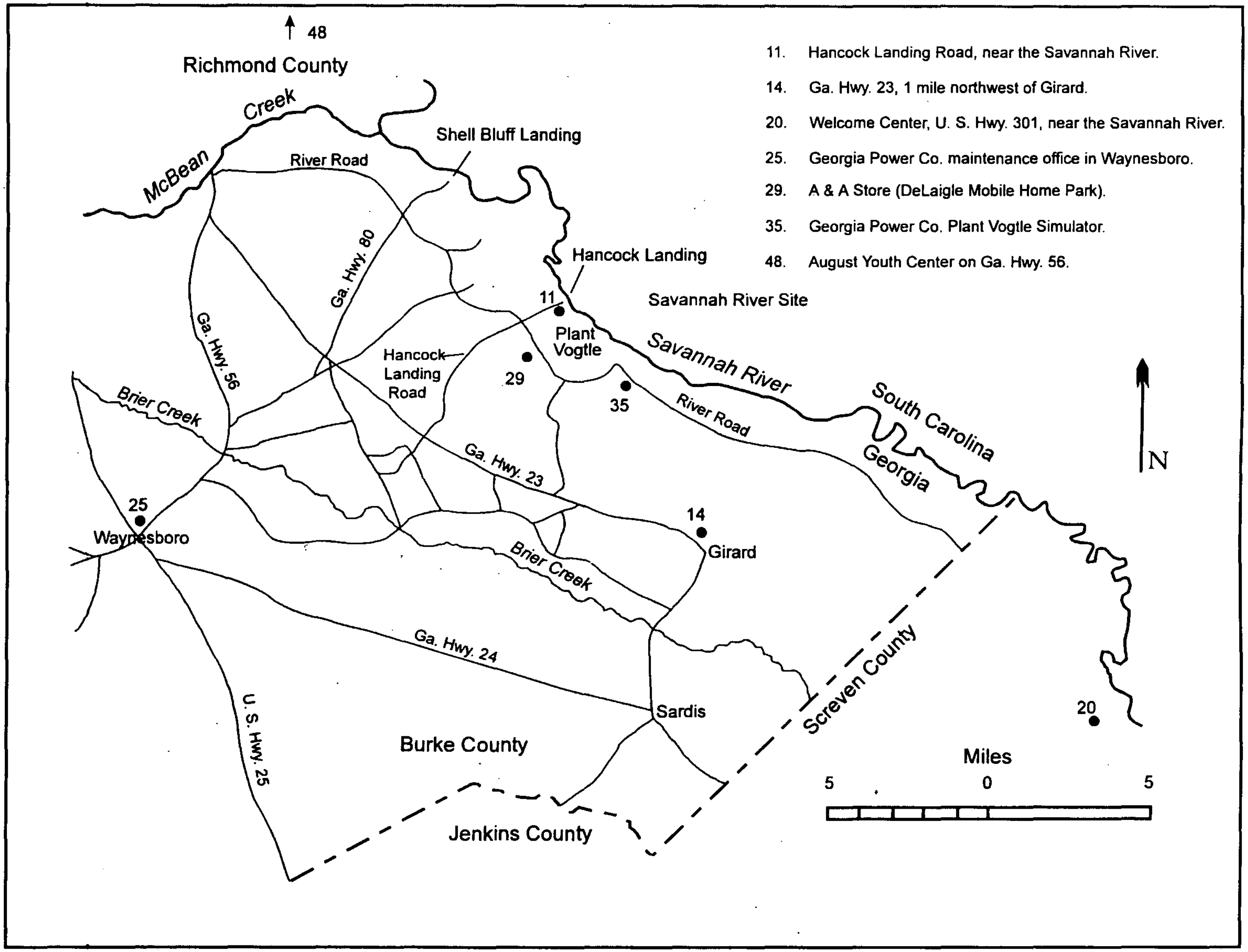
Figure 4. Savannah River Site atmospheric tritium releases 1954-1994. Lower data curve represents values corrected for radioactive decay to 1996. Data references are listed in Table 1. Modified from Summerour (1997).

GEOLOGY AND HYDROGEOLOGY

Geologic Setting

Summerour and others (1994) described the geologic framework of the Tritium Project study area. Huddlestun and Summerour (1996) refined that framework through the examination of more than 9,000 feet of core samples. The core samples were from six Tritium Project sites (TR92-1 through TR92-6), the Georgia Geologic Survey McBean site, two Trans-River Flow Project sites (Girard and Millers Pond) and 11 Georgia Power Company sites in Georgia (B-246 and VG-1 through VG-8) and South Carolina (VSC-3 and VSC-4) (Figure 7). Only three of these cores reached "basement" (TR92-6, Millers Pond, and Girard). Other important geologic data were obtained by the Trans-River Flow Project (Clarke, and others, 1994; Falls, and others, 1997a), and by the United States Department of Energy (Fallaw and Price, 1992 and 1995).

The generalized stratigraphic framework of the study area consists of approximately 1,000 feet of relatively unconsolidated sediments sitting on a metamorphic or sedimentary "basement". The metamorphic portion of the "basement" consists of Paleozoic gneisses and schists correlated with the Belair Belt of the Georgia Piedmont (D. C. Prowell, personal communication, 1997). The consolidated sedimentary portion of the "basement" consists of Triassic sandstones, siltstones, and conglomerates correlated with the Newark Supergroup (Snipes, and others, 1993).



11. Hancock Landing Road, near the Savannah River.
14. Ga. Hwy. 23, 1 mile northwest of Girard.
20. Welcome Center, U. S. Hwy. 301, near the Savannah River.
25. Georgia Power Co. maintenance office in Waynesboro.
29. A & A Store (DeLaigle Mobile Home Park).
35. Georgia Power Co. Plant Vogtle Simulator.
48. August Youth Center on Ga. Hwy. 56.

Figure 5. Locations of Environmental Protection Division rainfall collection sites. Site #48 is located in Augusta. Modified from Summerour (1997).

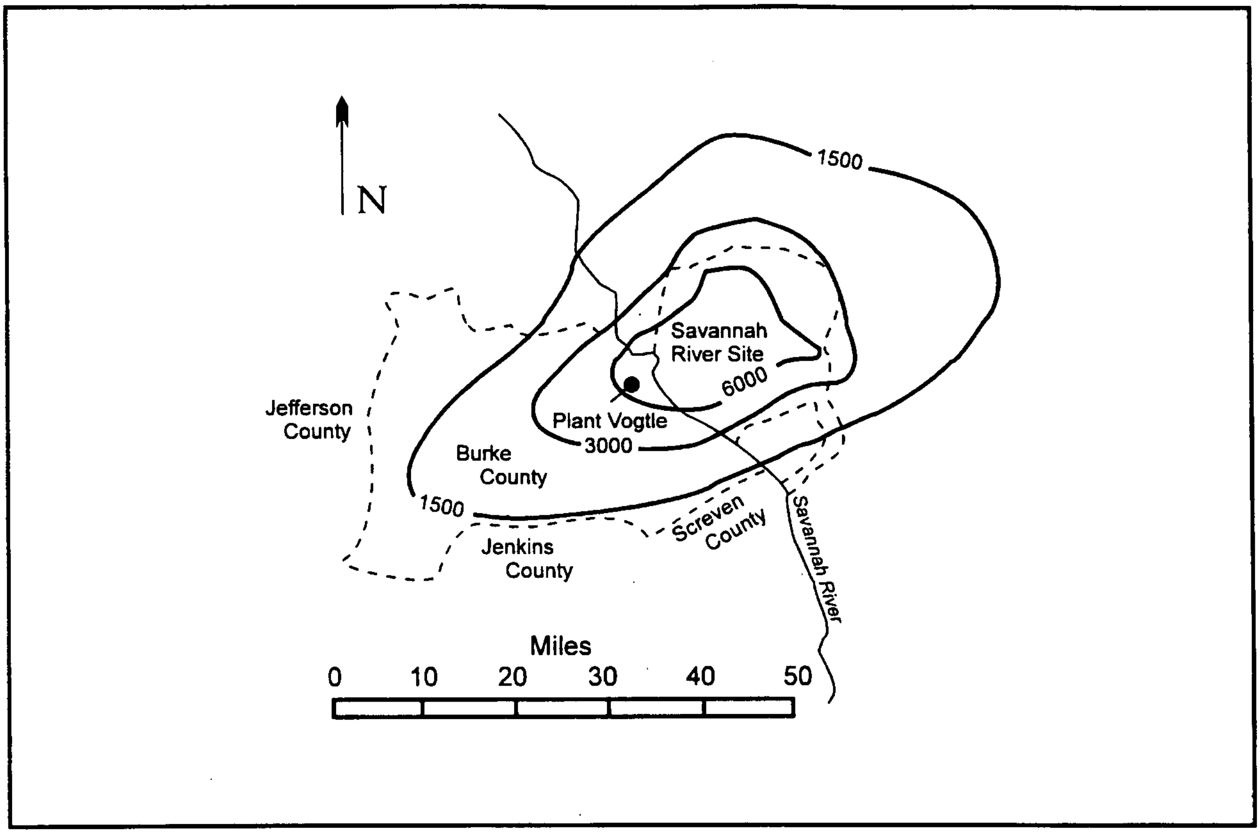


Figure 6. Directional distribution of tritium in rainfall for Savannah River Site-Burke County area, based on analyzed rainfall samples (1982-1986). Values are stated in picoCuries per liter. Modified from Murphy, and others (1991).

The Cretaceous-Tertiary strata within the study area consist of a southeast dipping series of Upper Cretaceous, Paleogene, and Neogene carbonate and siliciclastic sediments. These fluvial, coastal marine, and shallow inner neritic marine deposits lie within a transitional "zone" between the Atlantic and Gulf Coastal Plain provinces (Zullo, and others, 1992) (Table 2). Within this transitional zone, abrupt lithologic variations are common, causing difficulty with local and regional correlations.

Late Cretaceous deposits of the study area consist of nonmarine, fluvial and deltaic sediments of the basal Cape Fear Formation and the Oconee Group. These two stratigraphic units are characterized by a series of fining-upward sequences. Each fining-upward sequence (where preserved) consists of poorly-sorted coarse sands that grade upward into the kaolin beds that "cap" each sequence. These kaolin beds act as confining units within and between the Cretaceous aquifers in the study area.

Paleocene deposits of the study area consist of the marginal marine undifferentiated Black Mingo Formation and the nonmarine, fluvial Snapp Formation. The Snapp Formation consists of a single fining-upward sequence that creates a confining bed above the more permeable undifferentiated Black Mingo Formation (Huddlestun and Summerour, 1996).

The Eocene Claiborne and Barnwell Groups occur at the top of the Cretaceous-Tertiary stratigraphic package in Burke County. Both Groups are composed of shallow marine clastics and carbonates. Barnwell Group sediments compose most surface exposures in

Burke County (Hetrick, 1992). Detailed discussions of all Cretaceous and Tertiary stratigraphic units and regional correlations are presented in Fallaw and Price (1992 and 1995); Fallaw, and others (1992); Falls, and others (1997a and 1997b); Harris and Zullo (1992); Huddlestun and Summerour (1996); and Summerour, and others (1994).

Hydrogeologic Setting

Aadland, and others (1992) developed a regional hydrostratigraphic framework for the Savannah River Site and surrounding areas. Summerour, and others (1994) adopted and slightly modified this framework for the Tritium Project Phase I report (Figure 8). Huddlestun and Summerour (1996) further refined the hydrostratigraphic framework for eastern Burke County.

Detailed discussion of South Carolina hydrostratigraphic terminology is presented in Clarke, and others (1996) and Falls, and others (1997a and 1997b). The vertical sequence of aquifers in the study area is shown in Figure 8.

Upper Three Runs Aquifer

The predominantly clastic Upper Three Runs aquifer is the updip equivalent of the carbonate Upper Floridan aquifer (Summerour, and others, 1994). In eastern Georgia, the down-gradient transition between the two aquifers occurs between the Girard and Millhaven well cluster sites (Figure 2). At the Millhaven site, the Upper Floridan aquifer overlies the Gordon aquitard (Clarke, and others, 1996).

In the Tritium Project study area, the Upper Three Runs aquifer is an anisotropic multi-layered unconfined aquifer composed of late Eocene Barnwell Group siliciclastics and carbonates (Summerour, and others, 1994). The lithologic framework of the Upper Three Runs aquifer consists of (in descending order); the Tobacco Road Sand, the Dry Branch Formation, and the Clinchfield Formation (Figure 8). The Tobacco Road Sand is a poorly-sorted, medium- to coarse-grained sand with only local occurrences of clay minerals that might affect ground-water movement. The Dry Branch Formation consists of the Irwinton Sand Member (a well-sorted, fine- to medium-grained noncalcareous sand) and the Griffins Landing Member (a moderately well-sorted, medium-grained, calcareous sand that becomes more argillaceous downdip). Isolated occurrences of Twiggs Clay lithology within the Dry Branch Formation (Huddlestun and Summerour, 1996) contribute to localized confinement of the lower portion of the Upper Three Runs aquifer. The Utley Limestone Member of the Clinchfield Formation is a fossiliferous, variably sandy and glauconitic limestone. Examination of core material from the study area shows the presence of moldic porosity within the Utley (Huddlestun and Summerour, 1996). Tritium Project drilling operations commonly encountered large voids within the Utley Limestone Member (Summerour, and others, 1994) that resulted in sudden drops of the drill rod and in the partial loss of drilling fluids. At least one local commercial driller reported similar losses of drilling fluid at this stratigraphic horizon (T. Rowell, personal communication, 1992). These several lines of evidence suggest that karstic flow may be an important component of ground water movement in the lower portion of the Upper Three Runs aquifer.

Rose and James (1993) informally divided the Upper Three Runs aquifer into Hydrogeochemical Unit 1-consisting of the sands of the upper Barnwell Group (Dry Branch Formation) and Hydrogeochemical Unit 2-consisting of the calcareous sediments (Utley Limestone Member and parts of the Lisbon Formation.

Summerour, and others (1994) refined the definition of Unit 1 to include the Tobacco Road Sand and refined the definition of Unit 2 to include the calcareous Griffins Landing Member

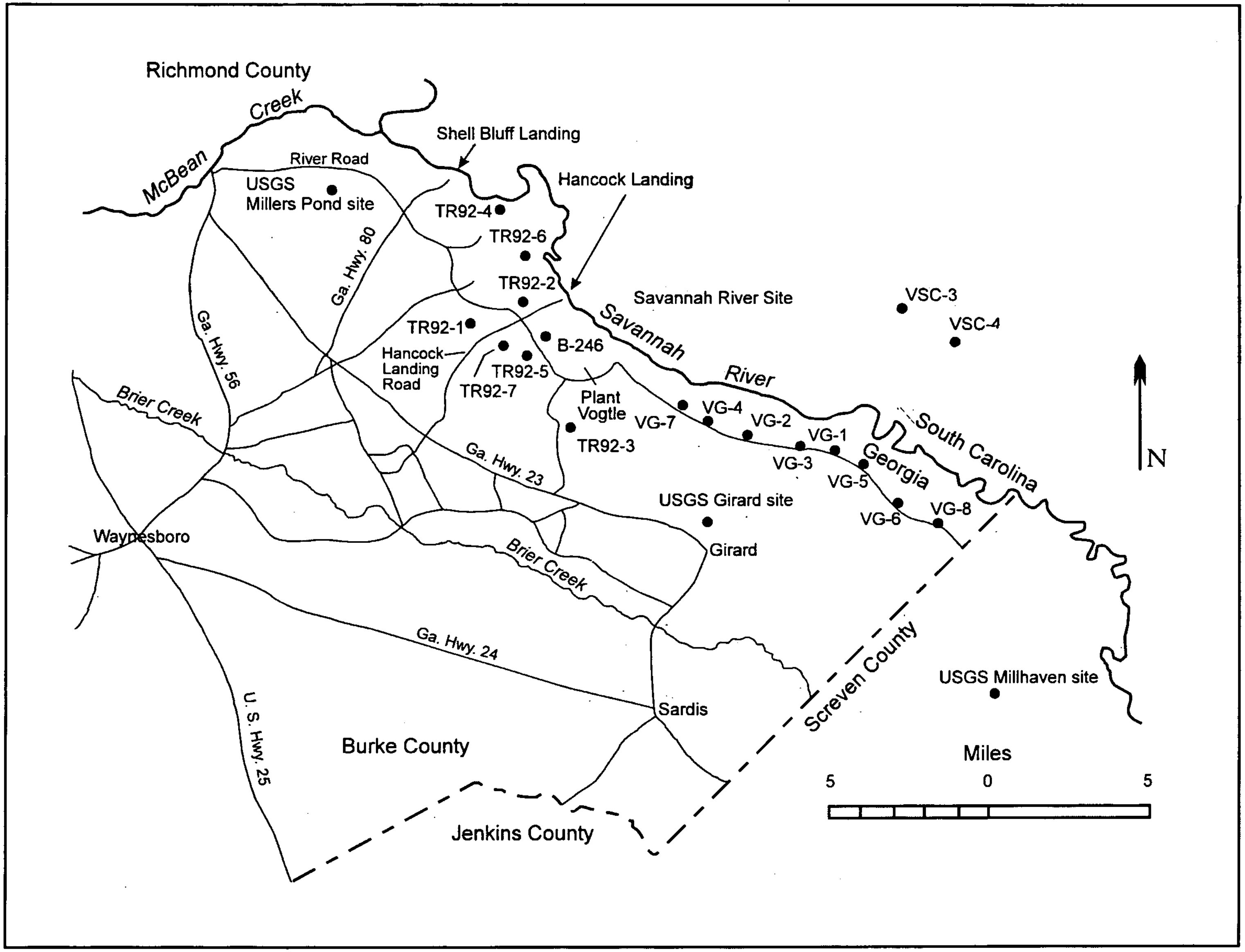


Figure 7. Index map of core sites used to develop the lithostratigraphic framework of the Tritium Project and Trans-River Flow Project. Modified from Huddlestun and Summerour (1996).

Table 2. Chart showing formations present in southern Atlantic Coastal Plain and eastern Gulf Coastal Plain Provinces and the formations present in both provinces.

Southern Atlantic Coastal Plain Province	**Both provinces**	**Eastern Gulf Coastal Plain Province**
Tobacco Road Sand		
Dry Branch Formation Irwinton Sand Member Griffins Landing Member		Dry Branch Formation Twiggs Clay lithofacies
Lisbon Formation- McBean Limestone Member		Lisbon Formation undifferentiated sand Blue Bluff Member
		Still Branch Sand Bennock Millpond Sand Member
	Congaree Formation	
Snapp Formation		
undifferentiated Black Mingo Formation		
Steel Creek Formation		
	Gaillard Formation	
Black Creek Formation		
	Pio Nono Formation	
Cape Fear Formation		

Data from Zullo and others (1992) and Huddlestun and Summerour (1996).

of the Dry Branch Formation and to exclude the Lisbon Formation.

Hydrogeochemical Units 1 and 2 are calcium-bicarbonate water types with 80 to 90 percent of the ionic content due to dissolved calcite (Rose and James, 1993). Hydrogeochemical differences between Unit 1 and Unit 2 include higher concentrations of total dissolved solids, sodium, calcium, magnesium, bicarbonate, and sulfate in Unit 2, as compared with Unit 1.

Ground-water monitoring wells in Burke and Screven Counties that measure water conditions in the Upper Three Runs aquifer are shown in Table 3. Clarke, and others (1994) identified Millers Pond well TW-4 as an Upper Three Runs aquifer monitoring well, but did not identify the lithostratigraphic interval. Core from the Millers Pond site shows that well TW-4 is screened in the McBean Limestone Member of the Lisbon Formation (Huddlestun and Summerour, 1996) and, therefore may not be within the Upper Three Runs aquifer, as defined in this report.

Thayer, and others (1992), used sieve analyses of 88 sand samples from South Carolina to estimate Upper Three Runs aquifer porosity values of 27 to 41 percent (mean value 35 percent) and hydraulic conductivity values of 76 feet per day. Clemson University aquifer tests at site TR92-1 yielded Upper Three Runs transmissivity values of 479 feet^2 per day for well TR92-1A (Griffins Landing Member of the Dry Branch Formation) (Moore, and others, 1992). In comparison, Clemson University aquifer tests at the Millhaven site yielded transmissivity values of 1,860 feet^2 per day and hydraulic conductivity values of 27 feet per day

Burke County Hydrologic Units	Age	Lithostratigraphy-This report		Lithostratigraphy-South Carolina
Upper Three Runs Aquifer	Late Eocene	Barnwell Group	Tobacco Road Sand	Tobacco Road Sand
			Dry Branch Formation Irwinton Sand Member Griffins Landing Member Twiggs Clay Member	Dry Branch Formation
			Clinchfield Formation Utley Limestone Member	Clinchfield Formation
Gordon Aquitard	Middle Eocene	Claiborne Group	Lisbon Formation McBean Limestone Member undifferentiated sand Blue Bluff Member	Tinker Formation Santee Limestone
Gordon Aquifer			Still Branch Sand Bennock Millpond Sand Member	Warley Hill Formation
	Early Eocene		Congaree Formation	Congaree Formation
Millers Pond Aquifer System	Paleocene	Oconee Group	Snapp Formation	Snapp Formation
Dublin Aquifer System			undifferentiated Black Mingo Formation	Ellenton Formation
	Late Cretaceous	Oconee Group	Steel Creek Formation	Steel Creek Formation
Midville Aquifer System			Gaillard Formation Black Creek Formation	Black Creek Formation (or Group)
			Pio Nono Formation	Middendorf Formation
Appleton Aquitard			Cape Fear Formation	Cape Fear Formation

Figure 8. Correlation chart showing lithostratigraphic and hydrostratigraphic units in the Tritium Project study area. Hydrostratigraphic terminology is from Aadland, and others (1992) and Falls and Baum (1995). Lithostratigraphic terminology is from Huddlestun and Summerour (1996), Falls, and others (1997a and 1997b), and Clarke and West (1997).

for Upper Floridan well TW-1 (Clarke, and others, 1996).

Gordon Aquitard

The Gordon aquitard (or confining unit) underlies the Upper Three Runs aquifer (Figure 8) in the study area (Aadland, and others, 1992; Falls, and others, 1997a). In Burke County, this aquitard consists of the Middle Eocene Lisbon Formation and less permeable portions of the underlying Still Branch Sand (Huddlestun and Summerour, 1996). In Savannah River Site literature, the Gordon aquitard includes the "green clay" of Root (1980) and the marls and clays of the Lisbon and Santee Formations (Harrelson, and others, 1997). Analysis of a core sample of the Gordon aquitard from Girard in Burke County, indicates a vertical hydraulic conductivity of 3.34×10^{-4} feet per day and a porosity of 44 percent (Leeth, and others, 1996).

Gordon Aquifer

The clastic Gordon aquifer is the updip equivalent of the carbonate Lower Floridan aquifer (Clarke, and others, 1994). In eastern Georgia, the transition between the two aquifers is down-gradient from the Millhaven well cluster site. Ground-water monitoring wells screened within the Gordon aquifer are shown in Table 4.

In the Tritium Project study area, the confined Gordon aquifer consists of Claiborne Group siliciclastics. The hydrostratigraphic framework of the Gordon aquifer consists of the lower portion of the Middle Eocene Bennock Millpond Sand Member of the Still Branch Sand and the Early to Middle Eocene Congaree Formation (Figure 8). Huddlestun and Summerour (1996) described the lower portion of the Bennock Millpond Sand Member as a fine to coarse, moderately-to poorly-sorted sand. The Congaree Formation is described as ranging from carbonaceous, argillaceous, fine-grained sand to clean, medium-grained sand.

Rose and James (1993) classified Gordon aquifer water as a calcium-bicarbonate water-type and included the Gordon aquifer in their hydrogeochemical Unit 3. Summerour, and others (1994) noted the geochemical similarities between hydrogeochemical Units 2 and 3.

Thayer, and others (1992), used sieve analyses of 382 sand samples from South Carolina to estimate Gordon aquifer porosity values of 27 to 40 percent (mean value 35 percent) and hydraulic conductivity values of 97 feet per day. At the Savannah River Site, Robertson (1990) and Robertson and Thayer (1992) reported Gordon aquifer hydraulic conductivity values of 220 feet per day to 49 feet per day, decreasing from northwest to southeast (downdip). Robertson and Thayer (1992) attributed these differences to a downdip decrease in mean grain size and a downdip increase in mud content of the Gordon aquifer sediments.

Clarke, and others (1996) estimated Gordon aquifer horizontal hydraulic conductivity values of 22 to 69 feet per day (mean value 42 feet), near Millhaven, Screven County, Georgia. Leeth, and others (1996) estimated Gordon aquifer horizontal hydraulic conductivity values of 52 to 95 feet per day (mean value 55 feet per day) at the Girard well cluster site (Figure 7). Clemson University aquifer tests at site TR92-1 yielded a Gordon aquifer transmissivity value of 112 $feet^2$ per day and a hydraulic conductivity value of 11 feet per day for TR92-1B (Moore, and others, 1992).

The Gordon aquifer is present, but thin, in northern Burke County where the Congaree Formation is absent in the Georgia Geologic Survey McBean core, but is 13 feet thick in the Millers Pond core (Figure 7). The Bennock Millpond Sand Member is absent at Millers Pond, but is 36 feet thick in the McBean core (Huddlestun and Summerour, 1996).

Table 3. Upper Three Runs aquifer monitoring wells with corresponding stratigraphic units.

Well number	Stratigraphic unit
TR92-1E through TR92-1I	Tobacco Road Sand
Girard TW-1	Tobacco Road Sand (?)
Millhaven TW-1 (Upper Floridan aquifer) (Upper Three Runs aquifer equivalent)	Late Eocene Barnwell Group equivalent
TR92-1J, TR92-2A, TR92-4A2, TR92-6A2	Irwinton Sand Member, Dry Branch Formation
TR92-1A, TR92-1K, TR92-1L	Griffins Landing Member, Dry Branch Formation
TR92-5A	Griffins Landing Member, Dry Branch Formation Utley Limestone Member, Clinchfield Formation
TR92-1M	Utley Limestone Member, Clinchfield Formation
Millers Pond TW-4	McBean Limestone Member, Lisbon Formation

Sources: Clarke, and others (1994 and 1996); Summerour, and others (1994); Leeth, and others (1996); W. F. Falls, personal communication (1997).

Table 4. Gordon aquifer monitoring wells with corresponding stratigraphic units.

Well number	Stratigraphic unit
TR92-1B, TR92-4B, TR92-6B	Bennock Millpond Sand Member
TR92-2B, TR92-3B, TR92-5B	Congaree Formation

Source: Summerour, and others (1994)

Millers Pond Aquifer System

Within the Tritium Project study area, the Millers Pond aquifer system consists of the following components (Figure 8) (Falls, and others, 1997a and 1997b):

1. The Millers Pond aquitard, which is composed of the kaolin of the upper portion of the Late Paleocene Snapp Formation.

2. The Millers Pond aquifer, which is composed of the lower kaolinitic sands of the Snapp Formation and the upper portion of the underlying undifferentiated Black Mingo Formation.

Summerour, and others (1994), following Aadland, and others (1992), referred to the Millers Pond aquifer as the Meyers Branch "aquifer" within the "Ellenton" Formation. The Millers Pond aquifer was formally introduced by Clarke, and others (1996). Millers Pond aquifer system lithostratigraphic and hydrogeologic data are presented in Clarke, and others (1996); Falls and Baum (1995); Falls, and others (1997a and 1997b); Leeth, and others (1996); and Clarke and West (1997). Millers Pond aquifer monitoring wells and their corresponding stratigraphic units are listed in Table 5.

Dublin Aquifer System

In the Tritium Project study area, the Dublin aquifer system consists of the following components (Figure 8) (Falls, and others, 1997a and 1997b):

1. The upper Dublin aquitard, which is composed of clays of the lower portion of the undifferentiated Black Mingo Formation.

Table 5. Millers Pond aquifer monitoring wells with corresponding stratigraphic units. South Carolina equivalents are shown in parentheses.

Well number	Stratigraphic unit
TR92-1C	lower Snapp Formation
Millers Pond TW-5a	upper undifferentiated Black Mingo Formation (Ellenton Formation)

Sources: Summerour, and others (1994); Clarke, and others (1994 and 1996); Falls, and others (1997a)

2. The upper Dublin aquifer, which is composed of sands of the basal undifferentiated Black Mingo Formation and the sands of the upper Steel Creek Formation (Falls, and others, 1997a).
3. The lower Dublin aquitard, which is composed of the white clay and sandy clay at the top of the upper Gaillard Formation.
4. The lower Dublin aquifer, which is composed of sand in the upper Gaillard Formation.

Dublin aquifer system lithostratigraphic and hydrogeologic data are presented in Clarke, and others (1994 and 1996); Falls, and others (1997a and 1997b); Leeth, and others (1996); and Clarke and West (1997). Dublin aquifer wells and their corresponding stratigraphic units are listed in Table 6.

Midville Aquifer System

In the Tritium Project study area, the Midville aquifer system consists of the following components (Figure 8) (Falls, and others, 1997a and 1997b):

1. The upper Midville aquitard, which is composed of laminated black clays of the lower portion of the Gaillard Formation.
2. The upper Midville aquifer, which is composed of the lower sand interval of the Gaillard Formation.
3. The lower Midville aquitard, which is composed of interbedded clays and sands at the top of the Pio Nono Formation.
4. The lower Midville aquifer, which is composed of sands of the Pio Nono Formation and the uppermost sands of the Cape Fear Formation at Girard (Falls, and others, 1997b; Clarke and West, 1997).

Midville aquifer system lithostratigraphic and hydrogeologic data are presented in Clarke, and others (1994 and 1996); Falls, and others (1997a and 1997b); Leeth, and others (1996); and Clarke and West (1997). Midville aquifer wells and their corresponding stratigraphic units are listed in Table 7.

Underlying the Midville aquifer system is the Appleton aquitard, composed of all but the uppermost part of the Cape Fear Formation. The Appleton aquitard is the basal unit of the Southeastern Coastal Plain Hydrogeologic Province (Aadland, and others, 1992).

Structural Features

Seismic reflection survey data from Savannah River Site indicate the presence of three major basement blocks bounded by northeast trending faults. These blocks may be Paleozoic and Mesozoic structures reactivated by later compressional stresses and strike/slip movements (Domoracki, and others, 1994; Domoracki, 1995; Waddell, and others, 1995). The "middle" block is the buried Triassic Dunbarton graben basin (Figure 9), which is the most important basement structural feature in the study area (Marine and Siple, 1974; Snipes, and others, 1992 and 1993). Simultaneous gravity and magnetic modeling indicates that the

Table 6. Dublin aquifer monitoring wells with corresponding stratigraphic units. South Carolina equivalents are shown in parentheses.

Well number	Stratigraphic unit
TR92-1D (upper Dublin)	lower undifferentiated Black Mingo Formation (lower Ellenton Formation)
TR92-6C, Millers Pond TW-6 (upper Dublin)	Steel Creek Formation
Millers Pond TW-7, Girard TW-2, Millhaven TW-4 (lower Dublin)	upper Gaillard Formation (upper Black Creek Group (undivided))

Sources: Summerour, and others (1994); Clarke, and others (1994 and 1996); Leeth, and others (1996); Falls, and others (1997a)

Table 7. Midville aquifer monitoring wells with corresponding stratigraphic units. South Carolina equivalents are shown in parentheses.

Well number	Stratigraphic unit
Millers Pond TW-3 (upper Midville)	lower Gaillard Formation (Black Creek Group (undivided))
TR92-6D, Millers Pond TW-1, TW-2, Girard TW-3, Millhaven TW-5 (lower Midville)	Pio Nono Formation (Middendorf Formation equivalent) uppermost Cape Fear Formation (Girard site)

Sources: Clarke, and others (1994 and 1996); Leeth, and others (1996); Falls, and others (1997a)

Dunbarton basin is approximately 30 miles long, eight to 10 miles wide, and 5,500 feet deep (Cumbest, and others, 1992; Snipes, and others, 1993).

Northwest of the Dunbarton basin, the basement rocks primarily consist of Paleozoic greenschist facies metavolcanics and amphibolite facies schists and gneisses (Cumbest, and others, 1993; Snipes, and others, 1993). In the Tritium Project study area, the Millers Pond and TR92-6 cores (Figure 7), north of the Dunbarton basin, terminate in weathered biotite gneisses. Southeast of the Dunbarton basin, in Barnwell County, South Carolina, core hole C-6 penetrated a Paleozoic gneiss and in Allendale County, South Carolina, core hole C-10 penetrated a pink Paleozoic granite (Figure 1 in Snipes, and others (1992) and Figure 1a in Clarke and West (1997).

The only core within the study area that penetrates into the Dunbarton basin is the Girard core (Huddlestun and Summerour, 1996; Leeth, and others, 1996). Within the Dunbarton basin, core samples show the presence of typical Triassic Newark Supergroup-type quartz sandstones, mudstones, and conglomerates (Siple, 1967; Marine and Siple, 1974; Chowns and Williams, 1983; Cumbest, and others, 1992; Snipes, and others, 1993; Leeth, and others, 1996).

The southeastern boundary fault (or fault zone) of the Dunbarton basin is the Martin fault (Figure 9) (Snipes, and others, 1993). Faye and Prowell (1982) referred to this fault as the Millett fault. The Martin fault offset ranges from 75 to 100 feet at the pre-Cretaceous unconformity to approximately 21 to 30 feet of offset at the top of the Late Eocene Dry Branch Formation (Snipes, and others, 1995b).

The northwestern boundary fault of the Dunbarton basin has been named the Pen Branch fault by Snipes, and others (1992 and 1993). Based upon data from Savannah River Site wells, geophysical logs, and seismic surveys, the Pen Branch fault consists of a 1.8 mile wide zone of subparallel faults and occasional fault splays (Snipes, and others, 1992 and 1993; Domoracki, 1995). The Pen Branch fault is a high-angle reverse fault, within the Coastal Plain sediments (Snipes, and others, 1992 and 1993; Domoracki, 1995). At the base of the Coastal Plain sedimentary package, the Pen Branch fault zone is slightly sinuous with a strike range of N 53-57^0 E (Domoracki, 1995).

Mesozoic fluvial sequences within the northwestern part of the Dunbarton basin are consistent with normal down-to-the-southeast boundary fault movement, i.e., the basin was lower than the erosional surface of the crystalline terrain to the northwest (Snipes, and others, 1993). Compression and strike/slip related movement along the Pen Branch fault zone occurred from Late Cretaceous time to at least Late Eocene time (Domoracki, 1995; Brodie and Bartholomew, 1997). The present position of the paleo-erosional surface (pre-Cretaceous unconformity), northwest of the Pen Branch fault, is 80 to 100 feet lower than the basinal sediments. This structural relief suggests that the Pen Branch fault was reactivated sometime after the Triassic. The reactivation resulted in reverse (down-to-the-northwest) movement due to intraplate tectonic compression (Prowell and Christopher, 1993). At the top of the Late Eocene Dry Branch Formation, the fault offset is approximately 30 feet (Snipes, and others, 1995b). The shallowest apparent deformation within the Pen Branch fault zone affects the lower portions of the Late Eocene Tobacco Road Sand (Stieve, and others, 1994). A shallow seismic reflection survey of the Savannah River channel shows that the Pen Branch fault occurs beneath the river channel near Hancock Landing (Henry, 1995).

PROCEDURES

Domestic Water Wells

Summerour, and others (1994) sampled 109 domestic and public water supply wells, during Tritium Project Phase I. Fifteen wells were identified as yielding water samples containing 500 picoCuries per liter or more of tritium (Summerour, and others, 1994). Most of these tritium-polluted wells were resampled at least once during Phase II (Figure 10, Appendix 1). Three additional wells were sampled upon the request of homeowners in the study area.

DeLaigle Well #3 was the original well from which tritium was first detected (Summerour, and others, 1994). During Phase II, a sub-investigation studied the construction of this well. In September 1995, a Georgia Geologic Survey drilling crew washed PVC debris and sediment from the damaged well to approximately -225 feet. After the washing process, sediment collapse within the lower part of the well prevented geophysical logging of the well. The six-inch PVC well casing was drilled out to -193 feet, using an eight-inch reaming bit. The drillers examined cuttings to identify debris from casing, grout, or screen. After the completion of drilling process, the well was plugged with a cement slurry, to curtail the suspected downward leakage of tritium-polluted groundwater from the damaged well into the Gordon aquifer.

Monitoring Wells

The fourteen operational Phase I monitoring wells were resampled during Phase II. One new monitoring well (TR92-6A2-Upper Three Runs aquifer) was drilled approximately 800 feet south-southwest of site TR92-6. This new well was a replacement for TR92-6A, which was dry. Nine additional Upper Three Runs monitoring wells were drilled at site TR92-1 for the vertical distribution study (discussed later).

Baseflow Studies

Freeze and Cherry (1979) and Domenico and Schwartz (1990) described three sources for

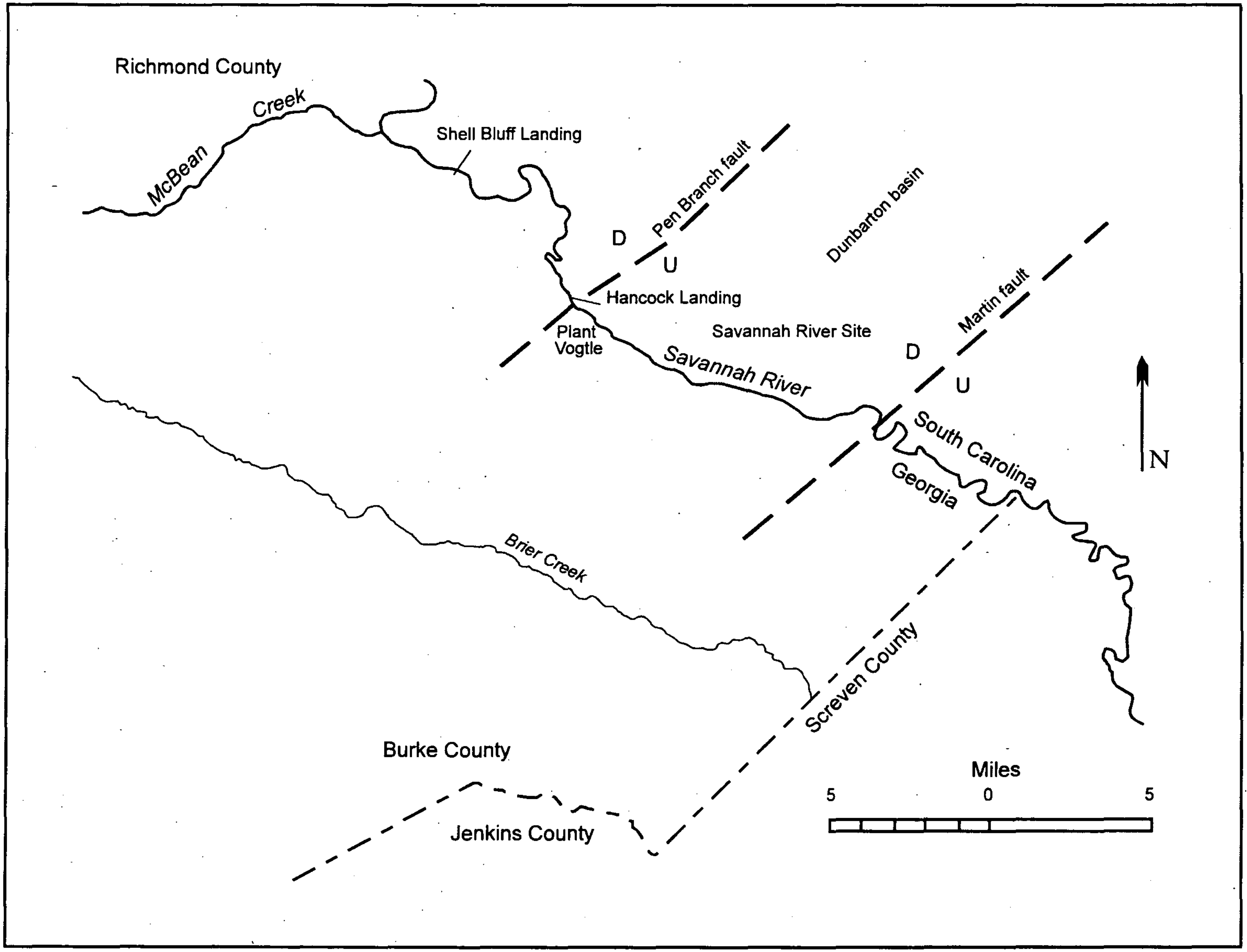


Figure 9. Map showing location of Dunbarton basin, Pen Branch fault, and Martin fault on the Savannah River Site and projected extensions into Georgia. Fault data is from Snipes, and others (1993). From Huddlestun and Summerour (1996).

water in streams: overland flow, underflow, and baseflow. Overland flow consists of rain water that moves over the land surface into stream channels. Underflow is water derived from soils and sediments above the water table, following precipitation events. Baseflow consists of water derived from the water table aquifer.

Because the number of springs and streams far exceeds the number of wells in the study area, baseflow studies are the best available method to evaluate the areal distribution of tritium in the Upper Three Runs aquifer. During Fall in Burke County, precipitation (and overland flow) is typically at its lowest level (Baker, 1979) and soil moisture (underflow) has been depleted by evapotranspiration. During these dry conditions, baseflow provides most of the water for springs and small streams. Samples from streams under such baseflow conditions represent a reasonable measure of Upper Three Runs aquifer geochemistry. Springs and first-order streams are the preferred sampling sites for baseflow studies (Summerour, and others, 1994; Summerour, 1997).

The initial baseflow study was conducted in November 1991, following the discovery of above-background levels of tritium in DeLaigle Well #3 (Summerour, and others, 1994). Subsequent baseflow studies were expanded to cover most of eastern Burke County and southern Richmond County (Figures 11 and 12). Procedures, data and conclusions from the 1991-1995 baseflow studies are presented in Summerour (1997).

Vadose Zone Tritium

The vadose zone is the interval of soil and rock between the land surface and the water table. Pore spaces within the vadose zone contain both water and gases. The ground water in this zone is derived from local rainfall and is generally moving downwards toward the water table. The relative concentrations of tritium in rainfall, in the vadose zone, and in the unconfined aquifer can be used to differentiate pathways for tritium into the aquifer.

The vertical distribution of tritium in the vadose zone was studied at well cluster site TR92-1. A Georgia Geologic Survey drilling crew collected vadose zone sediment samples (Table 8) from the Tobacco Road Sand on November 16, 1995. Using a Failing CF-15 drilling rig, sediment samples were collected by "dry coring" (no drilling mud or other fluid was used) to avoid sample contamination. This coring method resulted in an almost 100 percent recovery for the cored interval of 20.5 feet. The drilling crew used compressed air through the drill pipe to remove the samples from the core-barrel.

Once removed, the samples were quickly double bagged in "ziplock" bags to prevent loss of moisture. The bagged sediments were delivered to the University of Georgia Center for Applied Isotope Studies. Personnel at the Center for Applied Isotopes Studies used vacuum extraction to remove water from the core. The vacuum-extracted water samples were then analyzed using "Alkaline Electrolysis", as described in The United States Department of Energy Environmental Measurements Laboratory Procedures Manual, pages 4.5-58 through 4.5-62. The analyses were performed by Dr. Mike Neary. These high resolution analyses had a detection limit of 1 Tritium Unit or approximately 3.38 picoCuries per liter (M. Neary, personal communication, 1995). Low resolution analyses, used elsewhere in Phase I and Phase II, had a minimum detection limit of 100 picoCuries per liter (0.5 percent of Environmental Protection Agency Maximum Contaminant Limit).

Vertical Distribution of Tritium in the Upper Three Runs Aquifer

The vertical distribution of tritium in the Upper Three Runs aquifer was evaluated to

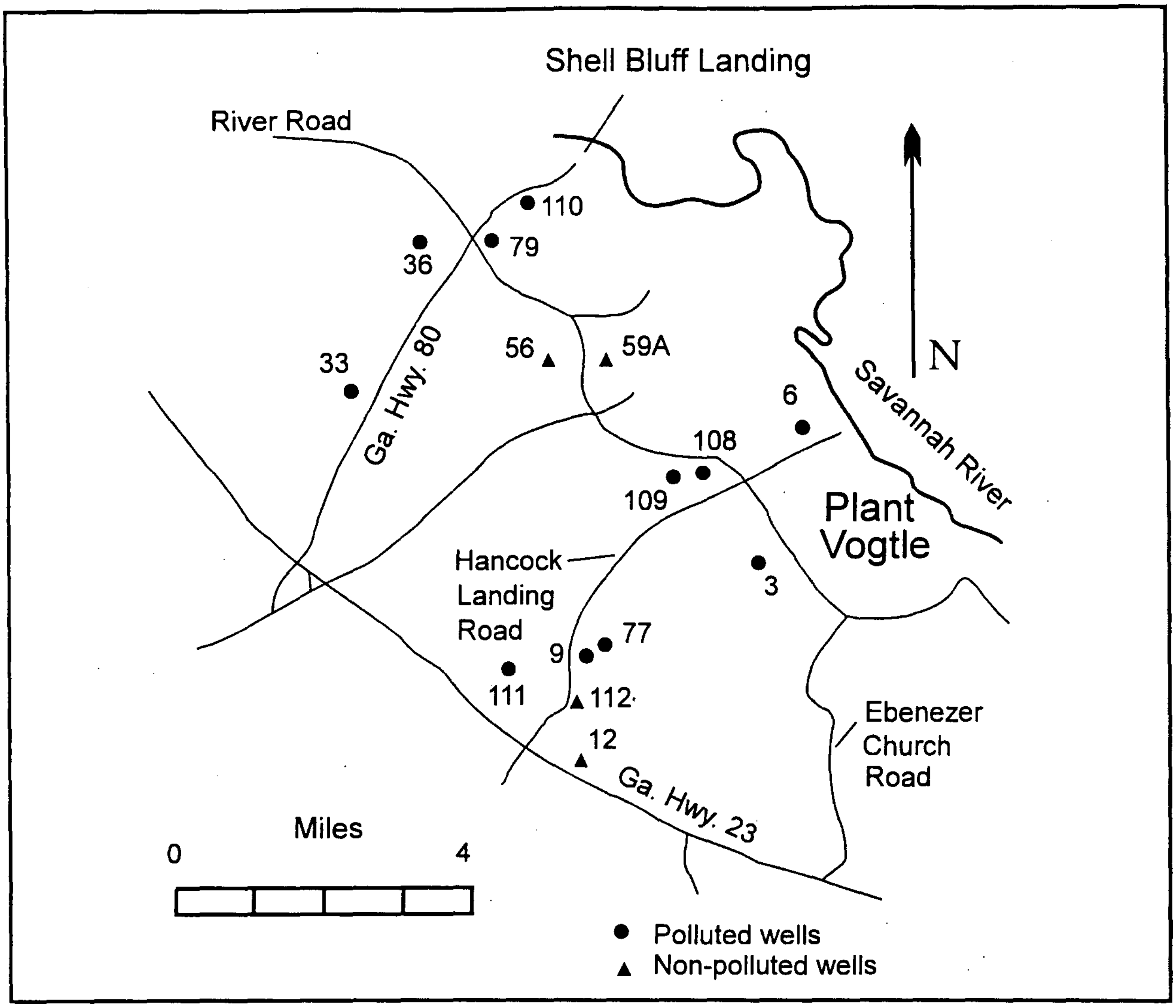


Figure 10. Map of the central portion of the Tritium Project study area, with approximate locations and identification numbers of domestic water wells sampled during Phase II. Results are listed in Appendix 1. Modified from Summerour, and others (1994).

provide information on which parts of the aquifer and on the pathway for tritium into the aquifer. This sub-investigation was conducted at site TR92-1 where one Upper Three Runs aquifer well (TR92-1A) already existed. Nine additional shallow bore holes were drilled, and monitoring wells with five-foot screen intervals were installed (Table 9, Figure 13).

Monthly water samples were collected from February 14 through May 16, 1996 to establish average tritium values for each well. During each pumping episode, where possible, three well volumes were pumped from each well before sample collection. The estimated well volume for each vertical distribution well is shown in Table 10.

Pen Branch Fault Seismic Survey

Savannah River Site data provide evidence of breakage, by the Pen Branch fault, of the Gordon aquitard in South Carolina. This breakage results in downward leakage of ground water from the Upper Three Runs

			29BB Augusta West 1993 1994 1995				
		28AA Blythe 1993 1994	29AA Hephzibah 1993 1994 1995	30AA Mechanic Hill 1993 1994 1995			
26Z Wrens 1993	27Z Matthews 1993 1994	28Z Keysville 1993 1994	29Z Storys Millpond 1993 1994 1995	30Z McBean 1992 1993 1994 1995	31Z Shell Bluff Landing 1991 1992 1993 1994 1995	32Z Girard NW 1991 1992 1993 1994 1995	
26Y Louisville	27Y Kellys Pond 1993 1994	28Y Gough 1993 1994 1995	29Y Waynesboro 1993 1994 1995	30Y Idlewood 1992 1993 1994 1995	31Y Alexander 1991 1992 1993 1994 1995	32Y Girard 1991 1992 1993 1994 1995	33Y Millett 1992 1993 1994 1995
				30X Perkins 1993 1994	31X Sardis 1993 1994	32X Hilltonia 1991	

Figure 11. Grid showing locations of United States Geological Survey 7.5 minute quadrangles covered by one or more of the first five baseflow studies (1991-1995). Quadrangle number/letter codes are from the United States Geological Survey well inventory. From Summerour (1997).

aquifer (T. J. Temples, personal communication, 1993). Henry (1995) showed the extension of the Pen Branch fault beneath the Savannah River near Hancock Landing (Figure 14). As part of Phase II, Waddell, and others (1995), of the University of South Carolina Earth Sciences Resource Institute, conducted a seismic reflection survey (GGS-1) to trace the extension of the Pen Branch fault into Georgia. This seismic survey, conducted in June, 1995, extended 7,620 feet from near Hancock Landing Road to near well cluster site TR92-5.

Seismic waves for this study were generated using a truck-mounted weight-drop system (Dobrin, 1976; Steeples and Miller, 1989; Waddell, and others, 1995). Seismic data were acquired using the common depth point (CDP) method, which improves the signal-to-

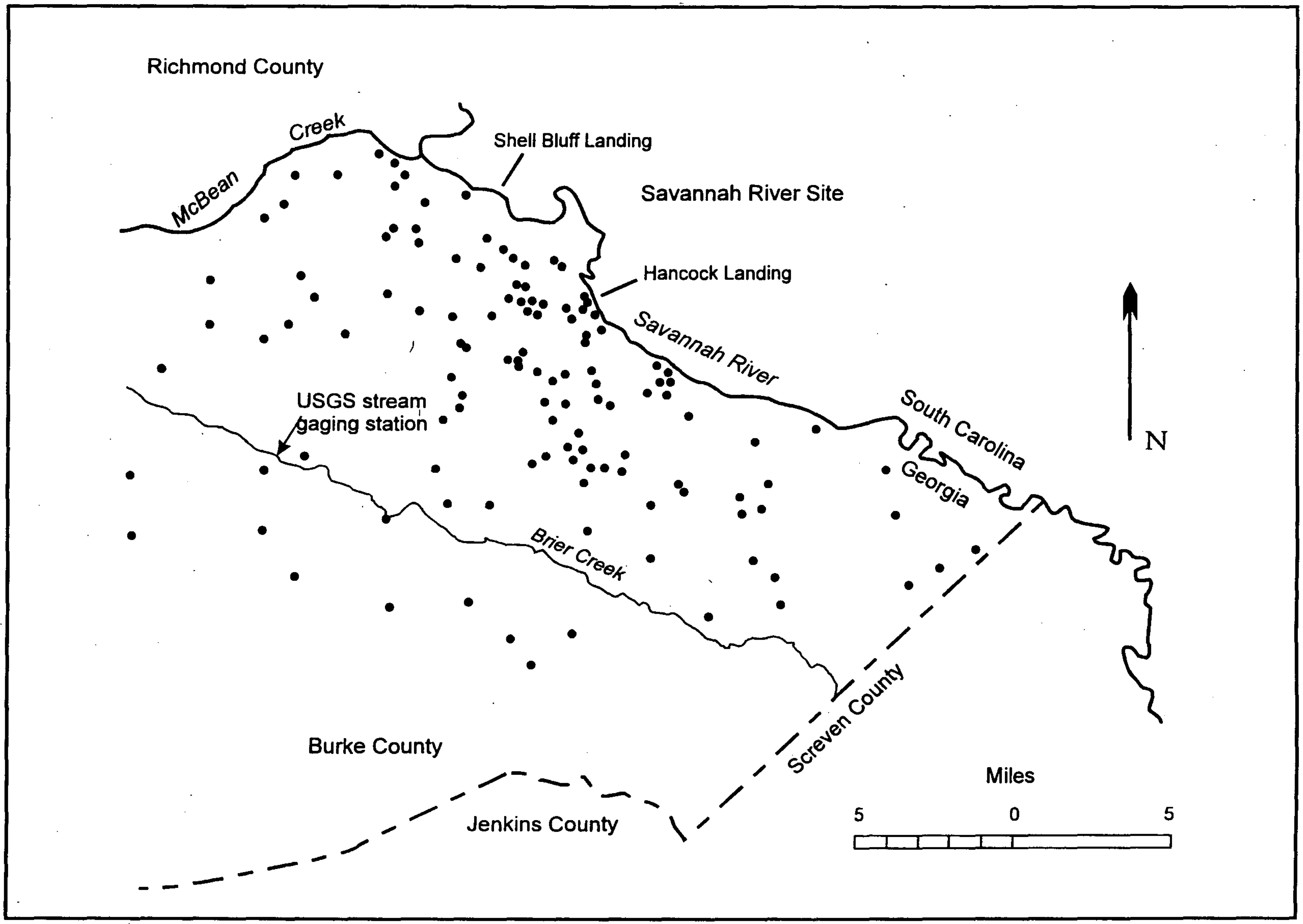


Figure 12. Approximate locations of sampling sites for the 1993 base flow study. Closely spaced sites may be shown as one site. Sites sampled outside of this map area are shown on United States Geological Survey 7.5 minute quadrangles in the Georgia Geologic Survey Technical Files. Modified from Summerour (1997).

Table 8. Intervals analyzed for vadose zone tritium from cluster site TR92-1.

Sample number	Interval
1	Surface to -1.5 ft.
2	-4 ft. to -5 ft.
3	-9.5 ft. to -10 ft.
4	-14.5 ft. to -15 ft.
5	-19.5 ft. to -20 ft.

noise ratio and enhances the coherent signal. The target depth of this study was -960 feet (estimated depth to local basement). Each spread of geophones consisted of 96 geophones spaced at 10 foot intervals, covering a distance of 960 feet (Waddell, and others, 1995). Waddell, and others (1995) describe these methods of this seismic reflection survey in greater detail.

Core Site TR92-7

Core site TR92-7 was drilled in late 1995-early 1996 to investigate further the Georgia extension of the Pen Branch fault. The core site was 73 feet southwest of SL (Station Location) 203 of seismic reflection line GGS-1. Site TR92-7 was cored to -730 feet and "bottomed" in the Gaillard Formation, above the contact with the underlying Pio Nono Formation. Following cessation of core drilling, surface casing was installed to the first limestone (-169 feet), to prevent borehole collapse.

After the completion of core drilling, an additional 130 feet was drilled by rotary mud method, for geophysical logging. The geophysical logging of the extended core hole was conducted in 1996, by Jerry Idler, United States Geological Survey, and included the following tests: acoustic velocity, caliper (diameter), focused resistivity, long normal resistivity, single point resistance, short normal resistivity, spontaneous potential, and natural gamma. Following the geophysical logging, the core hole was plugged and abandoned.

High Resolution Tritium Analyses

During Phase I, nine confined aquifer wells were installed at the six well cluster sites. Of these deeper wells, only one well, TR92-5C, yielded tritium results above low-resolution detection limits (100 picoCuries per liter). The measurable tritium in well (TR92-5C) was attributed to its proximity to the damaged DeLaigle Well #3 (Summerour, and others, 1994). In 1993, United States Geological Survey high-resolution analyses detected minute amounts of tritium in water samples from two confined aquifers at the Millers Pond well cluster site (Table 11) (Clarke, and others, 1994).

The presence of any tritium in these confined aquifers at the Millers Pond well cluster site suggested the need to investigate other confined aquifer wells for the presence of minute quantities (<100 picoCuries per liter) of tritium. High-resolution tritium analyses were conducted on water samples from ten confined aquifer wells in the study area (Table 12) (in addition to analyses of vadose zone water samples from site TR92-1).

Table 9. Summary of Upper Three Runs Aquifer monitoring wells at site TR92-1. Elevation of the site is 235 feet above Mean Sea Level.

Well number	Stratigraphic unit	Depth of pump below surface (feet)	Depth of well below surface (feet)	Screened interval below surface (feet)
TR92-1E	Tobacco Road Sand	no pump	20.5	15-20
TR92-1F	Tobacco Road Sand	no pump	24	18.5-23.5
TR92-1G	Tobacco Road Sand	temporary pump-30	38.5	33-38
TR92-1H	Tobacco Road Sand	temporary pump-40	49.5	44-49
TR92-1I	Tobacco Road Sand	37.5	60.5	55-60
TR92-1J	Dry Branch Formation Irwinton Sand Member	temporary pump-65	75.5	70-75
TR92-1A	Dry Branch Formation Griffins Landing Member	77.5	105	90-100
TR92-1K	Dry Branch Formation Griffins Landing Member	77.5	110.5	105-110
TR92-1L	Dry Branch Formation Griffins Landing Member	77.5	120.5	115-120
TR92-1M	Clinchfield Formation Utley Limestone Member	77.5	135.5	130-135

Table 10. Estimated well volumes of vertical distribution wells at site TR92-1, based on water level measurements of December 13, 1995.

Well	Water level-feet below surface	Well capacity-gallons
TR92-1E	15.77 ft.	3.09 gallons
TR92-1F	16.27 ft.	5.05 gallons
TR92-1G	15.96 ft.	14.71 gallons
TR92-1H	14.82 ft.	23.29 gallons
TR92-1I	15.01 ft.	29.70 gallons
TR92-1J	42.65 ft.	21.44 gallons
TR92-1A	51.46 ft.	35.60 gallons
TR92-1K	51.47 ft.	38.53 gallons
TR92-1L	51.17 ft.	45.26 gallons
TR92-1M	49.52 ft.	56.13 gallons

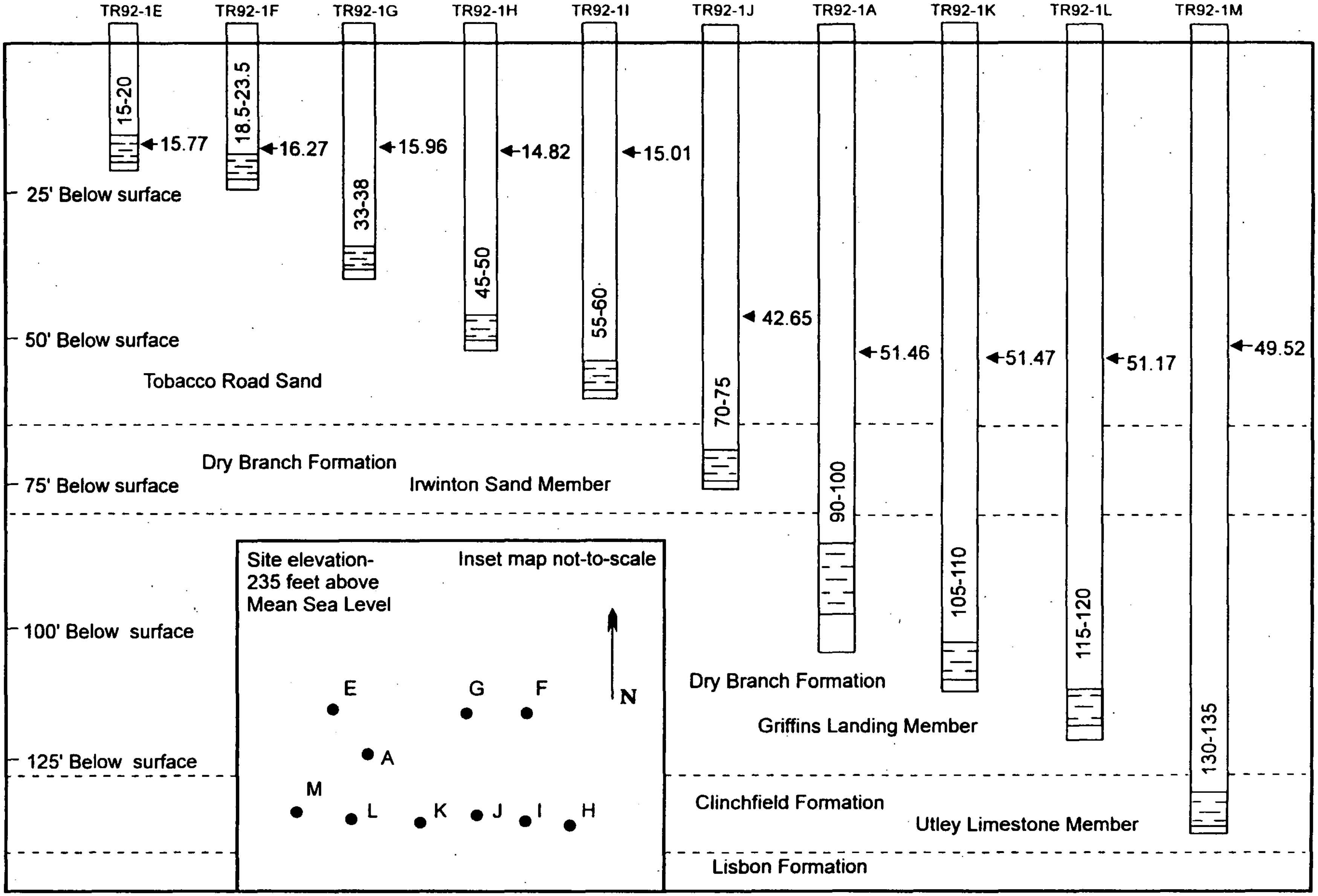


Figure 13. Site TR92-1 Upper Three Runs aquifer monitoring wells in order of depth. Inset map shows arrangement of wells at site. Numbers within the well column refer to screened interval below surface. Arrows indicate water levels of December 13, 1995. Water levels are not corrected for minute elevation differences between wells. Site elevation is 235 feet above Mean Sea Level.

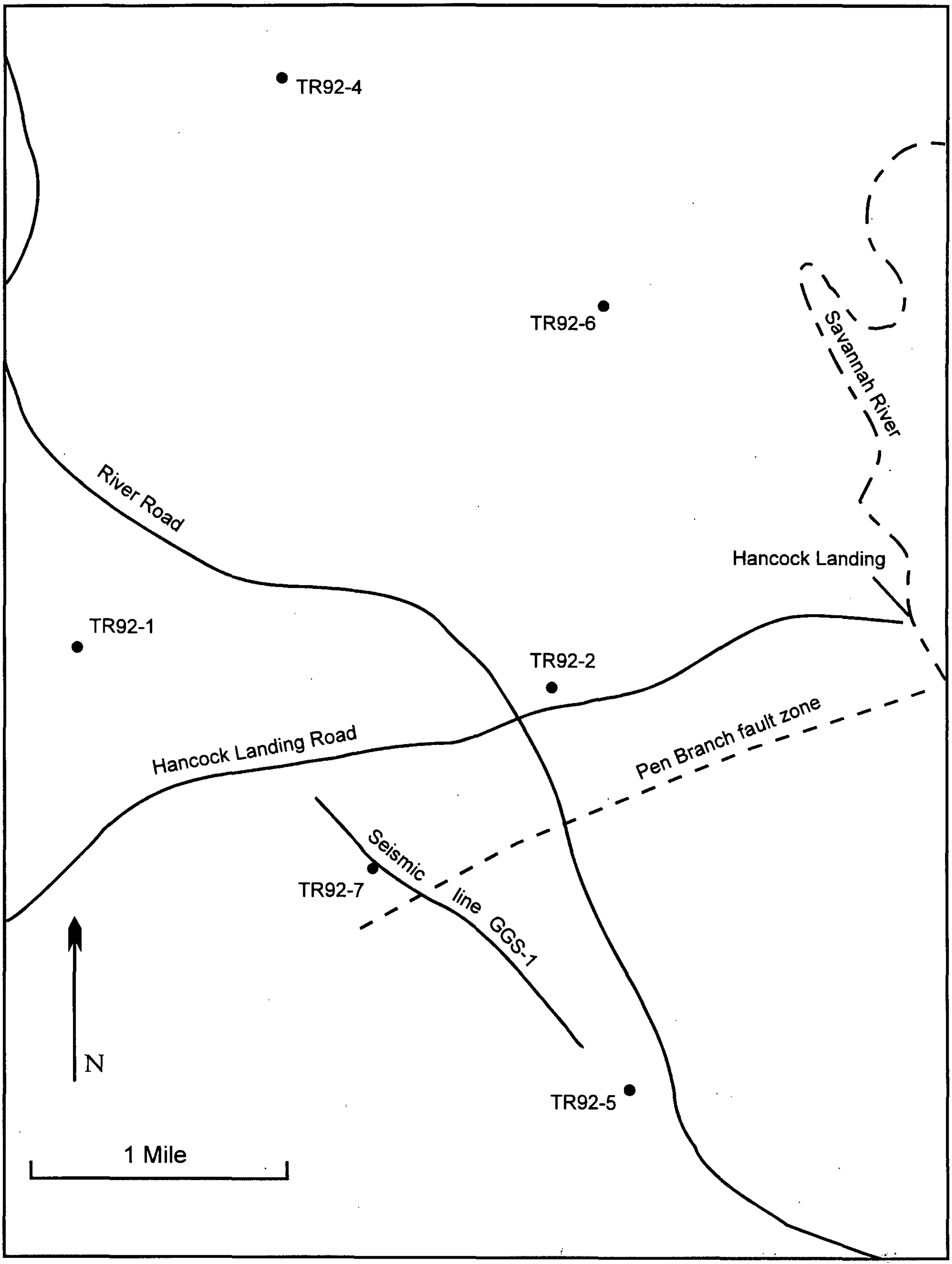


Figure 14. Map showing location of University of South Carolina seismic survey line GGS-1.

Table 11. High-resolution tritium values from the United States Geological Survey Millers Pond site.

Well number	Aquifer	Date collected	Results-picoCuries per liter
TW-5a	Millers Pond	2/09/93	3.19
TW-6	lower Dublin	1/23/93	3.83
TW-6	lower Dublin	5/05/93	2.23

Sources: Clarke, and others (1994) and J. S. Clarke, personal communication (1997).
Samples analyzed by Alberta Environmental Centre, Alberta, Canada.

Table 12. Tritium Project confined-aquifer monitoring wells sampled for high resolution tritium analyses.

Well number	Aquifer	Elevation-feet above mean sea level	Depth of well below surface (feet)	Screened interval (feet)
TR92-1B	Gordon	235	225	210-220
TR92-1C	Millers Pond	235	310	290-330
TR92-1D	Dublin	235	370	345-355
TR92-2B	Gordon	285	330	310-320
TR92-3B	Gordon	195	205	185-195
TR92-4B	Gordon	192	190	175-185
TR92-5B	Gordon	235	305	275-285
TR92-6B	Gordon	240	250	180-200
TR92-6C[1]	Dublin	240	500	450-500
TR92-6D[1]	Midville	240	853	800-831.5

[1] Drilled as part of the United States Geological Survey Trans-River Flow Project.

RESULTS

Domestic Water Wells

Nineteen domestic water wells were tested for tritium during Phase II (Appendix 1). The highest tritium concentrations in domestic water wells were along Hancock Landing Road (Figure 10). Compared with Phase I measurements, tritium concentrations appear to show a slight decline through time. These results are statistically analyzed in the Discussions and Conclusions section of this report. Table 13 shows Phase I versus Phase II results for selected domestic water wells.

Monitoring Wells

Phase II monitoring well results are presented in Appendix 2, except for site TR92-1 vertical distribution well results, which are presented in Appendix 3. Upper Three Runs aquifer tritium concentrations appear to be consistent with results from Phase I analyses (Table 14). Upper Three Runs aquifer wells TR92-2A and TR92-4A2 (Figure 2) yielded the highest tritium values, ranging from 1400 to 1700 picoCuries per liter (+/- 100) (Appendix 2). Again, these values are consistent with Phase I results.

Table 13. Comparisons of Phase I and Phase II median tritium values for selected domestic wells. Tritium values are listed in picoCuries per liter. More extensive comparisons are presented in Table 21.

Well number	**#3** [1]	**#6**	**#36**	**#77**	**#79**
Phase I median "n" = # of samples	1142 (n=19)	1150 (n=8)	720 (n=5)	650 (n=4)	775 (n=8)
Phase II median "n" = # of samples	950 (n=4)	1000 (n=2)	500 (n=2)	700 (n=2)	550 (n=2)

[1] Well drilled out and plugged by Georgia Geologic Survey, late 1995.

Table 14. Comparisons of Phase I and Phase II median tritium values for Upper Three Runs aquifer monitoring wells. Tritium values are listed in picoCuries per liter.

Well number	**TR92-1A**	**TR92-2A**	**TR92-4A2**	**TR92-5A**
Phase I median "n" = # of samples	200 (n=5)	1400 (n=5)	1600 (n=2)	1000 (n=4)
Phase II median "n" = # of samples	400 (n=9)	1400 (n=5)	1300 (n=4)	850 (n=6)

During Phase I and Phase II, monitoring well TR92-1A yielded the least consistent tritium values. The initial sampling of well TR92-1A, on June 25, 1992, yielded results that were below the detection limit (<100 picoCuries per liter) for tritium. After vigorous pumping during Clemson University aquifer tests in July 1992 (Moore, and others, 1992), subsequent TR92-1A samples measured 200 to 300 picoCuries per liter (+/- 100) (Summerour, and others, 1994). During Phase II, after approximately eight months without sampling, this well again yielded tritium values below detection limits. After more vigorous pumping for the vertical distribution sub-investigation, tritium values rose to 300 to 500 picoCuries per liter.

Baseflow Studies

Summerour (1997) described the results of five years of baseflow studies (1991-1995). Figure 15 shows a representative isopleth (tritium contour) map from the 1993 baseflow study. All five annual baseflow studies consistently show that the highest tritium values occur between River Road and the Savannah River, north of Hancock Landing Road (Figure 1). From this area, tritium concentrations, in Burke County, decrease in all directions.

During the five baseflow studies, tritium values ranged from below detection limits (<100 picoCuries per liter) to 2,200 picoCuries per liter +/- 200 (11 percent of Environmental Protection Agency Maximum Contaminant Level) (Summerour, 1997). Figure 16 shows the maximum baseflow tritium values within each 7.5 minute quadrangle for the five-year period.

Outward expansion of the study area during the 1993 and 1994 baseflow studies identified the western and southern boundaries of Burke County as the approximate margins of detectable tritium in surface waters. The same baseflow studies identified southern Richmond County as the approximate northern margin of detectable tritium in surface waters.

Vadose Zone Tritium

Results of high resolution analyses for tritium in vadose zone water samples are shown in Table 15 and Figure 17. Tritium values are relatively low near the top of the vadose zone but increase to a maximum of 869 picoCuries per liter (+/- 10.14) at -14.5 to -15 feet (Sample 4).

For comparison, the median value of tritium in local rainfall, between 1982 and 1992, measured 900 picoCuries per liter (+/- 300). This median value was based on 99 samples collected at Environmental Protection Division station #11 (Figure 5), on Hancock Landing Road, approximately three miles east of the vadose zone sampling site. Thus, tritium values near the base of the vadose zone are consistent with long term average rainfall data for the area. The median value for tritium in rainfall for the two most recent years (1991 and 1992) in the station #11 rainfall database is 500 picoCuries per liter (+/- 300 picoCuries per liter). Therefore, tritium values measured near the top of the vadose zone, at site TR92-1, are consistent with recent values of tritium in rainfall for the area.

Vertical Distribution of Tritium in the Upper Three Runs Aquifer

Tritium analysis results from the ten vertical distribution wells at site TR92-1 are given in Appendix 3. Seven of the ten wells vary by no more than 300 picoCuries per liter over the three- month sample period. One sample from well TR92-1I had significantly lower tritium values (300 picoCuries per liter) than the remaining six samples from that well (median value 800 picoCuries per liter). This low value seems anomalous and may be a sampling artifact.

Vertical distribution wells TR92-1L (Dry Branch Formation, Griffins Landing Member) and TR92-1M (Clinchfield Formation, Utley Limestone Member) show time-related differences in tritium values dependent on the duration of pumping (Table 16). Possible explanations for these inconsistent tritium values are considered in the Discussions and Conclusions section.

The average (median) tritium values for water samples from the vertical distribution wells are shown in Table 17 and Figure 18. Appendix 4 lists water levels measured in all site TR92-1 vertical distribution wells.

Tritium values increase with depth through the first 30 feet of the aquifer reaching a peak of 1,200 picoCuries per liter at -45 to -50 feet. Tritium values then decrease monotonically until at the base of the Upper Three Runs Aquifer, within the Utley Limestone Member, median tritium values are below the detection limit. For comparison, tritium concentrations at the top of the Upper Three Runs aquifer (600 picoCuries per liter +/- 100) are consistent with tritium concentrations observed at the base of the vadose zone (759 picoCuries per liter +/- 9), and tritium concentrations at the base of the Upper Three Runs aquifer are consistent with tritium concentrations in the Gordon aquifer (<100 picoCuries per liter).

High Resolution Tritium Analyses

High resolution analyses showed measurable tritium concentrations in eight of ten confined aquifer monitoring wells (Table 18). Tritium concentrations ranged from below detection to 23.66 picoCuries per liter (median value 4.06 picoCuries per liter). The tritium concentration in well TR92-5B (13.86 picoCuries per liter) may be attributed to point-source contamination from the damaged DeLaigle Well #3 (Summerour, and others, 1994), which is approximately 100 feet from well TR92-5B. For the other confined aquifer wells, there seems to be no stratigraphic trend for the tritium values.

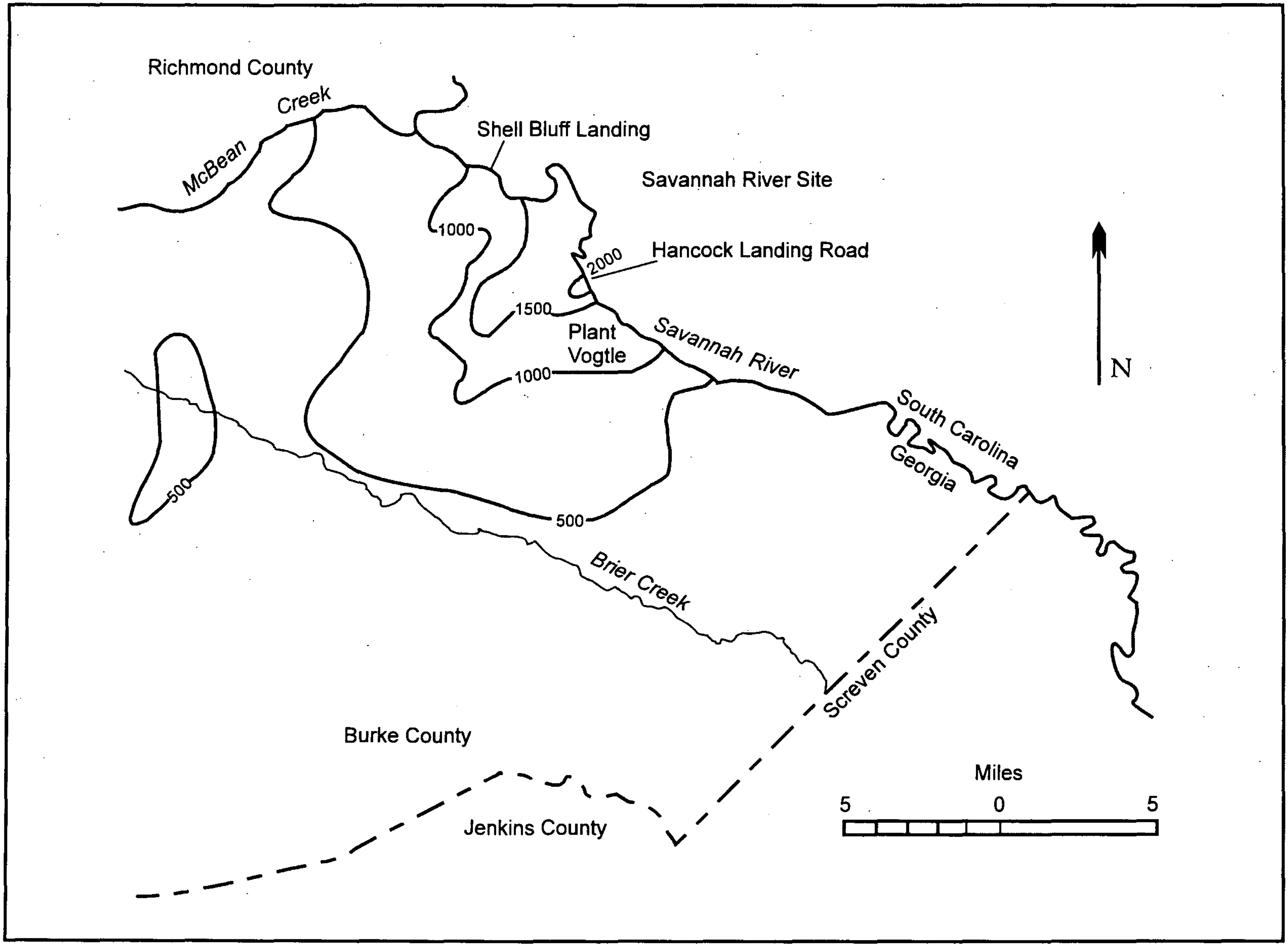


Figure 15. Isopleth map based on surface water tritium values of the 1993 base flow study, eastern Burke County, Georgia. Values are in picoCuries per liter. Modified from Summerour (1997).

			29BB Augusta West *<100 (1993)*				
		28AA Blythe *200 (1994)*	29AA Hephzibah *400 (1994)*	30AA Mechanic Hill *500 (1993)*			
26Z Wrens *<100 (1993)*	27Z Matthews *300 (1993)*	28Z Keysville *200 (1994)*	29Z Storys Millpond *600 (1993)*	30Z McBean *1000 (1992)*	31Z Shell Bluff Landing *2200 (1992)*	32Z Girard NW *1400 (1992)*	
26Y Louisville *<100 (1993)*	27Y Kellys Pond *200 (1993)*	28Y Gough *300 (1993)*	29Y Waynesboro *500 (1993)*	30Y Idlewood *1000 (1992)*	31Y Alexander *1300 (1992)*	32Y Girard *1300 (1991)*	33Y Millett *400 (1992)*
				30X Perkins *100 (1993)*	31X Sardis *200 (1993)*	32X Hilltonia *500 (1991)*	

Figure 16. Grid showing locations of United States Geological Survey 7.5 minute quadrangles covered by one or more of the first five baseflow studies (1991-1995). Also shown are the maximum tritium values (in picoCuries per liter) measured for each quadrangle during that time period. Quadrangle number/letter codes are from the United States Geological Survey well inventory. From Summerour (1997).

Pen Branch Fault Seismic Survey

The seismic profile GGS-1 is shown as Plate 1. Waddell, and others (1995) identified five seismic reflectors (lithologic and sequence boundaries) along this profile. They correlated these reflectors with Savannah River Site and Burke County stratigraphic data (Fallaw and Price, 1995; Summerour, and others, 1994) and Savannah River Site seismic data (Domoracki, 1995). The seismic reflectors are listed in Table 19.

Waddell, and others (1995) identified a series of depositional anomalies (Figures 19 and

Table 15. Results of vadose zone tritium analyses from cluster site TR92-1.

Sample number	Interval	Results
1	Surface to -1.5 ft.	388 pC/liter +/- 6.08
2	-4 ft. to -5 ft.	238 pC/liter +/- 4.39
3	-9.5 ft. to -10 ft.	722 pC/liter +/- 9.13
4	-14.5 to -15 ft.	869 pC/liter +/- 10.14
5	-19.5 to -20 ft.	759 pC/liter +/- 9.46

Table 16. Example of time-related tritium variations during pumping of well TR92-1M. Flow rate changed from 15 gallons per minute to 5 gallons per minute after approximately 2 minutes of pumping. Tritium values are listed in picoCuries per liter.

Duration of pumping	.5 minutes	1 minute	2 minutes	9 minutes	11 minutes
Sample number	S-7389	S-7390	S-7391	S-7392	S-7393
Tritium values	500	500	400	<100	<100

Pump started at 2:18 PM, May 16, 1996

20; Plate 1) on seismic profile GGS-1. These depositional anomalies are as follows:

1. A large, local, down-cutting unconformity or channel feature (C_1) occurs between SL 121 and SL 439. Channel feature C_1 is interpreted to be approximately 3,180 feet wide. The stratigraphic interval within the channel feature is interpreted to be approximately 500 (+/- 100) feet thick, from the middle of the Tertiary sequence to just below the top of the Pio Nono Formation.
2. Two small, local, down-cutting unconformities or channel features (C_2 and C_3) overliethe channel fill sediments of feature C_1. Channel feature C_2 occupies the middle 200 to 300 feet of the Tertiary sequence and is approximately 2,830 feet wide. Channel feature C_3 occupies a 100- to 200-foot interval within the upper portion of the Tertiary sequence and is approximately 2,320 feet wide.
3. A series of small channel cuts (C_4) with associated channel-fill sediments occurs between SL 490 and SL 559 in the upper portion of the Tertiary sediments.

Waddell, and others (1995) identified three structural features on seismic profile GGS-1 (Plate 1). Fault zone F_1 (Figure 20) consists of four high-angle, southward dipping faults that cut the basement and extend into the Coastal Plain sediments. The F_1 faults cut the top of the Pio Nono Formation and appear to be truncated by the channel feature C_1 (Figure 20, Table 20, Plate 1). Fault zone F_2 consists of four high-angle, south dipping faults that cut the basement and extend into the overlying Cretaceous sediments. The F_2 faults cut through the Gaillard Formation and penetrate the C_1 channel feature but do not extend into the overlying channel features (C_2 or C_3) (Figure 20, Table 20, Plate 1). Fault zone F_3 consists of five high-angle faults that cut the basement and extend for a short distance upwards into the Cape Fear Formation. The F_3 faults do not cut the top of the Cape Fear Formation nor are they cut by the channel features (Plate 1).

In addition to the major faults identified by Waddell, and others (1995), the seismic profile appears to show a large number of short fractures within the Cretaceous and Tertiary

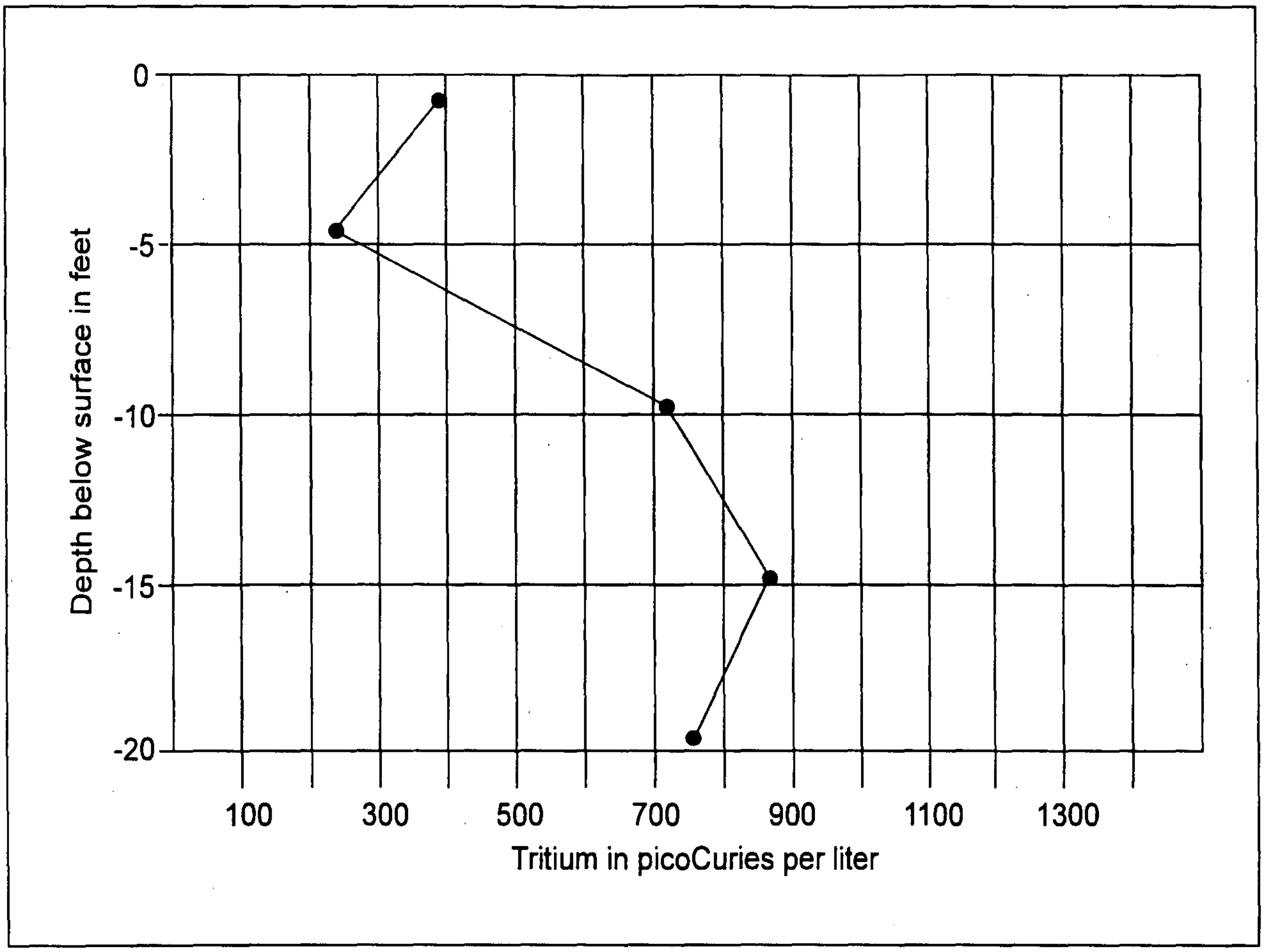


Figure 17. Vertical profile of vadose zone tritium values. Values are listed in Table 12. Each data point on the profile represents the midpoint of the sampled interval.

Table 17. Average (median) results of vertical distribution well sampling: February-May, 1996.

Well	Number of samples	Average tritium values-picoCuries/liter
TR92-1E	4	600
TR92-1F	4	800
TR92-1G	8	1000
TR92-1H	11	1200
TR92-1I	7	800
TR92-1J	1[1]	500
TR92-1A	9	400
TR92-1K	8	400
TR92-1L	11	100
TR92-1M	14	<100

1. One time sampling due to poor well recovery.

Table 18. Results of high resolution analyses from deeper Tritium Project monitoring wells.

Well number	Aquifer	Date collected	Results-picoCuries per liter
TR92-1B	Gordon	6/17/95	<3 pC/l[2]
TR92-1C	Millers Pond	6/17/95	4.06 pC/l +/- .68
TR92-1D	Dublin	6/17/95	23.66 pC/l +/- 1.35
TR92-1D	Dublin	11/16/95	9.06 pC/l +/- .44
TR92-2B	Gordon	6/16/95	5.4 pC/l +/- .34
TR92-3B	Gordon	6/16/95	5.75 pC/l +/- .34
TR92-4B	Gordon	6/17/95	<1.35 pC/l[2]
TR92-5B	Gordon	6/16/95	13.86 pC/l +/- .34
TR92-6B	Gordon	6/16/95	5.41 pC/l +/- .34
TR92-6C[1]	Dublin	11/09/95	1.89 pC/l +/- .10
TR92-6D[1]	Midville	11/08/95	4.06 pC/l +/- .20

1. Samples TR92-6C and TR92-6D collected by Fred Falls, United States Geological Survey. 2. Different detection limts are due to different sample counting times, i.e., longer counting times yield lower detection limits.

sediments (Figure 20). This disruption of the rocks appears to be most intense within the zone bracketed by the major faults (F_1 and F_2), but the disruption also extends both north and south of the major fault zones. These short faults or fractures dip at high angles both northwards and southwards. As most of the siliciclastic sediments within this zone are unlithified, these features may be stress release fault planes related to ductile deformation (W. F. Falls, written communication, 1997).

Core Site TR92-7

The interpretation of an apparent large channel feature (C_1) on seismic profile GGS-1 (Waddell, and others, 1995) raised several critical questions concerning the effect of this putative channel on local hydrogeology. Such questions include the following:

1. Are the channels real or are they geophysical artifacts?
2. How many aquitards are breached by the channel?
3. Is the Gordon aquitard (Lisbon Formation) present above the channel?
4. What is the age of the channel-fill deposits?

These questions were addressed by drilling core hole TR92-7, which was sited over the deepest part of the C_1 channel feature (Figure 20). Although the coring did not reach the projected base of the C_1 channel feature, more than 90 percent of the estimated vertical interval spanned by C_1 was penetrated by the core. A stratigraphic summary of core TR92-7 is presented in Figure 21.

DISCUSSIONS AND CONCLUSIONS

Time Trends of Tritium Concentrations

Time trends for tritium concentrations in the Upper Three Runs aquifer can be evaluated using water supply well data, ground-water monitoring well data, and baseflow data. The water supply well data-base contains twelve wells sampled during both Phase I and Phase II

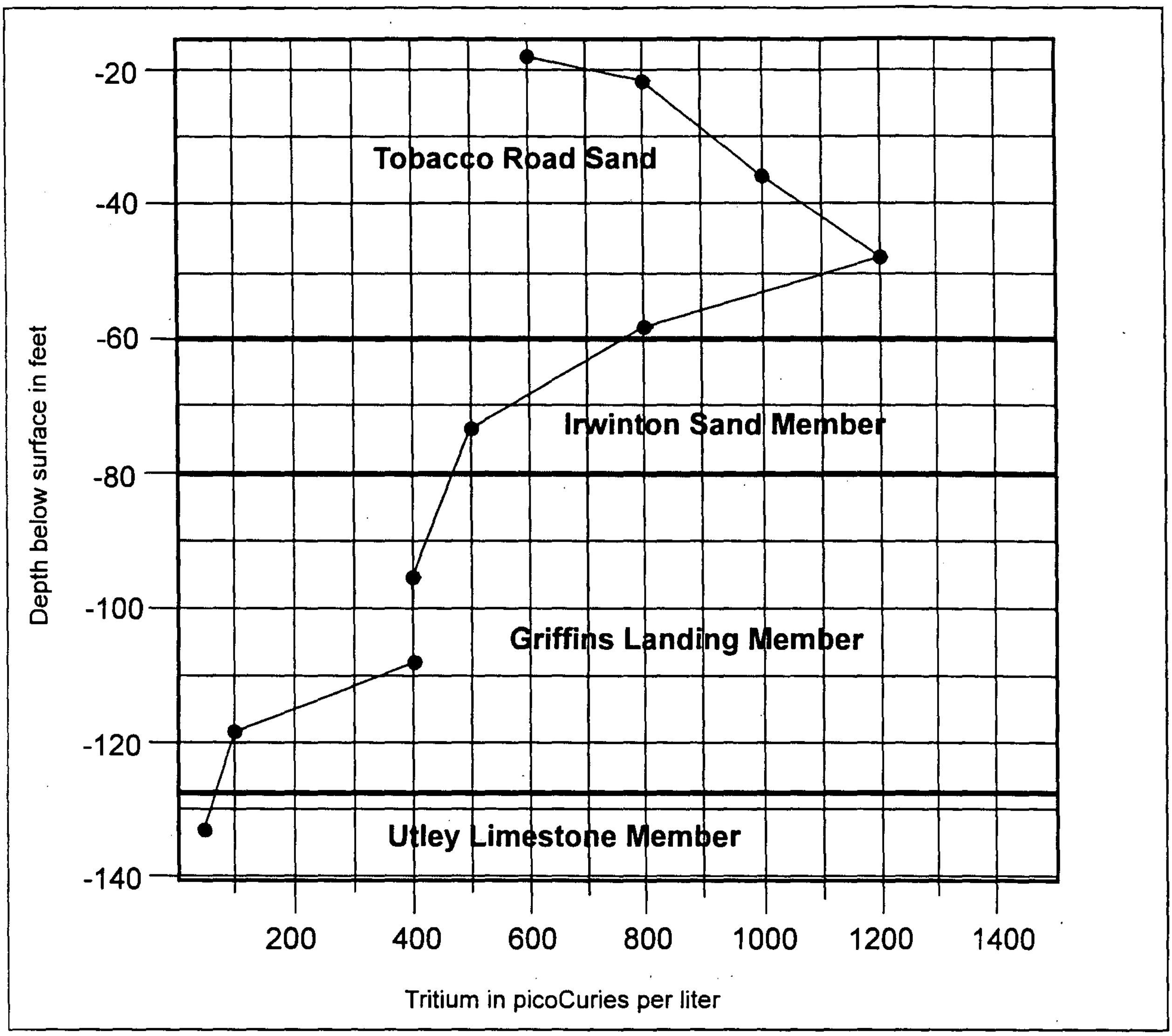


Figure 18. Vertical profile of tritium concentration within the Upper Three Runs aquifer at site TR92-1. Data are listed Appendix 3. Each data point represents the midpoint of the screened interval of the particular well. Tritium values are listed in Table 17.

Table 19. Seismic reflectors identified in profile GGS-1.

Seismic reflector	**Station locations**	**Comments**
top of Steel Creek Formation	1 through 140 and 360 through 750	Cretaceous-Tertiary boundary
top of Gaillard Formation	1 through 145 and 325 through 750	Truncated by channel feature C_1
top of Pio Nono Formation	1 through 152 and 245 through 750	Truncated by channel feature C_1
top of Cape Fear Formation	1 through 750	Basal unit of Coastal Plain sequence
top of Basement rocks	1 through 750	Paleozoic metamorphics Triassic Newark Supergroup

Source: Waddell, and others (1995)

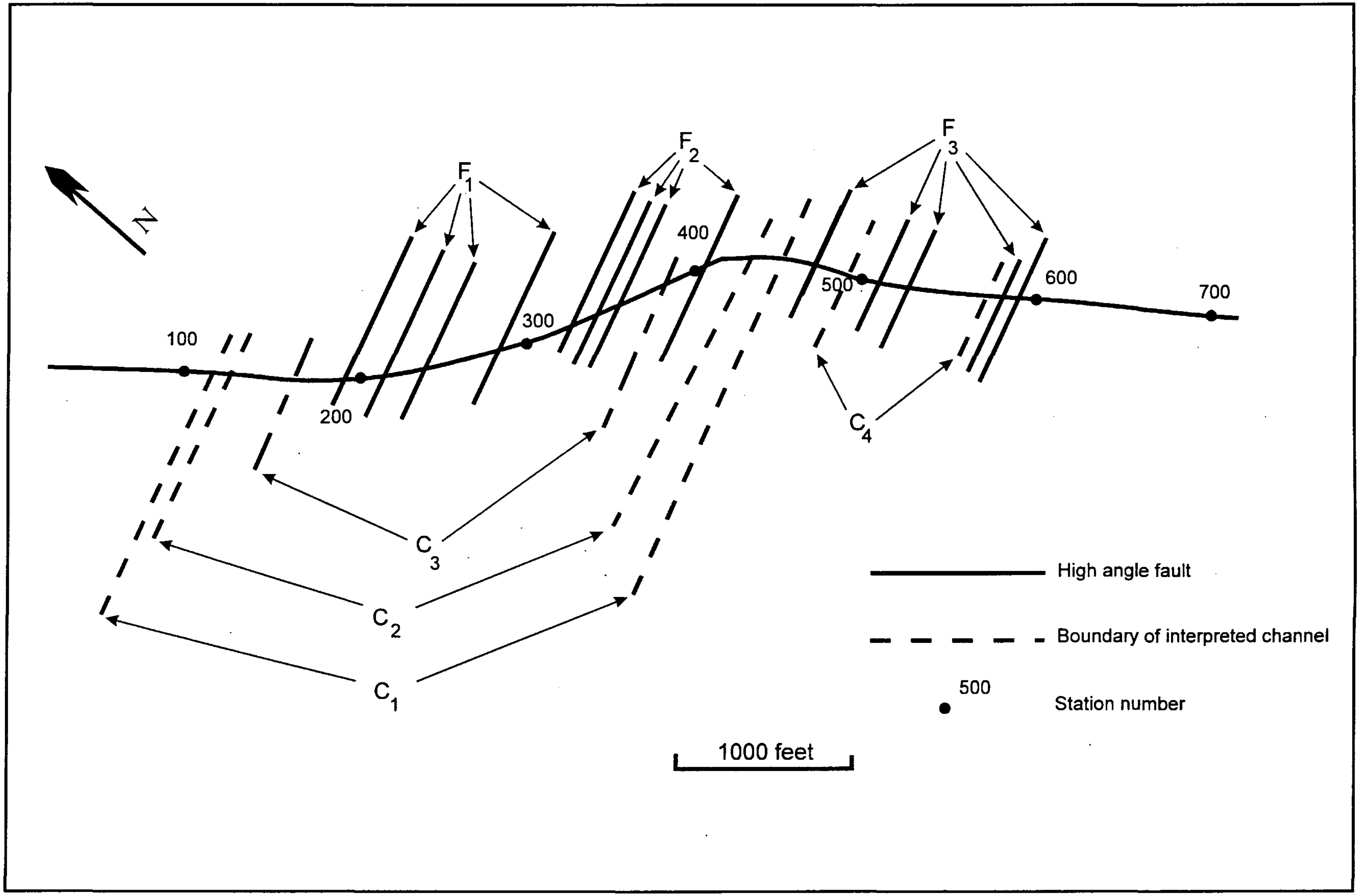
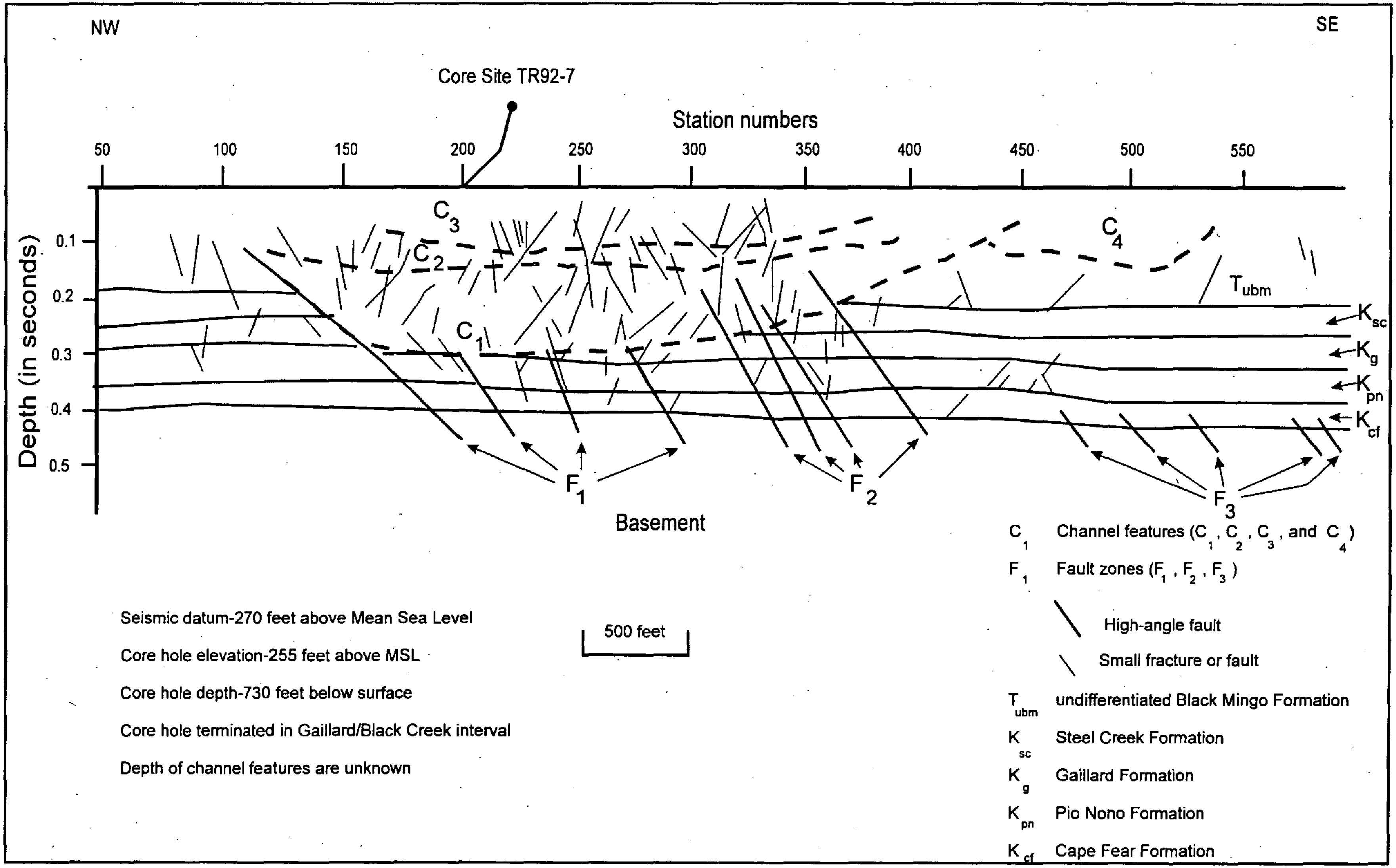


Figure 19. Map of seismic survey line GGS-1 with interpreted surface locations of fault zones (F_1, F_2, and F_3) and channel features (C_1, C_2, C_3, and C_4). Fault locations are vertical projections from the Cretaceous/basement contact. True orientations of faults and channels are unknown. All faults dip steeply southeast in Coastal Plain sediments. Data are from Waddell, and others (1995).



Seismic datum-270 feet above Mean Sea Level

Core hole elevation-255 feet above MSL

Core hole depth-730 feet below surface

Core hole terminated in Gaillard/Black Creek interval

Depth of channel features are unknown

C_1	Channel features (C_1, C_2, C_3, and C_4)
F_1	Fault zones (F_1, F_2, F_3)
\	High-angle fault
\	Small fracture or fault
T_{ubm}	undifferentiated Black Mingo Formation
K_{sc}	Steel Creek Formation
K_g	Gaillard Formation
K_{pn}	Pio Nono Formation
K_{cf}	Cape Fear Formation

Figure 20. Cross-section based on a portion of seismic survey profile GGS-1 showing interpreted seismic reflectors, channel features, fault zones, and the numerous small fractures (or faults). Modified from Waddell, and others (1995).

studies. The ground-water monitoring well database contains four wells sampled during both Phase I and Phase II studies. The baseflow database includes 24 sampling sites sampled during each of the five baseflow studies (1991-1995).

Domestic Water Wells

During the entire Tritium Project (1991-1997), 112 domestic water supply wells were sampled in eastern Burke County. Only 12 of these wells (sampled during both Phase I and Phase II) had tritium values at or above 500 picoCuries. These 12 wells represent a set of repeated-measure matched-pairs that can be statistically tested for significant differences (Table 21).

A preliminary evaluation of a larger set of tritium values showed that tritium concentrations in ground-water and surface-water samples do not follow a normal or log-normal frequency distribution and that variances in different populations are not equal. The non-normality of the frequency distribution and the non-equality of the variances preclude parametric analysis of the data (such as t-tests, analysis of variance, or regression analysis). However, there are a variety of non-parametric statistical tests that can be applied. Because of the high degree of skewness of the tritium data, the median rather than the mean will be cited as a measure of central tendency.

A Wilcoxon matched-pairs signed-ranks test (Siegel, 1956) was applied to the twelve water supply wells. The test compared measurements taken during Phase I (1991 to 1993) with those taken during Phase II (1994 to 1996). If there was more than one measurement from a well during Phase I or Phase II, a median value was used. The null hypothesis was that there was no difference between the Phase I and Phase II data (H_0: Phase I=Phase II). The alternative hypothesis was that Phase II tritium concentrations were different from the Phase I concentrations (H_1: Phase I≠Phase II). The Wilcoxon matched-pairs signed-ranks test yielded a T value of 4 and rejected the null hypothesis at the 0.01 probability level. In summary, the Phase II water supply well data are significantly lower that the Phase I data, with less than one chance in one hundred that this large a difference could be due purely to chance.

Monitoring Wells

Six ground-water monitoring wells were installed in the Upper Three Runs aquifer during Phase I and nine additional wells were installed during Phase II. Four of these wells were sampled during both Phase I and Phase II. These four wells represent a repeated-measure, matched-pairs, data set which can be tested using non-parametric statistics. Phase I and Phase II median tritium values for each Upper Three Runs aquifer monitoring well are shown in Table 14.

A Wilcoxon matched-pairs signed-ranks test (Siegel, 1956) was applied to the four water supply wells. The test compared tritium concentrations measured during Phase I (1991 to 1993) with those taken during Phase II (1994 to 1996). If there was more than one measurement from a well during Phase I or Phase II, a median value was used. The null hypothesis was that there was no difference in tritium values between the Phase I and Phase II (H_0: Phase I=Phase II). The alternative hypothesis was that Phase II tritium concentrations were different from the Phase I concentrations (H_1: Phase I≠Phase II). The Wilcoxon matched-pairs signed-ranks test yielded a T value of 2 and did not reject the null hypothesis. In summary, statistical analysis could not detect any differences between the tritium concentrations measured in the ground-water monitoring wells during Phase I and tritium concentrations measured during Phase II. However, the small sample size (four wells) may not be adequate to distinguish changes in tritium concentration.

Table 20. Subsurface structural features detected in seismic reflection profile GGS-1. Fault zone locations are shown in Figures 19 and 20 and Plate 1.

Structural feature	Approximate width	Comments
Fault zone F_1	1,200 feet	Faults appear to be truncated by channel feature C_1
Fault zone F_2	870 feet	Faults appear to penetrate channel feature C_1 but may be truncated by channel feature C_2.
Fault zone F_3	1,080 feet	Faults appear to not extend above the Cape Fear Formation.

Source: Waddell, and others (1995)

Baseflow Studies

Baseflow studies were conducted over a five-year period (1991-1995). Twenty-four stream stations were sampled in all five years. These 24 stations represent a repeated-measure, multiple matched-sample, data set which can be tested using non-parametric statistics. The annual baseflow data for these 24 stations are shown in Table 22.

A Friedman two-way analysis of variance by ranks (Siegel, 1956) was applied to the 24 stream stations. The test compared tritium concentrations measured during each of five years. The null hypothesis was that there was no difference between the tritium values during the five-year period (H_0: $H^3_{1991} = H^3_{1992} = H^3_{1993} = H^3_{1994} = H^3_{1995}$). The alternative hypothesis was that tritium concentrations were different from year to year (H_1: $H^3_{1991} \neq H^3_{1992} \neq H^3_{1993} \neq H^3_{1994} \neq H^3_{1995}$). The Friedman two-way analysis of variance by ranks yielded a test statistic, χ_r^2 of 76.59, which exceeded the critical value for χ_r^2 of 18.46 (probability = 0.001, n=24, k=5, df=4). Based on this analysis, the null hypothesis was rejected signifying that there was less than 1 chance in a thousand that the tritium values could differ this much purely due to chance. To determine which years contributed to this rejection of the null hypothesis, Wilcoxon matched-pairs signed-ranks tests (Siegel, 1956) were applied to the paired data from 1991-1992, 1992-1993, 1993-1994, and 1994-1995. The results are summarized in Table 23. All annual matched pairs showed significant differences except for the 1993-1994 pair.

The statistical analyses demonstrate that there are significant differences in the baseflow tritium values from year to year. Actual tritium values at each station show that the differences are due to overall decline in tritium concentrations. Most years show a significant decline in tritium, with the possible exception of 1994.

Within the baseflow data set, all stations show a tritium concentration decline through time. The largest decline is of 900 picoCuries per liter; the smallest decline is of 200 picoCuries per liter. There is a positive linear correlation (R = 0.7120) between the 1991 concentration and the amount of decline (1991 tritium concentration minus 1995 concentration). The percent decline ranges from 35.7 percent to 94 percent. The median percent decline is 59.17 percent. The decline in tritium concentration seen at the baseflow stations is too large to be due solely to radioactive decay. With a half-life of 12.35 years, tritium should have decayed by 20.12 percent during the five years of measurements. Between 16 and 74 percent of the decline in tritium abundance is attributable to factors other than radioactive decay. The most likely causes for the large declines seen at the baseflow stations are lateral transport of less tritiated water to the sampling station and dilution by relatively untritiated water.

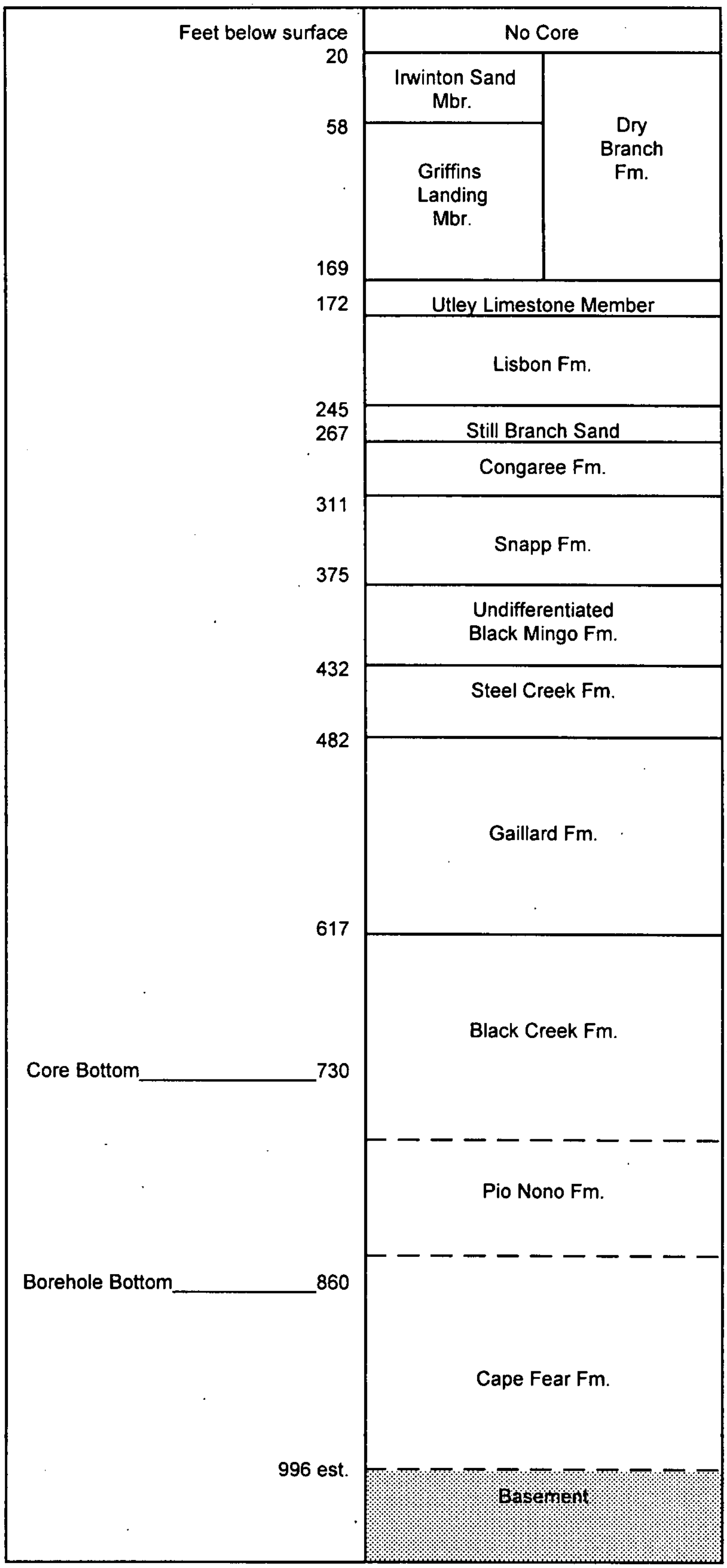


Figure 21. Stratigraphic section logged at site TR92-7.

Table 21. Wilcoxon matched-pairs signed-ranks test of significance of the difference between Phase I and Phase II values for tritium concentration in ground water from domestic water supply wells in eastern Burke County. "n" is the number of wells. $T_{calculated}$ is the calculated test statistic. $T_{critical}(0.01)$ is the critical value for T at a probability level of 0.01, i.e., there is a one chance in a hundred of obtaining a T value of this magnitude or less purely due to chance. Tritium concentrations are in picoCuries per liter. Wells are identified in Appendix 1.

Well number	**3**	**6**	**9**	**33**	**36**	**46**	**56**	**65**	**77**	**79**	**108**	**109**
Phase I median tritium value	1200	1100	1250	900	700	900	400	1600	650	600	2000	800
Phase II median tritium value	950	1000	1000	950	500	600	300	1500	700	550	1600	600
n=12 $T_{calculated}$= 4 $T_{critical}(0.01)$= 7 Null Hypothesis rejected												

Overall Time Trends

Two of the three databases (water supply wells, and baseflow data) show significant changes in tritium concentrations. Only the ground-water monitoring well data show no significant differences through time. It is likely that the non-significant result for the ground-water monitoring wells is due to the small sample size (four wells). The largest and most thorough data set (the baseflow data) shows highly significant changes from year to year. Therefore, we conclude that tritium levels in the Upper Three Runs aquifer have generally declined between 1991 and 1995.

Vertical Distribution of Tritium:- Vadose Zone and Upper Three Runs Aquifer

The vertical distribution of tritium, within the vadose zone and Upper Three Runs aquifer at site TR92-1, displays a variation of more than one order of magnitude (<100 to 1,200 picoCuries per liter) over a 135-foot depth interval (Tables 15 and 17). Allowing for the radioactive decay of the tritium, this variation with depth may represent the historical pattern of tritium introduction into the vadose zone and unconfined aquifer. This hypothesis is supported by a comparison of the vertical distribution of tritium at site TR92-1 with the record of atmospheric tritium releases at the Savannah River Site (Figure 22).

Figure 22 was constructed by assuming that: (1) the tritium concentration at the land surface corresponds to the most recent (1994) tritium release from the Savannah River Site; (2) the peak in vertical distribution (at -47.5 feet) corresponds to the 1984 peak in tritium releases; and (3) that the first tritium value below the detection level (at -117.5 feet) corresponds to 1955 levels of tritium that have since decayed to very low levels. The post-1984 tritium releases are proportionately scaled to the segment of the Upper Three Runs aquifer above the -47.5 foot stratigraphic tritium peak (i.e., the annual releases from 1984 to 1994 are evenly spaced from the -47.5 feet to the land surface). The tritium releases from 1984 to 1955 are proportionately scaled to the segment of the Upper Three Runs aquifer from the -47.5 foot tritium maximum to the -117.5 foot tritium low (i.e., the annual releases from 1955 to 1984 are evenly spaced from -47.5 to -117.5 feet). The resultant spacing, of the release data, results in a correlation coefficient of 0.7180 between the stratigraphic distribution and the historical distribution (after decay). Such two-step scaling is consistent with the division of the Upper Three Runs aquifer into "lower" and "upper"

Table 22. Tritium values, in picoCuries per liter, for 24 stream stations that were sampled during the 1991-1995 base flow studies. Data from Appendix 2, Summerour (1997).

Baseflow station	1991	1992	1993	1994	1995
31Z02SW-1 (SBL-11)	1600	1100	1100	900	700
31Z02SW-2 (SBL-10)	1400	1200	900	700	700
31Z04SE (SBL-9)	1200	1100	700	600	600
31Z14SE (SBL-8)	1000	900	500	500	500
31Z26SW (SBL-5)	1200	900	800	700	500
31Z30NW (SBL-3)	1300	1400	900	700	600
31Z40SW (SBL-2)	1000	700	600	500	300
32Z02SW (SBL-12)	1400	1100	1000	900	900
31Y17NE (A-5)	1000	1000	700	600	500
31Y27NW (A-2)	900	800	600	800	500
31Y28NW (A-1)	1100	800	600	500	500
31Y36NW (A-9)	600	800	300	400	300
31Y45SW (A-15)	600	500	100	300	200
31Y46NE (A-17)	600	400	100	50	100
31Y49NW (A-14)	500	500	100	300	300
32Y01NE (G-1)	1300	1100	800	700	500
32Y02SW (G-2)	1100	1100	400	400	300
32Y14NW (G-3)	900	600	300	400	300
32Y16NW (G-4)	1000	600	400	500	300
32Y18NE (G-11)	700	500	300	400	200
32Y20SW (G-9)	1000	700	300	400	400
32Y24SE (G-5)	800	500	200	300	50
32Y27SE (G-8)	800	400	300	200	200

components separated by a semiconfining layer (the Irwinton Sand Member), at site TR92-1.

The hypothesis of stratigraphic tracking of tritium releases to the atmosphere is complicated by groundwater flow patterns in the vadose zone, "upper" Upper Three Runs aquifer, and "lower" Upper Three Runs aquifer. These groundwater flow complications are caused by lithologic variations in the Barnwell Group sediments. The age relationship may be maintained, however, due to increasing length of flow paths with increasing depth (Freeze and Cherry, 1979; Rose, 1992 and 1993; S. Rose, personal communication, 1996). The hypothesis of stratigraphic tracking of historical tritium releases needs to be tested by age dating water from different horizons within the Upper Three Runs aquifer.

Table 23. Wilcoxon matched-pairs signed-ranks test for annual pairs of baseflow data. "n" is equal to the number of station pairs minus the number of pairs that do not differ. $T_{critical}$ is taken from Table G in Siegel (1956). Values of $T_{calculated}$ smaller than $T_{critical}$ result in rejection of the null hypothesis. Probabilities reflect a two-tailed test of significance.

	1991-1992	1992-1993	1993-1994	1994-1995
n, probability	n=21, p=0.01	n=23, p=0.01	n=21, p=0.05	n=16, p=0.01
$T_{calculated}$	11	0	106.5	3
$T_{critical}$	43	55	59	20
Null Hypothesis	rejected	rejected	do not reject	rejected

Tritium in Confined Aquifers

The occurrence of low but detectable levels of tritium in the Gordon, Millers Pond, Dublin, and Midville aquifers raises serious questions about how the tritium got there. Considering that Falls (1996, unpublished memorandum) obtained a radiocarbon age of 11,000 to 32,000 years for water in the Lower Dublin and Lower Midville aquifers in Burke County, there should be no tritium at all in these deeper aquifers.

There are several possible explanations for the tritium values observed in the deeper, confined aquifers. These possible explanations are:

1. There may be downward leakage of tritium-polluted water, from the Upper Three Runs aquifer, through the more permeable lithologies of the Gordon aquitard (McBean Limestone Member or Lisbon Formation sand).
2. The Pen Branch fault or the associated channel features may allow leakage into the confined aquifers.
3. Leakage may occur through the (grouted) annular spaces of the monitoring wells.
4. Tritium-polluted Upper Three Runs aquifer water may have leaked into the deeper aquifers during drilling of the monitoring wells.
5. Tritium may have contaminated the drilling mud during drilling of the monitoring wells.
6. Tritium-laden moisture may have condensed on the inner portions of casing above the water table.
7. Contact with tritium in the atmosphere may have contaminated the samples.

Explanations 1 and 2 are hydrogeologic in nature; explanations 3, 4, and 5 are related to drilling; and explanations 6 and 7 are related to sampling. Hydrogeologic explanations (1 and 2) cannot be dismissed without further investigation. Clarke, and others (1994) suggested lateral migration from recharge areas as one possible source for low levels of tritium in Millers Pond aquifer well TW-5a and lower Dublin aquifer well TW-6 at the Millers Pond site. Considering the radiocarbon dates (11,000 to 32,000 years) of water in these aquifers (W. F. Falls, unpublished memorandum, 1996), lateral migration seems an unlikely source. Data collected by the United States Geological Survey suggest that a minor amount of trans-river flow (from South Carolina into Georgia) is occurring within the deeper aquifers (J. S. Clarke, personal communication, 1997; Clarke and West, 1997). Whether the Pen Branch fault and/or related channel features play any role in trans-river flow is unknown at this time.

Of the three drilling related explanations (3 through 5), leakage through the annular space

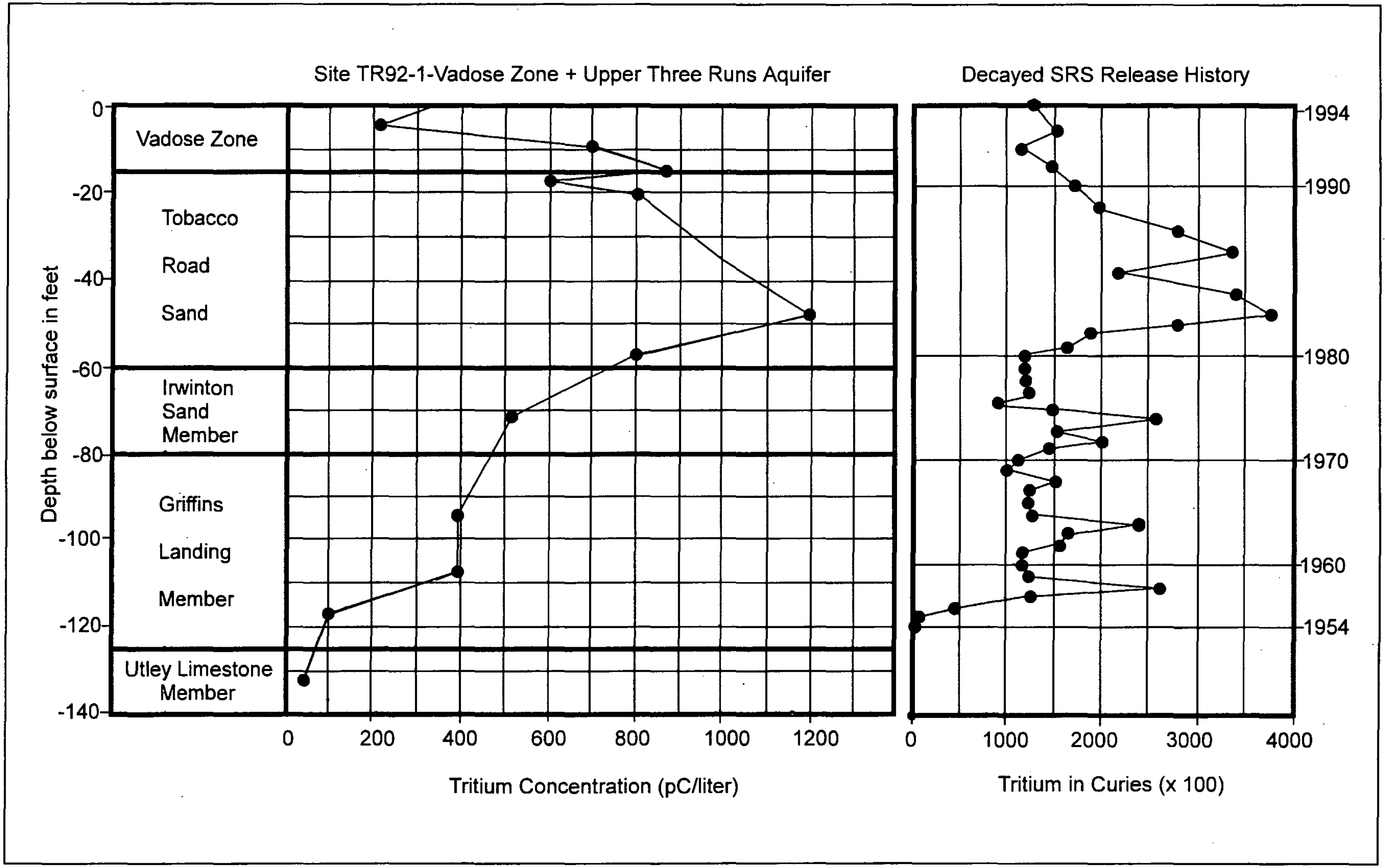


Figure 22. Comparison of a profile of site TR92-1 vertical tritium distribution (vadose zone+ Upper Three Runs aquifer) (left site of graph) and a vertical plot of the decayed Savannah River Site atmospheric release history (right side of graph). Note the different horizontal scales. Atmospheric release data references are listed in Table 1. The irregular vertical time scale (on right) is due to different scaling of the pre-1984 and post-1984 release data. See text for a discussion of scaling in this figure.

is unlikely because the monitoring wells were constructed to strict standards by experienced drilling crews from the Army Corps of Engineers and the Georgia Geologic Survey. If any annular space leakage occurred, we doubt that it would be enough to yield measurable tritium values in 10 confined aquifer monitoring wells at five Tritium Project well cluster sites and the United States Geological Survey Millers Pond site (Tables 11 and 18). Explanations 4 and 5 are also considered unlikely. Although the tritium-polluted Upper Three Runs aquifer was not cased-off during drilling, it is unlikely that sufficient tritium would be introduced to give the observed tritium values. The water used by the Georgia Geologic Survey drilling crew (from Burke County EMA #11-6 inch well) showed tritium values of only 17 picoCuries per liter when tested May 21, 1996. Again, it is unlikely that sufficient tritium would be introduced to give the observed tritium values in the confined aquifers. This is particularly true considering that many of the wells (sites TR92-1, TR92-6, and United States Geological Survey Millers Pond) were heavily pumped during an aquifer test before sampling for tritium.

Of the two sampling-related explanations (6 and 7), the condensation model is unlikely, because the wells were thoroughly purged before sampling. Air contamination of samples is unlikely as atmospheric contact was minimal during sampling. At this time, air contamination remains an untested hypothesis. Overall, there is insufficient evidence to distinguish between natural contamination of the deeper aquifers and human contamination due to drilling or sampling.

Subsurface Geology and Hydrogeology

Pen Branch Fault

The Savannah River channel seismic survey shows that the Pen Branch fault is a broad zone of disturbed rock in the vicinity of Hancock Landing (Figure 1) (Henry, 1995). This interpretation is consistent with the fault zone interpretation of seismic profile GGS-1 (Waddell, and others, 1995). Seismic survey GGS-1 results showed the presence of three fault zones (labeled F_1, F_2, and F_3) along the 7,620 foot seismic line. Waddell, and others (1995) correlated the F_2 fault zone with the Pen Branch fault, but did not attempt to correlate either F_1 or F_3 with other South Carolina faults.

The relationship between fault zone F_1 and NE-SW trending faults at the Savannah River Site is uncertain because the nearest sub-parallel seismic line at the Savannah River Site, SRS-7 (Domoracki, 1995), is approximately 6.7 miles to the northeast of seismic line GGS-1 (Figure 23). Possible correlations of the F_1 fault zone include the following:

1. The F_1 fault zone may be related to the F_2 (Pen Branch) fault zone (W. J. Domoracki, personal communication, 1997);
2. The F_1 fault zone may be the southwest extension of the Tinker Creek fault zone (Figure 42 in Domoracki, 1995);
3. The F_1 fault zone may be the southwest extension of the Upper Three Runs fault zone (Domoracki, and others, 1994; Figure 4 in Henry, 1995); or
4. The F_1 fault zone may represent a fault that has not previously been identified.

Correlation 1 seems most likely because fault zone F_1 lies approximately 270 feet northwest of fault zone F_2 (Pen Branch fault), on seismic line GGS-1. Correlation 2 is unlikely because the Tinker Creek fault zone lies approximately five miles northwest of the Pen Branch fault zone at the Savannah River Site (Figure 7 in Domoracki, 1995). Correlation 3 is unlikely because the Upper Three Runs fault zone lies approximately 5.4 miles northwest of the Pen Branch fault zone at the Savannah River Site (Domoracki, and others, 1994). Additionally, the Upper Three Runs fault zone displacement seems restricted to the basement (W. J. Domoracki, personal communication, 1997). Although the F_1 fault zone may represent a new, previously unidentified fault (Correlation 4), because of its close proximity to the Pen Branch fault zone, assignment of F_1 to the Pen Branch fault zone is the most parsimonious correlation.

On the seismic profile, a third set of minor basement offsets (F_3) lies approximately 740 feet to the southeast of the F_2 fault zone (Figure 20, Plate 1). Waddell, and others (1995) do not offer a correlation for fault zone F_3 with Savannah River Site fault zones. Based on the proximity of the F_2 and F_3 fault zones along seismic line GGS-1, F_3 is considered part of the Pen Branch fault zone.

Therefore, the Pen Branch fault is represented in eastern Burke County by a fault zone that is 0.86 miles wide. For comparison, the Pen Branch fault zone at the Savannah River Site is approximately 1.8 miles wide (Domoracki, and others, 1994). As identified in seismic profile GGS-1, the Pen Branch fault zone likely cuts the lower Dublin aquitard, the upper Midville aquitard, the lower Midville aquitard, and the basal Appleton aquitard. Whether the Pen Branch fault cuts the Gordon aquitard in the study area, remains uncertain.

Minor Fractures or Faults

Most of the short fractures (or stress-release faults) are in close spatial association with the Pen Branch fault zone. This association suggests that these features may be genetically related. This conclusion is supported by the higher density of minor fractures within the fault zone itself. The minor fractures appear to cut all of the stratigraphic seismic reflectors. These fractures may cut the lower Dublin aquitard, the upper Midville aquitard, and the lower Midville aquitard. The density of the fractures in the upper part of the profile suggests that the fractures may cut the upper Dublin and Millers Pond aquitards (Figure 20). It is unclear whether the fractures also cut the Gordon aquitard. The large number of fractures and the fact that they appear to cut most of the aquitards in the stratigraphic sequence suggests that there may be leakage between aquifers near the Pen Branch fault. Therefore, both the Pen Branch fault and the associated fracture system may provide pathways for the movement of tritium from the Upper Three Runs aquifer into deeper, normally confined aquifers.

Channel Features

The seismic profile GGS-1 (Waddell, and others, 1995) shows the presence of several apparent channel features. Three of these (C_1, C_2, C_3) appear to be stacked vertically. Channel feature C_4 is laterally separated from the other channel features. Core TR92-7, however, shows only the normal stratigraphic sequence, without any evidence of scour or channel fill. Therefore, we have two contradictory data sets. Until this discrepancy is resolved, the existence of the channel features remains unconfirmed.

If the channels are real, their origin is unclear. The proximity of the channels to the Pen Branch fault implies a genetic relationship between the two features. The channel feature C_1 and the overlying, smaller C_2 and C_3 features (Figure 20) can be interpreted as the composite result of a persistent channel complex overlying the down-thrown side of the Pen Branch fault zone (Waddell, and others, 1995). Two Savannah River Site seismic reflection surveys (PBF-18 and SRS-7) (Figure 23) show hints of similar stacked channels above the down-thrown side of the Pen Branch fault zone (Domoracki, 1995; M. G. Waddell and W. J. Domoracki, personal communication, 1997). A re-examination of the Savannah River seismic survey of Henry (1995) shows the possible existence of a buried channel feature near Hancock Landing (D. C. Leeth, United States Geological Survey, personal communication,

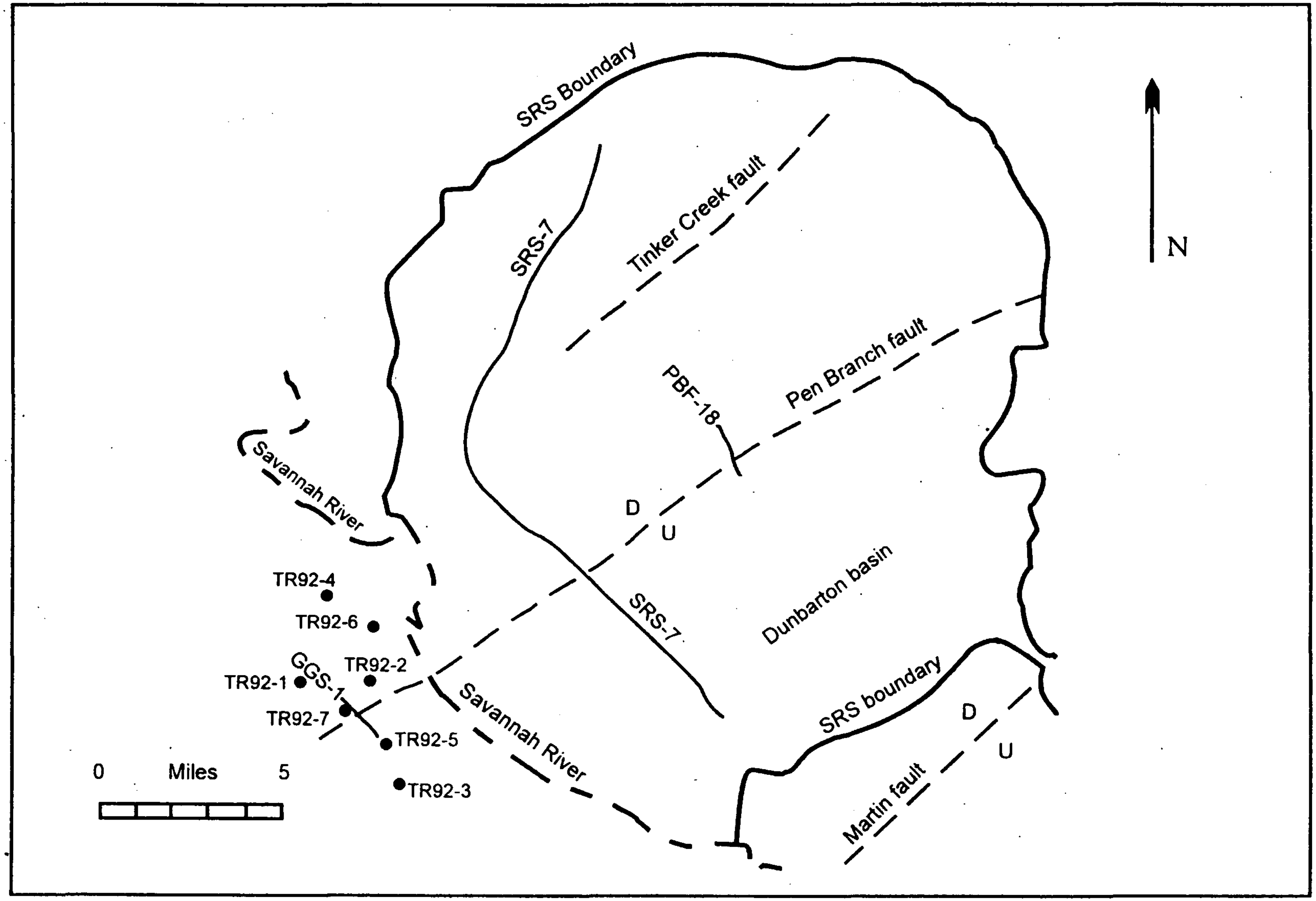


Figure 23. Map showing locations of seismic surveys GGS-1, SRS-7, and PBF-18, the Pen Branch fault, the Martin fault, and Tritium Project well cluster sites. Location of Tinker Creek fault and seismic surveys SRS-7 and PBF-18 are modified from Domoracki (1995).

1995; M. G. Waddell, personal communication, 1995). Isopach and structure contour anomalies, north of Plant Vogtle (Huddlestun and Summerour, 1996), may be due to the influence of both the Pen Branch fault zone and the buried channel features.

Any explanation for the channels would have to account for the dimension of the features. Although other subsurface channels have been identified at the Savannah River Site (Domoracki, 1995; M. G. Waddell and W. J. Domoracki, personal communication, 1997), there is nothing in either Georgia or South Carolina comparable to a buried channel more than 3,000 feet wide and approximately 500 feet deep.

If the channel features are real, aquitards within the channels would have been removed during episodes of down-cutting. Therefore, the channels, if real, could provide a potential pathway for the movement of groundwater (and pollutants) between aquifers.

Hydrogeology of the Upper Three Runs Aquifer at Site TR92-1

Lacking detailed aquifer test data, the generalized hydrogeologic description of the Upper Three Runs aquifer (at site TR92-1) is based on core sample data, hydrogeochemical data, and vertical distribution well data, at the site. The hydrologic components of the unconfined aquifer at site TR92-1 are listed in Table 24. Other discussions of the Upper Three Runs aquifer, in the study area, are included in the Introduction Section of this report.

In the vadose zone, groundwater flow is presumed to be downward, because of the permeable nature of the Tobacco Road Sand. In the "upper" Upper Three Runs aquifer, consistent static water levels in wells TR92-1E through TR92-1I (Figure 13), imply lateral flow in the Tobacco Road Sand, below the water table. Similar recovery rates, in wells TR92-1G and TR92-1H, imply consistent hydraulic conductivity values in the "middle" of the Tobacco Road Sand. The slow recovery rate of well TR92-1I suggests a possible decrease in hydraulic conductivity near the base of the Tobacco Road Sand.

At site TR92-1, the Irwinton Sand Member serves as a semiconfining layer, underlying the "upper" Upper Three Runs aquifer. The marked differences in static water levels in wells TR92-1I (basal Tobacco Road Sand) and TR92-1J (Irwinton Sand Member) (Table 25) suggest a contrast in hydrologic characteristics between these town units. The 27.6 foot difference in static water levels between TR92-1I and TR92-1J suggests a downward gradient from the Tobacco Road Sand into the Irwinton Sand Member.

Static water level differences between well TR92-1J (Irwinton Sand Member) and well TR92-1A (Griffins Landing Member) (Figure 13), imply a downward gradient from the semiconfining layer into the "lower" Upper Three Runs aquifer. Consistent static water levels in wells TR92-1A, TR92-1K, and TR92-1L imply lateral groundwater flow conditions in the "lower" Upper Three Runs aquifer.

Several characteristics of well TR92-1M suggest a dual-porosity model for the Utley Limestone Member (the basal part of the "lower" Upper Three Runs aquifer). During the initial stage of each pumping episode of well TR92-1M, the flow rate is 15 gallons per minute and tritium values are 400 to 500 picoCuries per liter. After approximately two minutes, the flow rate abruptly drops to 5 gallons per minute and the tritium values drop to $\leq$100 picoCuries per liter. The likely scenario for this two-phase pumping regime is that during the first two minutes of pumping, secondary, karstic porosity is the source of the vigorously flowing, tritiated water. After the karstic porosity is discharged, primary, intergranular porosity is the source for the less-vigorously flowing, less-tritiated (possibly older) water. Figure 24 shows the water level variations for well TR92-1M versus

Table 24. Hydrologic components of the Upper Three Runs aquifer at site TR92-1.

Hydrologic unit	**Stratigraphic unit(s)**	**Lithologies**
Vadose Zone	Tobacco Road Sand	Sand
"upper" Upper Three Runs aquifer	Tobacco Road Sand	Sand
semiconfining layer	Irwinton Sand Member, Dry Branch Fm.	Clayey Sand
"lower" Upper Three Runs aquifer	Griffins Landing Member, Dry Branch Fm. Utley Limestone Member, Clinchfield Fm.	Clay, sand, limestone Limestone, sand

Table 25. Differences in static water levels between vertical distribution wells TR92-1I and TR92-1J.

Well	**Stratigraphic unit**	**Screened interval-elevation above mean sea level**	**Water level-elevation above mean sea level**
TR92-1I	Tobacco Road Sand	175-180 feet	219.99 feet
TR92-1J	Irwinton Sand Member	160-165 feet	192.35 feet

water level variations for other selected vertical distribution wells.

Well TR92-1L (lower Griffins Landing Member) shows a similar change in tritium values with pumping. However, well TR92-1L does not experience a drop in flow rate during pumping.

Pathways

Summerour, and others (1994) presented a series of multiple working hypotheses for tritium pathways into the Upper Three Runs aquifer. These hypothetical pathways included: direct lateral transport, indirect lateral transport, point source pollution, upwards transport, downwards transport, and other pathways. Summerour, and others (1994) eliminated the first three of these hypotheses as not being consistent with the evidence available at the time. New data, collected during Phase II studies, allow further evaluation of the downwards transport and upwards transport models. The sixth hypothesis, "other pathways", requires either rejection of all other hypotheses or the proof of a new, unanticipated pathway.

Downwards Transport

The downwards transport model postulates that tritium entered the Upper Three Runs aquifer due to recharge by tritium-contaminated rainwater. Summerour, and others (1994) considered the Phase I data to be consistent with this model but not conclusive. In support of the model, Summerour, and others (1994) cited evidence that rainfall in Burke County is known to contain elevated levels of tritium and that the geographic distribution of tritium in the Upper Three Runs aquifer is consistent with the distribution map for tritium shown in Figure 6 (Murphy, and others, 1991).

Phase II studies show that tritium concentrations within the top five feet of the vadose zone (313 picoCuries per liter +/- 6) are consistent with recent (1991 and 1992) values for tritium in rainfall (500 picoCuries per liter +/- 300) at the nearest rainfall sampling station (Environmental Protection Division station #11) (Figure 4). Average (median) tritium concentrations for the entire 20-foot vadose zone interval (722 picoCuries per liter +/- 9) are consistent with long-term (1982 to 1992) rainfall

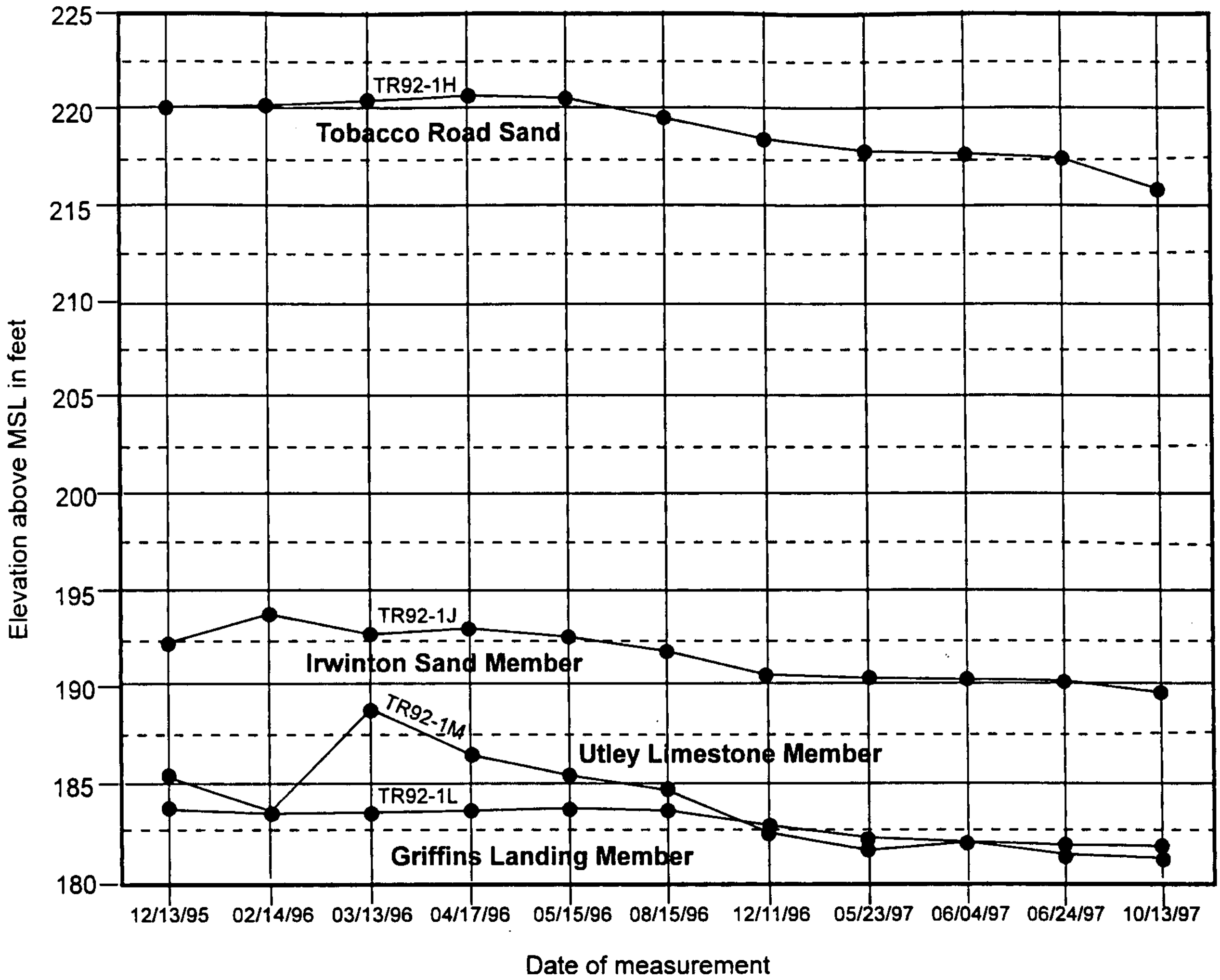


Figure 24. Water level variations in selected vertical distribution wells at site TR92-1. Water level elevations are included in Appendix 4. Site elevation is 235 feet above Mean Sea Level.

tritium concentrations from the same sampling station (900 picoCuries per liter +/- 300). These results are consistent with vadose zone-recharge by tritiated rainfall.

Tritium values at the base of the vadose zone (759 picoCuries per liter +/- 9.5) are consistent with tritium values at the top of the "upper" Upper Three Runs aquifer (600 picoCuries per liter +/- 100). This consistency suggests that the Upper Three Runs aquifer is being recharged by downward flow through the vadose zone. The vertical sequence of tritium values in the vadose zone and the Upper Three Runs aquifer are consistent with the record of Savannah River Site atmospheric tritium releases (corrected for radioactive decay).

A 1993 United States Geological Survey study (Crandall and Berndt, 1996) sampled surficial aquifer water wells in southern Georgia and northern Florida. One variable measured in that study was tritium concentration of the well water samples. Contouring of this tritium data (Figure 25) shows a tritium "plume" originating in Burke County, with an axis parallel to and coincident with the axis of the distribution map of tritium in rainfall (Figure 5). The furthest extent of the 50 picoCurie contour line, of Figure 25, is approximately 100 miles southwest from the center of the Tritium Project study area. As with Figure 5, the southwest orientation of the contour lines, of Figure 25, is likely a product of the prevailing northeast to southwest

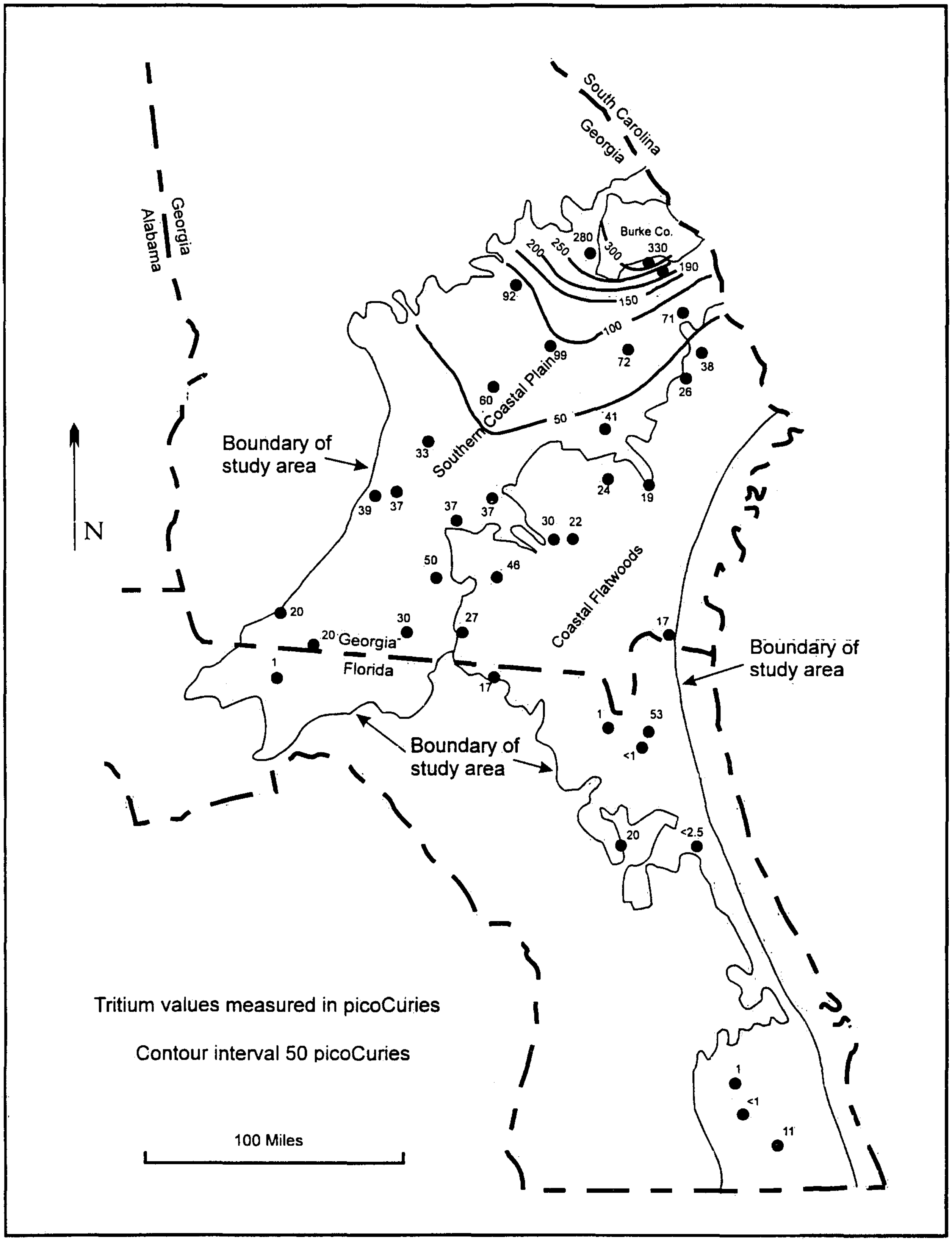


Figure 25. Contour map showing tritium values and locations of 37 wells tested by the United States Geological Survey in southern Georgia and northern Florida, in 1993. Modified from Crandall and Berndt (1996) Data for contours are from C. Crandall, written communitcation (1997).

wind direction (Arnett, and others, 1993; Summerour, and others, 1994) and the deposition of airborne tritium by washout. Beyond the 50 picoCurie contour line, tritium values are consistent with current background tritium values for the southeastern United States, which range from approximately 30 to 50 picoCuries per liter (S. Rose, personal communication, 1997). Wells showing lower than surface-water background values may be due to: (1) dilution by contribution of "pre-nuclear era" water from deeper or partially confined portions of the surficial aquifer; or (2) dilution by rainfall from storms that formed over the Gulf of Mexico or the Atlantic Ocean.

The shape of the tritium "plume" of Crandall and Berndt (1996) is consistent with the baseflow data from Burke County collected by the present authors. The only reasonable way to produce the observed distribution pattern of tritium shown in Figure 25 is through an airborne pathway, i.e., tritiated rainfall deposited by washout and/or rainout.

Although we lack a data-based map of the distribution of tritiated rainfall in Burke County, the preponderance of evidence suggests that the primary tritium pathway into the unconfined aquifer in Burke County is through aquifer recharge by tritiated rainfall.

Upwards Transport

Phase II data and Trans-River Flow Project data suggest that upwards flow is a possible secondary tritium pathway into Burke County confined aquifers. High resolution analyses for tritium in confined aquifers in Burke County show the presence of very low levels of tritium in the Gordon, Millers Pond, Dublin, and Midville aquifers. Samples from eight of ten confined aquifer monitoring wells (Table 18) show tritium concentrations above detection limits. In addition, the United States Geological Survey detected low levels of tritium in the Millers Pond and lower Dublin aquifers at Millers Pond (Table 11) (Clarke, and others, 1994). Considering that the water in these aquifers is very old compared with the half-life of tritium, there should be no tritium present in these aquifers. Therefore, either tritium is leaking into these aquifers or there is consistent contamination of the samples.

The United States Geological Survey Trans-River Flow Project has shown that it is hydrologically feasible for ground water in deep confined aquifers to move from the South Carolina side of the Savannah River into Georgia (Clarke and West, 1997). Tritium is known to occur within the Gordon aquifer under the Savannah River Site (Cummins, and others, 1991; Murphy, and others, 1991; Arnett, and others, 1992). It is therefore possible for tritiated ground water to move into Georgia.

The Pen Branch fault zone, associated minor faults, and possible channel features all disrupt confining beds in eastern Burke County. Such disruption allows for potential vertical movement of tritiated ground water. In addition, the Pen Branch fault zone connects areas of tritium pollution at the Savannah River Site with the center of the tritium "plume" in Burke County.

Therefore, upwards flow remains a possible secondary pathway for tritium into Georgia aquifers. Such a pathway is probably not a major factor in the tritium pollution of the unconfined aquifer, at the present time. However, the Pen Branch fault and the subsurface channel features may be potential pathways for tritium into those aquifers.

RECOMMENDATIONS

Based on the results of the Georgia Geologic Survey investigations on tritium in the ground water of Burke County, we make the following seven recommendations. The recommendations fall into the broad categories of technical studies and long-term monitoring.

Technical Studies

Recommendation 1. We recommend that the United States Department of Energy conduct or fund additional studies of the water table (Upper Three Runs) aquifer in eastern Burke County. Specifically we recommend that studies be conducted to evaluate the following characteristics of the water table aquifer:

1. The vertical distribution of tritium within the water table aquifer and vadose zone should be corroborated. Information on the vertical distribution of tritium has been measured at one site. At least of two additional sites are needed to generalize the results for eastern Burke County. This will provide important information on which parts of the aquifer are polluted, provide guidance to well drillers concerning the placement of domestic water wells, and provide information on the fate of tritium once introduced into the aquifer. This is an extension of recommendation 4(1) in Summerour, and others (1994).

2. The hydraulic properties of the Upper Three Runs aquifer should be established through aquifer tests. The hydraulic properties will allow the Georgia Department of Natural Resources to predict the horizontal and vertical flow rates within the aquifer and the effects of pumping on the aquifer. One nest of Upper Three Runs aquifer monitoring wells already exists at site TR92-1. This is the same as recommendation 4(3) in Summerour, and others (1994), which was not previously funded.

Recommendation 2. We recommend that the Department of Energy conduct or fund additional studies of the confining bed at the base of the water table aquifer in eastern Burke County. Specifically we recommend that measurements be made to assess the vertical hydraulic conductivity of the confining bed and the potential for leakage of tritiated ground water from the water table aquifer into the upper Gordon aquifer. This is the same as recommendation 5 in Summerour, and others (1994), which was not previously funded.

Recommendation 3. We recommend that the Department of Energy conduct or fund additional studies of the Pen Branch fault in Georgia. Specific studies should include the following:

1. Conduct additional seismic surveys to establish the geographic extent of the Pen Branch fault in Georgia.

2. Evaluate the effect of the Pen Branch fault on lateral and vertical ground-water flow and transport of tritium.

Recommendation 4. We recommend that the Department of Energy conduct or fund additional studies of the large-scale channel features detected in seismic profile GGS-1. Specific studies should include the following:

1. Conduct additional seismic surveys to establish the geographic extent of the channel features in Burke County. This can be done simultaneously with recommendation 3(1).

2. Evaluate the effect of the channel features on lateral and vertical ground-water flow and transport of tritium. This can be done simultaneously with recommendation 3(2).

Recommendation 5. We recommend that the Department of Energy conduct or fund studies concerning the occurrence of tritium in confined aquifers of eastern Burke County. Such studies would resolve the question of secondary pathways for tritium into Georgia aquifers.

Long-term Monitoring

Recommendation 6. We recommend that the Department of Energy establish or fund a long-term monitoring network for periodic sampling of ground water from both the Upper Three Runs aquifer and the Gordon aquifer in eastern Burke County. This network can use monitoring wells already constructed as part of Tritium

Project Phase I and as part of the Geological Survey Trans-River Flow Project.

Recommendation 7. We recommend that annual baseflow studies be incorporated as part of a long-term monitoring program. Baseflow studies are the best available method for evaluating the extent of pollution in the water table aquifer in Burke County. Annual baseflow studies will show whether the area of pollution is expanding or contracting.

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APPENDIX 1

Identification of wells sampled during Tritium Project Phase II by Environmental Protection Division personnel.

Owner/resident	**Date**	**Lab #**	**Tritium-picoCuries per liter**
3. A & A Store #3 (DeLaigle Mobile Home Park Well #3 [1]	9/28/94 2/27/95 5/03/95 7/10/95	S-6760 S-7011 S-7027 S-7098	900 +/- 100 1000 +/- 100 1000 +/- 100 900 +/- 100
6. Arthur Jackson	5/17/95 4/18/96	S-7036 S-7374	1200 +/- 200 800 +/- 100
9. Bill Sturgeon	10/26/94 4/18/96	S-6971 S-7373	1000 +/- 100 1000 +/- 100
12. Burke County EMA #11 4" well	5/21/96	S-7404	<100
33. Frank Wimberly	5/31/95 5/21/96	S-7042 S-7405	1000 +/- 100 900 +/- 100
36. George Wilson	5/31/95 5/21/96	S-7043 S-7406	600 +/- 100 400 +/- 100
46. Hug-A-Hog Plantation	2/27/95	S-7013	600 +/- 100
46A Hug-A-Hog Plantation II [2]	2/27/95	S-7014	<100
56. Julian Morris	9/28/94	S-6761	300 +/- 100
59A. Lamar Paul [3]	9/27/94	S-6754	<100
65. Mary Johnson	9/27/94	S-6753	1500 +/- 200
77. Walnut Run Ostrich Farm	10/26/94 4/18/96	S-6972 S-7372	600 +/- 100 800 +/- 100
79. Ralph Greer	9/28/94 4/18/96	S-6762 S-7371	500 +/- 100 600 +/- 100
108. Alma Crook [4]	9/27/94	S-6756	1600 +/- 200
109. Earl Mills	9/27/94	S-6755	600 +/- 100
110. Michael Kelly	11/08/94	S-6931	1200 +/- 200
111. Thomas Self	11/08/94	S-6932	1800 +/- 200
112. Joel Swanigin	2/27/95	S-7010	<100

1. Well pump removed 9/95 and well plugged by EPD (see text). 2. Well in front of trailer, across dirt road from #46. 3. Original well (59) plugged and replaced by owner in early 1994. 4. Well plugged in early 1995.

APPENDIX 2

Results of Tritium Analyses from Ground-Water Monitoring Wells. Cluster site locations are shown in Figure 2. All tritium values are in picoCuries per liter.

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-1A-Upper Three Runs	2/09/94	S-6714	<100
TR92-1A	9/28/94	S-6766	<100
TR92-1A	5/03/95	S-7028	<100
TR92-1A	2/14/96	S-7302	500 +/- 100
TR92-1A	3/13/96	S-7339	400 +/- 100
TR92-1A	4/17/96	S-7361	400 +/- 100
TR92-1A	4/17/96	S-7362	400 +/- 100
TR92-1A	6/24/96	S-7428	400 +/- 100
TR92-1A	6/24/96	S-7429	300 +/- 100
TR92-1B-Gordon	2/09/94	S-6715	<100
TR92-1B	9/28/94	S-6767	<100
TR92-1B	5/03/95	S-7029	<100
TR92-1B	6/17/95	High resolution	<3
TR92-1C-Millers Pond	5/03/95	S-7021	<100
TR92-1C	6/17/95	High resolution	4.06 +/- .68
TR92-1D-Dublin	5/03/95	S-7030	200 +/- 100
TR92-1D	6/17/95	High resolution	23.66 +/- 1.35
TR92-1D	11/16/95	High resolution	9.06 +/- .44

Other site TR92-1 results are shown in Appendix 3.

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-2A-Upper Three Runs	2/04/94	S-6712	1500 +/- 100
TR92-2A	9/28/94	S-6764	1400 +/- 100
TR92-2A	5/03/95	S-7024	1300 +/- 100
TR92-2A	6/21/96	S-7420	1700 +/- 100
TR92-2A	6/21/96	S-7421	1600 +/- 100
TR92-2B-Gordon	9/29/94	S-6765	<100
TR92-2B	5/03/95	S-7032	<100
TR92-2B	6/16/95	High Resolution	5.4 +/- .34
TR92-2B	6/24/96	S-7424	<100
TR92-2B	6/24/96	S-7425	<100

APPENDIX 2 (continued)

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-3B-Gordon	5/03/95	S-7025	<100
TR92-3B	6/16/95	High Resolution	5.75 +/- .34
TR92-3B	6/24/96	S-7422	<100
TR92-3B	6/24/96	S-7423	<100

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-4A2-Upper Three Runs	2/09/94	S-6713	1400 +/- 100
TR92-4A2	5/03/95	S-7026	1400 +/- 100
TR92-4A2	6/24/96	S-7449	1200 +/- 100
TR92-4A2	6/24/96	S-7450	1100 +/- 100
TR92-4B-Gordon	9/29/94	S-6763	<100
TR92-4B	5/03/95	S-7022	<100
TR92-4B	5/03/95	High Resolution	<1.35
TR92-4B	6/24/96	S-7451	<100

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-5A-Upper Three Runs	2/04/94	S-6710	900 +/- 100
TR92-5A	9/29/94	S-6758	800 +/- 100
TR92-5A	5/03/95	S-7031	900 +/- 100
TR92-5A	6/21/96	S-7415	900 +/- 100
TR92-5A	6/21/96	S-7416	700 +/- 100
TR92-5A	6/21/96	S-7417	600 +/- 100
TR92-5B-Gordon	5/03/95	S-7032	<100
TR92-5B	6/17/95	High Resolution	13.86 +/- .34
TR92-5C[1]	2/04/94	S-6711	400 +/- 100
TR92-5C	9/29/94	S-6759	500 +/- 100
TR92-5C	5/03/95	S-7033	400 +/- 100
TR92-5C	6/21/96	S-7418	400 +/- 100
TR92-5C	6/21/96	S-7419	100 +/- 100

1. 100 feet-screened in Gordon aquitard and Gordon aquifer.

APPENDIX 2 (continued)

Well Designation and Aquifer	Collection Date	Lab ID Number	Tritium Content
TR92-6A2 Upper Three Runs	5/30/95	S-7040	900 +/- 100
TR92-6A2	5/31/95	S-7041	1000 +/- 100
TR92-6A2	5/23/96	S-7409	1000 +/- 100
TR92-6A2	5/23/96	S-7410	800 +/- 100
TR92-6A2	5/23/96	S-7411	700 +/- 100
TR92-6B Gordon	9/28/94	S-6757	<100
TR92-6B	6/16/95	High Resolution	5.41 +/- .34
TR92-6C Dublin	11/09/95	High Resolution	1.89 +/- .10
TR92-6D Midville	11/08/95	High Resolution	4.06 +/- .20

APPENDIX 3

Results of low resolution tritium analyses from Upper Three Runs aquifer vertical distribution wells.

Well Number	Date Collected	Lab ID Number	Results-picoCuries per liter
TR92-1E (bailed) Tobacco Road Sand	2/14/96	S-7303	600
	3/13/96	S-7332	700
	4/17/96	S-7352	500
	5/16/96	S-7400	600
TR92-1F (bailed) Tobacco Road Sand	2/14/96	S-7304	900
	3/13/96	S-7333	800
	4/17/96	S-7353	700
	5/16/96	S-7399	800
TR92-1G Tobacco Road Sand	2/14/96	S-7305	1000
	2/14/96	S-7306	900
	3/13/96-	S-7334	1000
	3/13/96	S-7335	1000
	4/17/96-	S-7354	900
	4/17/96	S-7355	1100
	5/16/96	S-7397	900
	-5/16/96	S-7398	1000
TR92-1H Tobacco Road Sand	2/14/96	S-7307	1200
	2/14/96	S-7308	1300
	3/13/96	S-7336	1200
	3/13/96	S-7337	1300
	4/17/96	S-7356	1300
	4/17/96	S-7357	1200
	4/17/96	S-7358	1300
	5/16/96	S-7382	1100
	5/16/96	S-7383	1100
	5/16/96	S-7384	1100
	5/16/96	S-7385	1000
TR92-1I Tobacco Road Sand	2/14/96	S-7309	300
	2/14/96	S-7310	800
	3/13/96	S-7338	800
	4/17/96	S-7359	900
	4/17/96	S-7360	900
	5/16/96	S-7380	700
	5/16/96	S-7381	700
TR92-1J Dry Branch Fm.. Irwinton Sand Member	2/14/96	S-7311	500
TR92-1A Dry Branch Formation Griffins Landing Member	2/14/96	S-7302	500
	3/13/96	S-7339	400
	4/17/96	S-7361	400
	4/17/96	S-7362	400
	5/16/96	S-7394	300
	5/16/96	S-7395	300
	5/16/96	S-7396	400
	6/24/96	S-7428	400
	6/24/96	S-7429	300
TR92-1K Dry Branch Formation. Griffins Landing Member	2/14/96	S-7312	600
	3/13/96	S-7340	400
	3/13/96	S-7341	400
	4/17/96	S-7363	500
	4/17/96	S-7364	400
	5/16/96	S-7386	300
	5/16/96	S-7387	300
	5/16/96	S-7388	400

APPENDIX 3 (continued)

TR92-1L Dry Branch Formation. Griffins Landing Member	2/14/96	S-7313	<100
	3/13/96	S-7342	100
	3/13/96	S-7343	<100
	4/17/96	S-7365	400
	4/17/96	S-7366	100
	5/16/96	S-7376	300
	5/16/96	S-7377	300
	5/16/96	S-7378	200
	5/16/96	S-7379	<100
	6/24/96	S-7426	<100
	6/24/96	S-7427	<100
TR92-1M Clinchfield Formation Utley Limestone Member	2/14/96	S-7314	<100
	3/13/96	S-7344	400
	3/13/96	S-7345	<100
	4/17/96	S-7367	500
	4/17/96	S-7368	400
	4/17/96	S-7369	<100
	4/17/96	S-7370	<100
	5/16/96	S-7389	500
	5/16/96	S-7390	500
	5/16/96	S-7391	400
	5/16/96	S-7392	<100
	5/16/96	S-7393	<100
	6/24/96	S-7452	<100
	6/24/96	S-7453	<100

See text for explanation of tritium variations in wells TR92-1L and TR92-1M.

APPENDIX 4

Water level elevations in vertical distribution wells at site TR92-1 (in feet above Mean Sea Level). Water level elevations are not corrected for minute elevation variations between wells. Site elevation is 235 feet above Mean Sea Level. Diagram of wells is shown in Figure 13.

Well	12/13/95	02/14/96	03/13/96	04/17/96	05/15/96	8/15/96	05/23/97	06/04/97	06/24/97	10/13/97
TR92-1E	219.23	219.28	219.69	219.72	219.52	218.82	216.93	216.83	216.72	216.05
TR92-1F	218.83	218.85	219.32	219.42	219.23	218.38	216.45	216.37	216.23	215.56
TR92-1G	219.04	219.10	219.23	219.65	219.48	218.62	216.77	216.62	216.49	215.82
TR92-1H	220.18	220.22	220.50	220.78	220.60	219.73	217.84	217.74	217.59	215.94
TR92-1I	219.99	220.02	220.31	220.61	220.40	219.57	217.71	217.60	217.46	215.81
TR92-1J	192.35	193.85	192.82	193.00	192.63	191.95	190.43	190.44	190.31	189.80
TR92-1A	183.54	183.09	183.22	183.44	183.49	183.33	181.72	181.76	181.61	181.13
TR92-1K	183.53	183.30	183.23	183.45	183.48	183.36	181.70	181.78	181.40	180.82
TR92-1L	183.83	183.62	183.58	183.73	183.80	183.69	181.99	182.07	181.71	181.39
TR92-1M	185.48	183.67	188.91	186.64	185.43	184.64	181.74	181.97	181.39	181.21

Editor: Joseph Summerour

Seismic reflection survey conducted June, 1995, by Earth Sciences and Resources Institute, University of South Carolina

Seismic datum-270 feet above Mean Sea Level   Core hole elevation-255 feet above MSL

Core hole depth-730 feet below surface, terminating in the Gaillard/Black Creek interval

C_1-Interpreted channel features F_1-Interpreted fault zones

Tertiary/Cretaceous boundary-top of Steel Creek Formation

Major feature interpretations by Waddell, M.G.; Keith, J.F.; and Domoracki, W.J. (1995)

Minor fracture/fault interpretations by Shapiro, E. A. and Summerour, J. H.

ESRI
UNIVERSITY OF SOUTH CAROLINA

GEORGIA GEOLOGICAL SURVEY

PEN BRANCH FAULT
BURKE CO., GEORGIA

LINE GGS-1

MIGRATED STACK

DATUM 270 FT

N <--------------------------------

RECORDING PARAMETERS

DATE RECORDED	JUNE 1995	SOURCE ARRAY	NONE
CONTRACTOR	ESRI	RECEIVER ARRAY	3 PH/BUNCH
GROUP INTERVAL	10 FT	GEOPHONE NAT FREQ	40 HZ
SHOT INTERVAL	20 FT	ENERGY SOURCE EWG/	6 DROPS
RECORDER	OYO DAS/ 96 CHAN	SAMPLE RATE	0.5 MS
RECORDING FMT	SEG-2	RECORD LENGTH	1000 MS
NEAR OFFSET	10.0 FT	LOW-CUT FILTER	3 HZ
FAR OFFEST	960.0 FT	HIGH-CUT FILTER	ANTIALIAS

SPREAD CONFIGURATION

```
          SP   TR 1                          TR 96
          *     +----------------------------+
               10.0 FT                      960 FT
```

PROCESSING SEQUENCE

```
REFORMAT SEG-2 TO SEG-Y
NOTCH FILTER
    60. 180. 240. 300 HZ
F-K FILTER PIE-SLICE
    +.5 K 10-175 HZ
    TAPER 45 PTS.
RESAMPLE 1.0 MS
TRACE EDITS
GEOMETRY
CROOKED LINE COMMON MIDPOINT SORT
DATUM STATICS
   DATUM 270 FT
   VELOCITY 2953 FT/S (900 M/S)
SPHERICAL DIVERGENCE CORRECTION
VELOCITY ANALYSIS - CONSTANT VEL STKS
RESIDUAL STATICS - QUASI-SURF. CONSIST.
   PILOT 11 TR MIX  5 MS CORRELATION
   ITERATIVE WITH VEL. ANALYSIS
   4 INTERATIONS STATICS W/ VELOCITY
NMO/BP FILTER 40-50-200-250 HZ
AGC 150 MS
MUTE
STACK W/ ROOTN SCALING
BANDPASS FILTER 40-50-200-250 HZ
PREDICTIVE DECONVOLUTION
   GAP 10 MS OPERATOR 15 MS
   AUTOCORRELATION GATE 50-890 MS
TRACE MIX 5 PTS
   WEIGHTS .25 .5 1.0 .5 .25
BANDPASS FILTER 40-50-200-250 HZ
AGC 250 MS
MIGRATION - FINITE DIFFERENCE
   MIGRATION W/ 90 % OF STK VEL.
BANDPASS FILTER 40-50-200-250 HZ
AGC 250 MS
```

DISPLAY PARAMETERS

TRACES PER INCH	40.0	DATE PROCESSED	JULY 1995
INCHES PER SECOND	10.0	POLARITY	NORMAL

Georgia Geologic Survey

Information Circular 102

Plate 1.

Seismic Profile GGS-1
Burke County, Georgia

Modified from Waddell, and others (1995)