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Ecology
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Permanent

SRS ECOLOGY

ENVIRONMENTAL INFORMATION DOCUMENT

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JULY 2006

Washington Savannah River Company
Savannah River Site
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Prepared for the U.S. Department of Energy Under
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Chapter 2 - Vegetation
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Chapter 3 - Wildlife and Threatened and Endangered Species
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PREFACE

The SRS Ecology - Environmental Information Document (EEID, WSRC-TR-2005-00201), is the third iteration of a document originally conceived and produced in the early 1990s by scientists of what is now known as the Environmental Analysis Section of the Savannah River National Laboratory. The original document of the same title was released both as a paper copy and compact disc in 1994 (WSRC-TR-93-497) and was updated by WSRC-TR-97-0223 in 1997. The initial objective of the EEID was to provide a summary and overview of relevant environmental information and conditions at the Savannah River Site (SRS) at a level appropriate for incorporation into environmental documents, such as Environmental Impact Statements and Resource Conservation and Recovery Act (RCRA) Facility Investigation/ Remedial Investigation (RFI/RI) reports. Prior to the conception of the EEID, individual documents were produced whenever ecological information was required for regulatory documentation of any major project. As a result, the EEID has consistently been one of the most frequently referenced documents produced at SRS. The original EEID covered research and monitoring data available through approximately 1992. The first revision covered data available primarily through 1996, though some data are from 1997. The current iteration includes information as recent as 2004.

The original EEID was a massive undertaking made possible through the efforts of a large number of individual authors. The current EID was updated by the individuals listed as authors, but it contains copious information dating back to the original document. Therefore it is important that all those original authors be recognized here. They were: J. A. Bowers, A. L. Bryant, K. F. Chen, C. L. Cummins, B. R. del Carmen, K. L. Dixon, D. L. Dunn, G. P. Friday, N. V. Halverson, J. E. Irwin, R. K. Kolka, H. E. Mackey, Jr., J. J. Mayer, M. H. Paller, R. S. Riley, V. A. Rogers, W. L. Specht, H. M. Westbury, E. W. Wilde.

The following is an excerpt from the preface of the previous revision of the EEID and is included here because it still accurately characterizes the background and intent of the current document.

> *Since its establishment in the 1950s, the mission of the SRS was production of plutonium and tritium to support the defense, research, and medical programs of the United States. Currently all five production reactors on the Site are permanently shut down, a reflection of the changing world, the end of the Cold War and the reduction in the size of the U.S. nuclear weapons stockpile. The SRS mission now is focused on national security work, recycling and reloading of tritium, environmental cleanup and legacy waste management. Because of the unique capabilities at SRS, the Site is frequently evaluated for new missions.*

During the early 1990s, when the original EEID was being written, the U.S. Department of Energy (DOE) still planned to restart K Reactor and build a New Production Reactor; cold testing of the Defense Waste Processing Facility (DWPF) had begun; the water level of Par Pond had been drawn down for dam repairs; and the Federal Facilities Agreement (FFA), which would direct environmental restoration activities at SRS, had just been drafted. During the period 1993 through 1997, the status of the Site's facilities has changed dramatically. There are no further plans to operate existing reactors or build new ones, but an accelerator is being designed for tritium production. Par Pond has been filled again, DWPF is operating, and approximately 250 acres of waste sites have been put into remediation in accordance with the FFA. During this period, the focus of ecological and environmental research and monitoring has shifted from thermal and other reactor-related effects to waste site characterization and restoration, bioremediation, innovative natural resource management, and National Environmental Policy Act (NEPA) support.

The revised EEID reflects this shift in focus. The results of thermal effects studies are still included, but have been reduced in focus. Results from new studies, including toxicity studies, bioassessments, and urban wildlife studies have been added. Ongoing studies have been updated where new data exists; in many cases, however, the data in the original EEID are the most recent data available.

The EEID is not meant to be an exhaustive account of all ecological information related to the Savannah River Site. Reports on other studies are available through the Savannah River Technology Center, Savannah River Ecology Laboratory, Savannah River Forest Station and other organizations.

EXECUTIVE SUMMARY

The SRS Ecology Environmental Information Document (EEID) provides a source of information on the ecology of Savannah River Site (SRS). The SRS is a U.S. Department of Energy (DOE) - owned property on the upper Atlantic Coastal Plain of South Carolina, centered approximately 40 kilometers (25 miles) southeast of Augusta, Georgia. The entire site was designated a National Environmental Research Park in 1972 by the Atomic Energy Commission, the predecessor of DOE. This document summarizes and synthesizes ecological research and monitoring conducted on the three main types of ecosystems found at SRS: terrestrial, wetland and aquatic. It also summarizes the available information on the threatened and endangered species found on the Savannah River Site.

SRS is located along the Savannah River and encompasses an area of 80,267 hectares (310 square miles) in three South Carolina counties. It contains diverse habitats, flora, and fauna. Habitats include upland terrestrial areas, wetlands, streams, reservoirs, and the adjacent Savannah River. These diverse habitats support a variety of plants and animals, including many commercially or recreationally valuable species and several rare, threatened, or endangered species.

Soils are the basic terrestrial resource, influencing the development of terrestrial biological communities. Many different soils exist on the SRS, from hydric to well-drained, and from sand to clay. In general, SRS soils are predominantly well-drained loamy sands. Chapter 1, Soils, provides descriptions and shows the locations of the various soil types at SRS.

The SRS has 1,322 documented plant species, representing 151 separate taxonomic families. Chapter 2, Vegetation, discusses terrestrial land cover types found on the SRS including: landscaped areas around administrative and production facilities; grassland/forb/scrub-shrub communities, found in power line rights-of-way, forest openings, wildlife food plots, and recently clear cut or block-planted areas; natural pine or deciduous forests and pine plantations; bottomland hardwood forests along streams and within the Savannah River swamp; and the swamp forest along the Savannah River. The Savannah River Forest Station (SRFS), an office of the U. S. Forest Service, manages nearly 182,000 acres of pine plantations for commercial timber production. Thirty areas of the site, comprising 569 ha (1406 acres), have been protected as “set-aside” areas because they support unique vegetation communities, including natural pine stands, hardwood forests, riparian areas, swamp forests, and Carolina bays.

Chapter 3 contains two parts:

- Wildlife describes the diverse and abundant fauna found at the SRS due to its temperate climate and numerous habitats.
- Threatened and Endangered Species discusses the status of species of concern at SRS. The bald eagle, wood stork, red-cockaded woodpecker, shortnose sturgeon, and smooth purple cone flower, which are listed by the federal government as endangered, have been found on or in the vicinity of SRS.

Herpetofauna on the SRS include 17 salamanders, 27 frogs and toads, one crocodilian, 13 turtles, 9 lizards, and 36 snakes. SRS supports a diverse avifauna that includes migrant, seasonal, and permanent residents. Surveys have identified 255 species of birds, including five non-native or exotic species. Fifty-four of the 61 species of mammals found in South Carolina may occur on SRS. Developed areas on the site are utilized by 144 species, including amphibians, birds and mammals. Potentially valuable commercial and recreational wildlife resources are present on the SRS, but generally are not available for exploitation due to restricted access to the Site. Public hunts of white-tailed deer and wild pigs are the only available public recreational use of SRS wildlife. From 1965 to 2003, 41,392 deer and 11,290 pigs were killed during organized public hunts. Other game management activities at the SRS include trapping and removing wild pigs and beavers, and propagation of wild turkeys to stock other areas of the country.

The brother spike mussel, American swallow-tailed kite, and gopher tortoise, which are listed as endangered species by the State of South Carolina, have been found on or in the vicinity of SRS. The American alligator, listed as threatened by similarity of appearance, is a common inhabitant of SRS aquatic systems. In addition, many other plants and animals are found on the SRS that are considered species of special concern by state or federal government agencies.

The bald eagle, wood stork, red-cockaded woodpecker, shortnose sturgeon, and alligator are the most studied of these species of concern found on the SRS. The bald eagle is a permanent breeding resident of South Carolina and has been recorded as occurring in the SRS area since 1904. Three bald eagle nests are located on SRS, and between 1986 and 2003, 25 nestlings were fledged. Wood storks from the Birdsville colony near Millen, Georgia, and from additional colonies near the Birdsville colony forage at SRS. Data from studies begun in 1983 indicate that while SRS discharges to the Savannah River swamp may have adversely affected wood stork foraging areas, the constructed Kathwood Lake facilities more than compensated for any potential adverse effects. Since 1985, one component of the SRFS's wildlife management program has focused on improving red-cockaded woodpecker habitat. The 2003 population comprised 177 individuals in 45 breeding groups. Shortnose sturgeon spawn in the Savannah River upstream and downstream of SRS. However, there is no evidence that the population of shortnose sturgeon in the Savannah River is negatively impacted by SRS operations. The American alligator, due to its previous endangered status, has been extensively studied at the SRS. Recent research indicates that the alligator population on the SRS is increasing.

Chapter 4 (the largest chapter of this document), Streams, Reservoirs and the Savannah River, describes the physical and biological characteristics of SRS's aquatic resources and summarizes information from the many aquatic studies conducted through the years at SRS. Aquatic systems have been the major focus of ecological research at SRS primarily because of the impacts to them from reactor operations. From the middle 1950s until the late 1980s, cooling water from SRS nuclear reactors was released directly to small tributary streams or cooling reservoirs at temperatures in excess of 35° to 40°C (95° to 104°F) and frequently as high as 65° to 70°C (149° to 158°F).

Aquatic habitats at the SRS include six major streams, two large reservoirs, the Savannah River, and the Savannah River swamp system. The five streams that originate on, or pass through the SRS before flowing into the Savannah River are: Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Steel Creek, and Lower Three Runs. A sixth stream, Pen Branch, does not flow directly into the Savannah River, but joins Steel Creek in the Savannah River floodplain swamp. The upper reaches of Lower Three Runs were impounded in 1958 to form Par Pond, a recirculating cooling reservoir for cooling water from P and R Reactors. L Lake was formed in 1985 by damming Steel Creek above the Meyers Branch confluence to receive cooling water from L Reactor. Sections in Chapter 4 are devoted to each of the six streams, the two impoundments and the Savannah River, describing their hydrology, water chemistry and biota.

Upper Three Runs has the largest watershed of the six major SRS streams. It is the only stream to originate offsite and the only one that never received major thermal discharges, though it does receive discharges from a variety of industrial facilities. Beaver Dam Creek, with the smallest watershed and the lowest mean flows, received cooling water discharges from the heavy water facility and continues to receive discharges from a coal-fired power plant and its associated ash ponds. Fourmile Branch and Pen Branch have similar sized watersheds, lengths, and headwater characteristics. These streams received reactor cooling water from C and K reactors, respectively, at peak flows of approximately 11 m^3 /s, though the 1995 flows of 1 - 2 m^3 /s are more representative of natural flows. Steel Creek received cooling water discharges from P and L Reactors. Stream flow reached 24 m^3 /s when both reactors were discharging, but the 1995 flow of 2.4 m^3 /s is more representative of natural flows. Flows in Steel Creek downstream of the L Lake dam are controlled to meet or exceed regulated minimum flows downstream. Lower Three Runs has the second largest watershed of the site streams and has received effluent from P and R Reactors. Flows in Lower Three Runs downstream from Par Pond have not fluctuated as greatly as those in Steel Creek.

SRS surface water quality is monitored by routine and nonroutine programs. Intake and discharge of cooling water historically have been the main SRS activities affecting site surface water quality. Since cessation of reactor operations, the SRS waterways receive only permitted industrial discharges. Physical factors once affected by the high discharge flows associated with reactor operations, such as erosion, sediment load, and channel morphology, are no longer the issues. Recent studies have focused on chemical and biological systems related to specific effluents or waste sites and toxicity assessments of outfalls. In L Lake and Par Pond, recent efforts have focused on characterizing contaminants in the water and sediments related to the Par Pond drawdown, and to the potential shutdown of the river water pumping system.

Historic discharges of reactor cooling water influenced the algae and zooplankton communities in site waters by increasing flow, temperature, and nutrients relative to ambient conditions. Effects on stream systems included changes in species composition and increased productivity compared to non-thermal streams. Since studies began, the principal effect from P-Reactor operation on the lower food chain organisms of Par Pond was increased productivity. Species observed since the reactors ceased operating are primarily the same as those observed during operations, indicating that the algal community remained stable.

Thermal input and nutrient enrichment from once-through cooling water discharges to L Lake resulted in algal communities dominated by blue-green algae during the first two years after the lake was constructed. Since L Reactor ceased operating in 1988, the algal community has stabilized and become more typical of southeastern reservoirs.

Macroinvertebrates have been studied to assess the impacts of SRS discharges on aquatic systems. Macroinvertebrates in Upper Three Runs and its tributaries include rare species or combinations of species and the stream exhibits high species diversity. During reactor operation, fewer numbers and species of macroinvertebrates were found in the thermal portions of the affected streams than in the non-thermal areas of the same streams. Following final shutdown of individual reactors, macroinvertebrates recolonized the receiving streams to varying degrees. The L Lake macroinvertebrate populations fluctuated and were adversely affected by thermal discharges, but have become similar to those in other southeastern reservoirs since L Reactor ceased operating. The Par Pond macroinvertebrate community also showed evidence of thermal impacts during reactor operations, but has not been studied since 1989.

The SRS supports a diverse fish fauna in a variety of aquatic habitats. Fish assemblages in Upper Three Runs, the reaches of Pen Branch and Fourmile Branch above the reactors and Lower Three Runs are typical for unimpacted streams of similar size in the Southeast. Areas in Fourmile Branch and Pen Branch downstream of C and K Reactors largely were devoid of fish during reactor operations due to the high cooling water discharge flows and temperatures. These areas have been recolonized since the reactors ceased operating. The Steel Creek fish assemblage below the newly constructed reservoir was not significantly influenced by L-Reactor restart and operations except for the reach directly below L Lake, where increased discharges and emigration of L-Lake fish altered community structure.

The fish community in the lower half of L Lake developed as expected during the lake's early years, though the warmer temperatures near the reactor discharge point precluded normal community development in the upper half. Since L Reactor has ceased operating and nutrient loading as a result of Savannah River input has been reduced, the L Lake fish community has continued to change. Currently the community includes successfully reproducing, self sustaining populations of species common in southeastern reservoirs.

Apart from the congregation of some species in thermal areas and lower than average condition among adult largemouth bass, the Par Pond fish community has been typical of southeastern reservoirs. The Par Pond drawdown between 1991 and 1995 severely disturbed the fish community, reducing the density and number of species, and altering the size structure of individual species as a result of decreased habitat size and quality. However, the fish community rapidly recovered following refill.

Chapter 5 covers Wetlands and Carolina Bays of the SRS. Twenty percent of the SRS is classified as wetlands. The majority of these wetlands are bottomland hardwoods or cypress-tupelo forests. The remaining areas include wetlands surrounding the two large reservoirs (Par Pond and L Lake), scrub-shrub areas primarily along former thermal creeks and swamps, and 299 isolated upland wetland depressions or Carolina bays. Thermal releases to streams and impoundments degraded the wetlands along the creek corridors and portions of the SRS Savannah River swamp. The most obvious effect of the cooling water releases on wetland plant communities was canopy loss of wetland tree species. About 1020 ha of wetland tree canopy exhibited some degree of alteration as a result of SRS cooling water releases. Following cessation of cooling water releases to creeks and swamps, successional revegetation by scrub-shrub communities and a variety of persistent and non-persistent wetland species began and continues today. However, the developing wetland communities do not resemble the original cypress-tupelo forests.

Chapter 6, Supplemental Studies, identifies additional investigations and sources of data on the SRS natural environment. These include remote sensing data from the 1950s through the 1990s, ecological investigations at the Mixed Waste Management Facility, aquatic toxicity testing, and stream bioassessments.

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1.0 SOILS

The Savannah River Site is composed of an area of 80,267 hectares (310 square miles) in portions of Aiken, Allendale, and Barnwell counties of South Carolina, and is located along the Savannah River. This area has a wide range of habitats, ranging from well-drained upland forests to swamps, wetlands, and river systems. The entire Site has been designated as a National Environmental Research Park by the U.S. Department of Energy(DOE).

1.1 SRS SOILS

1.1.1 Geologic Origin

SRS is primarily located on the Aiken Plateau, within the southern portion of the South Carolina upper Atlantic Coastal Plain (Aadland et al., 1995). The Site is about 50 km (30 miles) southeast of the Fall Line. Atlantic Coastal Plain sediments are stratified sands, clays, limestones, and gravels that dip gently and thicken southeastward. The sediment ages range from Late Cretaceous to Recent. In the central SRS area, the sedimentary sequence is approximately 213 m (700 ft) thick. The Coastal Plain sediments are underlain by either crystalline basement rocks or Triassic-aged, consolidated sedimentary rocks (Wyatt and Harris, 2000). The primary geologic units exposed at land surface include: Quaternary alluvium, silty, clayey sands and conglomerates of the (probably Miocene) Upland Unit, clayey sands of the Late Eocene Tobacco Road Formation, sands and clays of the Late Eocene Dry Branch Formation, McBean Formation sands, Huber Formation sandy clays and Congaree Formation sands.. An SRS geologic map adapted from Prowell (1996) is presented in Figure 1-1.

Geomorphology

The Aiken Plateau, on which the central and northeastern portions of the SRS are located, is highly dissected and characterized by broad interfluvial areas with narrow, steep-sided valleys (Aadland et al., 1995). The southwestern portions of the SRS are located on erosional terraces identified by Cooke (1936) as Pleistocene marine terraces. The terraces represent successive marine recessions during the glacial epoch about 10,000 to 1 million years ago (Figure 1-2). The Brandywine Terrace is the highest and oldest. It lies adjacent to the Aiken Plateau and parallels the Savannah River at elevations between 45 and 76 m (150 and 250 ft) above sea level. The Sunderland Terrace, the second oldest, lies between 27 and 45 m (90 and 150 ft) above sea level. The Wicomico Terrace, the youngest, lies along the Savannah River flood plain, between the river and about 27 m (90 ft) above sea level (Cooke, 1936; Langley and Marter, 1973).

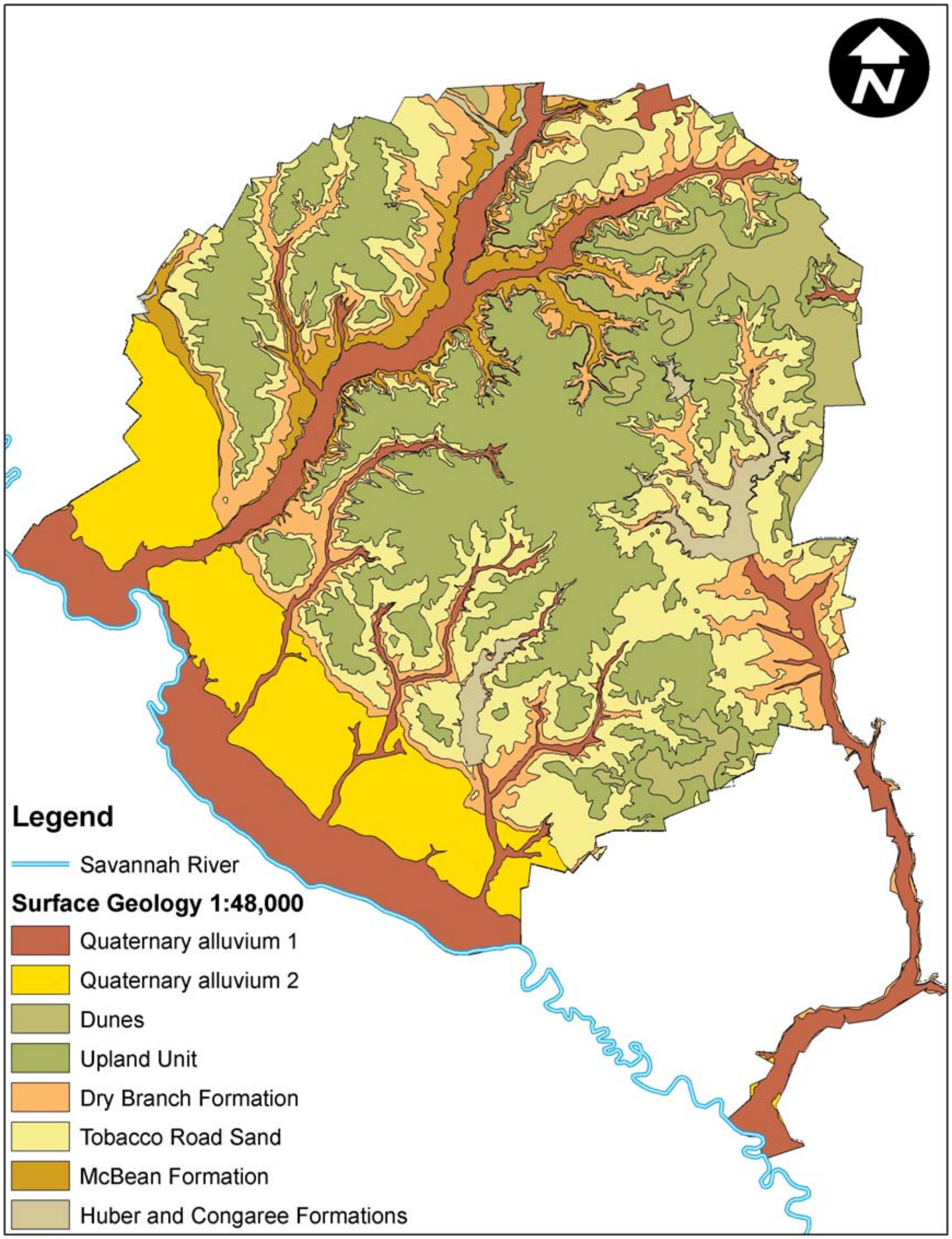

Figure 1-1. SRS Surface Geology (adapted from Prowell, 1996)

1.1.2 Soil Texture

Particle size, referred to as soil texture, is an important descriptor of soil character. Soil texture is the relative proportion of sand, silt, and clay particles in a soil mass. The basic textural classes, in order of increasing proportion of fine particles, are sand, loamy sand, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, and clay. The most common surface textures on SRS are sand and loamy sand, while the subsoil textures are usually sandy loam or sandy clay loam. Soil texture can have a significant impact on the physical and chemical characteristics of a soil series.

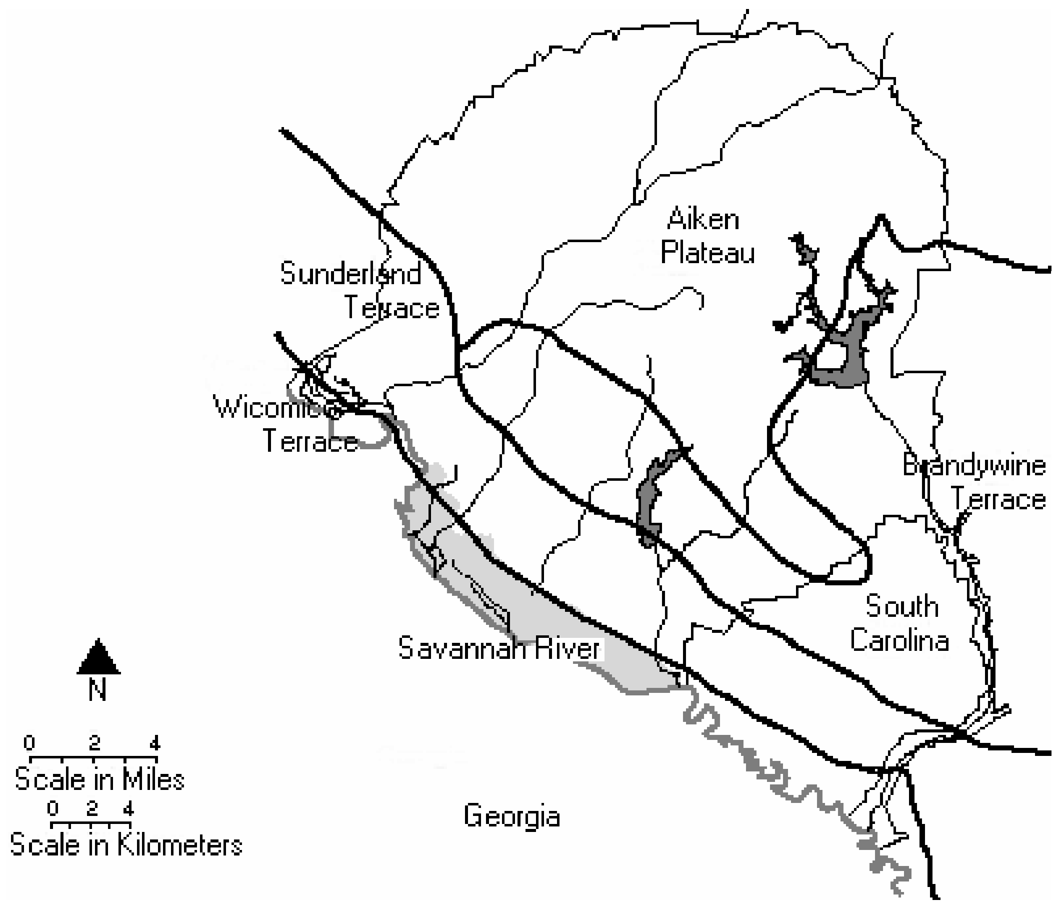

Figure 1-2. Location of Pleistocene Marine Terraces on SRS (Source: Langley and Marter 1973)

1.1.3 Inorganic and Radionuclide Concentrations

Data from Looney et al. (1990) and from investigations at SRS waste sites as part of the environmental remediation program were compared statistically. Differences between the two data sets were essentially insignificant; therefore, the data sets were combined to produce SRS-wide range of soil constituent concentrations. (Table 1-1)

1.2 SRS SOIL SURVEY

1.2.1 General Characteristics of SRS Soils

Many different soils exist on SRS, and, in some areas change within a short distance. SRS soils range from seasonally wet and hydric to well-drained. Composition ranges from mostly sand-sized particles with high hydraulic conductivity rates to high clay content with moderately low to low hydraulic conductivity rates. These differences, where the areas are large enough, are shown as a soil series within a mapping unit. A mapping unit is an area dominated by one major kind of soil accompanied by other similar soils. Four orders and 28 soil series are recognized on SRS. Of the 28 soil series, nine are on the list of hydric soils of the SRS. Hydric soils are formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic condition in the upper part (USDA, NRCS 2003). This is an important soil characteristic used for wetland identification. A soil series classification describes the soil's history, evolution, and current characteristics. On SRS, there are sizable areas where the upper 2 m (6 ft) of soil has been altered to the extent that the soil profile cannot be identified. These areas are placed in the taxonomic system at a higher level; therefore, less specific characteristics are given (Rogers 1990).

Table 1-1. Inorganic and Radionuclide Concentration Ranges for the Southeastern United States, Nationwide, and SRS.

Constituents	Southeastern U.S.[a]	Nationwide[b,c]	SRS
Metals (mg/kg)			
Aluminum	900 to 46,000	700 to 100,000	715 to 53,530
Antimony	N/A	N/A	<0.21 to 20
Arsenic	N/A	<0.1 to 97	<0.25 to 15.2
Barium	63 to 350	10 to 5,000	0.33 to 3,210
Beryllium	N/A	<1 to 15	0.02 to 5.9
Cadmium	N/A	N/A	<0.098 to 7.57
Chromium	11 to 60	1 to 2,000	<0.41 to 116
Iron	500 to 21,000	100 to >100,000	635 to 79,600<
Lead	2.8 to 26	<10 to 700	<0.16 to 35
Manganese	100 to 410	<2 to 7,000	<0.6 to 566
Mercury	N/A	<0.01 to 4.6	<0.0028 to 0.89
Nickel	2.8 to 18	<5 to 700	<0.1 to 228
Selenium	N/A	<0.1 to 4.3	<0.084 to 29.8
Thallium	N/A	N/A	<0.84 to 49.83
Vanadium	N/A	<7 to 500	<2.25 to 61
Zinc	<25 to 64	<5 to 2,900	<0.23 to 267
Radionuclides (pCi/g)			
Carbon-14	N/A	0.01 to 2.5	<0.0011 to 0.17
Cesium-137	N/A	0.01 to 3.5	<0.0003 to 2.21
Iodine-129	N/A	1E-05 to 9E-05	<7.69E-7 to <32.2
Potassium-40	N/A	3 to 20	0.066 to 11.6
Plutonium-239/240	N/A	0.009 to 0.04	<0.0016 to 4.11
Strontium-90	N/A	0.2 to 4.0	<0.01 to 13.2
Technetium-90	N/A	N/A	<0.0016 to 9.76
Thorium-232 and daughters			
Thorium-232	N/A	0.10 to 3.4	0.31 to 2.53
Actinium-228	N/A	N/A	<0.01 to 2.54
Radium-228	N/A	0.1 to 3.4	0.34 to 2.9
Thorium-228	N/A	N/A	0.21 to 17.9
Lead-212	N/A	N/A	0.013 to 3.2
Uranium-238 and daughters			
Uranium-238	N/A	0.12 to 3.8	0.18 to 2.42
Uranium-234	N/A	0.12 to 3.8	1.0 to 1.2
Thorium-230	N/A	0.12 to 3.8	0.18 to 2.27
Radium-226	N/A	0.23 to 4.2	0.19 to 2.03
Uranium-235	N/A	0.01 to 0.05	<0.0019 to 0.13
Gross alpha	N/A	N/A	<0.01 to 44.53
Nonvolatile beta	N/A	N/A	<0.01 to 54.82

Notes:
Source: PRC 1996.
N/A = Not Available.
mg/kg = Milligram per kilogram.
pCi/g = Picocuries per gram.
[a]Connor and Shacklette 1975.
[b]Shacklette and Boerngen 1984 (for inorganics).
[c]EPA 1994 (for radionuclides).

1.2.2 Soil Maps

An extremely valuable part of the SRS soil report (Rogers 1990) is the detailed soil map units which are included at the back of the survey on aerial photos at a scale of 1:15840 (4 in/mi). Map units are drawn on the photo and include the soil for which the unit was named, other similar associated soils, and, usually, small areas of dissimilar soils. Each soil series is described in the soils report (Rogers, 1990) to identify what a representative profile contains. Soils that have very similar profiles are placed into the same series. A soil series can have variation in the surface layer, but other major soil horizons will be similar. A description of the series is provided and includes information characteristic of the series, including presence horizons and depths, typical soil color and mottling of the horizons, texture of the horizons, permeability, and use suitability. The location of a typical example of the series is included for reference, and the relationships to other soil series, often in the same vicinity, are noted. Similar soil series are then grouped into Associations, which is a higher taxonomic classification. Because of the possibility of small areas of dissimilar soils, a field investigation to identify such inclusions should always precede any commitment to manage or build on the soil area. Fifty soil mapping units are recognized on SRS that are large enough to be shown on the photos at the publication scale used in the SRS soil report (Table 1-2). Special symbols on the map indicate other small but important soils, such as 1- to 3-acre wet areas (Rogers 1990).

1.2.3 Tabular Data

The SRS soil report gives soil classification in tabular form and describes each soil series in detail. Tables include climatic data for each area and information related to each map unit; acreage of each map unit within the individual counties; woodland productivity and wildlife-habitat management; building, sanitation, and construction limitations; water management; engineering, physical, and chemical properties; and soil and water features. By identifying the soil map unit of interest, the various tables can provide a great deal of preliminary information on the area and serve as a basis for a more detailed analysis of a specific site.

Table 1-2. Listing of Soil Mapping Units on SRS

Soil Unit Name and Slope	Total Acres
Ailey sand, 2-6% slopes	2,450
Albany sand, 0-6% slopes	940
Blanton sand, 0-6% slopes	38,767
Blanton sand, 6-10% slopes	3,200
Chastain clay, frequently flooded, nearly level	7,860
Dorovan muck, frequently flooded, nearly level	2,045
Dothan sand, 0-2% slopes	1,625
Dothan sand, 2-6% slopes	14,010
Eunola fine sandy loam, 0-2% slopes	310
Fluvaquents, frequently flooded, nearly level	4,550
Fuquay sand, 0-2% slopes	1,190
Fuquay sand, 2-6% slopes	20,674
Fuquay sand, 6-10% slopes	750
Hornsville sandy loam, 0-2% slopes	2,640
Kinston loam, frequently flooded, nearly level	600
Lakeland sand, 0-6% slopes	8,150
Lakeland sand, 6-10% slopes	320
Lucy sand, 0-2% slopes	400
Lucy sand, 2-6% slopes	1,590
Lucy sand, 6-10% slopes	440
Neeses loamy sand, 2-6% slopes	360
Norfolk loamy sand, 0-2% slopes	880
Norfolk loamy sand, 2-6% slopes	2,220
Ochlockonee loamy sand, occasionally flooded, nearly level	330
Ocilla loamy sand, 0-2% slopes	1,470
Ogeechee sandy loam, nearly level	1,780
Orangeburg loamy sand, 0-2% slopes	1,150
Orangeburg loamy sand, 2-6% slopes	5,110
Orangeburg loamy sand, 6-10% slopes	330
Pickney sand, frequently flooded, nearly level	10,290
Rembert sandy loam, nearly level	6,530
Shellbluff loam, frequently flooded, nearly level	2,000
Smithboro loam, nearly level	990
Tawcaw silty clay, frequently flooded, nearly level	2,750
Toccoa loam, frequently flooded, nearly level	310
Troup sand, 0-6% slopes	14,560
Troup sand, 6-10% slopes	1,920
Troup sand, 10-15% slopes	1,140
Troup and Lucy sand, 15-25% slopes	2,100
Troup and Lucy sand, 25-40% slope	650
Udorthents, firm, variable slopes	540
Udorthents, friable, variable slopes	5,940
Udorthents-Urban land, gently sloping	680
Urban land, gently sloping	510
Vaucluse sandy loam, 2-6% slopes	1,180
Vaucluse-Ailey complex, 6-10% slopes	6,580
Vaucluse-Ailey complex, 10-15% slopes	5,670
Wagram sand, 0-2% slopes	1,290
Wagram sand, 2-6% slopes	4,350
Williman sand, nearly level	1,977

Source: Rogers (1990)

1.3 SOIL GROUPS

1.3.1 Introduction

The SRS general soil map contains seven broad soil-association groups (Figure 1-3). The groups are named to coincide with the major soil series within the group; however, many of the soil series occur in more than one group. The general soil map does not contain sufficient detail for making management decisions on small land areas, but it is helpful in comparing the suitability of larger areas for general land use. It is excellent for locating specific soil types when the special properties, such as particle size, clay mineralogy, and hydrology, are known. The following subsections give a general description of each group.

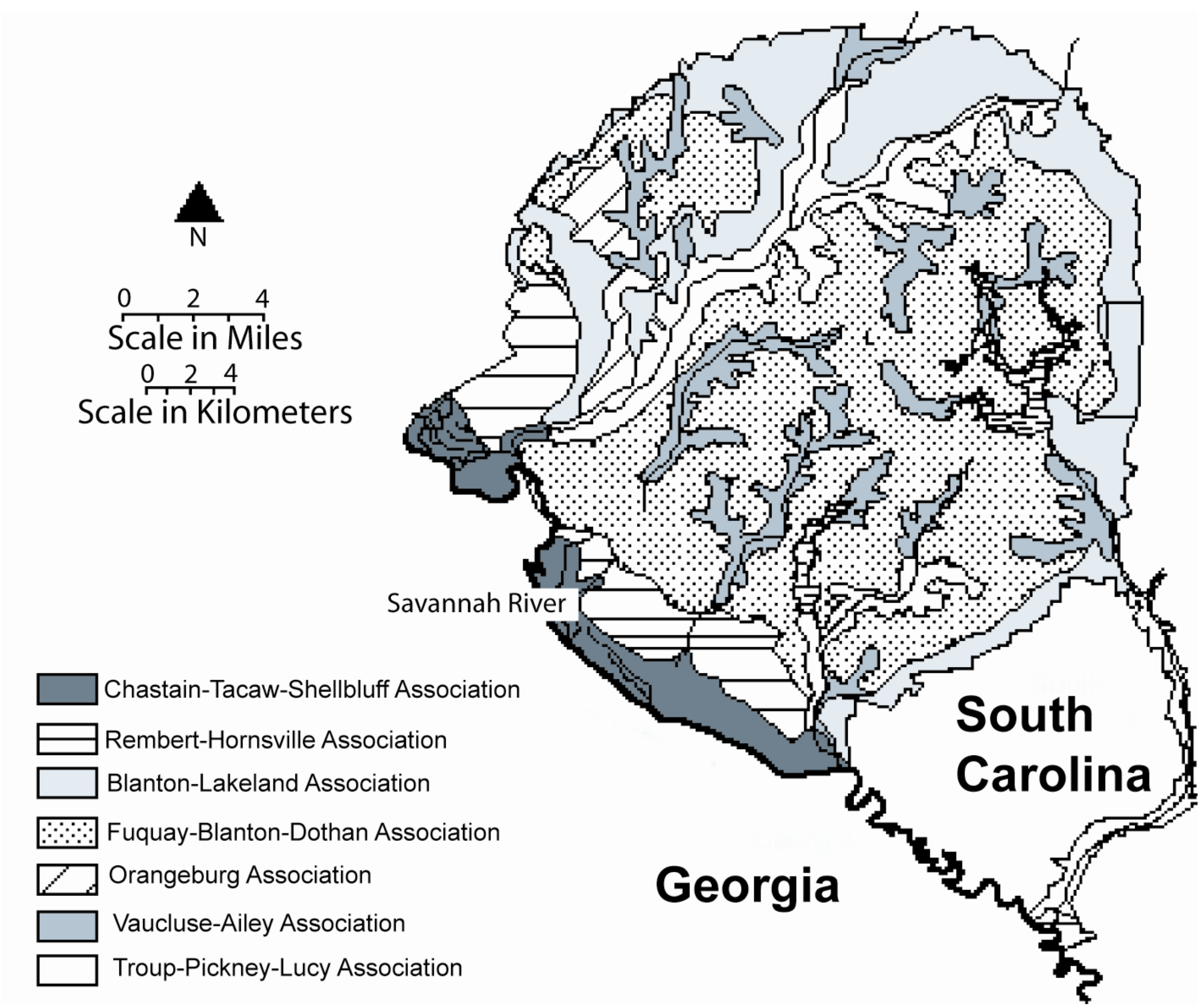

Figure 1-3. SRS General Soils Map

1.3.2 Chastain-Tawcaw-Shellbluff Association

The Chastain-Tawcaw-Shellbluff association consists of nearly level soils on the floodplains along the major streams, mainly along the Savannah River. This association makes up about 6% of the survey area. The association is about 60% Chastain soils, 20% Tawcaw soils, 15% Shellbluff soils, and 5% soils of minor extent.

Chastain soils are poorly drained and clayey to a depth of about 100 cm (40 in). Tawcaw soils are somewhat poorly drained and clayey in the upper part and loamy in the lower part. Shellbluff soils are well-drained and loamy to a depth of about 100 cm (40 in).

All the acreage in this association is wooded. The soils are suited for timber production, but not for sanitary facilities or building sites because of flooding and wetness.

1.3.3 Rembert-Hornsville Association

The Rembert-Hornsville association consists of nearly level soils on stream terraces. Rembert soils are poorly drained, and Hornsville soils are moderately well-drained. A few dirt roads and a railroad cross areas of this association. This association makes up about 7% of the survey area. It is about 30% Rembert soils, 18% Hornsville soils, and 52% other soils of minor extent.

Most of the acreage in this association is woodland. The soils are well suited for timber production. Generally, these soils are poorly suited for sanitary facilities and building sites because of wetness and slow permeability.

1.3.4 Blanton-Lakeland Association

The Blanton-Lakeland association consists of nearly level to sloping soils on uplands. Stands of longleaf (*Pinus palustris*) and loblolly pine (*P. taeda*) with an oak (*Quercus* spp.) understory grow on the broad sandy ridges. This association makes up about 18% of the survey area. It is about 40% Blanton soils, 20% Lakeland soils, and 40% other soils of minor extent.

Blanton soils are somewhat excessively drained. They have thick sandy surface and subsurface layers and loamy subsoil that is 100-200 cm (40-80 in) below the surface. These soils are commonly adjacent to more poorly drained soils. Lakeland soils are excessively drained and are sandy throughout. They are generally higher on the landscape than Blanton soils.

These soils are suited for timber production of species associated with drier sites. Because of the thick surface layer and subsurface layer, these soils are only fairly well suited for sanitary facilities. In most areas the soils are suitable for building sites. The more sloping areas, however, are not as well suited.

1.3.5 Fuquay-Blanton-Dothan Association

The Fuquay-Blanton-Dothan association consists of nearly level to sloping, well-drained soils on all of the broad upland ridges in the survey area, except for those in the northeastern section of SRS. This association makes up 47% of the survey area. It is about 20% Fuquay soils, 20% Blanton soils, 12% Dothan soils, and 48% other soils to a minor extent.

Fuquay soils are well-drained. They have moderately thick, sandy surface and subsurface layers and loamy subsoil that contains iron-rich brittle nodules of plinthite. Blanton soils are somewhat excessively drained. They have thick, sandy surface and subsurface layers and loamy subsoil. Dothan soils are well-drained. They have thick, sandy surface and subsurface layers. They have loamy subsoil that contains iron-rich nodules of plinthite.

These soils are suited for cultivated crops and are well suited for timber production. Most are suited for sanitary facilities. The sandy soils have moderate or severe limitations affecting some sanitary facilities. Most of the soils are suitable for building sites. The more sloping soils, however, are not as well suited.

1.3.6 Orangeburg Association

The Orangeburg association consists mainly of soils on broad upland ridges and in nearly level to sloping areas northwest of Upper Three Runs. Slopes generally are smooth. Planted loblolly pine is the dominant vegetation on this soil type. This association makes up about 2% of the survey area. It is about 70% Orangeburg soils and 30% other soils of minor extent. The Orangeburg soils have friable, red, loamy subsoil. The soils of this association are well suited for woodlands, sanitary facilities, building sites, wildlife habitat, and other uses.

1.3.7 Vaucluse-Ailey Association

The Vaucluse-Ailey association consists of sloping and strongly sloping soils in scattered areas around the head and sides of small drainage ways in the uplands. The areas are long and narrow. The vegetation on this association is mixed pine and hardwoods. This association makes up about 10% of SRS. It is about 25% Vaucluse soils, 15% Ailey soils, and 60% other soils of minor extent.

Vaucluse soils have a loamy surface layer and subsurface layer that have a combined thickness of less than 50 cm (20 in). Ailey soils have moderately thick, sandy surface and subsurface layers. Both soils have loamy subsoil with a brittle layer.

The soils are fairly well suited for timber production. Because of slow permeability, these soils are poorly suited for sanitary facilities. The soils are poor building sites because of the slope.

1.3.8 Troup-Pickney-Lucy Association

The Troup-Pickney-Lucy association consists of moderately steep and steep soils on uplands and nearly level soils on the floodplains along streams. The steeper areas are on the southeast bank of Upper Three Runs and along both sides of Tinker Creek. Areas of this association are long and narrow. This association has soils with the steepest slopes on SRS. The soils on the floodplains have a higher organic content than the other soils. Their vegetation is mostly hardwoods mixed with loblolly pine. This association makes up about 10% of the survey area. It is about 45% Troup soils, 40% Pickney soils, 10% Lucy soils, and 5% other soils of minor extent.

Troup soils are well drained. They have a thick, sandy surface and subsurface layers and loamy subsoil at a depth of 100-200 cm (40-80 in). Pickney soils are poorly drained. They have a thick black surface soil and are sandy throughout. Lucy soils are well drained. They have moderately thick sandy surface and subsurface layers and loamy subsoil at a depth of 50-100 cm (20-40 in).

The soils are fairly well suited for woodlands. These soils generally are poorly suited for sanitary facilities or building sites because of the steep slope and the flooding; however, some areas of more moderately sloping soils are available for such uses. The soils on floodplains are not suited for building sites.

1.4 GEOCHEMICAL AND PHYSICAL PROPERTIES OF SRS SOILS

1.4.1 Upland Soils

Metals, radionuclides, inorganic anions, organic compounds, and agricultural indicator parameters were analyzed for six representative upland soil series found on SRS.

The soils from unimpacted areas of the SRS are typical of soils found in moderately aggressive weathering conditions such as those found in the southeastern United States. The temperate climate and relatively high rainfall in the region result in leached soils with low concentrations of metals. In general, metal concentrations increase with depth and in proportion to the soil's clay content. Metal concentrations in this study were similar to those measured in previous studies and in regional, national, and global studies in similarly weathered environments. The mineralogy of the soil is dominated by quartz, and the primary clay material in SRS soils is kaolinite (Looney et al. 1990).

Specific soil characteristics that were evaluated were trace element concentrations, major element concentrations, bulk chemical properties that could affect the migration of chemicals through the soils, indicator parameters, physical properties, and mineralogy (Table 1-3). Detailed results of the study are presented in Looney et al. (1990).

Table 1-3. Soil Characteristics Measured in Upland Soils

Metals	Radiological Parameters	Other Inorganic Constituents	Agricultural Parameters	Organics
Aluminum	Gross alpha	Chloride	Cation exchange capacity	Total organic carbon
Arsenic	Gross beta	Cyanide	Exchangeable acidity	Total organic halogens
Barium	Strontium-90	Fluoride	Exchangeable base metals	
Cadmium	Uranium	Nitrate	pH	
Chromium		Nitrite		
Copper		Phosphate		
Iron		Sulfate		
Lead				
Lithium				
Magnesium				
Mercury				
Nickel				
Potassium				
Selenium				
Silver				
Sodium				
Zinc				

Source: Looney et al. (1990).

1.4.2 Wetland Soils

The SRS has 14,569 ha (36,000 acres) of wetlands and an additional 2,023 ha (5,000 acres) of bottomland that is subject to periodic flooding. Wetland soils representing five soil groups were analyzed for metals, organics, physical properties, and agricultural parameters (Table 1-4).

Overall, the chemical and physical composition of unimpacted SRS wetland soils is similar to those found in offsite wetland soils. The wetland soil compositions are broadly comparable to the upland soils characterized by Looney et al. (1990) (Dixon et al. 1997).

The study indicates that metal and inorganic concentrations are slightly higher in upland bays and depressional soils and distinctly higher in large stream floodplain soils than in the other soil groups sampled. Concentrations of metals and inorganics tend to decrease with increasing depth. More detailed results are presented in Dixon et al. (1997).

Table 1-4. Soil Characteristics Measured in Wetland Soils

Metals	Radiological Parameters	Other Inorganic Constituents	Agricultural Parameters	Organic Compounds
Aluminum	Tritium	Fluoride	Cation exchange capacity	Total organic carbon
Antimony		Nitrate + Nitrite	Percent solids	Total organic halogens
Arsenic		Phosphates, total (as Phosphorus)	pH	Dioxins/furans[a]
Barium		Silicon		Volatile organic compounds[a]
Beryllium		Sulfate		Semivolatile organic compounds[a]
Cadmium				Pesticide/herbicides[a]
Calcium				PCBs[a]
Chromium				
Cobalt				
Copper				
Iron				
Lead				
Lithium				
Magnesium				
Manganese				
Mercury				
Nickel				
Potassium				
Selenium				
Silver				
Sodium				
Sulfide				
Thallium				
Tin				
Vanadium				
Zinc				

Source: Dixon et al. (1997).
[a]Resource Conservation and Recovery Act (RCRA) Appendix IX Analyses

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2.0 VEGETATION

2.1 VEGETATON

The land cover of the Savannah River Site reflects past disturbances and manipulations that have occurred since the land was acquired in 1950. At that time, approximately 40% of the site was farm land, and the remainder was forested. Land management by the U.S. Forest Service has focused largely on timber management and watershed protection, changing the site's land to predominately forested areas. Early changes due to development of SRS were detailed by Dukes (1984).

2.2 TERRESTRIAL LAND COVER TYPES

2.2.1 Introduction

On the Savannah River Site, Batson et al. (1985) lists 1,322 vegetation species, representing 151 separate taxonomic families. These species occur over many habitat types, from upland well-drained forests to swamps and Carolina bays. More detailed descriptions of the land cover types and their associated vegetation can be found in Workman and McLeod (1990), Gladden et al. (1985), Jones et al. (1981), and Whipple et al. (1981). Species nomenclature in this chapter is according to Radford et al. (1968).

2.2.2 Nonforested Cover Types

2.2.2.1 Industrial/Transportation Related

The industrial land cover type includes administrative or production facilities and immediately contiguous surrounding areas (e.g., fly ash basins, borrow pits, and cleared areas). Roads, rights-of-way, and railroad facilities are transportation related. The industrial land cover type includes utility corridors and electric substations; however, cleared utility corridors are included based on the land cover actually present (e.g., grassland/scrub-shrub), and electrical substations were mapped as industrial. Borrow pits are considered to be active or reclaimed covered with grasses/scrub-shrub vegetation.

2.2.2.2 Grassland/Forb/Scrub-Shrub

Nonwoody plants dominate grassland/forb cover type, with more than 50% of the vegetation cover grasses and forbs. This land cover type occurs primarily on power line rights-of-way and in a few forest openings. The grassland/forb cover includes SRS wildlife food plots. Grassland/forb also includes land from which trees have been cleared recently, resulting in less than 10% canopy or crown closure. These are primarily areas where there has been recent clear-cutting and block-planting of primarily loblolly (*Pinus taeda*) or longleaf pine (*P. palustris*). Scrub-shrub includes predominantly bare soil, a scrub-shrub canopy of less than 25% closure, or young pine seedlings and saplings less than 5 years old and less than 6 m (20 ft) tall.

2.2.2.3 Open Water

Open water consists of natural or man-made areas that are continuously covered by water. There are approximately 2000 ha (5000 acres) of open water on SRS. Chapter 4-Streams, Reservoirs, and the Savannah River, has a complete discussion of the open water areas of SRS.

2.2.3 Forested Cover Types

2.2.3.1 Evergreen Forests

The coniferous forest land cover type includes areas with predominately coniferous trees that are at least 6 m (20 ft) tall. Pines, primarily longleaf and loblolly pine, dominate the evergreen forested areas. Slash pine (*P. elliottii*) and shortleaf pine (*P. echinata*) are also common on SRS. The U.S. Forest Service Management Plan established much of this cover type, although some natural coniferous stands still exist. Broad-leaved species, such as those oaks (*Quercus* spp.) that are tardily deciduous (maintain some of their leaves throughout the season) are not included. This cover type is generally located on dry upland sites and includes former agricultural fields. Understory species include black cherry (*Prunus serotina*), various oaks, persimmon (*Diospyros virginiana)*, and other species. The understory is generally sparse under densely planted pine stands. In areas that are more open, blackberry (*Rubus* spp.), dog-fennel (*Eupatorium compositifolium*), and broomsedge (*Andropogon* spp.) are common.

Areas that have had recent logging and regeneration planting occupy a transitional land-cover type. These areas, classified as scrub-shrub, include areas of evergreen and deciduous shrubs and small trees 6 m (20 ft) or less in height with a canopy cover of at least 25%. These areas are primarily old clear-cuts being managed for timber production and in the process of returning to productive forests. Most areas in this cover type will move into one of the forested types in 5-10 years, based on the growth rate of the trees.

2.2.3.2 Deciduous Forests

Upland hardwood cover types include areas where the dominant species are deciduous trees at least 6 m (20 ft) tall. An area is classified as a deciduous forest when deciduous trees compose at least 70% of the canopy layer. The deciduous forest class includes the upland hardwood forest and the mesic hardwood forest described by Whipple et al. (1981). On drier sites and sandy ridges, turkey, bluejack, and black-jack oaks (*Quercus laevis*, *Q. incana*, and *Q. marilandica*) dominate the canopy with longleaf pine present in various densities. In less xeric areas, other oaks and hickories (*Carya* spp.) also are present. Understory species at the drier sites include *Vaccinium* spp., hollies, (*Ilex* spp.) *Lespedeza* spp.; and various lichens. On mid- and lower slopes, the deciduous forest includes laurel oak (*Q. laurifolia*), yellow poplar (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), sweet-gum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), hickories, and holly. Understory on the more mesic sites include vacciniums, hollies, various ferns, grapes (*Vitis* spp.), sassafras (*Sassafras albidum*), dogwood (*Cornus florida*), and greenbriers (*Smilax* spp.). Although stands comprising predominantly deciduous species are not abundant on SRS, there are windbreaks and hedgerows on former homesteads that are important wildlife habitat. In addition to coniferous and deciduous forest stands, there are areas with both types of trees. Where more than a 30% intermixture of these two types occurs, they are generally classified as mixed forests.

2.2.3.3 Bottomland Hardwood Forests

Bottomland hardwood forests are found along SRS streams and on the “islands” or “ridges” of the Savannah River swamp and major drainages. Elevations of these ridges are high enough to avoid prolonged flooding during most years. Typical canopy species include water oak (*Q. nigra)*, laurel oak, sweetgum, elms (*Ulmus alata* and *U. americana)*, red maple, and yellow poplar (Good and Whipple 1982; Whipple et al. 1981; Jensen et al. 1984). Holly (*Ilex opaca*), redbay (*Persea borbonia)*, sweet bay (*Magnolia virginiana*), hackberry (*Celtis laevigata)*, and ironwood (*Carpinus caroliniana*) are common in the sub-canopy and understory. Greenbriers, grapes, and other vines are common in the shrub and ground layers. Herbaceous plants are less common due to the more dense shading.

2.2.3.4 Swamp Forests

The swamp forest is common along the western boundary of the site, adjacent to the Savannah River. This low-lying area is subject to prolonged inundation during one or several periods of the year. The Savannah River and, to a lesser extent, the several streams that empty into it control the hydrology of the swamp. Bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) dominated the historic swamp forest on SRS. Historical reactor operations impacted some areas of this cover type. In the sapling layer, occasional individuals of water ash and red ash (*Fraxinus caroliniana* and *F. pennsylvanica*), along with other water-tolerant bottomland hardwoods, may occur (Whipple et al. 1981). Vines and understory vegetation are generally sparse in the swamp forest.

Sections of the swamp forest that were impacted through increased siltation and thermal damage caused by reactor effluents are undergoing successional revegetation. These areas are covered in detail in Chapter 5—Wetlands and Carolina Bays of SRS.

2.2.3.5 Carolina Bays

Carolina bays occur throughout SRS. Currently, 299 confirmed or suspected Carolina bays have been identified (Kirkman et al. 1996) (Figure 2-1). Most are small; more than 80% are less than 3 ha (7 acres). The bays occur only in upland, interstream areas of the coastal plain of the Southeastern U.S. They are characterized by their elliptical or ovoid shape with a northwest/ southeast orientation of the long axis. Often they will have a sandy rim around the margin. Most bays are continually or seasonally flooded and are generally partially filled with inorganic clays and silts and/or organic peats. These shallow depressions contain hydric or mesic plant communities and range from lakes to marshes, bogs, or swamp forests (Schalles et al. 1989). The plant communities in the bays are highly variable and often are controlled by the magnitude of flooding and recent history. When SRS land was farmed, many of the bays were ditched and drained; they currently support a different vegetation community than if they had no ditch. This habitat is presented in more detail in Chapter 5-Wetlands and Carolina Bays of SRS.

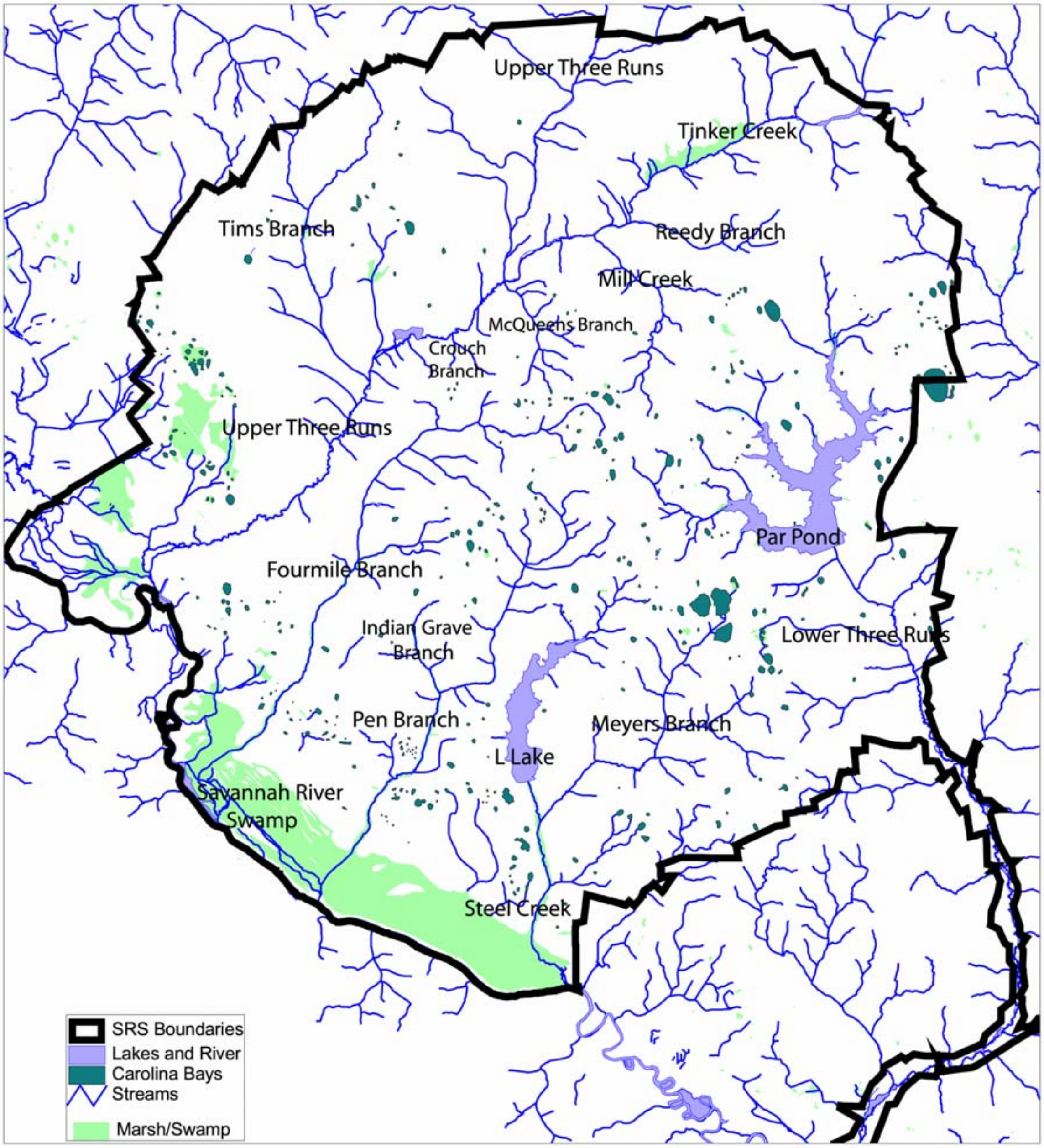

Figure 2-1. Locations of Carolina Bays on SRS (Kirkman et al. 1996)

2.2.4 Landcover Maps

Figure 2-2 - Figure 2-5 give a general overview of the major vegetation types on SRS. Analysis of aerial photography using multispectral sensors has produced a more detailed assessment of cover type, which has been mapped on U.S. Geological Survey (USGS) quadrangle maps. These maps generally are produced at a scale of 1:24,000 and represent an area of approximately 14,750 ha (57 sq mi).

"Nonforested Cover Types" and "Forested Cover Types" describe the more dominant land cover types. Chapter 4-Streams, Reservoirs, and the Savannah River covers areas dominated by water (streams, ponds, and reservoirs). Swamp forests and wetlands are covered in detail in Chapter 5-Wetlands and Carolina Bays of SRS.

2.2.5 Land Management

2.2.5.1 Introduction

The SRS has been administratively sub-divided into large land areas based on different overall management objectives by the Savannah River Forest Station (SRFS). These areas have changed over time as the objectives have shifted. Overall management strategy for SRS is guided by the Natural Resources Management Plan (DOE 1991), the Natural Resources Management Activities at the Savannah River Site Environmental Assessment (DOE 1993), and the Natural Resources Management Operations Plans of the Savannah River Site (USFS 1993). USFS-SR (2005) describes the manner in which the U.S. Forest Service proposes to manage the natural resources of the SRS over the next 5 to 10 years. It further updates and replaces the existing plan that was issued in 1991. The revised plan addresses the proposed management of wildlife, fisheries and botany resources, renewable forest products, engineering and environmental services, watersheds, wildland fires, research, DOE research set-aside areas and visual resources.

The basic planning unit for land management is the compartment, with each management area containing many compartments. The SRS is divided into 92 compartments, the boundaries of which are often roads, streams, or topographic divides (Figure 2-6). Each compartment is evaluated as a whole approximately every 10 years for management practices that need to occur within its boundaries. Each compartment is then sub-divided into stands, based on species composition, topography, or special circumstances such as set-asides, Carolina bays, research areas, etc. The stand is the unit that receives individual assessment for management and timber evaluation and silvicultural applications.

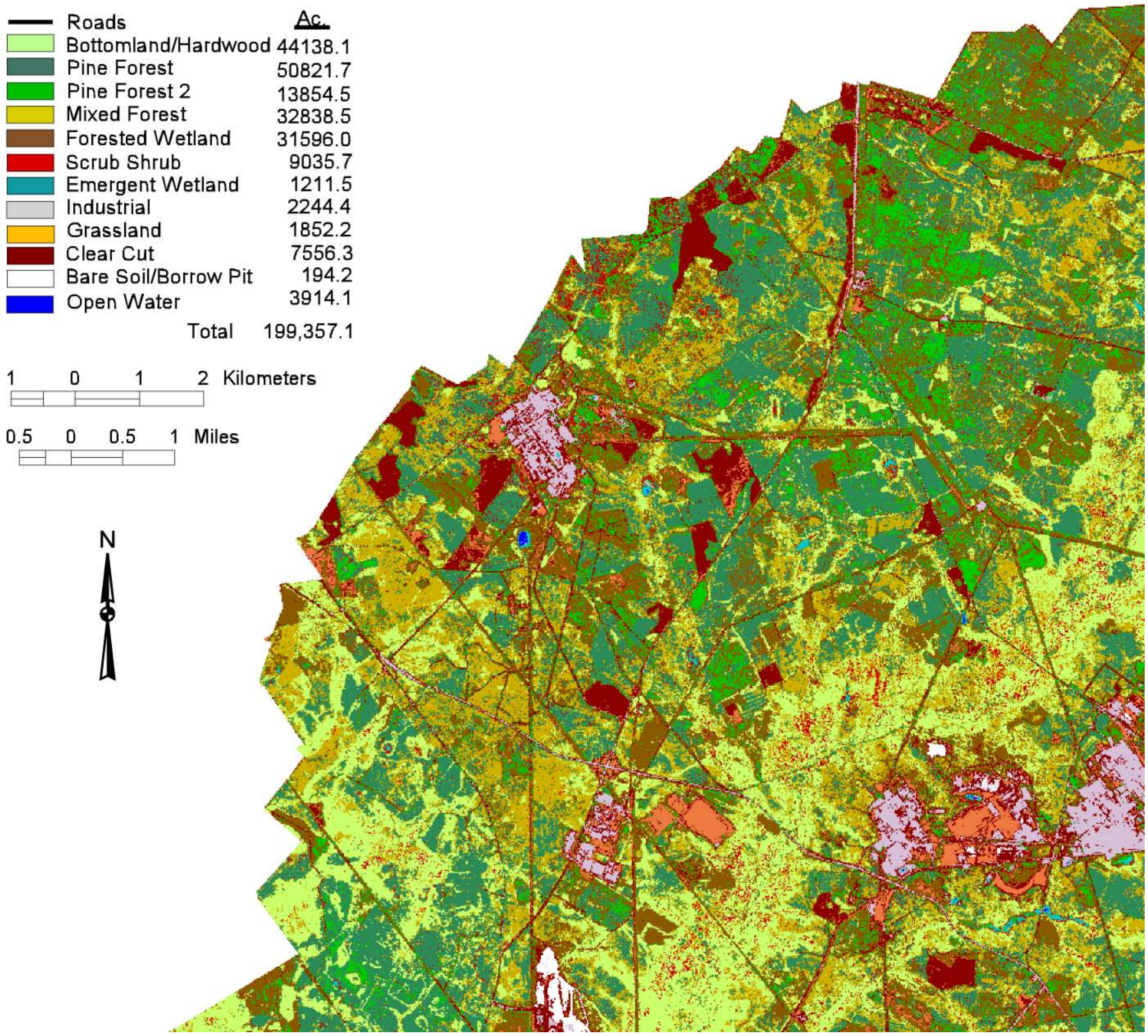

Figure 2-2. Major Vegetation Types and Approximate Areas on SRS - NW Quadrant

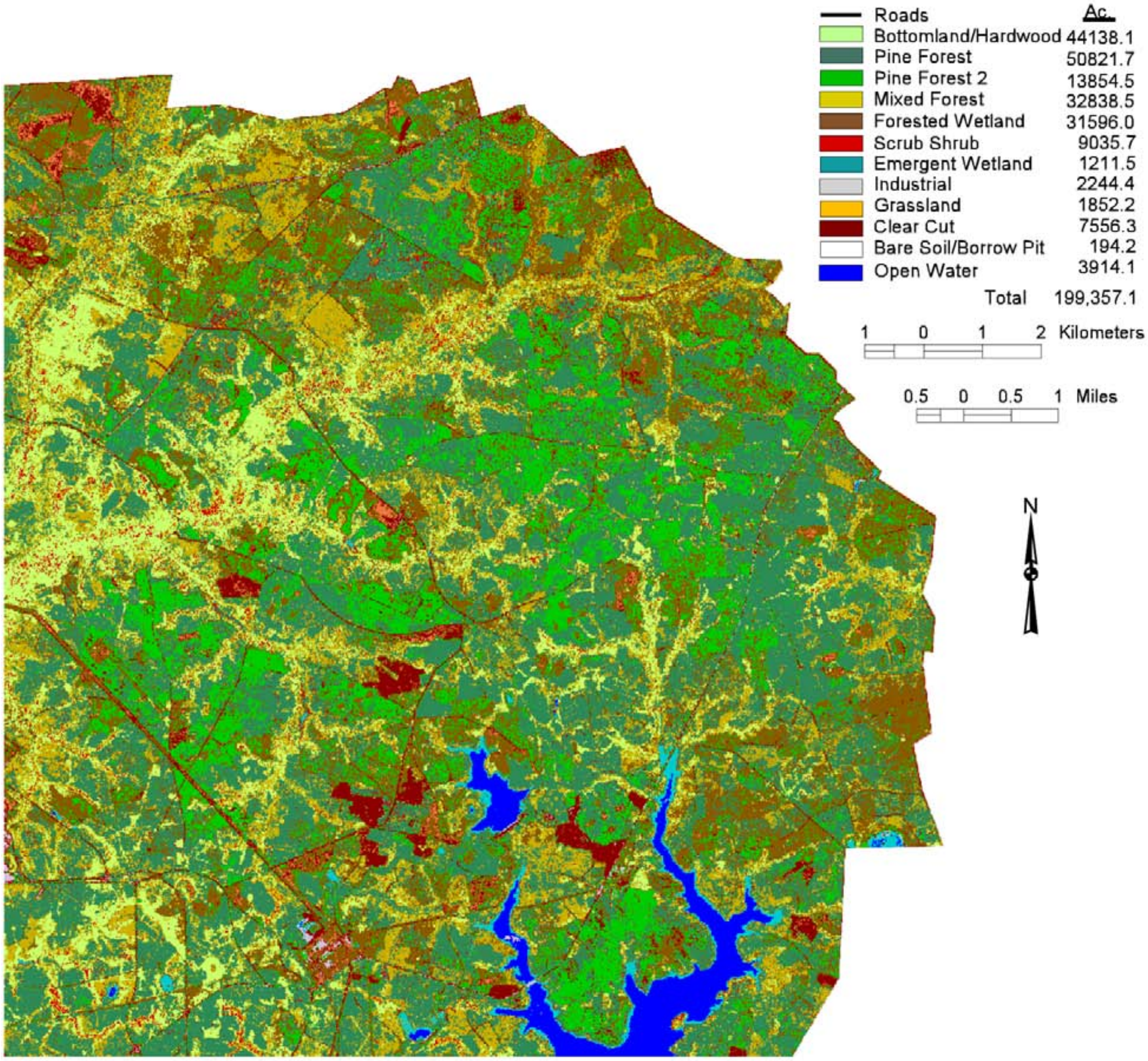

Figure 2-3. Major Vegetation Types and Approximate Areas on SRS - NE Quadrant

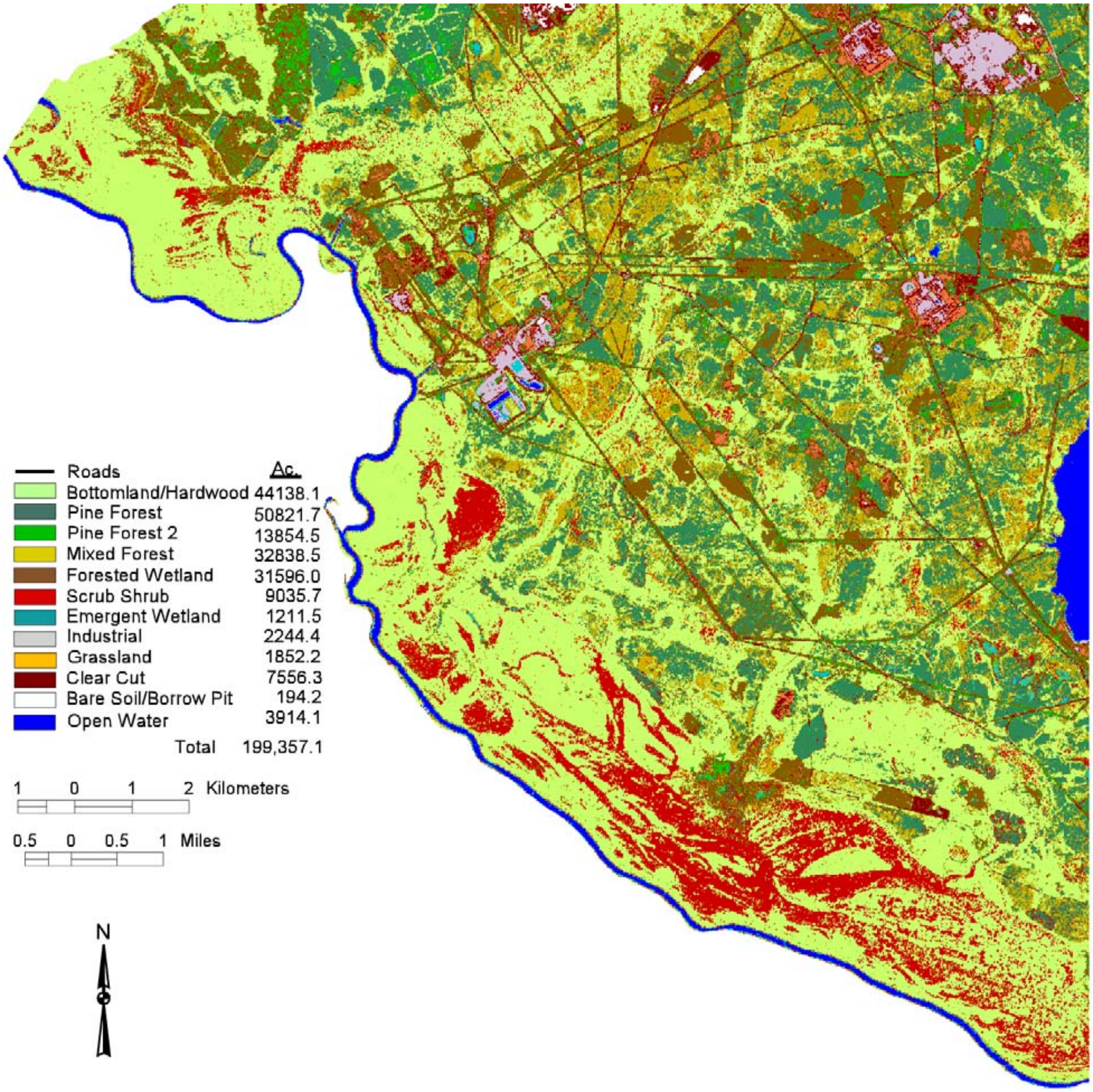

Figure 2-4. Major Vegetation Types and Approximate Areas on SRS - SW Quadrant

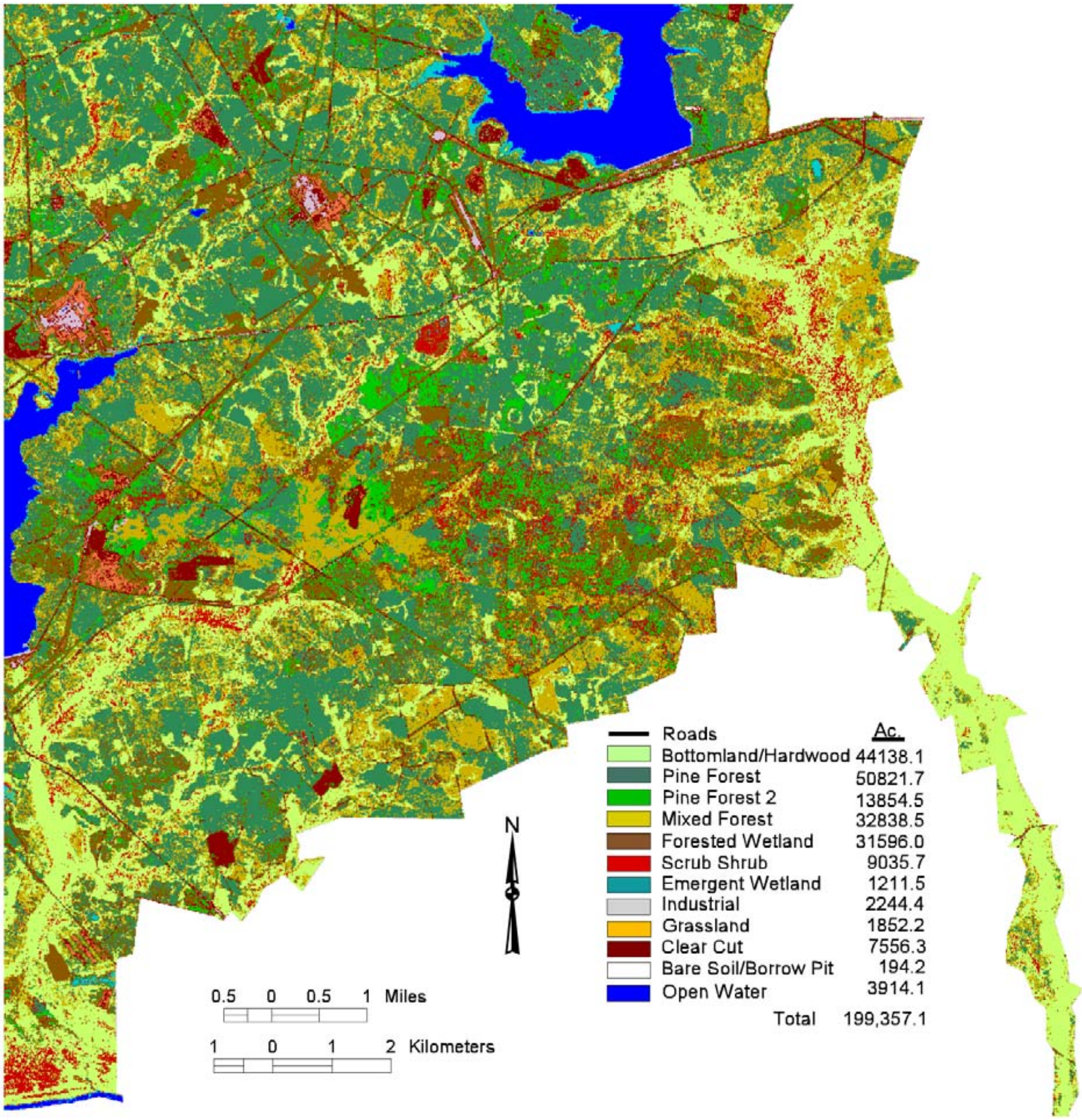

Figure 2-5. Major Vegetation Types and Approximate Areas on SRS - SE Quadrant

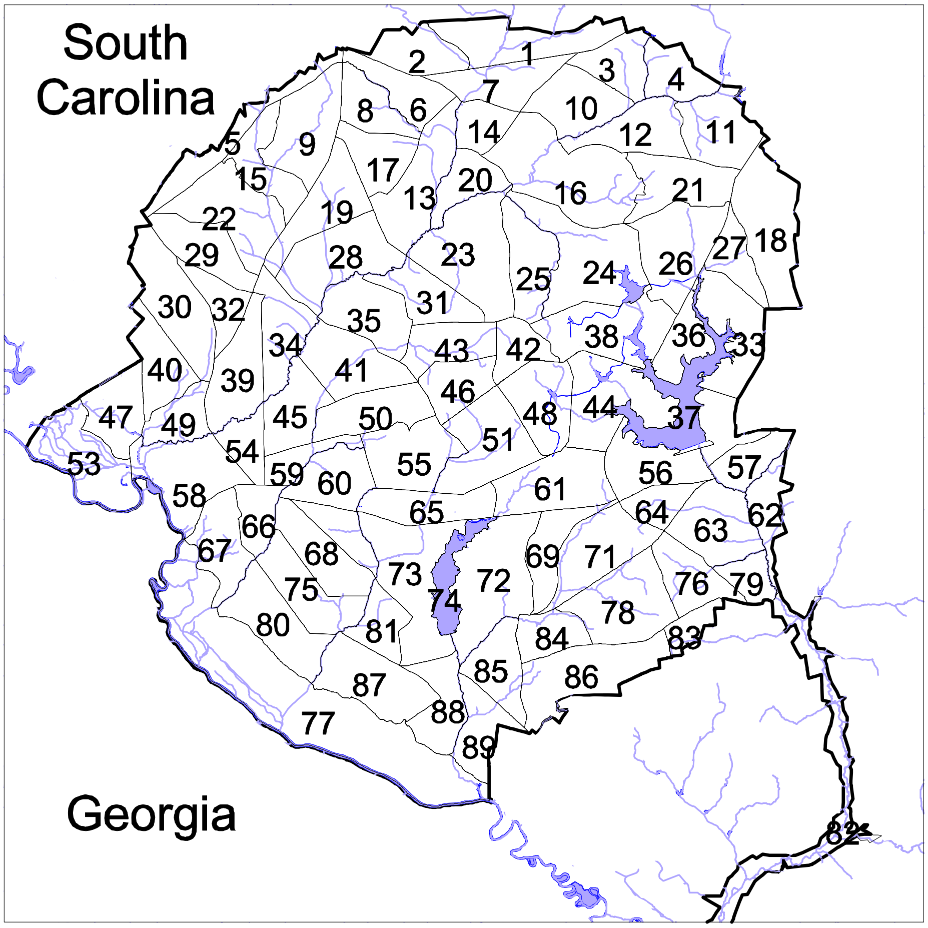

Figure 2-6. Boundaries of Management Compartments Used for Planning Forestry Activities by SFS.

2.2.5.2 Management Areas

Large scale management areas have changed at SRS over time based on changes in priorities and philosophies of resource management. Originally, the site was divided into two areas, the red-cockaded woodpecker (RCW) management area and the Core/Other area. These comprised approximately 31,182 ha (77,052 ac) and 48,455 ha (119,735 ac) respectively. In 1993 a new area of supplemental RCW management area was identified. It incorporated portions of both the core and the RCW areas into a management zone which was managed to provide future RCW nesting sites. This area was approximately 19,493 ha (48,168 ac) and reduced the Core and RCW areas to 26,007 ha (64,264 ac) and 34,840 ha (86,091 ac) respectively. In the 2001 resource management plan, the Core/Other Use area was sub-divided to into 4 separate areas based on geography and use. The new areas divided out of the Other Use area are the Crackerneck Area (4,540 ha, 11220 ac), the Savannah River Swamp (4,050 ha, 10,010 ac), and the Lower Three Runs Corridor (the "tail") (1,802 ha, 4,454 ac). The RCW and supplemental RCW areas were largely unchanged, while the Core/Other area was reduced to 15,531 ha (38,378 ac). Crackerneck is being managed primarily for wildlife habitat, and the swamp and tail areas are largely unmanaged areas of SRS.

2.2.5.3 Management Practices

Each forestry management area has general guidelines for forest practices, species selections, and rotation ages of the timber for harvest and reforestation. Rotation age is the average age of the trees in the stand at the time it is harvested. These are based on the desired primary and future uses for the management area. All pine species are managed under a 50 year rotation age in the Other Use and the Supplemental RCW management areas. Longleaf pine is managed under a 120-year rotation age in the RCW Habitat and Crackerneck management areas. Loblolly pine is managed under rotation ages of 100 years in the RCW Habitat area and 80 years in the Crackerneck area. These longer rotation ages allow the trees to become larger and provide benefits of nesting sites and wildlife habitat. Hardwood species are managed under a 150 year rotation in the Crackerneck area and 100 years in the other areas. The Savannah River Swamp and Lower Three Runs areas are not managed for timber production, so no rotation age guidelines are listed for these two management areas.

Additional management within each area is guided by the habitat needs of the goal. These could include understory removal and control in RCW related areas, or vegetation and shrub removal for security purposes in the Core Use area, or food plot or mast management activities in the Crackerneck area to support wildlife needs. Each management area consists of multiple compartments. These compartments are the functional planning units for long-term planning to support the management area purpose.

2.3 FIRE

2.3.1 Introduction

Fire is a natural component of many habitats and vegetative communities of the Upper Coastal Plain ecosystems. Many of the more xeric communities historically burned in a repetitive cycle and favored species of understory and overstory that were able to tolerate the periodic intrusion of fire. Many of the Carolina Bay and wetland ecosystems also show a history of periodic burning during periods of prolonged droughts. Fire is commonly used as a management tool under the current silvicultural practices employed on much of the SRS forested areas.

2.3.2 Wildfires

Wildfires were the most common burning influence on the development of the vegetation communities that came to be included in the SRS. Wildfires still continue to influence the SRS vegetation, although they have come to play a much smaller role due to effective suppression since 1989. The native Indians also used fire as a means of maintaining the pine savannah ecosystem that was part of their livelihood. The majority of current wildfires on SRS is due to lightning and storm events, although some are initiated by human causes. The number of fires varies among years due to conditions and weather patterns. The number of fires and acres burned since 1954 are listed in Table 2-1. Wildfires are typically extinguished as rapidly as possible, unless ecologically valid reasons are present to allow them to burn a particular habitat.

Table 2-1. Summary of Wildfires on SRS by Calendar Years

Calendar Year	Number of Fires	Acres Burned
1954-77	473	9,208
1978	32	251
1979	11	7
1980	24	251
1981	13	27
1982	16	7
1983	10	175
1984	6	5
1985	27	320
1986	4	249
1987	22	90
1988	8	99
1989[a]	3	6
1990	10	19
1991	9	1
1992	8	1
1993	15	43
1994	13	11
1995	11	26
1996	11	119
1997	3	2
1998	3	17
1999	12	285
2000	25	93
2001	6	7
2002	23	447

Source: SRFS (2003)

[a] USFS-SR assumed wildland fire suppression responsibilities in 1989.

2.3.3 Controlled Burns

The SRFS conducts an active program of controlled burning on SRS for multiple silvicultural reasons. Controlled burns are effectively utilized for site preparation prior to planting new pine plantations, for fuel reduction on the ground of current plantations, for railroad right-of-way maintenance, and for wildlife habitat enhancement. During a controlled burn, a specific acreage is identified and isolated, a fire ignition scheme carried out, and control of the burning acreage maintained until the management objective is obtained. Many factors influence the ability to conduct controlled burns, including wind speed and direction, temperature and humidity, fuel moisture content, and fuel volume. Only when all conditions are correct to ignite an area is a burn begun. Wildlife habitat improvement is the factor responsible for the largest portion of the controlled burning program. This is primarily associated with the RCW management for understory and mid-story removal to encourage colony habitat. Fuel load reduction is the second most common use of controlled burning on SRS. The SRFS attempts to burn approximately 4,047 ha (10,000 ac) to 6,070 ha (15,000 ac) annually, although this is variable depending on weather during the normal burning seasons. The normal burning cycles for production pine plantations is approximately 7 to 10 years between burn events. Burning for site preparation is generally conducted during the winter prior to planting the following spring.

2.4 COMMERCIAL TIMBER

2.4.1 Timber Acreage

The SRS timber crop is of prime commercial value. The Savannah River Forest Station (SRFS) of the U.S. Forest Service manages this resource under an established timber management plan that specifies management requirements for nearly 73,654 ha (182,000 acres) of commercial forest and more than 4,856 ha (12,000 acres) of nonforest land. Commercial operation provides pine sawtimber, pine pulpwood, hardwood sawtimber, and pulpwood (Table 2-2). This resource has been developed since 1953 through the planting or replanting of nearly 53,015 ha (131,000 acres) with approximately 135 million seedlings of various tree species and the seeding of longleaf pine on some acres (Table 2-3 and Table 2-4) (SRFS 2003).

Table 2-2. Summary of SRFS Timber Marketable Volume and Annual Growth, 2002

Net Marketable Volume as of 9/30/02 (hundred cubic feet)		
	Sawtimber	Pulpwood
Pine	2,636,224	1,718,918
Hardwood	1,109,500	924,100
Total	3,745,724	2,643,018
Predicted Annual Growth – Including Ingrowth		
Pine	4%	6%
Hardwood	3%	5%

Source: SRFS 2003

Table 2-3. Summary of Total Acres Planted and Seeded, FY 1953 – FY 2002

Fiscal Year	Planted Loblolly	Planted Slash	Planted Longleaf	Planted Hardwood	Direct Seeded Longleaf	Cumulative Total
1953-73	11,671	38,527	14,858	-	21,948	87,004
1974	1,051	-	101	-	-	88,156
1975	702	-	350	64	-	89,272
1976	620	-	468	12	-	90,372
1977	831	-	266	-	-	91,469
1978	1,033	-	310	-	-	92,812
1979	1,985	-	-	-	-	94,797
1980	1,994	-	160	-	-	96,951
1981	2,312	-	314	-	-	99,577
1982	2,537	-	-	-	41	102,155
1983	1,450	-	402	-	41	104,048
1984	1,913	-	239	-	31	106,231
1985	2,042	-	205	-	20	108,498
1986	2,026	-	221	-	-	110,745
1987	l,649	-	559	-	-	112,953
1988	2,148	-	540	-	-	115,641
1989	1,709	-	976	-	-	118,326
1990	1,995	-	821	-	-	121,142
1991	504	-	1,329	-	-	122,975
1992	566	-	1,183	54	-	124,778
1993	194	-	1,573	48	-	126,593
1994	297	-	1,672	121	-	128,683
1995	199	-	819	272	-	129,973
1996	399	-	463	189	-	131,024
1997	187	-	463	123	-	131,797
1998	138	-	232	44	-	132,211
1999	349	-	669	10	-	133,239
2000	206	-	629	5	-	134,079
2001	127	-	462	85	-	134,164
2002	61	-	259	14	-	164,498

Source: SRFS 2003

Table 2-4. Planting Summary (Gross Seedlings Planted by Species in Thousands), FY 1953 – FY 2002

Fiscal Year	Loblolly	Slash	Longleaf	Hardwood	Cumulative Total
1953-73	12,228[b]	40,298	50,029[a]	-	102,555
1974	546	-	50	-	103,151
1975	391	-	210	16	103,768
1976	337	-	255	6	104,366
1977	500	-	225	-	105,091
1978	550	-	225	-	105,866
1979	1,300	-	-	-	107,166
1980	1,530	-	160	-	108,856
1981	1,574	-	311	-	110,741
1982	1,578	-	41	-	112,360
1983	1,465	-	350	-	114,175
1984	1,550	-	279	-	116,004
1985	1,500	-	146	-	117,650
1986	1,500	-	200	-	119,350
1987	1,200	-	570	-	121,120
1988	1,517	-	477	-	123,114
1989	1,275	-	750	-	125,139
1990	1,400	-	750	-	127,289
1991	599	-	1,000	-	128,888
1992	500	-	910	14	130,312
1993	200	-	1,230	15	131,757
1994	223	-	1,254	39	133,273
1995	151	-	625	110	134,159
1996	289	-	347	71	134,866
1997	140	-	347	38	135,391
1998	103	-	174	10	135,678
1999	62	-	498	5	136,443
2000	154	-	472	1	137,070
2001	95	-	350	24	137,539
2002	46	-	195	4	137,784

Source: SRFS 2003
[a]1000 longleaf seedlings tabulated for each acre seeded.
[b]Includes 5000 cypress planted in FY 1972.

2.4.2 Timber Commercial Value

The commercial value of SRS standing timber in 2002, based on bids from previous years, was more than $400 million (Table 2-5). The cumulative value of timber sold on SRS from 1955 through 2002 was more than $74 million (timber sold may include uncut trees), and the cumulative value of timber cut for the same period was more than $85 million (Table 2-6 and Table 2-7) (SRFS 2003). The dollar values are not adjusted for inflation.

Table 2-5. Summary of Standing Timber Value, FY 1962 – FY 2002

Fiscal Year	Dollar Value	Fiscal Year	Dollar Value[a]
1962	$15,976,230	1982	92,108,240
1963	17,857,517	1983	91,976,122
1964	19,822,323	1984	103,084,852
1965	22,841,055	1985	94,812,504
1966	25,169,794	1986	117,481,333
1967	25,308,675	1987	118,898,339
1968	26,333,842	1988	134,872,708
1969	27,372,000	1989	151,465,057
1970	28,370,995	1990	169,909,264
1971	29,200,617	1991	170,248,875
1972	30,258,114	1992	228,362,034
1973	32,456,000	1993	374,199,885
1974	33,156,000	1994	411,090,620
1975	33,962,000	1995	501,701,630
1976	35,822,000	1996	450,251,376
1977	36,700,000	1997	398,528,143
l978	53,310,113	1998	505,014,804
1979	63,849,134	1999	519,469,572
1980	$70,234,047	2000	504,934,207
1981	83,930,420	2001	493,815,092
		2002	405,462,062

Source: SRFS 2003.
[a]Value of products are determined by weighted average of preceding 12 months high bid, times the volume of standing trees.

Table 2-6. Summary of Type and Value of Timber Sold, FY 1955 – FY 2002

Fiscal Year	Hundred Cubic Feet Pine Sawtimber	Hundred Cubic Feet Hardwood Sawtimber	Hundred Cubic Feet Pine Small Roundwood	Hundred Cubic Feet Hardwood Small Roundwood	Total Value Sold ($)	Cumulative Value Sold ($)
1955-73	68,328	-	273,884		4,245,160	4,245,160
1974	4,563		44,639		704,134	4,949,294
1975	1,509		30,386		538,978	5,488,282
1976	2,253		42,267		772,572	6,260,844
1977	2,905		54,647		881,805	7,142,649
1978	2,107		48,387		969,466	8,112,115
1979	5,174		46,130		1,373,737	9,485,852
1980	6,992		39,491		1,548,117	11,033,969
1981	13,819		20,869		1,468,699	12,502,668
1982	11,553		16,979		1,256,058	13,758,726
1983	12,484	1,145	16,401	3,632	1,295,222	15,053,948
1984	23,505	4,029	14,148	3,822	2,000,451	17,054,399
1985	9,795	2,249	14,063	1,575	1,216,167	18,270,566
1986	18,687	969	22,822	3,692	2,072,245	20,342,811
1987	20,256	392	24,432	3,162	2,261,324	22,604,135
1988	17,140	513	21,285	2,379	1,982,695	24,568,830
1989	18,821	209	17,686	32	2,399,602	26,986,432
1990	2,803	380	22,093	2,699	1,481,852	28,468,284
1991	27,921	3,580	29,084	769	4,378,618	32,846,902
1992	19,233	0	18,148	11	2,880,158	35,727,060
1993	17,353	0	17,569	104	3,460,011	39,187,071
1994	16,484	0	14,771	109	2,750,729	41,737,800
1995	17,692	153	23,793	177	4,783,568	46,521,368
1996	21,182	199	18,966	910	5,092,490	51,613,858
1997	15,916	59	12,670	533	2,869,396	54,483,254
1998	21,748	99	21,735	554	4,874,665	59,357,919
1999	31,511	100	13,404	230	3,155,537	62,513,456
2000	13,724	357	24,051	1,183	3,427,776	65,941,232
2001	19,890	395	24,519	1,919	4,394,352	70,335,584
2002	20,219	0	15,009	1,064	3,883,090	74,218,674

Source: SRFS 2003.

Table 2-7. Summary of Type and Value of Timber Cut, FY 1955 – FY 2002

Fiscal Year	Hundred Cubic Feet Pine Sawtimber	Hundred Cubic Feet Hardwood Sawtimber	Hundred Cubic Feet Pine Small Roundwood	Hundred Cubic Feet Hardwood Small Roundwood	Total Value Sold ($)	Cumulative Value Sold ($)
1955-72	34,182	40,567	287,100	13,073	3,960,501	3,960,501
1973	2,885	0	54,068	0	614,548	4,575,049
1974	993	0	41,213	0	686,144	5,261,193
1975	3,341	298	47,000	476	1,004,087	6,265,280
1976	985	75	55,925	698	931,870	7,197,150
1977	1,047	0	43,195	0	827,993	8,025,143
1978	7,092	418	30,925	664	1,096,620	9,121,763
1979	6,747	271	28,742	486	982,567	10,104,330
1980	15,158	2,476	24,877	1,409	1,369,259	11,473,589
1981	17,491	2,045	18,856	2,767	2,198,522	13,672,111
1982	15,200	1,742	19,829	2,678	1,701,463	15,373,574
1983	11,357	1,654	13,444	1,281	1,211,092	16,584,666
1984	19,554	2,785	18,710	4,195	2,380,124	18,946,790
1985	15,971	534	23,066	946	1,752,573	20,717,363
1986	10,034	184	13,731	1,083	1,139,573	21,856,936
1987	18,634	0	18,367	6,900	1,601,137	23,458,073
1988	16,582	722	17,626	1,169	2,115,273	25,573,346
1989	24,296	396	24,614	428	3,266,680	28,840,026
1990	12,190	380	23,010	3,114	2,129,758	30,969,784
1991	17,875	0	23,087	1,869	3,138,369	34,108,153
1992	13,524	407	16,910	761	2,758,696	36,856,849
1993	19,158	345	16,116	165	4,716,780	41,536,629
1994	15,615	18	16,132	50	3,433,597	44,970,226
1995	15,435	18	23,573	92	4,394,088	49,364,314
1996	24,119	167	22,467	1,536	5,148,281	54,512,595
1997	31,088	481	22,065	798	4,868,798	59,381,393
1998	19,702	41	39,.38	461	5,247,982	64,629,375
1999	31,702	359	22,739	1,633	6,515,727	71,145,102
2000	27,110	4,244	20,867	3,528	5,417,634	76,562,736
2001	24,448	94	19,391	1,676	4,280,090	80,842,826
2002	29,588	17	14,843	1,299	4,182,784	85,025,610

Source: SRFS 2003.

2.5 SET-ASIDE AREAS

The U.S. Department of Energy (DOE) designated a series of set-aside areas on SRS. The Savannah River Ecology Laboratory (SREL) selects and manages these sites as representative of major or unique vegetational communities on site. A set-aside task group comprised of representatives from DOE, Westinghouse Savannah River Company, SREL, U.S. Forest Service, and the SC Department of Natural Resources, is responsible for protecting the set-asides.

The set-aside program was initiated in 1967 to promote ecological research (Hillestad and Bennett 1982). The project began with 10 set-aside areas and now includes 30 designated areas and 5,668 ha (14,005 acres) (Figure 2-7). The set-aside program protects a variety of habitat types and includes examples of pine stands, hardwood forest, riparian areas, and swamp forest. Many of these areas contain Carolina bays and are the habitat for the site's threatened and endangered plants. Because the set-asides are within the SRS boundaries, they are subjects of long-term projects that are protected from routine public access. They also provide control areas for other ecological change studies, because they are subject to very few of the disturbances associated with other areas on SRS. More detailed information on the set-aside program and each set-aside can be found in Davis and Janecek (1997).

Many of the set-aside locations are reaching ages and age-class distributions where active intervention into the site is required for healthy maintenance of the characteristic habitat of the set-aside at the location. In these cases, an individual management plan for the set-aside is developed by the Forest Service, SREL, and SRNL for recommendation to the Forest Service Interdisciplinary Team and the Set-Aside Task Group for approval prior to intervention into set-aside locations.

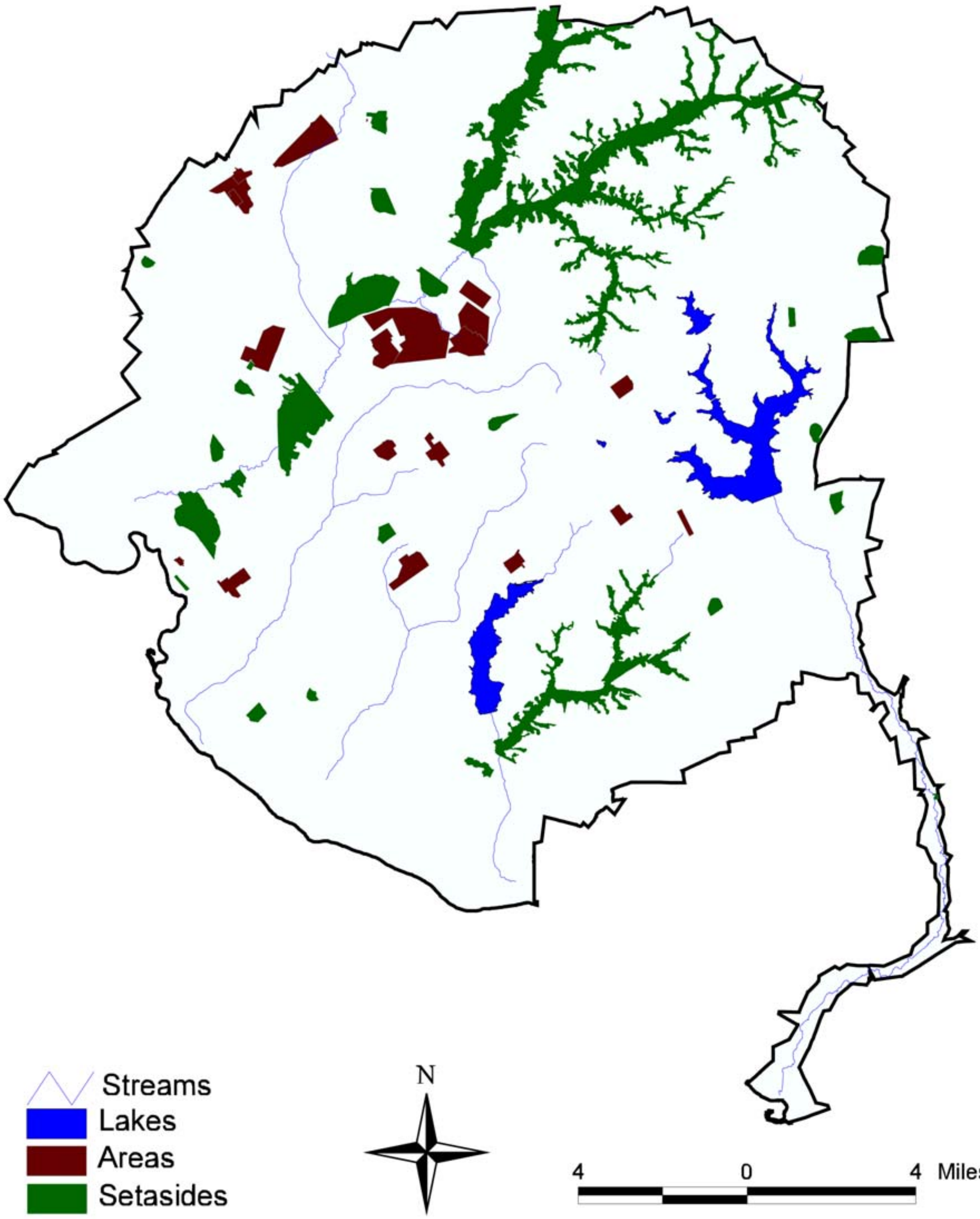

Figure 2-7. Location of SRS Set-Asides

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3.0 WILDLIFE AND THREATENED AND ENDANGERED SPECIES OF THE SRS

3.1 INTRODUCTION

The SRS supports abundant terrestrial and semiaquatic wildlife, as well as a number of species considered threatened or endangered. Since the early 1950s, the Site has changed from 67% forest and 33% agriculture to 94% forest, with the remainder in aquatic habitats and developed areas. Wildlife populations correspondingly shifted from forest-farm edge-utilizing species to a predominance of forest-dwelling species. The SRS now supports 44 species of amphibians, 60 species of reptiles, 255 species of birds, and 55 species of mammals. These populations include urban wildlife, several commercially and recreationally important species, and a few threatened and endangered species. Protection and restoration of all flora and fauna to a point where their existence is not jeopardized are principal goals of federal and state environmental programs. Those species of plants and animals afforded governmental protection are collectively referred to as “species of concern.” This chapter discusses the status of species of concern at SRS with emphasis on the biota listed or proposed as endangered or threatened by the U.S. Department of the Interior, U.S. Department of Commerce, or the State of South Carolina that currently exist onsite either as a permanent or temporary resident and that have habitual preferences or affinities for ecosystems present on SRS.

3.2 ECOLOGY AND MANAGEMENT OF A FORESTED LANDSCAPE: FIFTY YEARS ON THE SAVANNAH RIVER SITE

Kilgo and Blake (2005) address the ecology and management of the natural resources at SRS. Included are chapters on the site’s history, land management, physical environment, plant communities, various taxonomic animal groups, endangered species, and game species. Kilgo and Blake (2005) describe the management of these various resources over the 50-year period following the initial Federal acquisition of the lands encompassing the SRS.

3.3 NATURAL RESOURCES MANAGEMENT PLAN FOR THE SAVANNAH RIVER SITE

USFS-SR (2005) describes the manner in which the U.S. Forest Service proposes to manage the natural resources of the SRS over the next 5 to 10 years. It further updates and replaces the existing plan that was issued in 1991. The revised plan addresses the proposed management of wildlife, fisheries and botany resources, renewable forest products, engineering and environmental services, watersheds, wildland fires, research, DOE research set-aside areas and visual resources.

3.4 WILDLIFE

The SRS comprises a variety of diverse habitat types that support terrestrial and semiaquatic wildlife species. Since the early 1950s, the site has changed from 67% forest and 33% agriculture to 94% forest, with the remainder in aquatic habitats and developed areas (Workman and McLeod 1990). The wildlife correspondingly shifted from forest-farm edge utilizing species to a predominance of forest-dwelling species. The SRS now supports 44 species of amphibians, 59 species of reptiles, 255 species of birds, and 55 species of mammals. These populations include several commercially and recreationally important species, and a few threatened and endangered species.

3.5 HERPETOFAUNA

3.5.1 Introduction

SRS supports abundant herpetofauna because of its temperate climate and diverse habitats. The species of herpetofauna include 17 salamanders, 27 frogs and toads, 1 crocodilian, 13 turtles, 9 lizards, and 36 snakes (Table 3-1). Gibbons and Semlitsch (1991) provide an overview, description, and identification keys to the herpetofauna of SRS.

3.5.2 Taxonomic Listing of SRS Herpetofauna

Within the State of South Carolina, the total number of species and subspecies of amphibians and reptiles are 69 and 76, respectively (Conant and Collins 1991). Most of these occur on the SRS. The class Amphibia is represented on site by 2 orders, 11 families, 16 genera, and 44 species. The Reptilia are represented by 3 orders, 12 families, 41 genera, and 59 species. Except for the salamanders, 75% or more of the amphibian and reptilian orders found in South Carolina occur on the SRS. The reduced percentage of South Carolina salamanders on SRS (44.7%) is because many species are found only in the mountainous and Upper Piedmont regions of the state.

A few species of amphibians and reptiles, reported in earlier studies, have not been found in more recent efforts. Explanations for these apparent inconsistencies range from misidentifications to temporal changes in species distributions (Gibbons and Semlitsch 1991). These problematic species include the dusky salamander, Woodhouse's/Fowler's toad, gray tree-frog, Brimley's chorus frog, striped chorus frog, and northern water snake.

Several amphibian and reptile species are found in South Carolina and Georgia that have geographic ranges that encompass or closely approach the SRS. However, none have been documented on the SRS (Table 3-2) (Gibbons and Semlitsch 1991).

Class Order Family Scientific Name Common Name

Table 3-1. Taxonomic Listing of Amphibians and Reptiles of the SRS

Class	Order	Family	Scientific Name	Common Name
Amphibia	Caudata	Proteidae	*Necturus punctatus*	Dwarf Waterdog
		Amphiumidae	*Amphiuma means*	Two-Toed Amphiuma
		Sirenidae	*Siren lacertina*	Greater Siren
			S. intermedia	Lesser Siren
		Ambystomatidae	*Ambystoma talpoideum*	Mole Salamander
			A. opacum	Marbled Salamander
			A. maculatum	Spotted Salamander
			A. tigrinum	Tiger Salamander
		Salamandridae	*Notophthalmus viridescens*	Eastern (Red-Spotted) Newt
		Plethodontidae	*Desmognathus fuscus*	Dusky Salamandera
			D. auriculatus	Southern Dusky Salamander
			Plethodon glutinosus	Slimy Salamander
			Pseudotriton montanus	Mud Salamander
			P. ruber	Red Salamander
			Eurycea cirrigera	Two-Lined Salamander
			E. longicauda	Long-Tailed (Three-Lined) Salamander
			E. quadridigitata	Dwarf Salamander
	Anura	Pelobatidae	*Scaphiopus holbrookii*	Easten Spadefoot Toad
		Bufonidae	*Bufo terrestris*	Southern Toad
			B. quercicus	Oak Toad
			B. woodhousei	Woodhouse Toad
		Hylidae	*Acris gryllus*	Southern Cricket Frog
			A. crepitans	Northern Cricket Frog
			Hyla cinerea	Green Treefrog
			H. gratiosa	Barking Treefrog
			H. femoralis	Pine Woods Treefrog
			H. squirella	Squirrel Treefrog
			H. chrysoscelis	Cope's Gray Treefrog
			H. avivoca	Bird-Voiced Treefrog
			H. versicolor	Gray Treefrog
			Pseudacris triseriata	Striped Chorus Frog
			P. nigrita	Southern Chorus Frog
			P. ornata	Ornate Chorus Frog
			P. crucifer	Spring Peeper
			P. brimleyi	Brimley's Chorus Frog
			P. ocularis	Little Grass Frog
		Microhylidae	*Gastrophryne carolinensis*	Eastern Narrow-Mouthed Toad
		Ranidae	*Rana catesbeiana*	Bullfrog
			R. virgatipes	Carpenter Frog
			R. clamitans	Bronze or Green Frog
			R. palustris	Pickerel Frog
			R. areolata	Carolina Gopher Frog or Crawfish Frog
			R. grylio	Pig Frog
			R. sphenocephala	Southern Leopard Frog

Table 3-1. Taxonomic Listing of Amphibians and Reptiles of the SRS - continued

Class	Order	Family	Scientific Name	Common Name
Reptilia	Crocodilia	Alligatoridae	*Alligator missisippiensis*	American Alligator
	Chelonia	Chelydridae	*Chelydra serpentina*	Common Snapping Turtle
		Kinosternidae	*Sternotherus odoratus*	Common Musk Turtle
			Kinosternum subrubrum	Eastern Mud Turtle
			K. bauri	Striped Mud Turtle
		Emydidae	*Chrysemys picta*	Painted Turtle
			Clemmys guttata	Spotted Turtle
			Terrapene carolina	Eastern Box Turtle
			Pseudemys concinna	River Cooter
			P. floridana	Florida Cooter
			Deirochelys reticularia	Chicken Turtle
			Trachemys scripta	Slider Turtle
			Gopherus polyphemus	Gopher Tortoise
			Apalone spinifera	Spiny Softshell Turtle
	Squamata	Polychridae	*Anolis carolinensis*	Green Anole
		Phrynosomatidae	*Sceloporus undulatus*	Eastern Fence Lizard
		Teiidae	*Cnemidophorus sexlineatus*	Six-Lined Racerunner
		Scincidae	*Scincella lateralis*	Ground Skink
			Eumeces fasciatus	Five-Lined Skink
			E. laticeps	Broad-Headed Skink
			E. inexpectatus	Southeastern Five-Lined Skink
		Anguidae	*Ophisaurus ventralis*	Eastern Glass Lizard
			O. attenuatus	Slender Glass Lizard
		Colubridae	*Nerodia cyclopion*	Green Water Snake
			N. taxispilota	Brown Water Snake
			N. erythrogaster	Redbelly Water Snake
			N. fasciata	Banded Water Snake
			N. sipedon	Water Snake
			Carphophis amoenus	Worm Snake
			Cemophora coccinea	Scarlet Snake
			Lampropeltis getula	Common Kingsnake
			L. triangulum	Scarlet Kingsnake
			Pituophis melanoleucus	Pine Snake
			Regina rigida	Glossy Crayfish Snake
			R. septemvittata	Queen Snake
			Rhadinaea flavilata	Yellow-Lipped Snake
			Tantilla coronata	Southeastern Crowned Snake
			Seminatrix pygaea	Black Swamp Snake
			Storeria dekayi	Brown Snake
			S. occipitomaculata	Redbelly Snake
			Thamnophis sirtalis	Common Garter Snake
			T. sauritus	Eastern Ribbon Snake
			Virginia valeriae	Smooth Earth Snake
			V. striatula	Rough Earth Snake
			Heterodon platirhinos	Eastern Hognose Snake
			H. simus	Southern Hognose Snake
			Diadophis punctatus	Ringneck Snake
			Farancia abacura	Mud Snake
			F. erytrogramma	Rainbow Snake
			Coluber constrictor	Black Racer

Table 3-1. Taxonomic Listing of Amphibians and Reptiles of the SRS - continued

Class	Order	Family	Scientific Name	Common Name
Reptilia	Squamata	Colubridae	*Masticophis flagellum*	Coachwhip
			Opheodrys aestivus	Rough Green Snake
			Elaphe guttata	Corn Snake
			E. obsoleta	Rat Snake
		Elapidae	*Micrurus fulvius*	Eastern Coral Snake
		Viperidae	*Agkistrodon contortrix*	Copperhead
			A. piscivorus	Cottonmouth
			Sistrurus miliarius	Pygmy Rattlesnake
			Crotalus horridus	Timber or Canebrake Rattlesnake

Sources: Collins 1990; Conant and Collins 1991; Gibbons and Semlitsch 1991; Beltz 1995; Gibbons et al. 1997.
[a]Species whose presence on SRS has been reported but not recently confirmed or species with which taxonomic problems are associated.

Table 3-2. Species of Amphibians and Reptiles Whose Ranges Overlap or Approach the SRS, But Which Have Not Been Documented to Occur on the Site

Scientific Name	Common Name
Amphibians	
Ambystoma cingulatum	Flatwoods Salamander
A. mabeei	Mabee's Salamander
Hemidactylium scutatum	Four-Toed Salamander
Plethodon websteri	Webster's Salamander
Pseudobranchus striatus	Dwarf Siren
Stereochilus marginatus	Many-Lined Salamander
Bufo americanus	American Toad
Hyla andersoni	Pine Barrens Treefrog
Rana heckscheri	River Frog
Reptiles	
Apalone ferox	Florida Softshell
Eumeces egregius	Northern Mole Skink
Lampropeltis calligaster	Mole Snake
Crotalus adamanteus	Eastern Diamondback Rattlesnake

Source: Gibbons and Semlitsch 1991

3.5.3 Habitat Utilization

The amphibians and reptiles on SRS are year-round residents. SRS herpetofauna use a variety of aquatic and terrestrial SRS habitats (Table 3-3). Although some species are probably more widespread than indicated in Table 3-3, the documentation to support their presence in other habitats does not exist. Because of the lack of any habitat data on them, the striped chorus frog, Brimley's chorus frog, gray treefrog, gopher tortoise, and northern water snake, are not included in Table 3-3.

The highest overall herpetofauna species diversity is in aquatic habitats. More than 70% of the site's amphibian and reptile species use stream corridors and Carolina bays. Only 9% have been documented in the Savannah River. On average, slightly more than half (54%) of the amphibian species have been found in aquatic habitats, while 51% of the reptiles have been found in these areas.

Between 35% and 50% of the species have been collected from terrestrial habitats. The highest diversity is in bottomland hardwood forests, and the lowest is in old fields and clearcuts. In all of the terrestrial habitats except bottomland hardwood forest, amphibian diversity is lower than that of the reptiles. This is most likely due to the increased moisture or presence of wetter areas in bottomland forests. Both amphibians and reptiles have lower overall mean numbers of species in the terrestrial areas than in aquatic.

3.5.4 Seasonal Movement Studies

The temperate climate at the SRS, with hot and humid summers and mild winters, is generally favorable for herpetofauna. However, as ectotherms, amphibians and reptiles do exhibit seasonal variation in activity. The movement behavior of herpetofauna, especially amphibians, is positively correlated with temperature and rainfall.

One of the most studied aspects of this seasonal behavior is the movement patterns of amphibians to and from small ponds and Carolina bays. Studies have looked at the specific migration patterns of salamander species, while others have surveyed for all local species of amphibians and reptiles.

Table 3-3. Amphibian and Reptile Species Found in Ten Habitat Types at SRS

Species	Carolina Bays	Open Water Lakes and Ponds	Stream Corridor	Manmade Basin or Pit	River Swamp	River	Pine Forest	Upland Hardwood Forest	Bottom-land Hardwood Forest	Old Field and Clearcut
Dwarf Waterdog			X			X				
Two-Toed Amphiuma	X	X	X		X					
Greater Siren	X		X		X					
Lesser Siren	X	X	X		X					
Mole Salamander	X	X	X	X			X	X	X	X
Marbled Salamander	X	X	X	X	X		X	X	X	X
Spotted Salamander	X	X	X	X	X				X	
Tiger Salamander	X	X		X			X	X	X	
Eastern/Red-Spotted Newt	X	X	X	X	X	X	X	X	X	X
Dusky Salamander			X						X	
Southern Dusky Salamander			X						X	
Slimy Salamander	X						X	X	X	
Mud Salamander	X		X						X	
Red Salamander	X	X	X	X					X	
Two-Lined Salamander			X		X				X	
Long-Tailed Salamander			X		X				X	
Dwarf Salamander	X	X	X	X	X				X	
Eastern Spadefoot Toad	X		X	X			X	X		
Southern Toad	X	X	X	X	X		X	X	X	X
Oak Toad	X	X	X	X	X		X	X	X	X
Woodhouse Toad	X							X	X	
Southern Cricket Frog	X	X	X	X	X				X	
Northern Cricket Frog			X		X					
Green Treefrog	X	X	X		X		X	X	X	
Barking Treefrog	X	X	X	X	X		X	X	X	
Pine Woods Treefrog	X		X	X	X		X		X	
Squirrel Treefrog	X		X				X	X	X	
Cope's Gray Treefrog	X	X	X	X	X		X		X	
Bird-Voiced Treefrog	X		X		X				X	
Southern Chorus Frog	X	X	X	X			X	X	X	
Ornate Chorus Frog	X	X	X	X			X	X	X	
Spring Peeper	X	X	X	X	X		X	X	X	X
Little Grass Frog			X		X		X	X	X	

Table 3-3. Amphibian and Reptile Species Found in Ten Habitat Types at SRS - continued

Species	Carolina Bays	Open Water Lakes and Ponds	Stream Corridor	Manmade Basin or Pit	River Swamp	River	Pine Forest	Upland Hardwood Forest	Bottom-land Hardwood Forest	Old Field and Clearcut
Eastern Narrow-Mouthed Toad	X	X	X	X	X				X	X
Bullfrog	X	X	X	X	X					
Carpenter Frog	X	X	X		X				X	
Bronze Or Green Frog	X	X	X	X	X					
Pickerel Frog	X	X	X	X	X				X	
Carolina Gopher/Crawfish Frog	X	X							X	
Pig Frog	X	X	X		X				X	
Southern Leopard Frog	X	X	X	X	X				X	
American Alligator	X	X	X	X	X	X			X	
Common Snapping Turtle	X	X	X	X	X	X	X	X	X	X
Stinkpot	X	X	X	X	X				X	
Eastern Mud Turtle	X	X	X	X	X				X	
Striped Mud Turtle	X		X		X				X	
Painted Turtle	X									
Spotted Turtle	X	X	X						X	
Eastern Box Turtle	X	X	X	X			X	X	X	X
River Cooter			X		X	X				
Florida Cooter	X	X	X		X	X				
Chicken Turtle	X	X	X		X					
Slider Turtle	X	X	X	X	X					
Spiny Softshell Turtle		X	X			X				
Green Anole	X	X	X	X	X		X	X	X	X
Eastern Fence Lizard	X	X	X	X			X	X		X
Six-Lined Racerunner	X	X	X	X			X			X
Ground Skink	X	X	X	X			X	X	X	X
Five-Lined Skink		X	X		X				X	
Broad-Headed Skink	X	X	X	X	X		X	X	X	X
Southeastern Five-Lined Skink		X	X				X	X	X	X
Eastern Glass Lizard			X				X	X		X
Slender Glass Lizard			X				X	X		X
Green Water Snake	X	X								
Brown Water Snake		X	X		X	X				
Red-Bellied Water Snake	X	X	X		X				X	
Banded Water Snake	X	X	X	X	X	X			X	
Worm Snake			X						X	
Scarlet Snake	X	X	X	X			X	X	X	X

Table 3-3. Amphibian and Reptile Species Found in Ten Habitat Types at SRS - continued

Species	Carolina Bays	Open Water Lakes and Ponds	Stream Corridor	Manmade Basin or Pit	River Swamp	River	Pine Forest	Upland Hardwood Forest	Bottom-land Hardwood Forest	Old Field and Clearcut
Common Kingsnake	X	X	X		X			X	X	
Scarlet Kingsnake	X	X	X	X			X			X
Pine Snake							X	X		X
Glossy Crayfish Snake	X		X							
Queen Snake			X							
Yellow-Lipped Snake	X									
Southeastern Crowned Snake	X	X	X	X			X	X	X	
Black Swamp Snake	X		X							
Brown Snake	X		X	X	X		X	X	X	
Red-Bellied Snake	X	X	X	X				X	X	
Common Garter Snake	X	X	X	X				X	X	
Eastern Ribbon Snake	X	X	X		X					
Smooth Earth Snake	X	X		X				X		
Rough Earth Snake	X		X							
Eastern Hognose Snake	X	X	X	X			X	X		X
Southern Hognose Snake	X	X	X	X			X	X		
Ringneck Snake	X	X	X	X			X	X	X	
Mud Snake	X	X	X	X	X				X	
Rainbow Snake	X	X	X		X				X	
Black Racer	X	X	X	X	X		X	X	X	X
Coachwhip		X					X	X		X
Rough Green Snake		X	X		X			X	X	
Corn Snake		X	X				X	X	X	X
Rat Snake			X		X		X	X	X	X
Eastern Coral Snake	X						X	X		
Copperhead			X		X		X	X	X	X
Cottonmouth	X	X	X	X	X	X			X	
Pygmy Rattlesnake							X	X	X	X
Timber/ Canebrake Rattlesnake	X	X	X		X		X	X	X	X

3.6 AVIFAUNA

3.6.1 Introduction

SRS supports a diverse avifauna that includes migrant, seasonal, and permanent residents (Norris 1963). The documented avifauna species of SRS includes 1 loon, 2 grebes, 1 cormorant, 1 anhinga, 14 wading birds, 28 waterfowl, 16 raptors, 1 wild turkey, 1 quail, 6 rails, 18 shorebirds, 10 gulls or terns, 4 doves, 2 cuckoos, 6 owls, 3 goatsuckers, 1 swift, 1 hummingbird, 1 kingfisher, 8 woodpeckers, 9 flycatchers, 1 horned lark, 5 swallows, 1 jay, 2 crows, 3 chickadees, 3 nuthatches, 1 creeper, 6 wrens, 3 mockingbirds, 7 thrushes, 3 gnatcatchers, 2 pipits, 1 waxwing, 1 shrike, 1 starling, 5 vireos, 37 warblers, 1 old world sparrow, 10 blackbirds or orioles, 2 tanagers, 1 cardinal, 10 grosbeaks or buntings, and 15 sparrows (Table 3-8) (Norris 1963; Mayer et al. 1997). Mayer et al. (1997) provides an annotated checklist to the birds of the SRS.

3.6.2 Taxonomic Listing of Birds Found on the SRS

Sprunt and Chamberlain (1970) list 423 avian species documented for South Carolina. Approximately 60% of these species are known from the SRS. The class Aves is represented on SRS by 17 orders, 59 families, 154 genera, and 255 species. The major taxa not found on SRS are the lower Coastal Plain and shore bird guilds.

Several species documented for the SRS are based on a single observation and are mostly of birds not typically found in this region except as either rare transient visitors or accidental occurrences. These include the white-fronted goose, surf scooter, black scooter, peregrine falcon, American oystercatcher, sooty tern, white-winged dove, northern saw-whet owl, Bewick's wren, Sprague's pipit, Philadelphia vireo, Kirtland's warbler, and western meadowlark (Mayer et al. 1997).

3.6.3 Habitat Utilization

Because they are highly mobile, birds may utilize almost any habitat on SRS (Table 3-9). Pine forests (41% of the species) are most often used by birds, followed closely by upland hardwood forest (40%). Open terrestrial habitats (i.e., old fields, cleared rights-of-way and clearcuts) are used less frequently (27%).

Waterfowl and wading birds, as well as many upland species, use SRS aquatic habitats year-round. Sixty-seven percent use Carolina bays and emergent marshes. Sixty-eight percent of the upland species use this habitat type. Edge or shoreline areas accounted for high numbers of upland birds at Carolina bays and emergent marshes, stream, and small drainage corridors, and river swamp habitats. The aquatic birds are most common in large and small open water habitat (88% of the species).

Table 3-4. Taxonomic Listing of Birds of the SRS

Order	Family	Scientific Name	Common Name
Gaviiformes	Gaviidae	*Gavia immer*	Common Loon
Podicipediformes	Podicipedidae	*Podiceps auritus*	Horned Grebe
		Podilymbus podiceps	Pied-Billed Grebe
Pelecaniformes	Phalacrocoracidae	*Phalacrocorax auritus*	Double-Crested Cormorant
	Anhingidae	*Anhinga anhinga*	Anhinga
Ciconiiformes	Ardeidae	*Ardea herodias*	Great Blue Heron
		Butorides striatus	Green Heron
		Egretta caerulea	Little Blue Heron
		Bubulcus ibis	Cattle Egret
		Casmerodius albus	Great Egret
		Egretta thula	Snowy Egret
		E. tricolor	Tricolor Heron
		Nycticorax nycticorax	Black-Crowned Night Heron
		N. violaceus	Yellow-Crowned Night Heron
		Ixobrychus exilis	Least Bittern
		Botaurus lentiginosus	American Bittern
	Ciconiidae	*Mycteria americana*	Wood Stork
	Threskiornithidae	*Eudocimus albus*	White Ibis
Anseriformes	Cygninae	*Cygnus columbianus*	Tundra Swan
	Anserinae	*Branta canadensis*	Canada Goose
		Anser albifrons	Greater White-Fronted Goose
		Chen caerulescens	Snow/Blue Goose
	Anatinae	*Anas platyrhynchos*	Mallard
		A. rubripes	American Black Duck
		A. acuta	Northern Pintail
		A. crecca	Green-Winged Teal
		A. discors	Blue-Winged Teal
		A. americana	American Widgeon
		A. strepera	Gadwall
		A. clypeata	Northern Shoveler
		Aix sponsa	Wood Duck
	Aythyinae	*Aythya americana*	Redhead
		A. collaris	Ring-Necked Duck
		A. valisineria	Canvasback
		A. marila	Greater Scaup
		A. affinis	Lesser Scaup
		Bucephala clangula	Common Goldeneye
		B. albeola	Bufflehead
		Clangula hyemalis	Oldsquaw
		Melanitta fusca	White-Winged Scoter
		M. perspicillata	Surf Scoter
		M. nigra	Black Scoter

Table 3-4. Taxonomic Listing of Birds of the SRS - continued

Order	Family	Scientific Name	Common Name
	Erismaturinae	*Oxyura jamaicensis*	Ruddy Duck
	Merginae	*Lophodytes cucullatus*	Hooded Merganser
		Mergus merganser	Common Merganser
		M. serrator	Red-breasted Merganser
Falconiformes	Cathartidae	*Cathartes aura*	Turkey Vulture
		Coragyps atratus	Black Vulture
	Elaninae	*Elanoides forficatus*	Swallow-Tailed Kite
		Ictinia mississippiensis	Mississippi Kite
	Accipitrinae	*Accipiter striatus*	Sharp-Shinned Hawk
		A. cooperii	Cooper's Hawk
	Buteoninae	*Buteo jamaicensis*	Red-Tailed Hawk
		B. lineatus	Red-Shouldered Hawk
		B. platypterus	Broad-Winged Hawk
		Aquila chrysaetos	Golden Eagle
		Haliaeetus leucocephalus	Bald Eagle
	Circinae	*Circus cyaneus*	Northern Harrier
	Pandionidae	*Pandion haliaetus*	Osprey
	Falconinae	*Falco peregrinus*	Peregrine Falcon
		F. columbarius	Merlin
		F. sparverius	American Kestrel
Galliformes	Phasianidae	*Colinus virginianus*	Northern Bobwhite
	Meleagrididae	*Meleagris gallopavo*	Eastern Wild Turkey
Gruiformes	Rallidae	*Rallus elegans*	King Rail
		R. limicola	Virginia Rail
		Porzana carolina	Sora
		Porphyrula martinica	Purple Gallinule
		Gallinula chloropus	Common Moorhen
		Fulica americana	American Coot
Charadriiformes	Charadriidae	*Pluvialis squatarola*	Black-Bellied Plover
		Charadrius vociferus	Killdeer
	Haematopodidae	*Haematopus palliatus*	American Oystercatcher
	Scolopacidae	*Scolopax minor*	American Woodcock
		Gallinago gallinago	Common Snipe
		Limnodromus griseus	Short-Billed Dowitcher
		L.. scolopaceus	Long-Billed Dowitcher
		Actitis macularia	Spotted Sandpiper
		Tringa solitaria	Solitary Sandpiper
		T. melanoleuca	Greater Yellowlegs
		T. flavipes	Lesser Yellowlegs
		Calidris fusciollis	White-Rumped Sandpiper
		C. minutilla	Least Sandpiper
		C. melanotos	Pectoral Sandpiper
		C. alpina	Dunlin
		C. mauri	Western Sandpiper
		C. alba	Sanderling

Table 3-4. Taxonomic Listing of Birds of the SRS - continued

Order	Family	Scientific Name	Common Name
	Phalaropodidae	*Phalaropus lobatus*	Red-Necked Phalarope
	Larinae	*Larus delawarensis*	Ring-billed Gull
		L. atricilla	Laughing Gull
		L. philadelphia	Boneparte's Gull
		L. argentatus	Herring Gull
	Sterninae	*Sterna forsteri*	Forster's Tern
		S. antillarum	Least Tern
		S. fuscata	Sooty Tern
		S. caspia	Caspian Tern
		S. hirundo	Common Tern
		Chlidonias niger	Black Tern
Columbiformes	Columbidae	*Columba livia*	Rock Dove
		Zenaida macroura	Mourning Dove
		Z. asiatica	White-Winged Dove
		Columbina passerina	Common Ground Dove
Cuculiformes	Cuculidae	*Coccyzus americanus*	Yellow-Billed Cuckoo
		C. erythropthalmus	Black-Billed Cuckoo
Strigiformes	Tytonidae	*Tyto alba*	Barn Owl
	Strigidae	*Otus asio*	Screech Owl
		Bubo virginianus	Great Horned Owl
		Strix varia	Barred Owl
		Aegolius acadicus	Northern Saw-Whet Owl
		Asio flammeus	Short-eared Owl
Caprimulgiformes	Caprimulgidae	*Caprimulgus carolinensis*	Chuck-Wills-Widow
		C. vociferus	Whip-Poor-Will
		Chordeiles minor	Common Nighthawk
Apodiformes	Apodidae	*Chaetura pelagica*	Chimney Swift
	Trochilidae	*Archilochus colubris*	Ruby-Throated Hummingbird
Coraciiformes	Alcedinidae	*Ceryle alcyon*	Belted Kingfisher
Piciformes	Picidae	*Colaptes auratus*	Common Flicker
		Dryocopus pileatus	Pileated Woodpecker
		Melanerpes carolinus	Red-Bellied Woodpecker
		M. erythrocephalus	Red-Headed Woodpecker
		Sphyrapicus varius	Yellow-Bellied Sapsucker
		Picoides villosus	Hairy Woodpecker
		P. pubescens	Downy Woodpecker
		P. borealis	Red-Cockaded Woodpecker
Passeriformes	Tyrannidae	*Tyrannus tyrannus*	Eastern Kingbird
		T. dominicensis	Gray Kingbird
		T. verticalis	Western Kingbird
		Myiarchus crinitus	Great Crested Flycatcher
		Sayornis phoebe	Eastern Phoebe
		Empidonax virescens	Acadian Flycatcher
		E. traillii	Willow Flycatcher
		E. minimus	Least Flycatcher
		Contopus virens	Eastern Wood Pewee

Table 3-4. Taxonomic Listing of Birds of the SRS - continued

Order	Family	Scientific Name	Common Name
	Alaudidae	*Eremophila alpestris*	Horned Lark
	Hirundinidae	*Tachycineta bicolor*	Tree Swallow
		Riparia riparia	Bank Swallow
		Stelgidopteryx serripennis	Northern Rough-Winged Swallow
		Hirundo rustica	Barn Swallow
		Progne subis	Purple Martin
	Corvidae	*Cyanocitta cristata*	Blue Jay
		Corvus brachyrhychos	Common Crow
		C. ossifragus	Fish Crow
	Paridae	*Parus atricapillus*	Black-Capped Chickadee
		Poelice carolinensis	Carolina Chickadee
		Baeolophus bicolor	Tufted Titmouse
	Sittidae	*Sitta carolinensis*	White-Breasted Nuthatch
		S. canadensis	Red-Breasted Nuthatch
		S. pusilla	Brown-Headed Nuthatch
	Certhiidae	*Certhia americana*	Brown Creeper
	Troglodytidae	*Troglodytes aedon*	House Wren
		T. troglodytes	Winter Wren
		Thryomanes bewickii	Bewick's Wren
		Thryothorus ludovicianus	Carolina Wren
		Cistothorus palustris	Marsh Wren
		C. platensis	Sedge Wren
	Mimidae	*Mimus polyglottos*	Northern Mockingbird
		Dumetella caroliniensis	Gray Catbird
		Toxostoma rufum	Brown Thrasher
	Turdidae	*Turdus migratorius*	American Robin
		Hylocichla mustelina	Wood Thrush
		Catharus guttatus	Hermit Thrush
		C. ustulatus	Swainson's Thrush
		C. minimus	Gray-Cheeked Thrush
		C. fuscescens	Veery
		Sialia sialis	Eastern Bluebird
	Sylviidae	*Polioptila caerulea*	Blue-Gray Gnatcatcher
		Regulus satrapa	Golden-Crowned Kinglet
		R. calendula	Ruby-Crowned Kinglet
	Motacillidae	*Anthus spinoletta*	Water Pipit
		A. spragueii	Sprague's Pipit
	Bombycillidae	*Bombycilla cedrorum*	Cedar Waxwing
	Laniidae	*Lanius ludovicianus*	Loggerhead Shrike
	Sturnidae	*Sturnus vulgaris*	European Starling
	Vireonidae	*Vireo griseus*	White-Eyed Vireo
		V. flavifrons	Yellow-Throated Vireo
		V. solitarius	Solitary Vireo
		V. olivaceus	Red-Eyed Vireo
		V. philadelphicus	Philadelphia Vireo

Table 3-4. Taxonomic Listing of Birds of the SRS - continued

Order	Family	Scientific Name	Common Name
	Parulidae	*Mniotilta varia*	Black-and-White Warbler
		Prothonotaria citrea	Prothonotary Warbler
		Limnothylpis swainsonii	Swainson's Warbler
		Helmitheros vermivorous	Worm-Eating Warbler
		Vermivora chrysoptera	Golden-Winged Warbler
		V. pinus	Blue-Winged Warbler
		V. peregrina	Tennessee Warbler
		V. celata	Orange-Crowned Warbler
		V. ruficapilla	Nashville Warbler
		Parula americana	Northern Parula
		Dendroica petechia	Yellow Warbler
		D. magnolia	Magnolia Warbler
		D. tigrina	Cape May Warbler
		D. caerulescens	Black-Throated Blue Warbler
		D. coronata	Yellow-Rumped Warbler
		D. virens	Black-Throated Green Warbler
		D. cerulea	Cerulean Warbler
		D. fusca	Blackburnian Warbler
		D. dominica	Yellow-Throated Warbler
		D. pennsylvanica	Chestnut-Sided Warbler
		D. castanea	Bay-Breasted Warbler
		D. striata	Blackpoll Warbler
		D. pinus	Pine Warbler
		D. kirtlandii	Kirtland's Warbler
		D. discolor	Prairie Warbler
		D. palmarum	Palm Warbler
		Seiurus aurocapillus	Ovenbird
		S. noveboracensis	Northern Waterthrush
		S. motacilla	Louisiana Waterthrush
		Oporornis formosus	Kentucky Warbler
		O. agilis	Connecticut Warbler
		Geothlypis trichas	Common Yellowthroat
		Icteria virens	Yellow-Breasted Chat
		Wilsonia citrina	Hooded Warbler
		W. pusilla	Wilson's Warbler
		W. canadensis	Canada Warbler
		Setophaga ruticilia	American Redstart
	Ploceidae	*Passer domesticus*	House Sparrow
	Icteridae	*Dolichonyx oryzivorus*	Bobolink
		Sturnella magna	Eastern Meadowlark
		S. neglecta	Western Meadowlark
		Agelaius phoeniceus	Red-winged Blackbird
		Icterus spurius	Orchard Oriole
		I. galbula	Baltimore (Northern) Oriole
		Euphagus carolinus	Rusty Blackbird

Table 3-4. Taxonomic Listing of Birds of the SRS - continued

Order	Family	Scientific Name	Common Name
		E. cyanocephalus	Brewer's Blackbird
		Quiscalus quiscula	Common Grackle
		Molothrus ater	Brown-Headed Cowbird
	Thraupidae	*Piranga olivacea*	Scarlet Tanager
		P. rubra	Summer Tanager
	Fringillidae	*Cardinalis cardinalis*	Northern Cardinal
		Pheucticus ludovicianus	Rose-Breasted Grosbeak
		Coccothraustes vespertinus	Evening Grosbeak
		Guiraca caerulea	Blue Grosbeak
		Passerina cyanea	Indigo Bunting
		P. ciris	Painted Bunting
		Carpodacus purpureus	Purple Finch
		C. mexicanus	House Finch
		Carduelis pinus	Pine Siskin
		C. tristis	American Goldfinch
		Pipilo erythrophthalmus	Rufous-sided Towhee
		Passerculus sandwichensis	Savannah Sparrow
		Ammodramus savannarum	Grasshopper Sparrow
		A. leconteii	Le Conte's Sparrow
		A. henslowii	Henslow's Sparrow
		Pooecetes gramineus	Vesper Sparrow
		Aimophila aestivalis	Bachman's Sparrow
		Junco hyemalis	Dark-Eyed Junco
		Spizella passerina	Chipping Sparrow
		S. pusilla	Field Sparrow
		Zonotrichia leucophrys	White-Crowned Sparrow
		Z. albicollis	White-Throated Sparrow
		Passerella iliaca	Fox Sparrow
		Melospiza lincolnii	Lincoln's Sparrow
		M. georgiana	Swamp Sparrow
		M. melodia	Song Sparrow

Source: Mayer et al. 1997.

3.6.3.1 Waterfowl

Waterfowl use most of the suitable habitat available on SRS (Table 3-5). Mayer et al. (1986b) present extensive information pertaining to waterfowl use of SRS. Large numbers of waterfowl have wintered at the site since public access was restricted in the early 1950s and particularly since the construction of Par Pond and L Lake. The Savannah River Ecology Laboratory (SREL) has been conducting waterfowl research and surveys onsite for the past 30 years. This research has included work on waterfowl use of SRS, wood duck reproductive ecology, radionuclide and heavy metal uptake and contamination, and waterfowl wintering ecology (Mayer et al. 1986b).

Aerial surveys of the various impoundments and river swamp, and roost counts in the Steel Creek drainage have assessed waterfowl use of the SRS. The most abundant waterfowl species in the Savannah River swamp (determined by numbers counted) are consistently mallards and wood ducks. The four most abundant species of waterfowl at Par Pond and L Lake are lesser scaup, ring-necked ducks, buffleheads, and ruddy ducks.

3.6.3.2 Upland Game Birds

Several upland game bird species are found on SRS, including northern bobwhite, eastern wild turkey, woodcock, common snipe, and mourning dove. All except the common snipe are present on the SRS as permanent residents. The snipe is a common winter resident.

During the early 1960s there were many northern bobwhite on SRS. In the fall of 1961, the average covey size was 17 birds, and the density varied from 46 to 85 birds per 100 acres. Because of vegetation changes in site habitats (more pine forests and fewer old fields), Jenkins and Provost (1964) predicted that these numbers would decline. Although still common, there are fewer quail on site. However, the number of singing males did increase, based on surveys in the Crackerneck Wildlife Management Area in the northwest portion of the SRS Savannah River Swamp (USFS 1993).

In the winter of 1956-1957, mourning doves inhabited old field habitats at an estimated 7 birds per 100 acres. The local number of mourning doves increases during the fall and winter months because of the influx of migrants from the north (Jenkins and Provost 1964).

The eastern wild turkey was present in only very limited numbers in the early 1950s. In the late 1950s and early 1960s, the future survival of the wild turkey on the site was considered precarious (Jenkins and Provost 1964). In 1972, the South Carolina Department of Natural Resources initiated a program to propogate wild turkeys on SRS. Between 1973 and 1974, 48 birds from the Francis Marion National Forest were released on site. Eight hens and four gobblers were released at each of four locations. Food plots were established to supplement natural forage and facilitate trapping. Between 1977 and 2001, a total of 1,176 wild turkeys have been trapped on SRS (Table 3-6) and 847 have been used to stock areas in South Carolina, North Carolina, and Texas. The wild turkey is now common on the SRS.

On April 17, 2004, the first sport hunt for wild turkey took place in the SRS. The event was a special hunt for 20 randomly selected disabled sportsmen. Thirteen gobblers were harvested by ten different hunters. A second such special sport hunt, held on April 16, 2005, involved 24 disabled sportsmen who harvested 11 turkeys.

3.6.3.3 Introduced Species

Five non-native or exotic species of birds are found on the SRS: cattle egret, rock dove (common pigeon), house finch, European starling, and house sparrow. With the exception of the cattle egret, all of these species were introduced into eastern North America by man. The cattle egret established itself in the Americas without direct human intervention. The house finch is a western North American species that was introduced into the northeastern United States in about 1940. It was documented to have reached South Carolina in 1966 (Sprunt and Chamberlain 1970). In general, all introduced species are considered to be rare over the site as a whole (Arnett et al. 1993). However, within the developed or industrialized areas on the SRS, most of these species are considered either common or abundant in occurrence (Mayer and Wike 1997).

Table 3-5. Bird Species Found in Ten Habitat Types at SRS

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Common Loon	X				X					
Horned Grebe	X	X								
Pied-Billed Grebe	X	X		X	X					
Double-Crested Cormorant	X			X						
Anhinga	X	X	X		X	X				
Great Blue Heron	X	X	X	X	X					
Green Heron	X	X	X	X	X					
Little Blue Heron	X		X							
Cattle Egret	X	X								
Great Egret	X	X	X	X	X					
Snowy Egret	X				X					
Tricolor Heron	X			X						
Black-Crowned Night Heron	X									
Yellow-Crowned Night Heron	X	X		X	X					
Least Bittern	X	X								
American Bittern	X	X								
Wood Stork	X	X	X		X				X	
White Ibis	X	X	X		X					
Tundra Swan	X	X								
Canada Goose	X	X		X						
Greater White-Fronted Goose	X									
Snow/Blue Goose		X		X						
Mallard	X	X		X	X	X				
American Black Duck	X	X			X					
Northern Pintail	X	X			X					
Green-Winged Teal	X	X		X	X					

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Blue-Winged Teal	X	X		X	X					
American Widgeon	X	X			X					
Gadwall	X	X		X	X					
Northern Shoveler	X	X			X					
Wood Duck	X	X	X	X	X	X				
Redhead	X	X		X						
Ring-Necked Duck	X	X		X	X					
Canvasback	X									
Greater Scaup	X									
Lesser Scaup	X									
Common Goldeneye	X	X								
Bufflehead	X	X		X	X					
Oldsquaw	X									
White-Winged Scoter	X									
Surf Scoter	X									
Black Scoter	X									
Ruddy Duck	X	X		X	X					
Hooded Merganser	X	X		X	X					
Common Merganser	X									
Red-Breasted Merganser	X			X						
Turkey Vulture	X	X	X	X	X	X	X	X	X	X
Black Vulture	X	X	X	X	X	X	X	X	X	X
Swallow-Tailed Kite					X	X				
Mississippi Kite		X			X	X				
Sharp-Shinned Hawk		X	X		X		X	X	X	
Cooper's Hawk		X	X		X		X	X	X	
Red-Tailed Hawk	X	X	X	X	X	X	X	X	X	X
Red-Shouldered Hawk					X		X	X	X	

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Golden Eagle	X									
Bald Eagle	X	X			X	X				
Northern Harrier		X								X
Osprey	X	X			X	X				
Peregrine Falcon	X									
Merlin							X			
American Kestrel		X					X	X		X
Northern Bobwhite		X					X			X
Eastern Wild Turkey		X	X		X		X	X	X	X
King Rail		X	X							
Virginia Rail		X								
Sora		X								
Purple Gallinule	X	X	X							
Common Moorhen	X	X	X							
American Coot	X	X	X	X	X					
Black-Bellied Plover	X									
Killdeer	X	X								X
American Oystercatcher	X									
American Woodcock			X		X				X	
Common Snipe	X	X								X
Short-Billed Dowitcher	X									
Long-Billed Dowitcher	X									
Spotted Sandpiper	X	X								
Solitary Sandpiper	X	X								
Greater Yellowlegs	X	X								
Lesser Yellowlegs	X	X								
White-Rumped Sandpiper		X								
Least Sandpiper		X		X						
Dunlin	X									
Pectoral Sandpiper	X									
Western Sandpiper	X									

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Sanderling		X								
Northern Phalarope		X								
Ring-Billed Gull	X					X				
Laughing Gull	X									
Boneparte's Gull	X									
Herring Gull	X									
Forster's Tern	X	X								
Least Tern	X	X								
Sooty Tern	X									
Caspian Tern	X	X								
Common Tern		X								
Black Tern	X	X								
Rock Dove				X						X
Mourning Dove	X	X	X	X			X	X		X
White-Winged Dove										X
Common Ground Dove	X	X	X							X
Yellow-Billed Cuckoo		X						X	X	
Black-Billed Cuckoo								X	X	
Barn Owl							X	X		X
Screech Owl		X	X				X	X	X	
Great Horned Owl		X	X				X	X	X	
Barred Owl		X	X		X		X	X	X	
Northern Saw-Whet Owl							X	X	X	
Short-Eared Owl		X								X
Chuck-Wills-Widow		X					X	X	X	
Whip-Poor-Will		X								
Common Nighthawk		X					X	X		
Chimney Swift		X					X	X	X	
Ruby-Throated Hummingbird		X	X				X	X	X	
Belted Kingfisher	X	X	X	X	X					
Common Flicker		X	X		X		X	X	X	

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Pileated Woodpecker		X	X		X				X	
Red-Bellied Woodpecker		X	X		X		X	X	X	
Red-Headed Woodpecker		X	X				X	X		X
Yellow-Bellied Sapsucker		X	X		X			X	X	
Hairy Woodpecker		X	X		X				X	
Downy Woodpecker		X	X		X		X	X	X	
Red-Cockaded Woodpecker							X			
Eastern Kingbird		X	X							X
Gray Kingbird							X			
Western Kingbird							X			
Great Crested Flycatcher		X	X				X	X	X	
Eastern Phoebe		X	X							X
Acadian Flycatcher			X						X	
Traill's Flycatcher										X
Least Flycatcher		X								X
Eastern Wood Pewee		X	X				X	X		
Horned Lark										X
Tree Swallow										X
Bank Swallow			X							X
Northern Rough-Winged Swallow		X								X
Barn Swallow		X	X							X
Purple Martin		X								X
Blue Jay		X	X		X		X	X	X	X
Common Crow	X	X	X		X		X	X	X	X
Fish Crow	X	X	X		X		X	X	X	X
Black-Capped Chickadee		X					X	X		
Carolina Chickadee		X	X				X	X	X	

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Tufted Titmouse		X	X				X	X	X	
White-Breasted Nuthatch			X		X				X	
Red-Breasted Nuthatch							X			
Brown-Headed Nuthatch							X			
Brown Creeper		X					X	X	X	
House Wren		X	X				X	X		X
Winter Wren							X	X	X	
Bewick's Wren							X	X		
Carolina Wren		X	X		X		X	X	X	
Marsh Wren		X	X							
Sedge Wren	X									
Northern Mockingbird		X	X				X	X		X
Gray Catbird		X	X				X	X	X	X
Brown Thrasher		X	X				X	X	X	X
American Robin		X	X				X	X	X	X
Wood Thrush		X	X		X		X	X	X	
Hermit Thrush		X	X		X		X	X	X	
Swainson's Thrush		X			X		X	X	X	
Gray-Cheeked Thrush							X	X		
Veery					X		X	X	X	
Eastern Bluebird		X	X				X	X	X	X
Blue-Gray Gnatcatcher		X	X		X		X	X	X	
Golden-Crowned Kinglet		X					X	X		
Ruby-Crowned Kinglet		X					X	X	X	X
Water Pipit			X							X
Sprague's Pipit										X
Cedar Waxwing	X						X	X	X	X
Loggerhead Shrike		X								X
European Starling										X
White-Eyed Vireo		X	X		X		X	X	X	

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Yellow-Throated Vireo		X	X				X	X	X	
Solitary Vireo		X			X		X	X	X	
Red-Eyed Vireo		X			X		X	X	X	
Philadelphia Vireo		X								
Black-and-White Warbler		X	X				X	X	X	
Prothonotary Warbler		X	X		X		X	X	X	
Swainson's Warbler			X		X		X	X	X	
Worm-Eating Warbler							X	X		
Golden-Winged Warbler							X	X	X	
Blue-Winged Warbler					X		X	X	X	
Tennessee Warbler							X	X	X	
Orange-Crowned Warbler		X								X
Nashville Warbler		X					X	X	X	
Northern Parula		X	X		X		X	X	X	
Yellow Warbler		X	X							X
Magnolia Warbler							X	X	X	
Cape May Warbler							X	X	X	
Black-Throated Blue Warbler							X	X	X	
Yellow-Rumped Warbler		X	X				X	X	X	
Black-Throated Green Warbler					X		X	X	X	
Cerulean Warbler							X	X	X	
Blackburnian Warbler							X	X	X	
Yellow-Throated Warbler		X	X		X		X	X	X	

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Chestnut-Sided Warbler							X	X	X	X
Bay-Breasted Warbler					X		X	X	X	
Blackpoll Warbler							X	X	X	
Pine Warbler		X	X				X	X	X	
Kirtland's Warbler								X		
Prairie Warbler		X	X				X	X		
Palm Warbler		X								X
Ovenbird			X				X	X	X	
Northern Waterthrush		X	X				X	X	X	
Louisiana Waterthrush		X	X				X	X	X	
Kentucky Warbler		X	X		X		X	X	X	
Connecticut Warbler		X	X						X	
Common Yellowthroat		X	X						X	
Yellow-Breasted Chat		X	X						X	
Hooded Warbler		X	X		X				X	
Wilson's Warbler			X						X	
Canada Warbler							X	X	X	
American Redstart		X	X				X	X	X	
House Sparrow										X
Bobolink										X
Eastern Meadowlark		X	X							X
Western Meadowlark										X
Red-winged Blackbird	X	X			X					X
Orchard Oriole		X	X							X
Baltimore (Northern) Oriole		X	X				X	X		
Rusty Blackbird		X			X				X	
Brewer's Blackbird		X								X

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Common Grackle		X	X							X
Brown-Headed Cowbird		X	X							X
Scarlet Tanager		X					X	X	X	
Summer Tanager		X	X				X	X	X	
Northern Cardinal		X	X				X	X	X	
Rose-Breasted Grosbeak							X	X	X	
Evening Grosbeak							X	X		
Blue Grosbeak		X	X							X
Indigo Bunting		X	X				X	X	X	
Painted Bunting		X	X		X		X	X	X	
Purple Finch		X					X	X	X	
House Finch										X
Pine Siskin		X					X	X	X	
American Goldfinch		X					X	X	X	X
Rufous-sided Towhee		X	X				X	X	X	X
Savannah Sparrow		X								X
Grasshopper Sparrow										X
Le Conte's Sparrow		X	X							X
Henslow's Sparrow										X
Vesper Sparrow										X
Bachman's Sparrow		X	X				X	X	X	
Dark-Eyed Junco		X					X	X	X	X
Chipping Sparrow		X	X				X	X	X	
Field Sparrow		X	X							X
White-Crowned Sparrow		X								X
White-Throated Sparrow		X	X				X	X	X	
Fox Sparrow		X								X

Table 3-5. Bird Species Found in Ten Habitat Types at SRS - continued

Species	Large and Small Open Water Habitat[a]	Carolina Bays and Emergent Marsh[a]	Stream and Small Drainage Corridor[a]	Man Made Basins[a]	River Swamp	Large River Corridor	Pine Forest	Upland Hardwood Forest	Bottomland Hardwood Forest	Old Field, Cleared Right-of-way, and Clearcut
Lincoln's Sparrow		X								X
Swamp Sparrow		X								
Song Sparrow		X								X

Source: Mayer et al. 1997.
[a]Includes shore or edge areas.

Table 3-6. Numbers of Eastern Wild Turkeys Trapped on and Removed from SRS by SCDNR, 1977 - 2001

	Turkeys Trapped			Turkeys Removed		
Year	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
1977	12	8	20	12	4	16
1978	12	0	12	12	0	12
1979	10	6	16	6	6	12
1980	7	4	11	7	4	11
1981	6	0	6	6	0	6
1982	0	1	1	0	0	0
1983	44	19	63	44	19	63
1984	27	38	65	26	38	64
1985	12	13	25	11	11	22
1986	4	8	12	4	8	12
1987[a]	-	-	-	-	-	-
1988[a]	-	-	-	-	-	-
1989	9	22	31	9	21	30
1990	8	0	8	8	0	8
1991	32	25	57	32	9	41
1992	38	66	104	38	66	104
1993	11	28	39	11	28	39
1994	43	39	82	43	39	82
1995	19	12	31	19	12	31
1996	17	50	67	17	50	67
1997	17	92	109	16	92	108
1998	4	32	36	4	32	36
1999	28	0	28	28	0	28
2000	18	25	43	18	25	43
2001	8	11	19	8	4	12
Total	386	790	1,176	379	468	847

Source: Caudell 2004.
[a]Trapping not conducted during this year.

3.7 MAMMALS

3.7.1 Introduction

Habitats on SRS support most of the mammal species found in South Carolina. The site listing of mammals at the time of this revision includes 1 opossum, 3 shrews, 2 moles, 12 bats, 1 armadillo, 3 rabbits, 17 rodents, 14 carnivores, and 2 even-toed ungulates (Table 3-7). Cothran et al. (1991) provides a history of the study of mammals at the SRS, keys to the species, detailed species accounts, and an annotated bibliography on SRS mammals.

Table 3-7. Taxonomic Listing of Mammals of the SRS

Order	Family	Scientific Name	Common Name
Marsupialia	Didelphidae	*Didelphis virginiana*	Virginia Opossum
Insectivora	Soricidae	*Blarina carolinensis*	Short-Tailed Shrew
		Cryptotis parva	Least Shrew
		Sorex longirostris	Southeastern Shrew
	Talpidae	*Scalopus aquaticus*	Eastern Mole
		Condylura cristata	Star-Nosed Mole
Chiroptera[a]	Vespertilionidae	*Corynurhius rafinesquii*	Rafinesque’s Big-Eared Bat
		Eptesicus fuscus	Big Brown Bat
		Lasionycteris noctivigans	Silver-Haired Bat
		Lasiurus borealis	Eastern Red Bat
		L. cinereus	Hoary Bat
		L. intermedius	Northern Yellow Bat
		L. seminolus	Seminole Bat
		Myotis austroriparius	Southeastern Bat
		M. lucifugus	Little Brown Bat
		Nycticeius humeralis	Evening Bat
		Pipistrellus subflavus	Eastern Pipistrelle
	Molossidae	*Tadarida braziliendis*	Brazilian Free-Tailed Bat
Xenarthra	Dasypodidae	*Dasypus novemcinctus*	Nine-Banded Armadillo
Lagomorpha	Leporidae	*Sylvilagus floridanus*	Eastern Cottontail
		S. aquaticus	Swamp Rabbit
		S. palustris	Marsh Rabbit
Rodentia	Sciuridae	*Sciurus carolinensis*	Gray Squirrel
		S. niger	Fox Squirrel
		Glaucomys volans	Southern Flying Squirrel
	Castoridae	*Castor canadensis*	Beaver
	Muridae	*Oryzomys palustris*	Marsh Rice Rat
		Rethrodontomys humulis	Eastern Harvest Mouse
		Peromyscus polionotus	Old Field Mouse
		P. leucopus	White-Footed Mouse
		P. gossypinus	Cotton Mouse
		Ochrotomys nuttalii	Golden Mouse
		Sigmodon hispidus	Hispid Cotton Rat
		Neotoma floridana	Eastern Wood Rat
		Microtus pinetorum	Pine Vole
		Ondatra zibethicus	Muskrat
		Rattus norvegicus	Norway or Brown Rat
		R. rattus	Roof or Black Rat
		Mus musculus	House Mouse

Table 3-7. Taxonomic Listing of Mammals of the SRS - continued

Order	Family	Scientific Name	Common Name
Carnivora	Canidae	*Canis latrans*	Coyote
		C. familiaris	Feral Dog
		Urocyon cinereoargenteus	Gray Fox
		Vulpes vulpes	Red Fox
	Felidae	*Felis catus*	Feral Cat
		Puma. concolor	Mountain Lion
		Lynx rufus	Bobcat
	Mustelidae	*Lutra canadensis*	River Otter
		Mephitis mephitis	Striped Skunk
		Spilogale putorius	Spotted Skunk
		Mustela vison	Mink
		M. frenata	Long-Tailed Weasel
	Procyonidae	*Procyon lotor*	Raccoon
	Ursidae	*Ursus americanus*	Black Bear
Artiodactyla	Suidae	*Sus scrofa*	Wild Pig
	Cervidae	*Odocoileus virginianus*	White-Tailed Deer

Source: Cothran et al. 1991, except [a]from Menzel et al, 2003.

3.7.2 Taxonomic Listing of Mammals Found on the SRS

Golley (1966) and Webster et al. (1985) collectively list 61 terrestrial or semiaquatic mammals in South Carolina. Eighty-nine percent of these are either documented or suspected on SRS. Mammals that do not occur on SRS are those restricted to the mountainous habitats in the western part of the state. The class Mammalia is represented on the SRS by 8 orders, 17 families, 43 genera, and 55 species listed in Table 3-7.

Several SRS mammal listings are based on either anecdotal accounts or their potential occurrence based on range and habitat preference. These include the big brown bat, hoary bat, southeastern bat, little brown bat, swamp rabbit, and mountain lion (Cothran et al. 1991). At present, the status of these mammals on the SRS remains unconfirmed. In addition, several species of mammals have been documented to occur on site, but are either rare or transitory: the northern yellow bat, little brown bat, marsh rabbit, long-tailed weasel, and black bear.

The bats of SRS were studied by Menzel et al (2003) and it was noted that the diverse habitats of the SRS support a bat community of eleven species (Table 3-7), with the evening, eastern red, and Seminole bats being the three most common species. This comprehensive work on bats found at SRS also mentions that Brazilian free-tailed bats (*Tadarida brasiliensis*) have been detected on Site by acoustical surveys, but no individuals have been captured.

Most of the mammals found on SRS utilize terrestrial habitats (Table 3-8). Only 15% of the site's mammal species are semiaquatic. No truly aquatic mammals (Orders Cetacea, Pinnipedia, and Sirenia) occur on SRS.

Table 3-8. Mammal Species Found in the Five Major Habitats at SRS

Name	Old Fields and Clearcuts	Pine Plantations	Scrub Oak Longleaf Pine	Upland and Lowland Hardwoods	Aquatic and Semiaquatic
Virginia Opossum	X	X	X	X	
Short-Tailed Shrew	X	X	X		
Least Shrew	X	X		X	
Southeastern Shrew	X	X			
Eastern Mole	X		X	X	
Star-Nosed Mole	X				X
Silver-Haired Bat				X	
Red Bat	X	X		X	
Northern Yellow Bat				X	
Seminole Bat		X		X	
Evening Bat		X		X	
Eastern Pipistrelle		X		X	
Big-Eared Bat				X	
Eastern Cottontail	X	X	X	X	
Marsh Rabbit				X	X
Gray Squirrel		X	X	X	
Fox Squirrel		X	X		
Southern Flying Squirrel		X		X	
Beaver					X
Marsh Rice Rat	X			X	X
Eastern Harvest Mouse	X	X			
Old Field Mouse	X	X	X		
Cotton Mouse	X	X		X	
Golden Mouse	X	X	X	X	
Hispid Cotton Rat	X				
Eastern Wood Rat	X			X	
Pine Vole	X			X	
Muskrat					X
Gray Fox	X		X	X	
Red Fox	X				
Bobcat	X		X	X	
River Otter					X
Striped Skunk	X	X		X	
Spotted Skunk	X	X		X	
Mink				X	X
Long-Tailed Weasel	X			X	
Raccoon	X	X	X	X	X
Black Bear				X	
Wild Pig	X	X		X	
White-Tailed Deer	X	X	X	X	

Source: Cothran et al. 1991.

Among the terrestrial-adapted species, the more mobile ones can be found in any of the major habitats (Table 3-8). The Virginia opossum, eastern cottontail, cotton mouse, golden mouse, and white-tailed deer are habitat generalists. The southeastern shrew, silver-haired bat, northern yellow bat, seminole bat, evening bat, eastern pipistrelle, big-eared bat, fox squirrel, southern flying squirrel, hispid cotton rat, pine vole, eastern harvest mouse, eastern wood rat, red fox, long-tailed weasel, and black bear use more restricted habitats. Terrestrial SRS mammals use upland and lowland hardwoods most often, followed by old fields and clearcuts, pine plantations, and finally by scrub oak and longleaf pine habitats (Table 3-8).

The semiaquatic mammals of the SRS include the star-nosed mole, beaver, muskrat, rice rat, river otter, mink, and raccoon. The raccoon uses the broadest range of habitats. Beaver, muskrat, and river otter have the most restricted habitat requirements. The aquatic habitats used by these species include Carolina bays, emergent marshes, the river swamp, the edges of open water impoundments, and stream floodplains.

Even though mammal communities are not as diverse in the Southeast as some other vertebrate taxa, their numbers, biomass, and position in the food chain make them an important component of the food web. Mammals are being used more frequently to study and monitor the environmental fate and potential effect of various substances at the SRS. Raccoons have been used to study metal levels (Burger et al. 2002), specifically mercury (Lord et al. 2002) and radionuclides (Gaines et al. 2000). The cotton mouse (*Peromyscus gossypinus*) has also been examined as a potential indicator for the bioavailablity of heavy metals (Reinhart 2003).

3.7.3 Game Species and Furbearers

Several SRS mammals are commercially important game species or furbearers, including the Virginia opossum, eastern cottontail, marsh rabbit, gray squirrel, fox squirrel, beaver, muskrat, coyote, red fox, gray fox, bobcat, river otter, mink, long-tailed weasel, striped skunk, spotted skunk, raccoon, black bear, white-tailed deer, and wild pig. Aside from the public hunts for white-tailed deer and wild pigs, and the beaver and wild pig control programs, none of the aforementioned species populations is exploited on the SRS.

Organized hunts for white-tailed deer and wild pigs are the only recreational hunting allowed on the SRS. These hunts are necessary to control the site's deer and wild pig populations, reduce animal-vehicle collisions, and reduce depredations to newly planted forest regeneration stands and research areas by the wild pigs.

The SRS deer herd, estimated to be 25 animals in 1951, increased rapidly after the site was closed to the public. The herd now is estimated to be in the thousands (Table 3-9). By the early 1960s, deer-vehicle collisions were frequent. This and the potential for habitat degradation prompted the initiation of controlled public hunts in 1965 (Langley and Marter 1973). The public hunts were managed by the Savannah River Forest Station (SRFS) from 1965 to 1980, E. I. du Pont de Nemours from 1981 to 1988, and Westinghouse Savannah River Company after 1989. From 1965 to 2004, 41,392 white-tailed deer were killed during the public hunts (Table 3-9).

Table 3-9. Annual SRS White-tailed Deer Population Estimate and Harvest Data

			Animals Harvested			
Year	**Estimated Population**	**Deer/Vehicle Accidents**	**Number of Bucks**	**Number of Does**	**Total Annual Harvest**	**Mean Age of Deer (in years)**
1965	2591	19	80	118	198	2.00
1966	3074	16	244	297	541	1.85
1967	3081	30	481	551	1032	1.70
1968	2903	51	332	366	699[a]	1.63
1969	4070	63	443	445	888	1.54
1970	4248	58	417	447	864	1.67
1971	4475	48	418	446	864	1.68
1972	4677	50	403	405	808	1.70
1973	5250	62	511	570	1081	1.64
1974	5302	44	728	823	1551	1.80
1975	4701	48	519	519	1038	1.75
1976	4657	23	665	592	1257	1.81
1977	4089	35	620	651	1271	1.83
1978	3846	34	625	659	1284	1.75
1979	4163	25	550	528	1078	1.70
1980	4793	28	481	480	961	1.65
1981	5368	58	832	959	1791	1.64
1982	5157	49	987	1076	2063	1.68
1983	4247	41	732	865	1597	1.69
1984	3661	41	499	541	1040	1.75
1985	3770	38	487	532	1019	1.64
1986	3553	34	474	464	938	1.65
1987	3492	38	308	294	602	1.70
1988	3962	51	453	398	851	1.71
1989	4364	64	405	307	712	1.80
1990	4885	63	549	514	1063	1.89
1991	5375	104	576	516	1092	1.91
1992	5909	121	790	729	1519	1.70
1993	5364	111	739	813	1552	-[b]
1994	4848	128	826	765	1591	-[b]
1995	4381	99	564	591	1155	-[b]
1996	4551	66	815	875	1690	-[b]
1997	4079	51	654	709	1363	-[b]
1998	3736	92	643	651	1294	-[b]
1999	3356	47	492	511	1003	-[b]
2000	3211	50	240	54	294	-[b]
2001	4146	71			0	-[b]
2002	5500	67	629	689	1318	-[b]
2003	5338	80	588	541	1129	-[b]
Totals		2266	20,799	21,291	41,392	

Sources: Cothran et al. 1991; Novak 1997; WSRC 1997; WSRC 2004.
[a]Sex of one deer was not determined.
[b]Data not available at time of publication.

The SRS wild pig population originated from free-ranging domestic swine that were abandoned after the resident farmers relocated in 1952. These animals reproduced and expanded their distribution throughout the southwestern portion of SRS, along the Savannah River. In the mid-1970s, a second, smaller population of wild pigs was discovered along the Upper Three Runs drainage corridor in the northern part of the site. Based on morphological criteria, this second population was determined not to be derived from the original feral population along the Savannah River. This second population subsequently expanded throughout the northern half of SRS and merged with the original population in the late 1980s. Wild pigs currently inhabit approximately 70% of the site (Mayer and Brisbin 1991). From 1965 to 2003, 3,009 wild pigs were killed during the public hunts (Table 3-10); the average annual kill was 86 swine.

In 1985, USFS-SR began to control the numbers of these animals because of increases in both the size of the pig population and the damage they were wreaking on planted pine seedlings. Between 1985 and 1996, corral traps baited with corn were used. In 1992, trained dogs also were used to catch wild pigs for removal. Between 1985 and 2003, 8,281 wild pigs were removed from SRS, with an average of 436 taken annually.

As a result of increases in damage to forests and nuisance reports, SRFS began a beaver control program in 1983. Trapping is conducted in specific locations where problems have been identified. Since the implementation of this program, 4,028 beavers have been removed from the site (Table 3-11).

A census of small furbearers was initiated on the site in 1954 and continued annually through 1982. The trapping format was changed during the study, but the basic sampling format remained the same. A series of ten 10-trap lines was established and run along secondary roads on the Coastal Terrace (5 trap lines) and Aiken Plateau (5 trap lines). The trapping was conducted for 7 consecutive rain-free nights for a total of 700 trap nights per census. The furbearers most commonly taken were gray fox, raccoons, opossums, and bobcats. Other species captured during this study were striped skunks, red foxes, eastern cottontails, gray squirrels, feral dogs, and feral cats. The number of animals caught each year during the 29-year census fluctuated widely (Table 3-12). The gray fox, common during the first 11 years of trapping, declined during the subsequent sampling periods. The red fox, although never common, has virtually disappeared (Cothran et al. 1991).

Table 3-10. SRS Wild Pig Annual Harvest Data

Year	Public Hunt Harvest	WFS-SR Subcontract Trapper Harvest	Total Combined Annual Harvest
1965-1969	36	-	36
1970	34	-	34
1971	10	-	10
1972	17	-	17
1973	12	-	12
1974	38	-	38
1975	45	-	45
1976	176	-	176
1977	57	-	57
1978	28	-	28
1979	61	-	61
1980	32	-	32
1981	33	-	33
1982	189	-	189
1983	133	-	133
1984	104	-	104
1985	79	160	239
1986	123	238	361
1987	123	170	293
1988	146	326	472
1989	179	177	356
1990	134	302	436
1991	126	183	309
1992	168	503	671
1993	148	326	474
1994	105	627	732
1995	46	907	953
1996	107	876	983
1997	85	1,004	1,089
1998	62	1,000	1,062
1999	45	650	695
2000	38	61	99
2001	6	240	246
2002	174	259	433
2003	110	272	382
Total	3,009	8,281	11,290

Source: USFS-SR 2004

Table 3-11. Number of Beaver Trapped Annually on SRS

Year	Number of Beavers Trapped Per Year
1983	196
1984	44
1985	192
1986	148
1987	84
1988	- [a]
1989	- [a]
1990	- [a]
1991	- [a]
1992	153
1993	262
1994	327
1995	489
1996	519
1997	604
1998	670
1999	221
2000	44 [b]
2001	35 [b]
2002	21 [b]
2003	19 [b]
Total	4,028

Source: USFS-SR 2004
[a] Trapping not conducted during year.
[b] Some of these beaver were shot with a gun as opposed to being trapped.

Table 3-12. Number of Furbearers Captured During the Annual Furbearers Census

Year	Total Number	Gray Fox	Bobcat	Raccoon	Virginia Opossum	Striped Skunk	Red Fox
1954	123	73	14	20	4	2	10
1955	48	24	5	13	1	5	0
1956	71	35	12	15	2	0	7
1957	47	32	2	7	1	2	3
1958	36	20	2	9	3	1	1
1959	38	21	3	10	12	1	1
1960	56	22	8	16	3	3	4
1961	45	19	7	12	0	0	7
1962	58	35	6	9	3	2	3
1963	35	26	3	4	0	1	1
1964	56	36	2	14	2	2	0
1965	70	41	3	18	6	0	2
1966	46	8	10	19	8	0	1
1967	39	18	10	5	6	0	0
1968	72	22	5	28	15	2	0
1969	49	18	7	10	4	9	1
1970	47	24	5	7	7	4	0
1971	18	6	2	1	8	1	0
1972	48	1	1	10	28	8	0
1973	29	5	3	6	15	0	0
1974	42	8	2	10	19	3	0
1975	40	16	0	8	16	0	0
1976	33	15	3	3	10	1	0
1977	47	5	0	11	30	1	1
1978	42	9	2	9	22	0	0
1979	77	18	4	12	41	2	0
1980	138	45	5	38	47	3	0
1981	50	9	8	8	25	0	0
1982	65	2	1	5	56	1	0
Total	1,565	613	135	337	383	54	42

Source: Cothran et al. 1991.

3.7.4 Nine-Banded Armadillo

One recent addition to the mammals found on SRS is the nine-banded armadillo (*Dasypus novemcinctus*). This species originated in the Neotropics and has been extending its distribution northward into the United States since the mid 1800s (Mayer 1989; McBee and Baker 1982; Cothran et al. 1991). It was introduced into Florida between 1915 and 1922, and was reported from South Carolina by the mid 1980s. The nine-banded armadillo was first found on SRS in 1985 (Mayer 1989). Between 1985 and the early 1990s, all of this species' sightings were in the vicinity of Upper Three Runs. Since then, the armadillo has expanded its local range to include most of the SRS. Little is known about the armadillo population on SRS. Scientists are concerned that, as the population increases, fossorial armadillos may disturb and possibly breach waste unit closure caps, causing increased rainwater infiltration. A general summary of the nine-banded armadillo's biology is provided by McBee and Baker (1982).

3.7.5 Introduced Species

Six SRS mammals are either non-native or exotic species: the Norway rat, black rat, house mouse, feral dog, feral cat, and wild pig. All of these species were either intentionally introduced or unintentionally released onto the site. Most of these introductions occurred prior to 1951. In some instances, domestic dogs and cats have been abandoned since the acquisition of the Site. Of these introduced mammals, only the wild pig is considered to be abundant enough to be considered a nuisance.

3.8 URBAN WILDLIFE ON SRS

3.8.1 Introduction

The presence of wildlife species in developed areas on the SRS is common. A total of 144 species has been documented that use developed areas of SRS to some degree (Table 3-13). This total includes 15 amphibians (35% of the total amphibian species on SRS), 22 reptiles, (38%), 87 birds (41%), and 20 mammals (37%) (Mayer and Wike 1997). Most (53%) of these species are uncommon in developed areas. Some (29%) are common. A smaller number (14%) are rare. Only a few (4%) are abundant.

Overall, the percent taxonomic composition of the urban species is similar to that of the overall taxonomic composition for SRS wildlife. This is true for the total percent species composition and for the order of species abundance (i.e., birds are most common and amphibians are least common).

Given the right circumstances, the potential exists for any SRS wildlife species to be in one of the site's developed areas. Depending on the species, some occurrences may not be very likely. With the exception of a few species (house sparrow, house finch, rock dove, house mouse, Norway rat, and feral cat), observations indicated that densities of most wildlife species are higher in undeveloped areas than in developed areas.

Table 3-13. Species Listing of SRS Urban Wildlife

Name	Scientific Name	Abundance in Developed Areas[a]	Area of Observation
Class Amphibia			
Mole salamander	*Ambystoma talpoideum*	Uncommon	S, Z
Marbled salamander	*A. opacum*	Uncommon	Z
Eastern (red-spotted) newt	*Notophthalmus viridescens*	Uncommon	A, Z
Easten spadefoot toad	*Scaphiopus holbrooki*	Uncommon	Z
Southern toad	*Bufo terrestris*	Common	A, B, F, H, N, S, Z
Cope's gray treefrog	*Hyla chrysoscelis*	Common	A, Z
Green treefrog	*H. cinerea*	Common	A, D
Barking treefrog	*H. gratiosa*	Common	A, Z
Squirrel treefrog	*H. squirrella*	Uncommon	A
Spring peeper	*Pseudacris crucifer*	Uncommon	A
Eastern narrow-mouthed toad	*Gastrophryne carolinensis*	Uncommon	A, Z
Bullfrog	*Rana catesbianea*	Common	B, D, N, R, Z
Bronze (green) frog	*R. clamitans*	Common	Z
Southern leopard frog	*R. utricularia*	Common	B, H, N, S, Z
Class Reptilia			
American alligator	*Alligator mississippiensis*	Uncommon	A, D, F, H, L, M, P, T
Common snapping turtle	*Chelydra serpentina*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Eastern box turtle	*Terrepene carolina*	Uncommon	A
Yellow-bellied turtle	*Trachemys scripta*	Common	A
Green anole	*Anolis carolinensis*	Common	A, B
Eastern fence lizard	*Sceloporus undulatus*	Common	A
Eastern hognosed snake	*Heterodon platyrhinos*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Banded water snake	*Nerodia erythrogaster*	Common	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Scarlet snake	*Cemophora coccinea*	Uncommon	C, F, H, K, L, P
Scarlet kingsnake	*Lampropeltis triangulum*	Uncommon	A, C, F, H, K, L, P, R
Rainbow snake	*Farancia erytrogramma*	Rare	K
Rat snake	*Elaphe obsoleta*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Corn snake	*E. guttata*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Pine snake	*Pituophis melanoleucus*	Uncommon	C, F, H, K, L, P, R
Black racer	*Coluber constrictor*	Uncommon	E, H
Coachwhip	*Masticophis flagellum*	Uncommon	A
Ring-necked snake	*Diadophis punctatus*	Uncommon	A
Brown snake	*Storeria dekayi*	Uncommon	A
Pygmy rattlesnake	*Sistrurus miliarius*	Uncommon	A, B, H, P
Cottonmouth	*Agkistrodon piscivorus*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Copperhead	*A. contortrix*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Canebrake rattlesnake	*Crotalus horridus*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z

Table 3-13. Species Listing of SRS Urban Wildlife - continued

Name	Scientific Name	Abundance in Developed Areas[a]	Area of Observation
		Class Aves	
Pied-billed grebe	*Podilymbus podiceps*	Uncommon	A, D, P, R
Double-crested cormorant	*Phalacrocorax auritus*	Uncommon	R
Great blue heron	*Ardea herodias*	Uncommon	N
Green heron	*Butorides striatus*	Uncommon	N
Great egret	*Casmerodius albus*	Common	N
Tricolor heron	*Egretta tricolor*	Rare	N
Yellow-crowned night heron	*Nyeticorax violacea*	Rare	T
Canada goose	*Branta canadensis*	Rare	A
Lesser snow goose	*Chen caerulescens*	Rare	F, H
Mallard	*Anas platyrhynchos*	Uncommon	D
Pintail	*A. acuta*	Rare	D
Green-winged teal	*A. crecca*	Uncommon	D
Blue-winged teal	*A. discors*	Rare	F, H
American widgeon	*A. americana*	Rare	D
Gadwall	*A. strepera*	Rare	D
Northern shoveler	*A. clypeata*	Rare	D
Wood duck	*Aix sponsa*	Uncommon	A, S
Redhead	*Aythya americana*	Rare	D
Ring-necked duck	*A. collaris*	Uncommon	C, D, K, L, P, R
Lesser scaup	*A. affinis*	Common	D, T
Bufflehead	*Bucephala albeola*	Common	A, D, F, H, P
Ruddy duck	*Oxyura jamaicensis*	Rare	D, T
Hooded merganser	*Lophodytes cucullatus*	Common	D, P
Red-breasted merganser	*Mergus serrator*	Rare	D
Turkey vulture	*Cathartes aura*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Black vulture	*Coragyps atratus*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Mississippi kite	*Ictinia mississippiensis*	Uncommon	D, T
Cooper's hawk	*Accipiter cooperi*	Rare	A
Red-tailed hawk	*Buteo jamaicensis*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Red-shouldered hawk	*Buteo lineatus*	Uncommon	A, D, T
Bald eagle	*Haliaeetus leucocephalus*	Rare	A, H
Northern harrier	*Circus cyaneus*	Uncommon	A, C, D, E, H, P, R, S, Z
American kestrel	*Falco sparverius*	Common	A, C, D, L
Northern bobwhite	*Colinus virginianus*	Uncommon	A
Eastern wild turkey	*Meleagris gallopavo*	Uncommon	A, B, C, K, P
American coot	*Fulica americana*	Uncommon	C, K, L, P, R
Killdeer	*Charadrius vociferus*	Common	A, B, E, F, H, N, S, Z
Least sandpiper	*Calidris minutilla*	Uncommon	B, H
Rock dove	Columba livia	Abundant	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z

Table 3-13. Species Listing of SRS Urban Wildlife - continued

Name	Scientific Name	Abundance in Developed Areas[a]	Area of Observation
Class Aves - continued			
Mourning dove	*Zenaida macroura*	Common	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
White-winged dove	*Z. asiatica*	Rare	A
Barn owl	*Tyto alba*	Uncommon	C, N
Screech owl	*Otus asio*	Uncommon	S
Barred owl	*Strix varia*	Uncommon	C
Common nighthawk	*Chordeiles minor*	Common	A
Chimney swift	*Chaetura pelagica*	Common	F
Ruby-throated hummingbird	*Archilochus colubris*	Uncommon	A
Belted kingfisher	*Ceryle alcyon*	Uncommon	Z
Common flicker	*Colaptes auratus*	Uncommon	A
Pileated woodpecker	*Dryocopus pileatus*	Uncommon	A
Red-bellied woodpecker	*Melanerpes carolinus*	Uncommon	A
Eastern kingbird	*Tyrannus tyrannus*	Common	A, B, H
Great crested flycatcher	*Myiarchus crinitus*	Common	A, C, F, H
Horned lark	*Eremophila alpestris*	Uncommon	A
Barn swallow	*Hirundo rustica*	Common	A, B, C, E. F, K, H, L, P, R, S, Z
Northern rough-winged swallow	*Stelgidopteryx serripennis*	Common	A, B, E, H
Purple martin	*Progne subis*	Common	A
Blue jay	*Cyanocitta cristata*	Uncommon	A, E, H
Common crow	*Corvus brachyrhynchos*	Abundant	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Fish crow	*C. ossifragus*	Common	A, B, C, D, F, H, K, L, M, N, P, R, S, T, Z
Brown-headed nuthatch	*Sitta pusilla*	Uncommon	A
House wren	*Troglodytes aedon*	Uncommon	B
Bewick's wren	*Thryomanes bewickii*	Rare	B
Carolina wren	*Thryothorus ludovicianus*	Uncommon	A
Northern mockingbird	*Mimus polyglottos*	Abundant	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Gray catbird	*Dumetella carolinensis*	Uncommon	A
Brown thrasher	*Toxostoma rufum*	Uncommon	A
American robin	*Turdus migratorius*	Abundant	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Eastern bluebird	*Sailia sialis*	Common	A, B, E
Cedar waxwing	*Bombycilla cedrorum*	Uncommon	A
Loggerhead shrike	*Lanius ludovicianus*	Common	A, B, E, H, N, S, Z
European starling	*Sturnus vulgaris*	Abundant	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
White-eyed vireo	*Vireo griseus*	Uncommon	A
House sparrow	*Passer domesticus*	Abundant	A, B, C, D, H, K, L, M, N, P, R, S, T, Z
Eastern meadowlark	*Sturnella magna*	Uncommon	A, B, E
Red-winged blackbird	*Agelaius phoeniceus*	Common	A, H, S, Z
Common grackle	*Quiscalus quiscula*	Common	A, E, F, S, Z
Brown-headed cowbird	*Molothrus ater*	Uncommon	A, B, E
Northern cardinal	*Cardinalis*	Uncommon	A, B
Indigo bunting	*Passerina cyanea*	Rare	A
House finch	*Carpodacus mexicanus*	Common	A

Table 3-13. Species Listing of SRS Urban Wildlife - continued

Name	Scientific Name	Abundance in Developed Areas[a]	Area of Observation
Class Aves - continued			
Pine siskin	*Carduelis pinus*	Uncommon	A
American goldfinch	*C. tristis*	Common	A
Rufous-sided towhee	*Pipilo erythrophthalmus*	Uncommon	A
Dark-eyed junco	*Junco hyemalis*	Uncommon	A
Chipping sparrow	*Spizella passerina*	Common	A
White-throated sparrow	*Zonotrichia albicollis*	Uncommon	A
Class Mammalia			
Virginia opossum	*Didelphis virginiana*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Eastern mole	*Scalopus aquaticus*	Uncommon	B, K
Southern short-tailed shrew	*Blarina carolinensis*	Uncommon	H
Least shrew	*Cryptotis parva*	Uncommon	E
Little brown bat	*Myotis lucifugus*	Uncommon	B, F, K, M
Eastern cottontail	*Sylvilagus floridanus*	Common	A, B, E, F, H
Eastern gray squirrel	*Sciurus carolinensis*	Uncommon	A
Cotton mouse	*Peromyscus gossypinus*	Common	A, E
Cotton rat	*Sigmodon hispidus*	Uncommon	A
House mouse	*Mus musculus*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Norway rat	*Rattus norvegicus*	Uncommon	A, B, C, D, F, H, K, L, M, N, P, R, S
Coyote	*Canis latrans*	Uncommon	A, B, E, P, T
Feral dog	*C. familiaris*	Uncommon	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Gray fox	*Urocyon cinereoargenteus*	Uncommon	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Bobcat	*Lynx rufus*	Rare	D
Feral cat	*Felis catus*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Striped skunk	*Mephitis mephitis*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Raccoon	*Procyon lotor*	Common	A, B, C, D, E, F, H, K, L, M, N, P, R, S, T, Z
Wild pig	*Sus scrofa*	Uncommon	F, S
White-tailed deer	*Odocoileus virginianus*	Uncommon	A, Z

Source: Mayer and Wike 1997.
[a]Abundance refers to the presence in the appropriate subhabitat(s) within developed areas.

Approximately 2% of the birds and 5% of the mammals on the SRS are non-native or exotic species that are established in the local area. No non-native species of amphibians or reptiles is established on SRS. Such foreign species often are commensals with man's developed habitats, surviving and thriving better in urban subhabitats than in rural or undeveloped areas. The frequency of occurrence of exotic birds and mammals is more than double in developed areas than for the site as a whole (Mayer and Wike 1997).

3.8.2 Development and Industrialized Subhabitat Utilization

Most of these species were found to use developed subhabitats with landscaping away from buildings and other structures. As the developed aspect of a subhabitat became more complex, the species diversity of urban wildlife decreased. Of the eight subhabitats surveyed, landscaped areas away from buildings had the most use by the broadest (69%) number of species (Table 3-14). The 186/183 basins had the lowest use (5%), based on the number of species recorded. The most common use of the urban subhabitats was for foraging and feeding (99% of the species). The least frequent use was for reproduction (courting or mating; 29% of the species) (Table 3-15) (Mayer and Wike 1997).

3.8.3 Summary of Potential Impacts

The potential impacts from the presence of urban wildlife within developed areas can be either positive or negative, and can affect either humans or the wildlife. The potential impacts to humans from wildlife in urban subhabitats include contaminant transport, physical harm, disease transmission, and destruction of property. The potential impacts to wildlife include physical harm and contaminant exposure (Mayer and Wike 1997).

Table 3-14. Summary of Wildlife Use of SRS Urban Subhabitats

	Percent of Each Taxa				
SRS Urban Subhabitat	**Amphibians (N=15)**	**Reptiles (N=22)**	**Birds (N=87)**	**Mammals (N=20)**	**Total (N=144)**
Interiors of buildings and structures	6.7	68.2	10.3	50.0	24.3
Exteriors of buildings and structures	13.3	72.7	31.0	55.0	38.9
Landscaped areas around buildings and structures	20.0	90.9	42.5	75.0	52.1
Landscaped areas and lawns	13.3	95.5	67.8	85.0	68.8
Construction laydown yards or salvage storage areas	0.0	27.3	10.3	25.0	13.9
Roads and parking lots	13.3	31.9	37.9	60.0	37.5
All terrestrial subhabitats	11.1	64.4	40.0	70.0	47.1
Storm water runoff or drainage ditches	26.7	9.1	13.8	30.0	16.7
Storm water runoff retention basins	93.3	22.7	27.6	20.0	32.6
Settling and seepage basins	40.0	18.1	25.3	0.0	22.2
Reactor 183/186 basins	0.0	0.0	8.0	0.0	4.9
All aquatic subhabitats	40.0	12.5	18.7	12.5	19.1

Source: Mayer and Wike 1997.

Table 3-15. Type of Habitat Use by SRS Urban Wildlife

	Percent of Each Taxa				
Type of Use	**Amphibians (N=15)**	**Reptiles (N=22)**	**Birds (N=87)**	**Mammals (N=20)**	**Total (N=144)**
Foraging, feeding	100.0	100.0	98.9	95.0	98.6
Shelter	100.0	86.4	48.3	80.0	63.9
Courting, mating	100.0	13.6	16.1	50.0	29.2
Denning, nesting, egg-laying	100.0	9.1	18.4	55.0	30.6
Rearing or development of young	100.0	9.1	18.4	55.0	30.6
Loafing, resting, perching, roosting	100.0	27.3	71.3	60.0	66.0
Transient, dispersal	100.0	86.4	77.0	85.0	81.9
Presence only, no documented specific use	0.0	0.0	1.2	0.0	0.7

Source: Mayer and Wike 1997.

3.9 FEDERAL ENDANGERED SPECIES ACT

The Endangered Species Act of 1973, as amended (DOI 1973), is intended to prevent the further decline of endangered and threatened species and to bring about the restoration of these species and their habitat (USFWS 1999). The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) jointly administer this act. As of September 2005, the act protected 1268 species of native flora and fauna (mammals, birds, reptiles, amphibians, crustaceans, plants, and other life forms). Of these, 993 species are listed as endangered, and 275 species are listed as threatened (USFWS 2005). A species can be listed federally as either endangered or threatened, depending on its status and the degree of the threat. “Endangered” refers to a species or subspecies that is in danger of extinction throughout all or a significant portion of its range. “Threatened” characterizes any species or subspecies that is likely to become endangered in the foreseeable future throughout all or a significant portion of its range. In addition, species may also be classified as “threatened due to similarity of appearance.” This classification is afforded to various species to ensure against excessive taking and to continue necessary protection of similar-appearing species that are still classified as threatened. When a species is proposed for either endangered or threatened status, areas essential to its survival or conservation may be proposed as “critical habitats.” The process of determining a critical habitat is similar to the one for listing a species, and the two procedures often parallel. SRS contains no areas that have been designated a critical habitat for any species.

Compliance with the Endangered Species Act requires federal agencies to consult with the USFWS or the NMFS regarding the implementation of a proposed action. If the USFWS or NMFS indicates that an endangered or threatened species (or one proposed as such) or critical habitat could be present in the area of a proposed action, a biological assessment must be prepared. This assessment is used as a basis for evaluating the effects on federally protected species through the formal consultation process.

3.10 STATE OF SOUTH CAROLINA ACTS AND PROGRAMS

The State of South Carolina's program for plants of concern recognizes and protects federally listed species and maintains an unofficial state list (Knox and Sharitz 1990) which identifies its potentially threatened and endangered plant species. An early survey of South Carolina by Jones and Dunn (1983) identified 31 species of plants that they considered endangered or threatened. These species all were found in forested community types, which were the only communities examined. Rayner et al. (1986) compiled the first government-sponsored list of threatened and endangered species in South Carolina.

The South Carolina Department of Natural Resources’ Heritage Trust Progam currently lists threatened and endangered species in the state. It collects data, maintains occurrence records, and revises the list of rare plants (Knox and Sharitz 1990). The South Carolina Nature Conservancy also is active in the listing of species. The state list has no legislative basis and therefore does not afford legal protection to flora. The Heritage Trust Program and the South Carolina Nature Conservancy use the list to determine habitat protection priorities.

The State of South Carolina has a Nongame and Endangered Species Conservation Act (Section 50-15, 1976, S.C. Code of Laws). Rules established to implement the act protect federally listed endangered and threatened wildlife that occur in South Carolina (Code of Laws of South Carolina, Chapter 123, Revision 150 [1988]), sea turtles (Code of Laws of South Carolina, Chapter 123, Revision 150 [1988]; 150.1), and predatory birds of the orders falconiformes (hawks and eagles) and strigiformes (owls) (Code of Laws of South Carolina, Chapter 123, Revision 150-160 [1976]). Additions to the state protection listings can be made by the South Carolina Department of Natural Resources.

3.11 THREATENED AND ENDANGERED PLANTS ON SRS

SRS has a diverse flora with 1322 species and varieties of 558 genera (Batson et al. 1985). Within this flora exist several unusual and rare species, two of which are listed as Federally endangered; they are the smooth purple coneflower (*Echinacea laevigata*), and pondberry (*Lindera melissifolia*) (Table 3-16).

A map (Figure 3-1) illustrates the locations of rare or threatened plant populations on the SRS (Knox and Sharitz 1987a and b, 1988a and b; Thompson personal communication 2004).

In addition to the smooth purple cone flower and pondberry, other plants are expected to be added as species of special concern in South Carolina in the future: blue wild indigo (*Baptisia australis*), Chapman’s sedge (*Carex chapmanii*), Collin’s sedge (*C. collinsii*), long sedge (*C. folliculata*), and Candy bulrush (*Scirpus etuberculatus*).

Table 3-16. Federal or South Carolina Endangered or Threatened Plants and Animals Known to Occur on the SRS

Species	Status[a]
Plant	
Echinacea laevigata (smooth purple coneflower)	FE/ 3 colonies on SRS
Lindera melissifolia (pondberry	FE/ at least one colony known on SRS
Animals	
Haliaeetus leucocephalus (bald eagle)	FT/ 4 former nesting sites/no active sites
Picoides borealis (red-cockaded woodpecker)	FE/ numerous colonies on SRS
Mycteria americana (wood stork)	FE/ feed in SRS swamps and reservoirs
Acipenser brevirostrum (shortnose sturgeon)	FE/ eggs and larvae collected from Savannah River adjacent to SRS
Elanoides forficatus (American swallow-tailed kite)	SE/ 1 sighting reported
Gopherus polyphemus (gopher tortoise)	SE/ 1 reported; habitat on site
Myotis austroriparius (southeastern myotis)	ST/
Condylura cristata (star-nosed mole)	SE/
*Corynorhinus rafinesquii (*southeastern big-eared bat*)*	SE/

[a]FE = Federally endangered.
FT = Federally threatened.
SE = State endangered.
ST = State threatened.

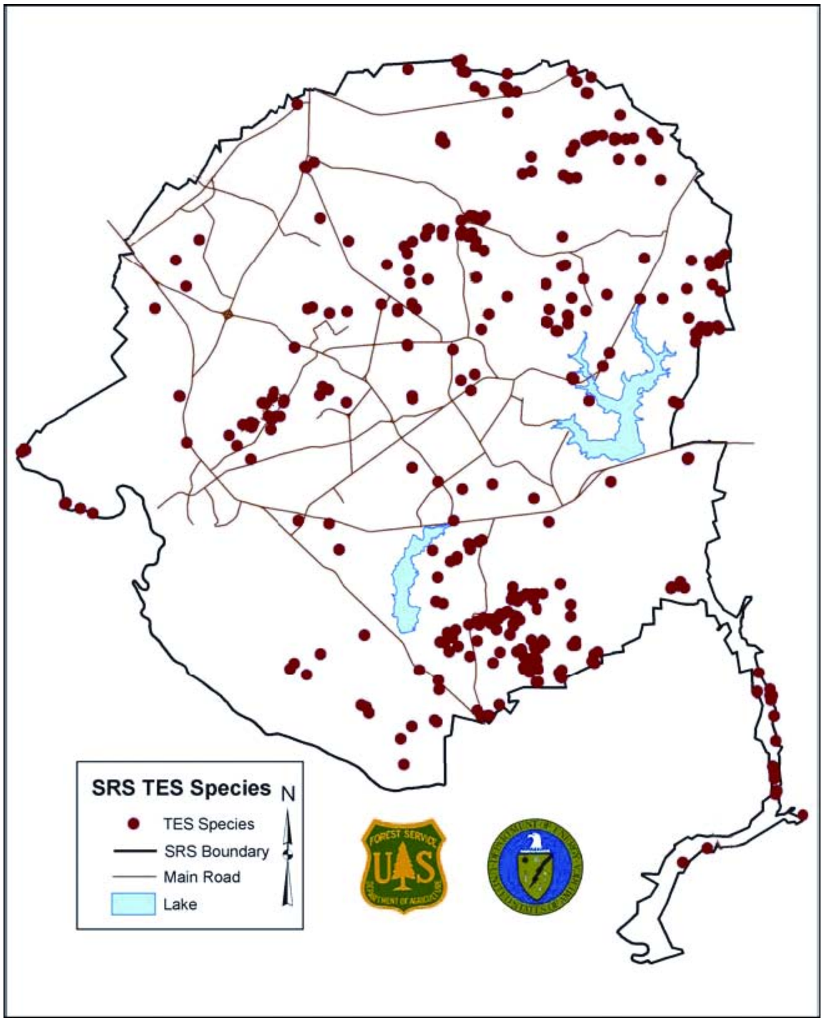
3.12 THREATENED AND ENDANGERED INVERTEBRATES ON SRS

3.12.1 Introduction

Historically, the interest in endangered species has centered on the larger vertebrate species. In recent times, interest has grown rapidly in flora and is slowly gaining momentum among the invertebrate taxa. There are now more than 40 species of mollusks listed as endangered within the SRS region, but only 6 arthropods. Scientists have realized that aquatic mollusks, especially the filter-feeding bivalves, are sensitive indicators of water quality. Because of this and their inherently cryptic nature, evaluation of their populations can be difficult. Among the aquatic arthropods, the Insecta are under-recognized within the endangered species program for their ecological importance and sensitivity. Upper Three Runs, a high-quality blackwater stream on SRS, is home to more than 550 species of aquatic insects, some of which are rarely collected in the southeastern United States (Morse et al. 1980, 1983).

3.12.2 Brother Spike Mussel

The brother spike mussel (*Elliptio fraterna*), listed as endangered by the State of South Carolina, has been identified only in the Chattahoochee and Savannah Rivers. Aspects of the natural history and distribution of this organism are poorly known. The 1972 collection of a single *Elliptio fraterna* from the Savannah River near SRS was the first such collection of a living individual since the species was described in 1852 (Britton and Fuller 1980).



Source – A. Thompson personal communication 2004

Figure 3-1. Location of Rare and Threatened Plant Species on the SRS

3.12.3 Mill Creek Ellipto

The Mill Creek elliptio (*Elliptio hepatica*), now considered a distinct mussel species, has been collected from Upper Three Runs, Mill Creek, and Tinker Creek on SRS. It is considered localized and rare. Currently, the species is not listed by either the federal government or the State of South Carolina (Hyatt 1994).

3.12.4 American Sandburrowing Mayfly

The American sandburrowing mayfly (*Dolania americana*), a relatively common organism in Upper Three Runs on SRS, is listed by the federal government as a candidate species for federal protection. This mayfly's habitat is clean, shifting sand substrate (Peters and Peters 1977). Based on its distribution, it appears to prefer soft, slightly acidic, clear waters containing very small amounts of organic and inorganic pollution. This species would be sensitive to any impacts or disturbances involving increased siltation, organic loading, or toxic releases.

3.13 THREATENED AND ENDANGERED FISHES ON THE SRS

3.13.1 Shortnosed Sturgeon

The shortnose sturgeon is one of the three endangered species of fish that occurs on or near SRS.

Two species of sturgeon, the Atlantic (*Acipenser oxyrhynchus*) and the shortnose (*A. brevirostrum*), occur in the Savannah River (Paller et al. 1986). The shortnose sturgeon, first documented in the Savannah River near SRS in 1982 (Muska and Matthews 1983), is rare and is listed as an endangered species in the United States by the NMFS (50 Code of Federal Regulations [CFR] 17.11 and 17.12).

Muska and Matthews (1983) and Specht (1987) have reviewed the biology of the shortnose sturgeon which is restricted to the east coast of North America. Breeding populations normally are associated with estuary-river complexes having a strong flow of freshwater. The shortnose sturgeon's endangered species status has stimulated recent investigations that have shown it to be more abundant in some drainage systems than had been known previously (Brundage and Meadows 1982). Reproducing populations have recently been studied from Canada to Georgia (Marchette and Smiley 1982; Heidt and Gilbert 1978, Brundage and Meadows 1982; Dadswell 1979a and b; Dovel 1978; McCleave et al. 1977; Squiers and Smith 1978; Taubert 1980a and b; Taubert and Reed 1978).

The species is primarily anadromous, but access to the sea is apparently not a requirement for reproductive success. Landlocked populations have been reported in the Holyoke Pool section of the Connecticut River (Taubert 1980a and b) and in the Lake Marion-Moultrie system in South Carolina (Marchette and Smiley 1982).

Spawning occurs between February and May, depending on the latitude. Ripe and spent females have been collected from January to April in the Savannah River (Marchette and Smiley 1982). Females typically spawn every third to fifth year while males spawn every second year (Dadswell 1976). In the Savannah River some individuals spawn in consecutive years (Collins et al. 1992).

The major factor governing spawning appears to be temperature, although other factors include the occurrence of freshets and substrate character (Dadswell et al. 1982). Several investigators have reported shortnose sturgeon spawning occurring between 9 to 12°C (48.2 to 53.6°F) (Heidt and Gilbert 1978; Dadswell 1979a and b; Taubert 1980a and b; Buckley and Kynard 1981).

In northern rivers, the spawning grounds are in regions of fast flow (40 to 60 cm/sec[1.3 to 2 ft/sec]) with gravel or rubble bottoms (Taubert 1980a and b; Buckley 1982; Pekovitch 1979). This apparently has been confirmed for the Savannah River population (Hall et al. 1991). Collins et al. (1992) identified three areas of potential spawning habitat in the Savannah River at River Km 179-190, 220-230, and 275-278 (River Miles 111-118, 137-143, and 171-173). These areas have moderate to strong current (50-100 cm/sec[1.6 to 3.2 ft/sec]) and a substrate of gravel or submerged logs. The spawning location between River Km 220-230 is adjacent to SRS.

Currently, up to 38% of the Savannah River population is the result of stocking hatchery produced juveniles, however, some of the stocked juveniles do not imprint on the Savannah River and have been captured from the Ogeechee, Edisto and Cooper rivers and Winyah Bay (Smith et al. 2002a and b).

3.13.2 Robust Redhorse

There are three suckers in the genus *Moxostoma* in the Savannah River in the general vicinity of SRS. One of these, the notchlip redhorse (*M. collapsum*) is fairly common and is not currently considered as being threatened or endangered. A second, the brassy jumprock is a currently undescribed species of uncertain geographical range and abundance. The third, the robust redhorse (*M. robustum*) has a unique conservation status. There is a memorandum of understanding signed by Georgia DNR, Georgia Power Company (GPC), the U.S. Fish and Wildlife Service, and the U.S. Geological Survey (among others), taking a pre-listing approach for organizing and developing conservation strategies to recover this species.

For over 120 years, the robust redhorse was thought to be extinct. Historically, the robust redhorse was found in Atlantic slope drainages from the Pee Dee River in North Carolina to the Altahama River in Georgia (DeMeo 2001). Currently, native populations are known to occur in the Oconee River between Sinclair Dam and Dublin, Georgia; in a short upper coastal plain segment of the Ocmulgee River in Georgia; and in the Savannah River from the Augusta Shoals to far downstream in the coastal plain (Barret 2000; DeMeo 2001; R. E. Jenkins, pers. comm.). A single specimen was also collected from the Pee Dee River in North Carolina (DeMeo 2001). It is possible that small numbers will also be found in other areas as more surveys are conducted that target the habitats preferred by this species.

Average adult size is approximately 63 cm and 4.1 kg, but can exceed 70 cm and weigh up to 8 kg.

Studies indicated that robust redhorse populations consisted largely of old individuals with little evidence of substantial recruitment (Looney 1998). The robust redhorse is now the subject of a multi-agency recovery effort, which as resulted in the artificial propagation and restocking of juvenile fish in Georgia and South Carolina rivers (DeMeo 2001). Primary threats to this species are habitat loss due to impoundment, siltation, and other types of habitat alteration. Laboratory studies have demonstrated that fine sediment particles that settle in gravel can entrap eggs and larvae and suffocate them (Dilts and Jennings 1999). Predation on the young by introduced flathead and blue catfish may also pose a threat (DeMeo 2001). These problems are compounded by the limited geographical range of this species and its current low numbers.

Habitat information has been taken largely from the robust redhorse website (www.robustredhouse.com) and from DeMeo (2001). This species occurs primarily in Piedmont and upper Coastal Plain sections of large rivers. Piedmont reaches are often along the Fall Line and usually characterized by rocky shoals, outcrops, and pools. Upper Coastal Plain reaches usually have sandy bottoms interspersed with shoals and occasional gravel beds.

Nonspawning adults often prefer relatively deep and moderately swift water near outside river bends, often in association with sunken logs, fallen trees, and other woody debris. Some juvenile robust redhorse (<40 cm) have been collected from Clarks Hill Reservoir on the Savannah River suggesting the robust redhorse is tolerant of lentic habitats for at least a portion of its life cycle. These fish were originally stocked into the Broad River and moved downstream (DeMeo 2001).

Gravel bars found downstream from the New Savannah Bluff Lock and Dam support substantial numbers of spawning robust redhorse (T. Jones, pers. comm.). Spawning of the robust redhorse was observed by Freeman and Freeman (2001) in this area and in the Oconee River. Spawning occurred during late April through late May at temperatures ranging from 17 - 26.7 °C. Preferred spawning habitat included water depths between approximately 0.3 – 1.1 m, current velocities between 0.26 and 0.67 m/s, and a substrate dominated by coarse gravel with minimal fine particles and sufficient intra-gravel flow to aerate the eggs and larvae.

The robust redhorse is a long-lived fish that can reach an age of 27 years and take five or six years to attain sexual maturity (R.E. Jenkins, personal communication).

The primary food of adult robust redhorse consists of bivalve mollusks, which are crushed with the heavy, molariform pharyngeal teeth. Specimens from the Oconee River consumed the introduced Asiatic clam, *Corbicula fluminea*.

3.13.3 Bluebarred Pygmy Sunfish

The bluebarred pygmy sunfish (*Elassoma okatie*) is considered to be imperiled or potentially so because of rarity or restricted range (G2/G3). In South Carolina it is listed as a species of special concern. It is listed by the State of Georgia as (S1), critically imperiled because of extreme rarity. The Savannah River and Edisto River populations are sufficiently genetically distinct that they should be managed separately (Quattro et al. 2001a).

The diminutive species only reaches 28.7 mm SL for adult males. Females average 21 mm LS (Rohde and Arndt 1987).

This species is known only from the New River, Edisto River, and Savannah River drainages in South Carolina and Georgia (Quattro et al. 2001a). Within the Savannah River drainage, it is found as far west as Boggy Gut Creek in Richmond County, Georgia (Rohde and Arndt 1987). Horwitz (in ANSP 1993) reported an unidentified species of *Elassoma* from the Savannah River swamp which may be this species. There are only three known species of *Elassoma* from the Savannah River Drainage and in his report, Horwitz clearly identifies the banded pygmy sunfish (*E. zonatum*) and the Everglades pygmy sunfish (*E. evergladei*) plus a form identified only as "pygmy sunfish species B."

The primary habitat for this species is roadside ditches and backwaters of creeks with brown stained water and abundant vegetation including bladderwort, duckweed, alligatorweed, pondweed, spatterdock, rushes and grasses. Virtually nothing is known about the biology of the bluebarred pygmy sunfish to date. Genetic evidence fails to rule out the possibility that the bluebarred pygmy sunfish and the Carolina Pigmy sunfish (*E. boehlkei*), another species of special concern, are the same species, though it appears that they probably are separate (Quattro et al. 2001b).

3.14 THREATENED AND ENDANGERED HERPETOFAUNA ON THE SRS

3.14.1 Introduction

Herpetofauna are members of the classes Amphibia and Reptilia. Government agencies seem to be somewhat slow in protecting reptiles and amphibians. The sea turtles, known to frequent the South Carolina coast, have enjoyed protected status for some time. However, there is encouraging news with recent developments in protecting other species of turtle, frog, salamander, snake, and lizard.

3.14.2 Amphibians

The Carolina crawfish frog, also known as the Carolina gopher frog, is a subspecies of *Rana aerolata*. This is the only one of five amphibian species listed as candidate species for federal protection that has been reported from SRS. The Carolina crawfish frog is a member of the group of stubby-appearing frogs whose habits of nocturnal activity and daytime retreat to crawfish and gopher tortoise holes or other hiding places conceal them from casual observation. The species is infrequently collected on SRS. The Carolina subspecies is distinguished by its small, closely packed warts and heavy ventral marking that gives a marbled appearance (Conant and Collins 1991). Gibbons and Semlitch (1991) reported hearing the Carolina crawfish frog calling on the SRS.

3.14.3 Reptiles

3.14.3.1 Introduction

The only reptile found at SRS listed as threatened or endangered is the gopher tortoise (*Gopherus polyphemus*), which is a state endangered species. The American alligator is listed as “Threatened Due to Similarity of Appearance.” This classification means that the species itself is not threatened, but is given special consideration because it closely resembles a listed taxon (in this case, the very rare American crocodile), and its protection and regulation will benefit the endangered species it resembles.

3.14.3.2 Snakes

Other reptile species found on SRS that are not currently listed as threatened or endangered, but are candidate species for listing, include the pine or bull snake (*Pituophis melanoleucus*) and the Southern hognose snake (*Heterodon simus*). Neither of these species is considered rare at SRS; however, they are not common and are collected infrequently (Gibbons and Semlitch 1991).

3.14.3.3 Gopher Tortoise

Although the gopher tortoise (*Gopherus polyphemus*) was believed to be gone from Aiken County by the early part of the century, their historic range extends as far north on the Coastal Plain as the North Carolina-South Carolina border. In 1992, a reproducing population of tortoises was discovered on private property near Aiken State Park, suggesting that there may be other small relict populations that have not yet been discovered.

In 1986, an employee of the Savannah River Forest Station (SRFS) observed a live tortoise and three or four burrows near Par Pond. However, these burrows were in a lowland hardwood forest with fairly dense canopy closure, suggesting that this tortoise may have been released on site. In 1992, an employee of Savannah River Ecology Laboratory (SREL) found a gopher tortoise shell at Flamingo Bay, but its origins are also unknown. Gopher tortoise sightings also have been reported offsite near the Snelling barricade in 1996. Other evidence for gopher tortoises as a resident species of the SRS was the discovery of a tortoise and its burrow near Deer Kill Road on May 25, 1996, by researchers from SREL. The burrow was near a powerline right-of-way in a young longleaf pine (*Pinus palustris*) stand with plentiful herbaceous vegetation for forage material. This pine stand is on a fairly large sand ridge near the northern perimeter of the SRS. Although no other tortoises were found in this longleaf pine stand, isolated individuals may have been able to persist on the Savannah River Site in small numbers, and suitable habitat exists to support a colony on the SRS.

In the fall of 2001 researchers from SREL moved approximately100 gopher tortoises to the SRS with the goals of re-establishing a protected population, evaluating efficacy of relocation as a strategy, and developing a general model for relocation of tortoise species (Tuberville et al., 2003).

3.14.3.4 Alligator

3.14.3.4.1 <u>Introduction</u>

The American alligator (*Alligator mississippiensis*) (Figure 3-2), has been studied extensively at SRS (Murphy 1977, 1981; Smith et al. 1981, 1982a and b; Seigel et al. 1986). These earlier studies are summarized in Volume VI of the Comprehensive Cooling Water Study Final Report (CCWS) (Mackey 1987). Seigel (1989) and Brandt (1989) more recently documented work with SRS alligators.

3.14.3.4.2 <u>Protection History</u>

The American alligator is the largest reptile on SRS, reaching a length in excess of 3.7 m (12 ft) and a weight of 150 kg (325 lb) (Murphy 1981). Although abundant as late as 1890, alligators in the United States dwindled by the mid-20th century to fewer than 100,000, primarily from intense hunting and habitat destruction (King 1972). State game laws restricting the harvest of alligators were moderately useful in stabilizing populations, but it was not until federal protection was enacted in the 1960s and 1970s that populations began to recover. Recovery of this species has proceeded so well that the USFWS has reclassified it from endangered/ threatened to threatened due to similarity of appearance (USFWS 1992a).

Figure 3-2. American Alligator (*Alligator mississippiensis*)

3.14.3.4.3 <u>General Life History</u>

The general life history of the American alligator is well known. Courtship occurs in the late spring, and females lay about 20 to 50 eggs in late June and July. Hatching occurs in late summer, and females have been reported to guard both the nest and the newly hatched young. Hatchlings remain together for up to two years, then gradually disperse into the surrounding environment. Growth rates and ages at maturity are not fully known, but estimates from Florida and Louisiana suggest it may take as long as 10-12 years for alligators to reach sexual maturity. Maturation may occur more slowly in the northern portion of the range, such as in South Carolina (Murphy 1981). Alligators will feed on most aquatic and semiaquatic vertebrates and some terrestrial animals. American alligators have relatively broad temperature tolerances; the critical thermal maximum is estimated at 38°C (100.4°F) and animals have survived exposure to temperatures as low as 2-4°C (35.6-39.2°F) (Colbert et al. 1946; Smith et al. 1982b; Hagan et al. 1983).

3.14.3.4.4 <u>Aquatic Habitats on SRS</u>

3.14.3.4.4.1 Introduction

The two major types of aquatic habitats of importance to alligators on SRS include riverine (flowing water) and lacustrine (lake) systems (Figure 3-3). The riverine systems includes Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, Lower Three Runs (below Par Pond), and the Savannah River adjacent to the SRS and its associated swamp. The lacustrine systems include Par Pond, Pond B, Pond C, L Lake, numerous Carolina bays, abandoned farm ponds, and beaver ponds.

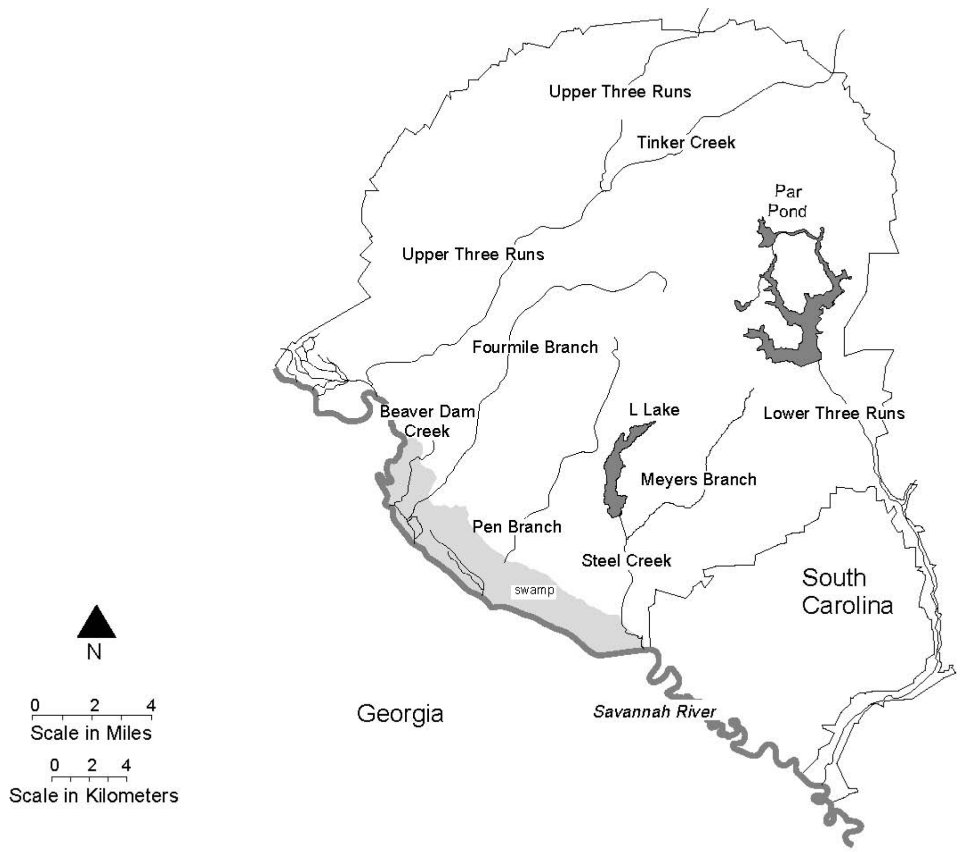


Figure 3-3. Major Aquatic Habitats at SRS

3.14.3.4.4.2 Alligator Populations in the Par Pond System

Studies on the ecology of alligators on SRS focused primarily on the Par Pond system (including Ponds B and C and the precooler ponds; Figure 3-4), which harbors the largest population of American alligators onsite (Murphy and Brisbin 1974; Murphy 1981).

Murphy (1981) suggested that many of the unusual characteristics of the Par Pond population (low reproductive rate, low density, adult-biased population structure) was the result of "reproductive asynchrony," i.e., males come into breeding condition earlier than females, resulting in a low frequency of mating, and, therefore, fewer nests. Distributions of alligators in Par Pond changed seasonally, with adult males using thermally affected areas during the winter. The use of these thermally altered sites may have permitted a longer yearly activity period for adult males, with subsequent alteration of the timing of reproduction. However, two alternative explanations might also apply. First, as Murphy (1981) noted, SRS is near the northwestern edge of the range of the American alligator. Data from other reptiles suggest that northern populations frequently have lower reproductive and growth rates than southern populations (Tinkle 1961; Fitch 1985), probably as a result of shorter growing seasons. Growth rates of juvenile alligators from Par Pond were found to be slower than those of juveniles from Louisiana. Second, most previous studies of alligators have been conducted in marsh habitats, which are a better quality habitat for alligators than the open waters of Par Pond.

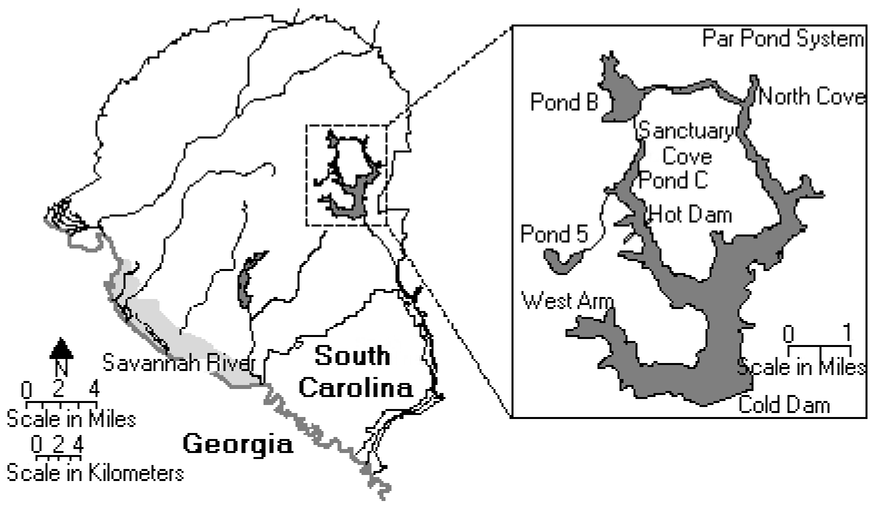


Figure 3-4. Par Pond System

More recent work comparing previous study results with current population estimates has shown an increase and change in distribution by size class. The estimated population size went from 110 adults and juveniles in 1974 to 197 in 1988 (Table 3-17). Although the sex ratio changed from 3.2:1 (male:female) to 2.6:1 between 1977 and 1988 (Table 3-17**,** Figure 3-5), this is not considered a statistically significant change. Size distribution changed from a population dominated by large individuals to one of smaller animals (Figure 3-6). Reproductive success in the Par Pond alligator population almost doubled the population between 1974 and 1988. Brandt (1989) calculated an average annual population exponential rate of increase of 0.06 (Figure 3-7), which projects a population of more than 320 individuals by the year 2000.

Beginning in June 1991, the Par Pond water level was lowered approximately 6 m (20 ft), reducing the reservoir surface area by almost 50%. The water level remained down until August 1994, when the lake began to passively refill by retaining rainfall and runoff that had previously been siphoned over the dam. In February 1995, water was pumped from the Savannah River to the reservoir to complete the refill. Full pool was reached in March 1995. Throughout the drawdown, SREL monitored the effects on the alligator population. Chapter 4, Section 4.8, Par Pond discusses the drawdown of Par Pond.

Although it was documented that several adult alligators left the reservoir soon after the initial reduction in the water level, most of the resident animals did not leave the reservoir during the four years the water level was reduced. Alligator clutch size and hatchling weight was monitored during the summer of 1994. Both were significantly lower in 1994 than in previous years, when the lake was at full pool (Table 3-18). However, nests were less frequently depredated and hatch rates were higher, so smaller clutch sizes and hatchling weights may have been offset by the increased rate of hatching. At the time of this writing, there were no data on the survival rates of the smaller hatchlings (Brisbin et al. 1997).

Table 3-17. Estimated Population Size and Sex Ratios for Alligators Inhabiting Par Pond, 1972-1974, 1976, and 1986-1988

Year	Category	Size Ratio adult: juvenile	Population Estimate	Confidence Interval (method)	Sex Ratio male: female	Nests/ Year
1972-1974[a]	Adults		70	29-143 (Lincoln)	3.7:l	
	Juveniles		40	19-72 (Lincoln)	1.8:1	
	Total		110	48-215 (Lincoln)	3.2:1	2.3
1976		1.43: 1[b]			3.6: 1	2.3
1986-1988[c]	Adults		108	97-120 (Lincoln)	2.5:1	
	Juveniles		83	45-121 (Jolly)	3.1:1	
	Total		197[c]		2.6:1	

Source: Brandt 1989.
[a]1972-1974 data from Murphy 1977.
[b] Ratio for coastal South Carolina populations in 1976 was 0.4:1.
[c] 1988 total population includes 6 animals 1.25-1.5 m that were captured but not represented in earlier estimate.

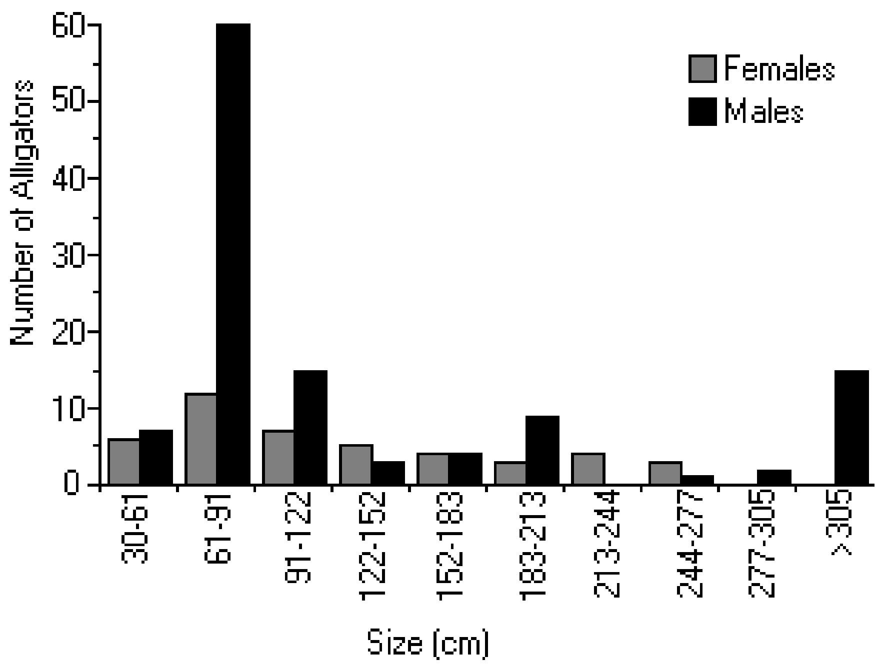


Figure 3-5. Size and Sex Structure of Alligators Captured in Par Pond, 1986-1988 (Source: Brandt 1989)

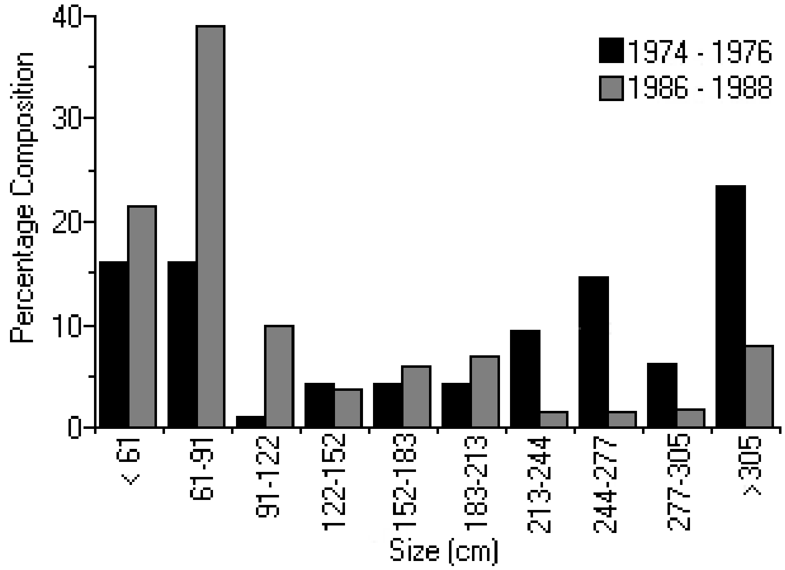


Figure 3-6. Size Distribution of Alligators in Par Pond, 1974-1976 and 1986-1988 (Source: Brandt 1989)

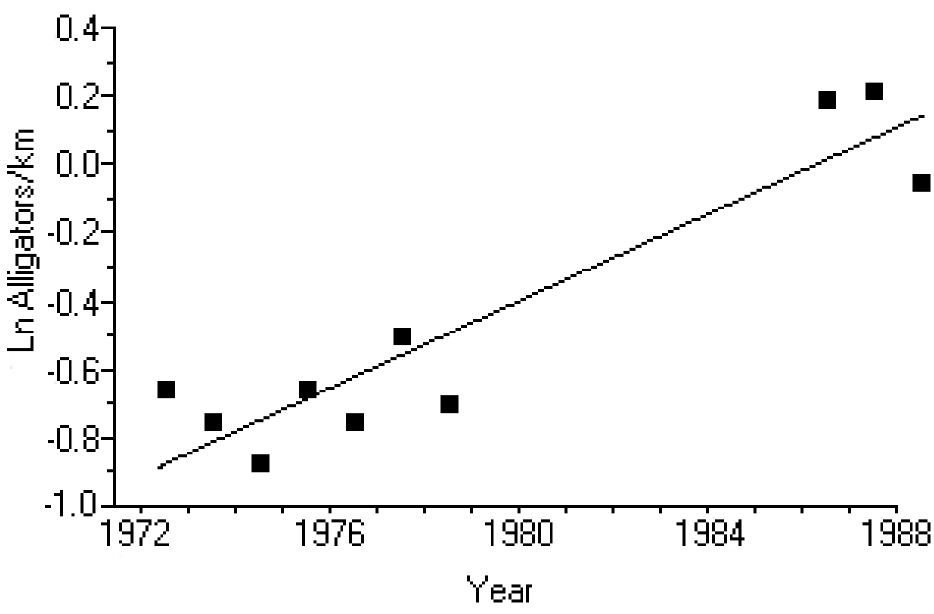


Figure 3-7. Alligator Population Growth in Par Pond 1972-1988 (Source: Brandt 1989)

Concentrations of total mercury and cesium-137 in alligator tissues were analyzed. The source of mercury in Par Pond is not known, but it is believed to have come from industries on the Savannah River, which served as the major source of water for Par Pond. Cesium-137 was released into the reservoir system in the early 1960s and has been decaying ever since, but there are measurable concentrations in the sediments. The concentrations of mercury in alligator tissues before and after refill were not statistically different (Table 3-19). The concentrations of cesium-137 in alligator tissues were not significantly different between pre-drawdown and postrefill (Brisbin et al. 1997).

3.14.3.4.4.3 Alligator Populations in Beaver Dam Creek

Beaver Dam Creek has a high frequency of alligator sightings. The high density of alligators may be due to the availability of a relatively undisturbed, high-quality habitat and the moderate thermal effluent discharged into the creek. This thermal regime is not extreme enough to exceed the critical thermal maximum of the species and may contribute to alligator success by enhancing growth and survival through year-round foraging and decreased mortality from freezing temperatures. Size distribution of the Beaver Dam Creek population (Figure 3-8) shows a high representation of juveniles and subadults, suggesting successful recruitment into the population (Seigel 1989).

Table 3-18. Mean Clutch Size, Mean Hatchling Weight, Hatching Rate, and Number of Depredated Nests in 1994 Versus 1981-1988

	Clutch Size X (N)[a]	Hatchling Weight (g) X (N)	Hatching Rate (range)	Percent of Depredated Nests
1994[b]	43.5+2.9 (6)	43.7+0.4 (95)	49.9% (65.9-41.7%)	0%
1981–1988[c]	48.8+1.3 (8)	50.7+0.4 not known	48.3%+9.1(76-22%)	25%

[a]Data are presented as means + standard error, with N for each given in parentheses.
[b]Source: Brisbin et al. 1997.
[c]Source: Brandt 1989.

Table 3-19. Tissue Mercury Concentrations (mg/g dry mass) in American Alligators from the Par Pond Reservoir Before and After the Reservoir was Refilled.[a]

	Liver	Muscle	Scute
Before Refill	15.30+2.65(11)	3.87+0.44(13)	5.84+0.90(18)
After Refill	12.09+7.77(2)	8.05+4.43(3)	3.97+0.98(17)

Source: Brisbin et al. 1997.
[a]Data are presented as means + standard errors, with N for each given in parentheses.

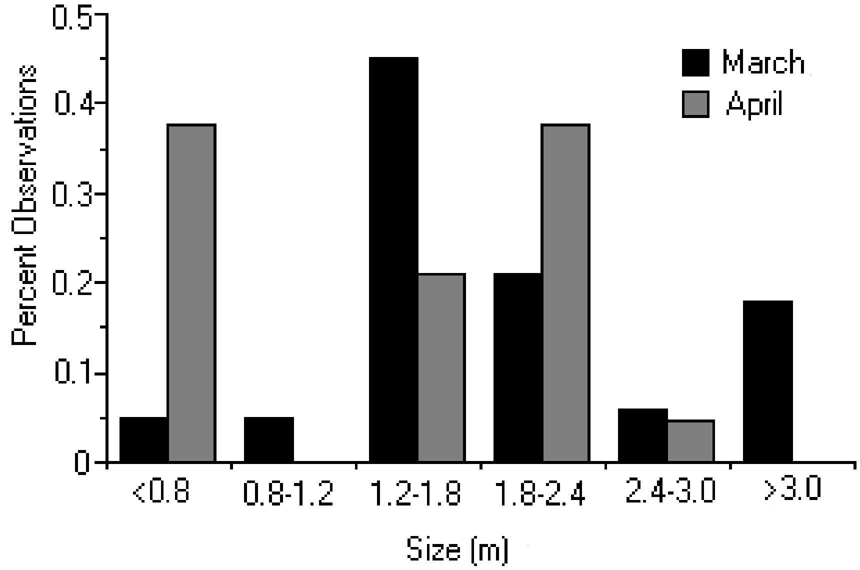


Figure 3-8. Size Structure of the Beaver Dam Creek Alligator Population as Assessed by Aerial Surveys in 1984 (Source: Seigel 1989)

3.14.3.4.4.4 Alligator Populations in Steel Creek Below L Lake

Steel Creek below L Lake supports a small population of alligators in all areas of the drainage, with most animals concentrated in the delta. Seigel (1989) found evidence of nesting activity. Although alligators are known to exist in L Lake and have been collected there, no quantitative data on population size are currently available (Gladden et al. 1988).

3.14.3.4.4.5 Alligator Populations in Fourmile Branch

During the operation of C Reactor, Fourmile Branch was not a suitable alligator habitat and supported no population. Although the Fourmile Branch delta did contain some suitable habitat, no alligators were observed there prior to 1980 (Murphy 1981). However, more recently, there has been a relatively high frequency of alligator sightings in Fourmile Branch. Although the population is small, it uses the delta and lower stream channel. No reproduction has been documented. The source of individuals in Fourmile Branch is most likely Beaver Dam Creek because of its close proximity and large alligator population. The shutdown of C Reactor may have lead to sufficient habitat recovery to support an alligator population (Seigel 1989).

3.14.3.4.4.6 Alligator Populations in Pen Branch

Pen Branch received thermal effluent from K Reactor until 1988, and high flows and temperatures during reactor operation almost certainly precluded use of the drainage by alligators. Even though individuals were reported moving upstream during reactor outages, and alligators are sighted occasionally in Pen Branch, no large or self-sustaining population exists there. Cessation of reactor operations may have provided suitable habitat, but the distance of Pen Branch from a pool of immigrants (Seigel 1989) may have slowed the rate at which the Pen Branch population would have developed.

3.14.3.4.4.7 Alligator Populations in Other SRS Areas

Other areas on SRS provide potential alligator habitat, but there is little information on these populations. Although Lower Three Runs, dammed in 1958 to form Par Pond, supports a self-sustaining population directly below the dam, the remainder of the creek has not been surveyed for alligator use (Murphy 1981). Upper Three Runs provides a minimum of suitable habitat (Murphy 1981), and few alligators have been sighted there (Seigel 1989). Except for Steeds Pond, which supported a moderate population of alligators until it was drained in 1984, there is no evidence that any of the ponds and Carolina bays on SRS support alligator populations (Seigel 1989). The Savannah River swamp system appears to contain suitable habitat for alligators (Murphy 1981), and although alligators are seen there regularly, difficulty in sampling makes it impossible to estimate the size of the population (Seigel 1989).

3.15 THREATENED AND ENDANGERED AVIFAUNA ON SRS

3.15.1 Introduction

Current and past observations and SRS records indicate that 17 species of birds listed as threatened or endangered by the federal or state government occur or have been sighted on SRS. This group includes the federally endangered red-cockaded woodpecker (*Picoides borealis*), bald eagle (*Haliaeetus leucocephalus*), Kirtland's warbler (*Dendroica kirtlandii*), and wood stork (*Mycteria americana*); the State of South Carolina listed Bewick's wren (*Thyromanes bewickii*), swallow-tailed kite (*Elanoides forficatus*), and the peregrine falcon (*Falco peregrinus*), .

3.15.2 Bald Eagle

3.15.2.1 Introduction

With a wingspan of 1.8-2.3 m (6-7.5 ft), the bald eagle (*Haliaeetus leucocephalus*) is the largest raptor commonly observed on SRS. The coloration of an adult bald eagle is unmistakable, being uniformly dark brown with a white head, neck, and tail (Figure 3-9). This species exhibits a variety of plumage coloration patterns associated with the age of the bird. Bald eagles begin to molt into the characteristic adult plumage during their fourth or early fifth year of age. Adult bald eagles typically weigh between 3 and 5 kg (6.6-11 pounds) (Sprunt and Chamberlain 1970).

Figure 3-9. Bald Eagle (*Haliaeetus leucocephalus*)

The bald eagle is a permanent South Carolina resident and is most abundant in the coastal region (Sprunt and Chamberlain 1970). As many as 200 nesting pairs of bald eagles may have been in the state historically. By the late 1950s, these numbers had dropped to about 100 pairs. This decline in South Carolina and other locations in the eastern United States has been attributed to the negative effect on bald eagle reproduction of persistent pesticides and other environmental contaminants (Murphy and Coker 1978). In 1978, only 15 nesting pairs of eagles could be found in South Carolina (Murphy and Coker 1978). Primarily as a result of restrictions on pesticide use, the number of bald eagle nesting pairs in the state have been increasing since 1981 (Mayer et al. 1986) with 105 nesting pairs being found in South Carolina in 1996.

As the number of nesting pairs and mating success of bald eagles along the South Carolina coast increased during the early 1980s, a greater number of fledged young have dispersed into inland areas. The successful colonization of more inland portions of the state has largely been the result of the man-made impoundments on the Santee-Cooper and Savannah River drainages. These impoundments provide both extensive forage habitat and aquatic prey base for bald eagles immigrating inland from coastal territories (Mayer et al. 1986).

As in South Carolina, populations of bald eagles have increased over much of their range in the lower 48 states. As a result, the status of the bald eagle was changed from endangered to threatened in July 1995.

3.15.2.2 Bald Eagle Use of SRS

Records of bald eagle sightings in the central Savannah River area date back to 1904 (Murphey 1937). The presence of this species on SRS was documented as early as May 1959, when an adult bald eagle was observed on the newly filled Par Pond (Norris 1963). At least two more sightings were recorded for Par Pond during that year. One of these birds, seen in September, was an immature bald eagle (Norris 1963). Par Pond has been and continues to be the location of most of the eagle sightings on SRS. Jenkins and Provost (1964) reported that two bald eagles had been recorded on SRS, neither being permanent residents, nor breeders. Langley and Marter (1973) also noted that three bald eagles were observed as transients near Par Pond. Bald eagles were sighted on Par Pond “once or twice a week” in the winter of 1971-72 (Mayer et al. 1986). Between 1971 and 1975, bald eagles were seen regularly on Par Pond from late September or early October to mid-March. In the late 1970s and early 1980s, both adult and immature bald eagles were observed on Par Pond during the annual SRS Christmas Bird Count in December (Mayer et al. 1986). Dukes (1984) stated that a few bald eagles had been observed on Par Pond, but that no resident population of this species existed onsite. This species has apparently increased on SRS as a result of the inland colonization. Sightings of bald eagles on site have continued to increase (Table 3-20). Between 1986 and 1992, the estimated numbers of bald eagles wintering on SRS increased from two to six birds (SRFS 1993).

3.15.2.3 SRS Bald Eagle Study

A one-year study of bald eagle use of SRS was conducted between September 1984 and August 1985 (Mayer et al. 1985). Ground or aerial surveys were conducted on the Par Pond system at least twice per month. The location, date, time of day, number of adult and immature birds, and behavior were recorded. Thirty-six bald eagles were sighted in 31 instances. Most (91.7%) of these sightings were reported in the vicinity of Par Pond (Figure 3-10) with 66.7% of sightings specifically on Par Pond (Mayer et al. 1985). Fewer eagles were seen on Pond C (24.2%), Pond B (6.1%), and Pond 2 (3.0%). On Par Pond, the Big Lake section adjacent to the Cold Dam had the most use (22.7%), followed by Loyals Lair (18.2%), and then the Hot Arm, North Arm, and Pump House Cove in the South Arm (each at 13.6%). On Pond C, most of the sightings were between the main lake and Sanctuary Cove. In part, the thermal fish kills on Pond C attracted bald eagles to that impoundment (Gladden et al. 1985). Sightings on Pond C were of birds feeding on dead fish in the littoral zone (Mayer et al. 1985). Of all the bald eagles sighted during the study, 72% were adults and 13% (10) were paired birds. Of these five pairs, two pairs were composed of two adults, two were composed of two immatures, and one was an adult/immature pair.

Bald eagles were seen during every month of the one-year study. Most of the birds (63.9%) were seen during the winter and spring (November through May). This was also the period when most of the immature birds (90.0%) were observed. Only one immature bald eagle was seen in the fall during the study, and none was observed during the summer (Mayer et al. 1985). The conclusion of the study was that bald eagle use of SRS was more common than previously had been known. The apparent increase was postulated to be the result of either poor earlier documentation or a recent increase in the use of the site by this species.

Table 3-20. Number of Bald Eagles Observed During Four Annual Surveys at SRS

Year	Audubon Christmas Bird Count	SRS Waterfowl Aerial Surveys	SRS Wood Stork Aerial Surveys	Par Pond/ L-Lake Boat Surveys	Total
1978	2	-	-	-	2
1979	1	-	-	-	1
1980	0	-	-	-	0
1981	0	1	-	-	1
1982	1	1	-	-	2
1983	0	2	-	-	2
1984	1	0	-	-	1
1985	2	0	-	-	2
1986	0	0	-	-	0
1987	0	3	-	3	6
1988	4	0	-	8	12
1989	2	9	-	5	16
1990	5	7	-	0	12
1991	8	3	2	3	16
1992	3	14	11	23	51
1993	4	16	13	23	56
1994	4	9	5	17	35
1995	3	5	4	-	12
1996	2	9	9	16	36

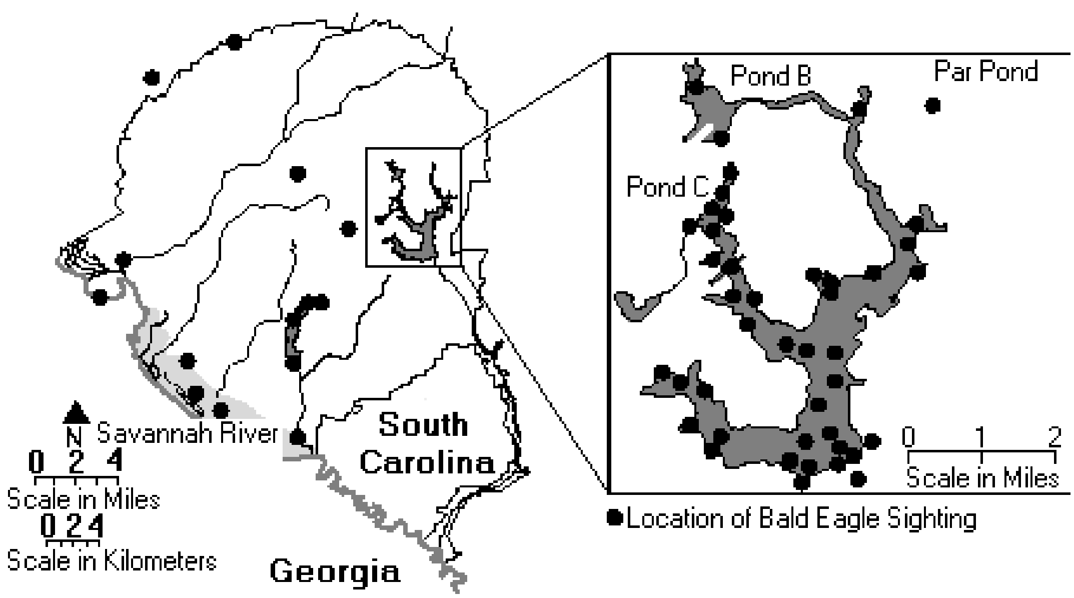


Figure 3-10. Location of Bald Eagle Sightings on SRS (Source: Mayer et al. 1986)

3.15.2.4 Supplemental SRS Observations

Data collection subsequent to Mayer et al. (1985) continued until January 1986 (Mayer et al. 1986). Twenty-two bald eagles were observed between September 1985 and January 1986. Seven of the sighting localities were new records for SRS. Bald eagle use of L Lake was reported within one month of its completion of filling. An immature bird was seen feeding on dead fish in the outflow of L Lake Dam, and three adult bald eagles were observed soaring above the lake (Mayer et al. 1986).

3.15.2.4.1 Adult to Immature Ratio

Based on a total of 197 bald eagle sightings recorded for the site between 1959 and 1992, the overall observed age class ratio was 1.6 adults to 1.0 immature (Figure 3-11). This is similar to the regional age class composition of two adults for every immature (Mayer et al. 1986).

3.15.2.4.2 Social Organizations

Most sightings (95%) of bald eagles on SRS were of solitary birds; however, social groupings of between two and five bald eagles have been observed. Pairs of birds are the most common social grouping observed. One social grouping of five immature bald eagles was observed soaring over the main lake section of Par Pond in 1992.

3.15.2.4.3 Seasonal Use

Banding studies have documented mid-summer migration to the northern states and Canada of bald eagles that have nested in the southeast (Sprunt and Chamberlain 1970). These birds return south in the fall or early winter to nest and rear their young and remain there until late spring (Sprunt and Chamberlain 1970). Most of the bald eagles are observed on SRS during the fall and winter when this species is nesting and wintering in South Carolina (Figure 3-11). Birds seen during the summer are most likely transients migrating either north or south.

Percentage of Total Number of Birds Observed

Season	Adults	Immatures
Winter	24	11
Spring	9	8
Summer	5	5
Fall	24	14

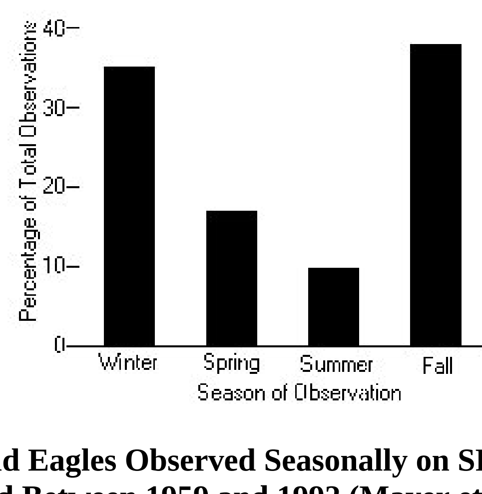


Figure 3-11. Percentage of Adult and Immature Bald Eagles Observed Seasonally on SRS, Based on a Total of 197 Birds Observed Between 1959 and 1992 (Mayer et al. 1986)

3.15.2.4.4 Diet and Forage Behavior

In South Carolina, the diet of bald eagles consists almost exclusively of fish. However, these raptors are also known to prey on ducks, American coots (*Fulica americana*), herons, and small mammals. Bald eagles will opportunistically feed on carrion, usually in the form of dead fish. This species often reportedly steals food from ospreys rather than foraging for prey themselves (Sprunt and Chamberlain 1970). Observations of foraging activities of bald eagles on SRS indicate a varied diet composed of fish (largemouth bass [*Micropterus salmoides*]), waterfowl (coots [*Fulica americana*] and buffleheads [*Bucephala albeola*]), small mammals (gray squirrel, [*Sciurus carolinensis*]), and carrion (thermally killed fish and road-killed small mammals) (Mayer et al. 1986, 1988).

3.15.2.4.5 Records of Marked/Tagged Birds

Less than 2% of the 197 recorded observations of bald eagles using SRS consisted of birds that were marked or tagged. Two of the birds observed during the one-year study were marked. One of these birds had been tagged as a fledgling along the South Carolina coast north of Charleston. The second bird was of unknown origin because the tagging method and color were neither registered with nor known to either the USFWS or the Raptor Information Center (Mayer et al. 1985). The adult female bald eagle of the original nesting pair at Eagle Bay was marked with an orange wing tag that indicated it was a fledgling on either the Cooper River or near Georgetown during the 1978-1981 nesting seasons (Mayer et al. 1988). Based on this small sample, the bald eagle nesting population along the South Carolina coast now is documented as being one of the contributing sources of birds that use SRS.

3.15.2.4.6 Reproductive Biology

The nesting season for bald eagles in South Carolina is midwinter. The nest, usually built in a tall pine, is a huge mass of sticks, bark, grass, moss, and other debris. Bald eagles typically return and add materials to the same nest year after year. After many seasons' use, bald eagle nests can attain very large proportions. The typical clutch consists of two eggs, but can range in size from one to four. Incubation requires approximately 35 days. Both adults in the nesting pair participate in incubating the eggs and feeding the young (Sprunt and Chamberlain 1970).

3.15.2.5 Bald Eagle Nesting on SRS

Two confirmed bald eagle nesting territories have been documented on SRS (Figure 3-12). The first (the Eagle Bay nesting territory) was discovered on May 21, 1986. By June 6, 1986, the nest and the presence of two juvenile bald eagles was confirmed (Mayer et al. 1988). Seven bald eagle chicks were hatched and fledged from that nest between 1986 and 1988 (Table 3-21). In 1989, both the nest and the single hatchling produced that season were presumed lost when extreme winds (87 mph) knocked the nest out of the tree in April. The South Carolina Department of Natural Resources installed a braced wooden and wire platform in the area of the original nest and constructed an artificial nest of pine limbs and twigs. The pair initiated nesting in 1990, but abandoned the nest by February of that year. A pair of great blue herons (*Ardea herodias*) took over the nest later that same month.

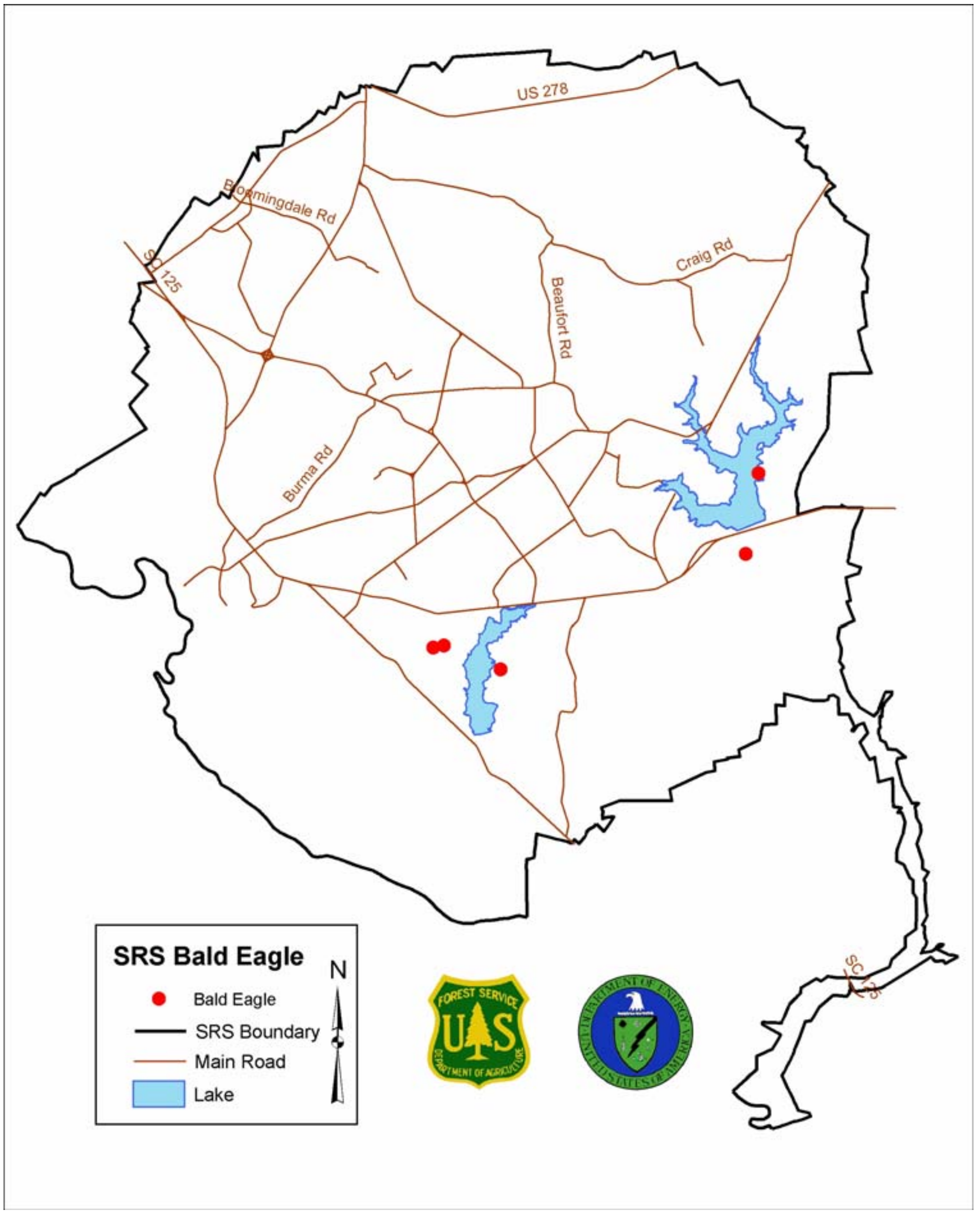


Figure 3-12. Location of the Bald Eagle Nests on SRS (A. Thompson, pers. comm)

Table 3-21. Number of Nestlings Fledged by the Bald Eagle Nesting Pairs on SRS

	Annual Number of Nestlings Produced	
Year	**Eagle Bay Nest Site**	**Pen Branch Nest Site**
1986	2[a]	-
1987	2	-
1988	3	-
1989	0[b]	-
1990	0	2[a]
1991	0	2
1992	0	2
1993	1	2
1994	0	1
1995	0	1
1996	1	2
1997	0	2
1998	0[c]	2[d]
1999	0[c]	0
2000	0[c]	0
2001	0[c]	0
2002	0[c]	0[c]
2003	0[c]	0[c]
Total	9	16
Average/yr attempted	0.8	0.8

Source: Kilgo and Blake 2005.
[a]First year nest was known to exist.
[b]Single nestling produced, presumed lost when nest was dislodged during a windstorm.
[c]No nesting was attempted.
[d]The parents abandoned a fall breeding attempt, but renested three months later and produced two young. Those young fledged prematurely, but were rescued and taken to the S.C. Center for Birds of Prey at Charleston, where they were eventually "hacked" (released) back into the wild.

In June of 1990, the second bald eagle nesting location (on Pen Branch) was discovered. Although initially believed to be the displaced pair from Eagle Bay, neither of the nesting bald eagles at Pen Branch was marked. Two chicks were observed at that nest during the first year. The Eagle Bay nest site was completely inactive in 1991, while the Pen Branch nest again produced two nestlings (Table 3-21). In 1992, a pair of bald eagles initiated and then abandoned nesting at Eagle Bay. During that same year, the pair at the Pen Branch nest produced two nestlings. In 1993, a pair of eagles initiated a nest at Eagle Bay, and two newly hatched bald eagle chicks were observed in the nest in March of that year. Two chicks again were observed at the Pen Branch nest in the 1993 nesting season. In 1994, the Eagle Bay nest fell and was replaced a second time. It produced no chicks that year. In 1995 a pair nested and laid one egg that was not successfully incubated. One nestling was hatched in 1996. In 1994, 1995, and 1996, two chicks were fledged successfully from the Pen Branch nest (Hart et al. 1996).

A third nest was discovered east of Par Pond after the 1995-1996 nesting season. The status of this nest is unknown as of this writing.

3.15.2.6 Bald Eagle Management on SRS

The U.S. Forest Service Savannah River Forest Station began an active management program in 1986 for the Eagle Bay nesting territory and in 1990 for the Pen Branch nesting territory. These management plans encompass primary and secondary management zones for protecting the nesting territories and key areas along the shores of both Par Pond and L Lake for perching and roosting activity. Through the use of management zones and because of the distances between the two nests and existing SRS facilities, it is expected that activities at SRS will have no adverse effect on the bald eagle.

Other considerations in the management of eagles at SRS are related to disease and potential uptake of constituents of conern. A two-year study of the eagles at SRS suggests that mecury from prey items may pose a risk because SRS nestlings had higher concentrations than other SC nestlings (Bryan et al, 2002). However the same study concluded that cesium is not a threat. In the late 1990s two eagles were found dead on the SRS and tested positive for the affliction known as avian vacuolar myolenopathy (AVM). This pathogen has affected eagle populations in many other parts of the US and is thought to be transmitted to the eagles through the American coot which is one of their favorite prey items.

3.15.3 Golden Eagle

3.15.3.1 History in South Carolina

The golden eagle (*Aquila chrysaetos*) is a rare resident in the mountains of northwestern South Carolina, but is found during the winter in other areas of the state (Sprunt and Chamberlain 1970). Records of this species in the central Savannah River area date back to at least 1933 (Murphey 1937). Even then, the golden eagle was considered locally to be rare (Murphey 1937). There have been no documented nesting records for this species in South Carolina (Mayer et al. 1985, 1986).

3.15.3.2 Golden Eagle Sightings

Sightings of golden eagles on SRS are rare (Mayer et al. 1985, 1986). Although SRS is not ideal golden eagle habitat, it does provide potential wintering habitat for this species (Mayer et al. 1985, 1986). Only three golden eagles have been recorded as being sighted on SRS (Table 3-22). All of the sightings have been on Par Pond. The first was an immature bird that spent several weeks on Par Pond during December 1972-January 1973. The second observation was of an adult golden eagle during the 1978 SRS Christmas Bird Count survey on Par Pond. The last series of observations, in December 1991 on Par Pond, were assumed to have been multiple sightings of the same adult bird. Since recent numbers of this species have not substantially increased in this region of the southeastern United States, the level of use of SRS also is not expected to increase.

Table 3-22. Golden Eagle Sightings on SRS

Year	Age Classification	Location	Source
1972-1973[a]	Immature	Par Pond	Mayer et al. 1985, 1986
1978	Adult	Par Pond	Mayer et al. 1985, 1986
1991[a]	Adult	Par Pond	1991 SRS Christmas Bird Count and SREL aerial surveys

[a] Based on a number of observations made of what was assumed to be the same individual.

3.15.4 Red-Cockaded Woodpecker

3.15.4.1 Introduction

The red-cockaded woodpecker (*Picoides borealis*) (Figure 3-13) was included in the federal list of endangered species in 1970 due to the declines in local populations, its perceived rarity, and the apparent reduction in available nesting habitat (Lennartz and Henry 1984). Although the red-cockaded woodpecker was once common, its current status largely can be attributed to its unique life history requirements and how they are affected by the reduction of mature pine forests. The red-cockaded woodpecker is a native of the southern pine forests of the United States with the largest populations found in the Coastal Plain forests of the Carolinas, Florida, Alabama, Mississippi, Louisiana, and eastern Texas. Populations are also found in the Sandhills forests of the Carolinas. An endangered species recovery plan (Lennartz and Henry 1984) prepared for the USFWS describes the life history, ecology, and historic and current status of the species.

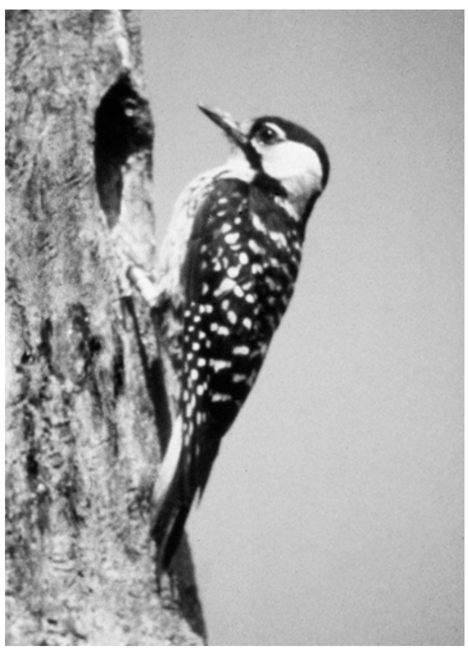


Figure 3-13. Red-Cockaded Woodpecker (*Picoides borealis*)

3.15.4.2 Breeding

The red-cockaded woodpecker is a cooperative breeder; auxiliary or helper birds aid the mated pair with incubation, feeding, and brooding. Groups with helpers generally have higher reproductive success. These groups are nonmigratory and maintain year-round territories around their nesting and roost trees. Groups can range in size from only the mated pair to nine birds, including helpers and fledglings. The normal group size is two to four birds prior to nesting and four to six birds after fledging. Nesting season is usually April and May, with clutch initiation in late April or early May. Clutch size is generally between two and five eggs. Incubation takes approximately 10 days, and fledging occurs between 26 and 29 days after hatching. Juveniles remain in their natal territory through summer into fall. Juvenile females disperse during late fall, winter, and early spring, while some juvenile males may remain with their clan and become helpers (Lennartz and Henry 1984).

3.15.4.3 Habitat

3.15.4.3.1 <u>Cavity Excavation</u>

The red-cockaded woodpecker is the only North American species that uses exclusively living pines for cavity excavation. The birds use many species of pines, prefer trees over 70 years old, and may actively select trees suffering from heart rot. They are often associated with longleaf pines (*Pinus palustris*) because of the high incidence of heart rot in older trees. The same cavity trees may be used for many years, possibly decades, and the trees used by a group tend to be located in what are referred to as clusters. Trees in most clusters are within a 460-m (1500-ft) diameter area in open stands of pine with sparse midstories. Dense hardwood midstories may cause red-cockaded woodpeckers to abandon the area. This may be due to more intense interspecific competition from other woodpecker species (Lennartz and Henry 1984) or other cavity-dwelling competing species, particularly the flying squirrel.

3.15.4.3.2 <u>Foraging</u>

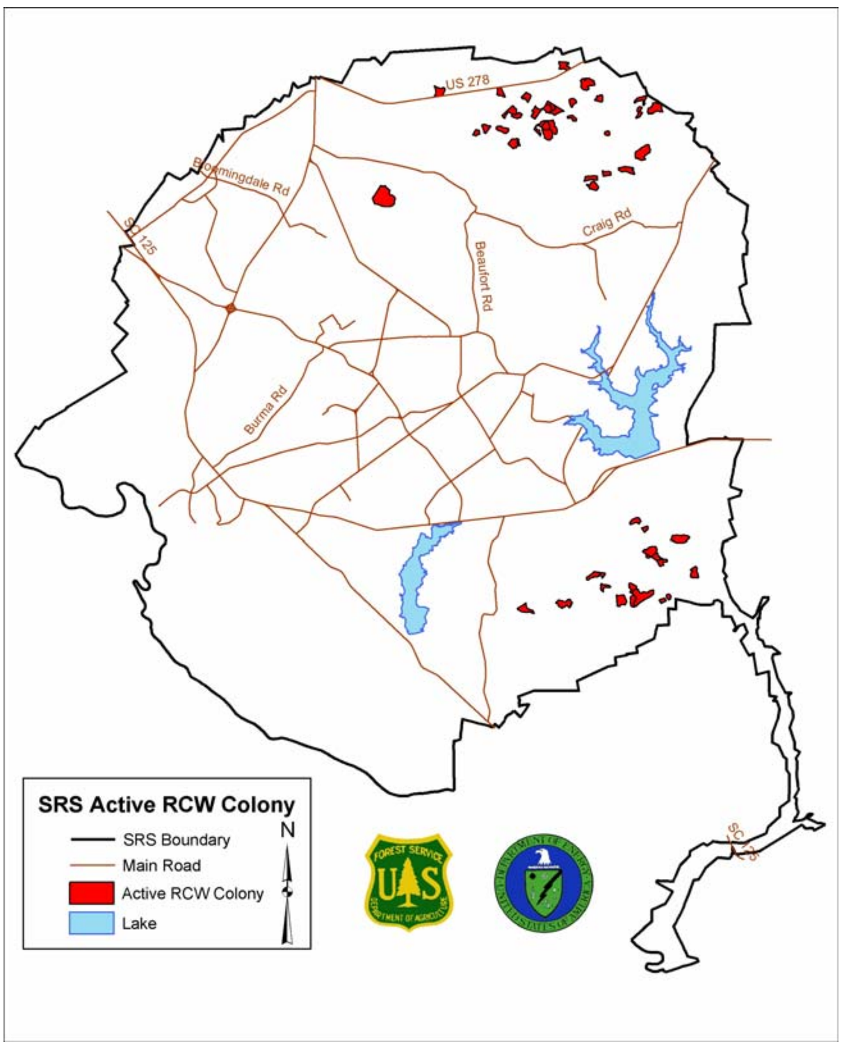
Red-cockaded woodpeckers also prefer to forage on living pines. Other tree species, such as cypress, also are used, but primarily when pine foraging areas are low quality. The preferred habitat is more than 50% basal area in pine, more than 24 pine stems per acre larger than 10 in. in diameter at breast height, and at least 30 years old. Based on the relationship of home range, available foraging area, and reproductive success, a group of red-cockaded woodpeckers requires for survival and productivity at least 125 acres of well-stocked pine or pine-hardwood stands more than 30 years old (Lennartz and Henry 1984).

3.15.4.3.3 <u>Relationship Between Population Numbers and Suitable Habitat</u>

Since its listing as an endangered species, the red-cockaded woodpecker has been the focus of extensive research and population studies. Active clusters on federal lands may exceed 3000; however, there are documented losses of active clusters in recent literature. Red-cockaded woodpecker population trends will most likely parallel the trends in availability of suitable habitat. On federal lands, there is a significant positive correlation between old-growth longleaf-slash pine (*Pinus palustris - P. elliotti*) communities and active red-cockaded colonies. Stands of old-growth pines are a scarce and declining resource throughout the South. Total acreage declined by 13% over the last 30 years.

3.15.4.4 Savannah River Forest Station (SRFS) Management Program

Since 1985, the SRFS wildlife management program at SRS has been working to improve red-cockaded woodpecker habitat. In 1991 and 2000 the SRFS issued and updated extensive management plans for the RCW. In the 2000 plan, management areas at SRS were rearranged to provide a primary and a supplemental management area with the goal of managing a total of almost 39,000 hectares of RCW habitat. The management plan describes the means by which the population goal of 418 RCW groups at SRS will be reached. Population management through banding and marking individuals, monitoring group composition, and transloction from other areas are part of the program. Management of nesting and foraging habitat are critical components and include midstory removal and control, thinning, artificial cavities, cavity restrictors, predator and cavity competator controls, and prescribed burning (Edwards et al. 2000).



Source – A. Thompson, personal communication 2004

Figure 3-14. Location of Red-Cockaded Woodpecker Colonies on SRS

3.15.4.5 SRS Population

During the 2003 breeding season, the red-cockaded woodpecker population inhabiting SRS consisted of 116 adults, making up 45 breeding groups (Table 3-23). The number of fledglings was 59 and helpers at the nest numbered 14. A total of 45 groups was active during the breeding season with the 34 successful breeding groups producing 134 eggs. Sixty-nine young were banded in the nests, 59 of which fledged. The total population at the close of the breeding season was 177 individuals (Johnston, 2003).

Status of all colonies at the end of the 2003 breeding season is shown in Table 3-24.

Table 3-23. Numbers of Documented Red-Cockaded Woodpeckers on SRS

	Northern Subpopulation		**Southern Subpopulation**		**Total**	
Year	Male:Female	No. Groups	Male:Female	No. Groups	Male:Female	No. Groups
1985	2:NA[a]	3	0:0	2	2:NA	5
1986	1:1	1	1:1	2	2:2	3
1987	2:1	1	1:3	2	3:4	3
1988	0:2	2	0:2	2	0:4	4
1989	2:2	2	3:1	2	5:3	4
1990	3:2	4	2:2	3	5:4	7
1991	2:3	5	1:5	3	3:8	8
1992	2:3	6	4:4	4	6:7	10
1993	7:4	6	7:4	5	14:8	11
1994	6:9	7	11:6	6	17:15	13
1995	10:7	10	10:9	8	20:6	18
1996	7:13	12	14:9	10	21:22	22
1997	11:9	13	10:10	11	21:19	24
1998	7:14	17	7:14	11	14:28	28
1999	17:15	20	8:14	11	25:29	31
2000	12:23	22	14:7	12	26:30	34
2001	11:17	26	8:16	11	19:33	37
2002	23:19	28	7:11	14	30:30	42
2003	12:20	30	8:17	15	20:37	45

[a]NA = not available

Table 3-24. Red-cockaded woodpecker production by group and year, Savannah River Site, South Carolina (Johnston 2003)

Group	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
						Northern Subpopulation						
1.00			1/1	1/2	1/2	1/1	1/2	2/l	3/0	0/2	2/l	1/1
2.00	0/0	2/l	0/1	2/0	1/0	1/1	0/3	3/0	0/1	2/0	1/1	0/0
3.00	0/2	3/0	1/1	0/0	1/2	2/l	0/2	1/0	2/l	1/1	3/0	0/2
18.00	0/0*	0/2	1/2	0/0	0/0	0/0	1/2	1/12	0/1	1/0	1/3	1/2
18.17											2/0	0/0*
19.00	2/l	2/l	1/2	2/2	1/2	1/0	0/0	1/1	0/3	1/1	1/0	0/1
19.A									Oil	I/O	I/O	III
20.00							0/0	0/2	1/2	0/2	0/2	0/0
20.50								0/0*	0/0	0/1	$0/0^+$	
22.14							$0/0^+$	$0/0^+$	0/0	1/0	1/1	0/2
22.22												$0/0^+$
23.05							0/0	0/2	0/2	0/0	0/0	2/0
23.44								0/0	0/2	0/0	0/0	0/0*
24.01						0/0	0/0	2/1	0/1	0/0	*2/0*	0/2
24.04				2/0	1/1	1/1	2/0	1/2	1/1	0/2	2/0	1/1
24.05	0/0	0/0	1/1	2/0	0/0	2/1	1/2	3/0	1/1	1/1	0/0	0/0
24.17									0/0	1/0	3/0	2/1
24.26												0/0
24.32										0/0	0/0	0/0
24.33					0/3	0/2	0/1	0/0	1/1	0/1	0/0	0/2
24.49											0/2	1/0
25.18				0/1	1/1	1/0	0/0	0/0*	1/1	1/1	1/3	1/1
25.43				0/1	0/0	1/1	1/2	2/1	1/1	0/3	1/2	1/0/1?
26.16										0/0	0/2	0/0
26.32											0/0	0/2
27.33										0/0	0/2	0/1
28.00	0/0	0/0	1/1	1/1	1/2	1/1	1/0	1/2	0/1	1/0	0/0	0/0
28.04							0/0	0/1	1/1	0/0	2/0	1/0
30.00							0/0*	0/1	0/2	0/2	.0/0	0/1
30.26									0/0*	$0/0^+$		
30.81												$0/0^+$
30.82										$0/0^+$	$0/0^+$	$0/0^+$
						Southern Subpopulation						
5.00	0/0	1/0	1/1	2/0	3/0	1/1	1/2	1/0	1/2	0/1	0/0	0/2
15.00				1/1	2/0	1/1	1/1	1/3	2/l	1/2	2/l	0/3
16.00	2/l	2/l	1/1	3/1	2/1	1/1	1/1	*0/0*	1/2	0/1	0/2	1/2
39.00	1/1	1/2	2/1	0/2	1/1	1/1	1/2	0/3	0/0	0/2	2/0	0/0
40.00		1/1	0/2	0/2	2/2	1/2	0/2	2/2	1/0	2/l	0/2	2/2
43.00	1/2	3/0	4/0	2/l	2/2	2/l	1/1	0/2	3/0	2/2	1/1/I?	1/0/1?
79.06				2/0	0/0	0/0	0/3	0/1	2/l	1/2	0/2	0/1
80.28			1/1	1/2	3/l	1/0	2/l	2/0	1/1	0/2	1/1	1/1
80.33											0/0	1/1
80.49									0/0	1/1	0/1	0/0
81.22											0/0*	0/0*
82.36												$0/0^+$
82.42					0/0*	0/2	1/1	0/1	3/l	1/1	0/0	1/1
82.106					0/2	2/1	0/1	0/0	0/0	*0/1/1?*	1/1	1/1
82.107								1/0	1/0		0/0	0/3
Totals	6/7	14/8	17/15	20/16	21/22	21/19	14/28	24/30	26/30	19/32/l	30/29/l	20/37/2

Numbers represent the number of male/female fledglings.

*, + denote clusters of a solitary male/female adult respectively

3.15.5 Wood Stork

3.15.5.1 Introduction

During the last 50 years, the North American breeding population of the wood stork (*Mycteria americana*) (Figure 3-15) has decreased from an estimated 20,000 breeding pairs in the early 1930s to 4800 pairs in 1980 and 3650 pairs in 1983 (Ogden and Nesbitt 1979; Ogden and Patty 1981). This population decline prompted the U.S. Department of Interior (DOI) to list the wood stork as an endangered species (DOI 1993). The number of breeding pairs in the early to mid-1980s remained relatively stable at approximately 4000-5000 pairs (Coulter 1986a). More recently (1993-1996) more than 6000 breeding pairs have been estimated for this species (USFWS 1996).

3.15.5.2 Birdsville Colony

The DOI identified 23 colonies of wood storks in Florida and Georgia in the proposed listing (DOI 1993). The Birdsville Colony, the most northern and inland colony, is located at Big Dukes Pond, a 567-ha (1400-acre) cypress swamp, 12.6 km (7.8 mi) northwest of Millen, Jenkins County, Georgia (32°52'N, 82°03'W). This wood stork colony (Figure 3-15) was believed to be the source of storks observed at the Steel Creek delta in the SRS Savannah River swamp during 1980-1982 (Smith et al. 1982a and b). The SRS Savannah River swamp is 45 km (28 miles) from the Birdsville Colony, a distance within the 60-70 km (37-43 mi) maximum radius that wood storks can travel during daily feeding flights (Bryan and Coulter 1987; Coulter 1993).

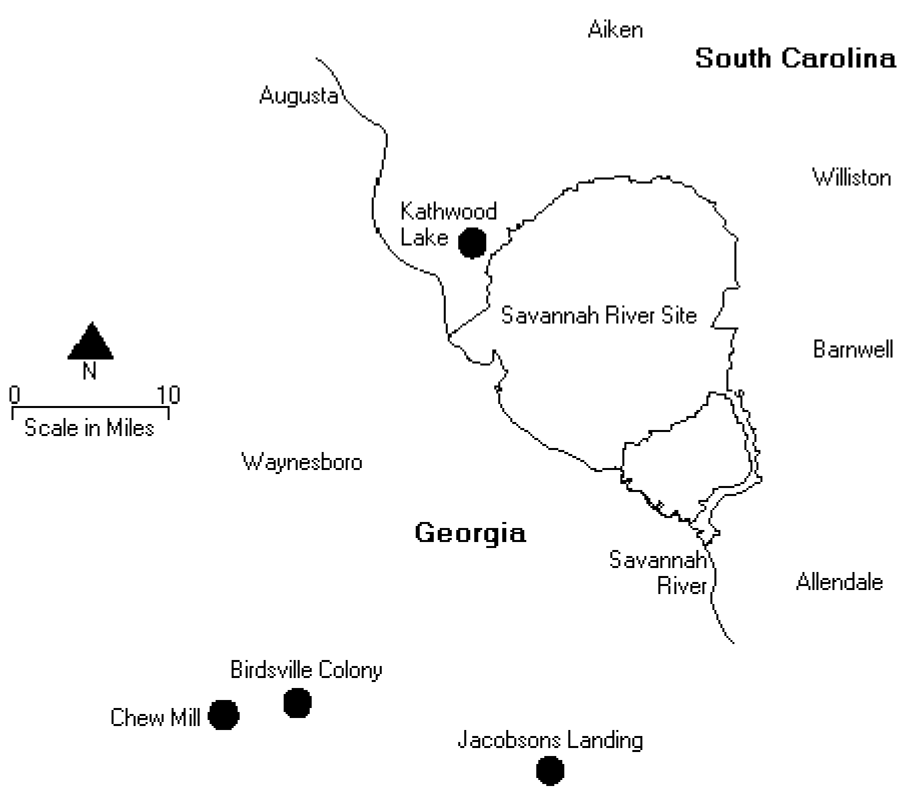


Figure 3-15. Location of Kathwood Lake and Nearby Wood Stork Colonies

3.15.5.3 Chew Mill Pond Colony

Wood storks first nested in Chew Mill Pond, approximately 6 km (3.7 mi) southwest of the Birdsville Colony, in 1993. Chew Mill Pond had a history of being a wood stork foraging site and a wading bird rookery. Researchers consider it to be an overflow or satellite colony of the Birdsville Colony. It has a more stable hydrology than the Big Dukes Pond.

3.15.5.4 Jacobsons Landing Colony

The Jacobsons Landing rookery, with 36 stork nests, was discovered in 1995. It is approximately 38 km (23.6 mi) southeast of the SRS in Screven County, Ga. In 1996, it contained an estimated 40 wood stork nests.

3.15.5.5 Effect of Reactor Operations

In 1983, studies were initiated to assess the potential effects of the operation of SRS on the wood stork (Meyers 1984). The study objectives included

- determining the foraging locations of storks from the Birdsville Colony
- characterizing the habitat, water quality, and fish density and biomass at foraging sites
- determining food resources used by wood storks from the Birdsville Colony
- assessing the importance of the SRS Savannah River swamp to wood storks

Much of the data and information presented here are summarized from the studies and reports by the Savannah River Ecology Laboratory (SREL) (Meyers 1984; Coulter 1986a,b, and c, 1987,1988, 1989, 1991, 1993; Bryan 1992a and b, 1994, 1995, 1996; Bryan et al. 1997, 1998, 1999, 2000, 2001, 2002, 2003).

3.15.5.6 Savannah River Swamp

The SRS Savannah River swamp comprises about 3800 ha (9400 acres) bordering the Savannah River on the southwestern edge of SRS (Jensen et al. 1984). The swamp area, including the deltas of Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek, contains nonpersistent and persistent emergent wetlands, deciduous forest wetlands (including cypress-tupelo forest), and scrub-shrub wetlands. Earlier studies placed particular emphasis on wood stork use of the Steel Creek delta (Meyers 1984; Coulter 1986b and c) because the forage potential of this area would be reduced due to increased water depths associated with L Reactor restart in October 1985. Although the cooling water used by L Reactor was cooled in L Lake, the water volume below L Lake increased the water depth in areas of the Steel Creek delta where storks have been observed foraging. Because it was anticipated that the Steel Creek delta could be lost as a foraging site for wood storks following L Reactor restart, alternate foraging ponds were built at the site of Kathwood Lake on the National Audubon Society's Silver Bluff Plantation Sanctuary (Figure 3-15) (Mackey 1985).

3.15.5.7 Birdsville Colony Survey

SREL wood stork studies began in 1983 (Meyers 1984). During the first year, there were only a few observations made at the colony. From 1984 through 1989, the study of the breeding biology of the storks expanded. Since 1980, the maximum number of active nests in the colony has been determined to document colony growth and overall colony reproductive success (Table 3-25). In 1984 and 1985, unsuccessful nests also were included in measuring breeding success (Coulter 1986a). Storks begin to arrive at the Birdsville Colony in early March. Breeding and chick rearing are variable from year to year and usually extend from March through May with fledglings dispersing from the colony from late May through mid-summer. Reproductive success, which is estimated as the number of chicks fledged per nest (Table 3-26), has varied yearly, as affected by predation (primarily raccoons), intraspecific aggression, violent storms, and the availability of prey (Coulter and Bryan 1995).

Table 3-25. Number of Active Nests in the Birdsville, Chew Mill Pond, and Jacobsons Landing Colonies

	Number of Active Nests				
Year	**Birdsville**	**Chew Mill Pond**	**Jacobsons Landing**	**Date Maximum Number of Nests were Counted**	**Source**
1980	About 100[a]			-	Meyers 1984
1981	Failed			-	Meyers 1984
1982	About 60[a]			-	Meyers 1984
1983	113[b]			-	Meyers 1984
1984	About 100			-	Coulter 1986b
1985	About 108			-	Coulter 1986c
1986	160			May 14	Coulter 1987
1987	193			May 26	Coulter 1988
1988	101			May 31	Coulter 1989
1989	126			June 13	Coulter 1991
1990	259			June 1	Coulter 1991
1991	270			May 22	Bryan 1992a
1992	243			May 19	Bryan 1992b
1993	330	44			Bryan 1994
1994	230	65			Bryan 1995
1995	245	45			Bryan 1996
1996	189	95	40		Bryan et al. 1997

[a]Estimated from ground and aerial surveys.
[b]Actual counts from 26 trees.

Table 3-26. Reproductive Success of Wood Storks at the Birdsville Colony

Year	Mean Number of Young per Nest[a]	Source
1980	About 2[b]	Meyers 1984
1981	0[c]	Meyers 1984
1982	No data	Meyers 1984
1983	2.19	Meyers 1984
1984	2.39[d], 2.04[e]	Coulter 1986b
1985	2.50[d], 0.33[e]	Coulter 1986c
1986	2.86[d], 2.68[e], 2.16[f]	Coulter 1987
1987	2.33[d], 2.0[e], 1.96[g]	Coulter 1988
1988	1.80[d], 0.35[e]	Coulter 1989
1989	1.88[d], 0.63[e]	Coulter 1991
1990	2.67[d], 0.63[e]	Coulter 1991
1991	1.95[e]	Bryan 1992a
1992	1.40[d], 2.10[e, h]	Bryan 1992b
1993	2.5[i]	Bryan 1994
1994	0.9[i]	Bryan 1995
1995	1.9[i]	Bryan 1996
1996	1.9[i]	Bryan et al. 1997

[a]Young at least five weeks old.
[b]Estimated from ground or aerial surveys.
[c]Colony failed in 1981.
[d]Chicks at least 50 days old; this does not include whole nests that were lost.
[e]Chicks at least 50 days old; this includes whole nests that were lost.
[f]Includes the 25% decline in numbers of nests recorded during the ground censuses.
[g]Includes the 20% decline in numbers of nests recorded during the ground censuses.
[h]Previously unpublished data.
[i]Fledged young/nest.

3.15.5.8 Foraging Surveys 1983-1989

3.15.5.8.1 Introduction

Storks have been followed by an airplane from the colony to foraging sites in all years of the surveys. The majority of foraging sites (75%) were in Jenkins, Burke, and Emanuel counties, Georgia (Hodgson et al. 1987, 1988). Storks and other wading birds were counted at each foraging site, and the water depth and the minimum distance to the shore were measured. In 1983, Meyers (1984) recorded five original foraging habitat types, including a shrub swamp that was incorporated into different swamp types of later surveys. Drainage ditches, hardwood swamps, and natural ponds were additional types of foraging sites used in 1984 (Coulter 1986b). In 1985, Carolina bays were added (Coulter 1986b). In 1984 and 1985, there were a few forage sites that did not fit into the general classification, including logging roads and powerline rights-of-way. These were listed as "other" in the survey reports (Coulter 1986a and b). The average straight-line distance between the colony and the foraging sites is in Table 3-27.

3.15.5.8.2 Foraging Habitats

The foraging habitats described in this section include (in parentheses) the comparable category of the USFWS system for classifying wetland habitats (Cowardin et al. 1979). Black gum (*Nyssa sylvatica*) and cypress (*Taxodium distichum*) swamps (palustrine forested) were the predominant species at the swamp foraging sites. Hardwood swamps (palustrine forested) had a mix of hardwood tree species including red maple (*Acer rubrum*) and sweetgum (*Liquidambar styraciflua*). Shrub swamps (palustrine scrub-shrub) contained predominantly buttonbush (*Cephalanthus occidentalis*). Natural ponds (palustrine unconsolidated shore/lacustrine littoral unconsolidated shore) contained open water with little or no vegetation. Carolina bays (forested wetland/palustrine scrub-shrub/persistent emergent) are common in east-central Georgia. Man-made ponds (palustrine unconsolidated shore/lacustrine littoral unconsolidated shore) included agricultural and fish ponds. Drainage and agricultural ditches are also common. Open marshes (palustrine emergent) were usually seasonally flooded pastures. Table 3-28 summarizes the types and frequency of foraging habitats commonly used by wood storks from the Birdsville Colony. Water quality parameters (including temperature, pH, dissolved oxygen concentration, turbidity, and conductivity) were measured at each foraging site (Coulter 1986a).

The wood storks foraged in various wetland habitat types (Table 3-28). Storks were followed most frequently to swamps; the most common were blackgum and cypress swamps (Hodgson et al. 1988; Coulter 1993; Coulter and Bryan 1993). The extent of the canopy cover ranged from completely open (marsh or pond) to completely closed (swamp). Most sites had little understory or woody vegetation. At all sites, the water was either still or very slowly moving.

Table 3-27. Mean Distances of Wood Stork Foraging Sites from the Birdsville Colony, 1983-1989

Year	Number of Storks	Mean Distance (km)[a]	Standard Deviation	Source
1983	30	17.39	15.60	Coulter 1986a
1984	55	13.75	13.16	Coulter 1986a
1985	39	11.94	7.87	Coulter 1986a
1986	36	11.85	8.33	Coulter 1987
1987	44	13.2	12.97	Coulter 1988
1988	40	9.1	7.35	Coulter 1989
1989	47	12.1	11.38	Coulter 1991

[a]To convert kilometers to miles multiply by 0.6214.

Table 3-28. Wood Stork Foraging Site Habitat Types in East-Central Georgia, 1983-1989

Habitat Type	1983 Number (%)	1984 Number (%)	1985 Number (%)	1986 Number (%)	1987 Number (%)	1988 Number (%)	1989 Number (%)
Blackgum swamp	14 (31)	10 (20)	6 (29)	7 (23)	4 (18)	-	-
Hardwood swamp	-	4 (8)	-	2 (6)	2 (9)	11 (38)	8 (19)
Cypress swamp	13 (28)	7 (14)	6 (29)	9 (29)	3 (14)	3 (10)	10 (23)
Shrub swamp	8 (17)	-	-	-	-	-	-
Carolina bay	-	-	3 (14)	-	-	-	-
Open marsh	9 (20)	3 (6)	-	1 (3)	2 (9)	5 (17)	2 (5)
Natural pond	-	2 (4)	-	-	1 (4.5)	-	-
Man-made pond	2 (4)	11 (22)	2 (9)	5 (16)	3 (13.5)	4 (14)	7 (16)
Drainage ditch	-	4 (8)	-	-	-	-	-
Other	-	9 (18)	4 (19)	7 (23)	7 (32)	6 (21)	16 (37)
Total	46 (100)	50 (100)	21 (l00)	31 (100)	22 (100)	29 (100)	43 (100)

Source: Coulter (1986a, 1987, 1988, 1989, 1991)

3.15.5.8.3 Vegetation Structure

The vegetation structure of a wetland may contribute to its suitability as a foraging site for wood storks, or a dense canopy may obscure a site from a flying stork. The birds may not be able to land if the understory is dense. Aquatic vegetation may make it difficult for the birds to wade through the water and grope with their bills. Most sites had little aquatic vegetation, although a few sites had dense submergent or emergent vegetation. Submergent vegetation included species such as *Myriophyllum* spp. and algae; emergents included lotus (*Nuphar luteum*), water lily (*Nymphaea odorata)*, bladderwort (*Utricularia inflata*), *Ludwigia* spp., and various species of duckweeds, sedges, and rushes.

3.15.5.8.4 Water Depth

The median water depth at the foraging sites was 18-26 cm (7-10 inches) during the 7 years of the survey (Coulter 1986a, 1987, 1988, 1989, 1991). The water depths ranged from 0 to 63 cm (0-25 in). Meyers (1984) suggested that the length of the legs of storks set an upper limit to water depth at about 50 cm (20 inches). Kahl (1963) stated that wood storks fed in water between 15 and 50 cm (6 and 20 inches) deep.

3.15.5.8.5 Major Diet Components

Regurgitation and stomach samples and recent literature indicate the major component of the diet of wood storks is sunfish (*Lepomis* spp.). Mosquito fish (*Gambusia* sp.) were common at many sites, but storks do not seem to prefer this species (Depkin et al. 1992).

3.15.5.9 SRS Savannah River Swamp Surveys

3.15.5.9.1 Introduction

Wood storks were reported in the vicinity of SRS before the site was established in 1952 and before the discovery of the Birdsville Colony (Murphey 1937). E. E. Murphey, describing the status of storks in the area in the early 1900s, noted that the birds probably did not breed locally, but that flocks of more than 30 birds were seen regularly in August and September. In June 1956 and July 1957, storks were recorded on SRS (Norris 1963). In July 1973 and 1974, flocks of 200 and more than 400 storks, respectively, were observed in the Steel Creek delta (Coulter 1986a). Storks have been followed from the Birdsville Colony to SRS (Meyers 1984; Coulter 1986a). Some of the birds observed foraging in the SRS Savannah River swamp may be storks from farther south, either nonbreeders or birds already finished breeding for the year (Coulter 1986a).

3.15.5.9.2 Results of the Aerial Surveys

More than 900 aerial surveys were conducted to census feeding or roosting storks in the SRS Savannah River swamp from mid-June 1983 through mid-October 1996 (Table 3-29). Wood storks are most commonly observed in the SRS Savannah River swamp during July and August (Table 3-30). In addition to the swamp and Kathwood Lake, wood storks have been observed foraging in the following locations on SRS: "RR site" (1993, 1994, 1996); Craigs Pond (1994, 1996); Sarracenia Bay (1994, 1996); Peat Bay (1994, 1996); Thunder Bay (1994); Eagle Bay (1994); Steel Creek Bay (1995); Robbins Station (1995) (Figure 3-16).

Wood stork surveys were conducted in the years 1998, 1999, 2000, and 2002. In 1998 thirty-two surveys observed 41 storks in the Savannah River Site Swamp (SRSS) and one bird at a Carolina bay. In 1999 335 storks were observed in 27 surveys, all of them foraging in Carolina bays. Twenty surveys were conducted in 2000 and 15 were done in 2002, no storks were observed during either year (Bryan et al 1999, 2000, 2001, 2002, 2003, 2004).

Table 3-29. Number of Aerial Surveys Used to Monitor the Number of Wood Storks on the SRS Savannah River Swamp, 1983-1996

	Number of Woodstorks Counted During Aerial Surveys						
Year	**Steel Creek Delta**	**Interdelta Area**	**Pen Branch Delta**	**Interdelta Area**	**Four Mile Creek Delta**	**Beaver Dam Creek**	**Total Number of Surveys**
1983	87	0	6	0	0	170	35
1984	95	0	21	102	46	106	89
1985	9	0	9	236	346	0	120
1986	81	0	0	0	94	15	115
1987	139	0	0	0	11	0	123
1988	6	1	0	0	0	0	143
1989	9	1	5	6	6	2	99
1990	1	0	0	0	12	0	12
1991	1	16	1	17	36	7	34
1992	9	79	70	10	0	4	41
1993	22	1	16	68	55	6	40
1994	21	2	1	0	5	1	29
1995	5	7	0	1	0	0	26
1996	4	0	0	0	1	0	16
Totals	480	100	129	439	611	311	
Average Storks/ Area/Year	34.29	7.14	9.21	31.36	43.64	22.21	
Average Storks/ Area/Survey	0.55	0.11	0.15	0.50	0.69	0.35	

Source: Meyers 1984; Coulter 1986a, 1987, 1988, 1989, 1991, 1993; Bryan 1992a and b, 1994, 1995, 1996, Bryan et al. 1997.

Table 3-30. Number of Wood Storks Observed in the SRS Savannah River Swamp during Aerial Surveys, 1983-1996.

Period	Number of Storks	Percent of Total
Before June	45	2.1
June 1-15	123	5.6
June 16-30	146	6.7
July 1-15	588	26.8
July 16-31	425	19.4
Aug 1-15	207	9.4
Aug 16-31	191	8.7
Sept 1-15	171	7.8
Sept 16-30	274	12.4
After Sept	24	1.1
Total	2,194	100.0

3.15.5.9.3 Stream Flows and Numbers of Foraging Storks

3.15.5.9.3.1 Sources of Water Flow

The water depth in the Savannah River swamp is dependent on the water flow from the Savannah River and site streams. The swamp receives overflow from the Savannah River during flooding. The river flow and the amount of water that reaches the swamp are influenced by the amount of water discharged from the Clarks Hill (Lake Thurmond) Dam, almost 160 km (99 mi) upstream. The water level in the swamp also depends on the water that flows into the swamp from Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and other smaller streams on SRS. The water flow in these streams depends on rainfall and the outflow of water from L Lake (Steel Creek), Par Pond (Lower Three Runs), and the D-Area power plant. Meyers (1984) suggested that water depth may affect the suitability of a wetland as a wood stork foraging site on SRS.

3.15.5.9.3.2 Flow Effect on Number of Wood Storks

Both the number of observations of wood storks and the number of wood storks counted during aerial surveys of the SRS Savannah River swamp are greater in the areas of the swamp receiving lower flows, especially in the flow class of 1.4 to 2.8 m^3/sec (51 to 100 ft^3 /sec) (Figure 3-17). The one area that may be different is an area of sloughs between the Fourmile Branch and the Pen Branch deltas.

3.15.5.9.3.3 Foraging Use

Data from the aerial wood stork surveys of the SRS Savannah River swamp and the studies at the Birdsville Colony suggest that the SRS Savannah River swamp probably is not used extensively during the breeding or prefledging phases of the Birdsville Colony. Most of the observations of storks on SRS occur during the late-nestling or the post-fledging period. Larger numbers of wood storks have been observed foraging in the SRS Savannah River swamp following successful breeding and fledging years at Birdsville (1983, 1984, 1986, and 1987) than after less successful years (1985 and 1988).

Both high (> 100 ft^3/sec [< 2.8 m^3/sec]) and low flows (< 50 ft^3/sec [< 1.4 m^3/sec]) from the SRS creeks probably limit the usefulness of the swamp as a foraging site. During periods of low flow (< 50 ft^3/sec [< 1.4 m^3/sec]) the streams are more confined to their channels, and habitats are not suitable for stork foraging. During periods of high flow, water depths may be limiting. Flows and flooding patterns also can affect vegetation patterns, thus influencing available foraging sites. Typical wood stork foraging sites have reduced quantities of both submerged and emergent macrophytes (Coulter 1986c). Moderate flows (< 50 ft^3/sec, but < 150 ft^3/sec [< 1.4m^3/sec but < 4.2 m^3/sec]) to the SRS deltas during the summer months probably would maintain wood stork foraging sites in the SRS Savannah River swamp.

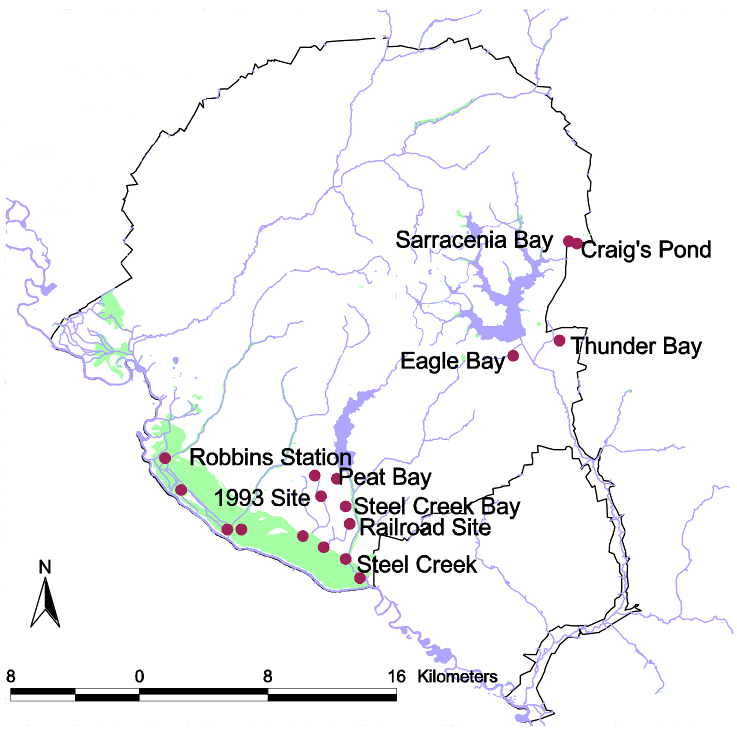


Figure 3-16. Wetlands on the Savannah River Site where storks foraged in 1993, 1994, 1995, or 1996

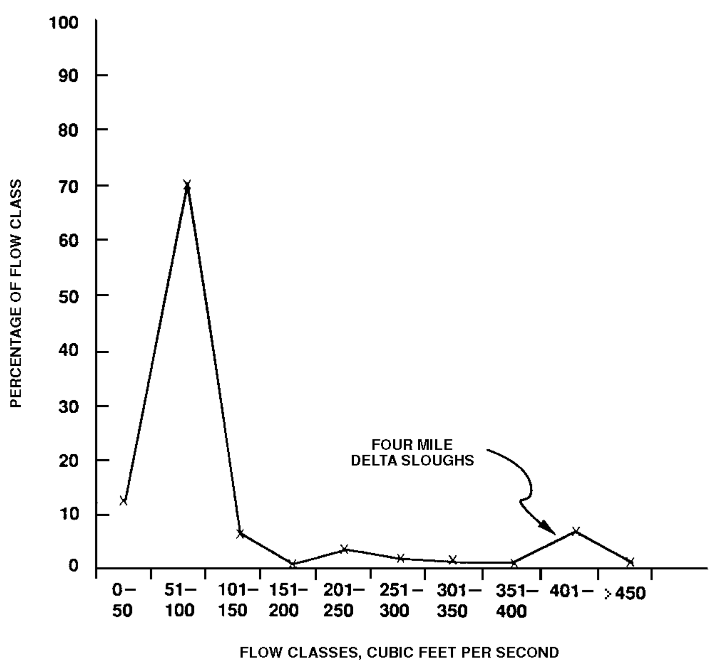


Figure 3-17. Percentage of Wood Storks Observed in the SRS Swamps from 1983 to 1988 under Different Stream Flow Classes

3.15.5.10 Par Pond

From late June 1991 through March 1995, the water level in the Par Pond reservoir was lowered approximately 6 m (20 ft) due to structural anomalies found in the dam impounding that system. Twenty surveys of the reservoir system monitored for possible wood stork use of the reservoir during the initial drawdown. A single stork was observed on Pond C on July 18, 1991. Stork numbers gradually increased to a maximum of 84 on September 19, 1991 and then declined through mid-October, when the storks were last seen on the reservoir (Bryan 1992a).

No storks have been observed foraging in the Par Pond system since 1991 (Bryan 1992b, 1994, 1995, 1996; Bryan et al. 1997).

3.16 THREATENED AND ENDANGERED MAMMALS ON SRS

3.16.1 Introduction

Either the DOI (USFWS 1992a) or the State of South Carolina (SCWMRD 1992) lists eight species of mammal that have historically resided in South Carolina as endangered or threatened; these include four bats, the black bear, two subspecies of cougar, and the red wolf (Table 3-31). With the exception of Rafinesque's big-eared bat (*Corynurhius rafinesquii*), the occurrence of these mammals on SRS is unconfirmed. It is improbable that breeding populations of the other seven species exist on SRS.

3.16.2 Bats

The gray bat (*Myotis grisescens*) and Indiana bat (*Myotis sodalis*) have not been found on SRS, nor does the site provide caves or cave-like areas, which are the preferred habitat for these species. The small-footed bat (*Myotis leibii*) and Rafinesque's big-eared bat are not federally listed, but are recognized as threatened and endangered, respectively, by South Carolina. There is no information regarding the presence of the small-footed bat on SRS (Cothran et al. 1991), and its status is unconfirmed. Two specimens of Rafinesque's big-eared bat were collected from SRS and placed in the University of Georgia Museum of Natural History, but field surveys of bats in 1979 were unsuccessful in confirming the presence of this species (Cothran et al. 1991), Golley (1966) did not report any of the four listed species of bats in his account of South Carolina mammals. However, Menzel et al (2003) captured seven adult females and one adult male Rafinesque's big-eared bat on the SRS.

3.16.3 Carnivores

The black bear (*Ursus americanus*) is considered a possible rare transient traveling along the Savannah River; no permanent populations of this species are expected to occur on SRS (Cothran et al. 1991). The eastern cougar (*Felis concolor couguar*) and Florida panther (*F. c. coryi*) are federally listed as endangered; their home ranges historically included South Carolina (USFWS 1992a). Although there have been reports of cougars in the area, none has been confirmed, and it is unlikely that either of these subspecies is a permanent resident on SRS. The red wolf (*Canis rufus*) once ranged throughout South Carolina, but the present population exists primarily in captivity (USFWS 1992b). Red wolves recently have been released by USFWS on Bull’s Island, SC, the Alligator River National Wildlife Refuge, NC, and in the Great Smoky Mountains National Park (recaptured and released in 1998) (Mayer, J. J. Westinghouse Savannah River Company. Personal communication with K. K. Patterson, Dunaway & Fletcher, Inc. 1997).

Table 3-31 Endangered and Threatened Mammals of South Carolina

Scientific Name	Common Name	Federal Status[a]	State Status[b]	Critical Habitat[c]	Status on SRS[d]
Myotis grisescens	Gray Bat	endangered	none	no	unconfirmed
Myotis sodalis	Indiana Bat	endangered	endangered	yes	unconfirmed
Myotis leibii	Small-footed Bat	none	threatened	no	unconfirmed
Corynurhius rafinesquii	Rafinesque's Big-Eared Bat	none	endangered	no	confirmed
Ursus americanus	Black Bear	none	threatened	no	rare transient
Felis concolor couguar	Eastern Cougar	endangered	endangered	no	unconfirmed
Felis concolor coryi	Florida Panther	endangered	none	no	unconfirmed
Canis rufus	Red Wolf	endangered	none	no	unconfirmed

[a]Federal Status USFWS 1992a.
[b]State Status SCWMRD 1992.
[c]Critical Habitat USFWS 1992b.
[d]Status on SRS Cothran et al. 1991; Golley 1966; USFWS 1992a, b; Menzel et al 2003.

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4.0 STREAMS AND RESERVOIRS

The southeastern United States has abundant freshwater resources, which provide diverse ecosystems. Five main basins drain SRS. The five streams that originate on, or pass through SRS before entering the Savannah River are Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Steel Creek, and Lower Three Runs. A sixth stream, Pen Branch, does not flow directly into the Savannah River, but joins Steel Creek in the Savannah River floodplain swamp. The upper reaches of Lower Three Runs were impounded in 1958 to form Par Pond. L Lake was formed in 1985 by damming Steel Creek. The purpose of Chapter 4 is to describe and define the physical and biological characteristics of these systems and provide a synopsis of the many aquatic studies conducted through the years at SRS.

4.1 INTRODUCTION

In previous versions of this document much space was devoted to information about stream flow and chemistry. That information has been eliminated from this edition. To obtain stream flow data please go to the Internet and follow one of these procedures.

For historical stream flows:

- Go to http://nwis.waterdata.usgs.gov/usa/nwis/discharge
- Under "Site Identifier" check "Site Number" and press the "Submit" button.
- Type in "0219" and select "match from the start" and press the "Submit" button.
- Using "Site Name" to identify the station that you are interested in, select the appropriate "Site Number" and click on this number.
- Select the time period for which you want the data and select the form of data you want (graph, file saved to disk, file displayed to browser, etc.) and press the "Submit" button. Remember, the time period available for each station depends on whether the station is still active and when the most recent set of data was validated and loaded.

For more recent provisional (not validated) stream flow data:

- Go to http://waterdata.usgs.gov/nwis/dv
- Under "Site Identifier" check "Site Number" and press the "Submit" button.
- Type in "0219" and select "match from the start" and press the "Submit" button.
- Using "Site Name" to identify the station that you are interested in, select the appropriate "Site Number" and click on this number. By default, the data for the most recent 31 days will be displayed. For other displays select the parameters followed by "Output Display"

Chemical Parameters

Summaries of chemical data for Site streams can be obtained from the most recent Annual SRS Environmental Report or from the most recent Integrated Operable Unit (IOU) report for the specific IOU. If more detailed information or raw data are needed, permission to download the appropriate data can be obtained from the IOU project which is administered by Closure Business Unit/Soil and Groundwater Projects - Project Team Leads.

4.2 UPPER THREE RUNS

4.2.1 Drainage Description and Surface Hydrology

4.2.1.1 General Description

Upper Three Runs is a large, cool (annual maximum temperature of 26.1°C [79°F]), blackwater stream in the northern part of SRS (Figure 4-1). With headwaters arising offsite, near Aiken, Upper Three Runs drains an area of approximately 545 km^2 (209 mi^2) and discharges directly into the Savannah River. Upper Three Runs is approximately 40 km (25 mi) long, with the lower 28 km (17 mi) within the boundaries of SRS. Upper Three Runs receives more water from underground sources (Dublin-Midville aquifer system) than the other SRS streams; hence, it has low conductivity, low hardness, and low pH values (Specht 1987). An excellent summary of information about Upper Three Runs written by Mast and Turk (1999) is available at http://pubs.usgs.gov/circ/circ1173/circ1173a/chapter13.htm.

4.2.1.2 Effluent Contribution

Upper Three Runs is the only major tributary on SRS that never has received major thermal discharges. Its two significant tributaries are Tinker Creek, the largest, and Tims Branch. Above its confluence with Tims Branch, Upper Three Runs is relatively unimpacted. Beginning in late 1988, Upper Three Runs began receiving effluents from the F-/H-Area ETF, which discharges into the creek just downstream of the Road C bridge. Tims Branch receives industrial wastes from the fuel fabrication facilities (300-M Area) and the Savannah River National Laboratory (700-A Area) including nonprocess cooling water, steam condensates, process effluents, and treated groundwater effluents. Three smaller tributaries of Upper Three Runs originating from the 200-F and the 200-H Separations Areas carry ambient temperature cooling water, steam condensates, powerhouse wash-down waters, and ash disposal basin effluents.

Upper Three Runs, either directly or via tributaries, receives the following NPDES-permitted discharges: cooling water, blowdown, stormwater, lab drains, air stripper discharge, steam condensate, M-Area wastes, process-water, Consolidated Incineration Facility wastewater, neutralization wastewater, and F/H ETF wastewater.

4.2.1.3 Flow Measurements

The U.S. Geological Survey measures flow at several locations on Upper Three Runs. Flow statistics are available for Upper Three Runs at SRS Road A, above SRS Road C, and near New Ellenton (Highway 278) (Figure 4-2). Records for the most downstream station (Upper Three Runs at Road A) date back to June 1974 (no records from February 1978 through September 1978). All flow metering stations within the Upper Three Runs drainage have been closed and no stream flow data exist past 30 September 2002.

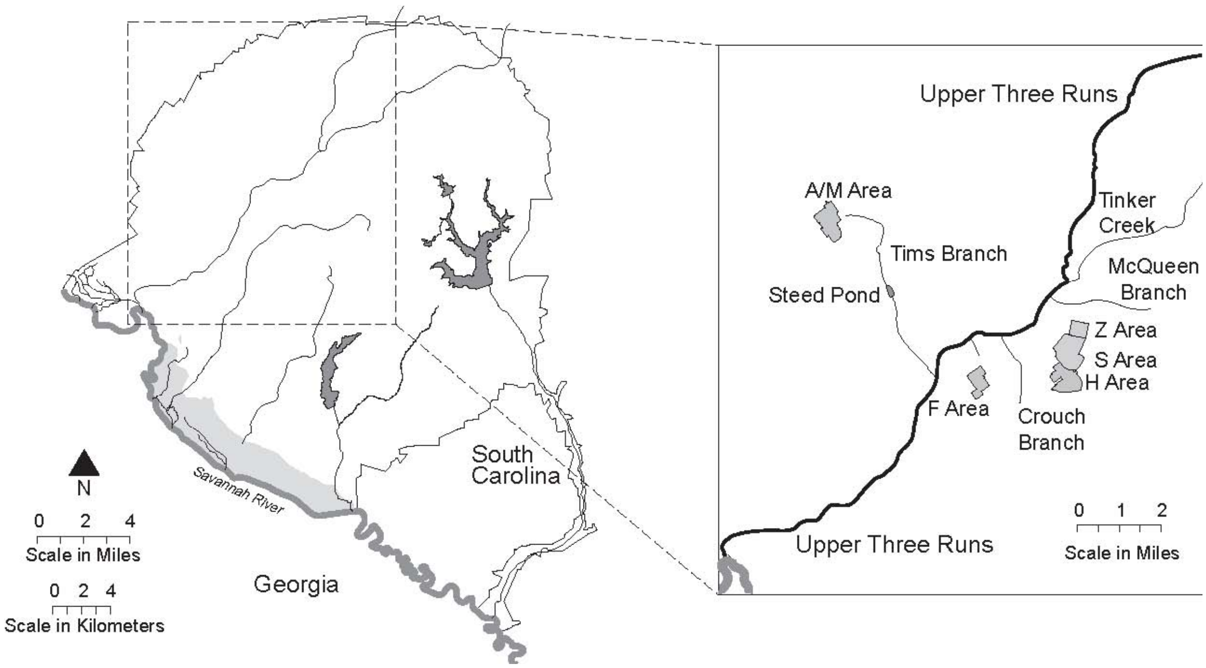


Figure 4-1. Location of Upper Three Runs on SRS and S-Area

01 near New Ellenton (Hwy 278)
02 above Road C at SRS
03 at Road A at SRS

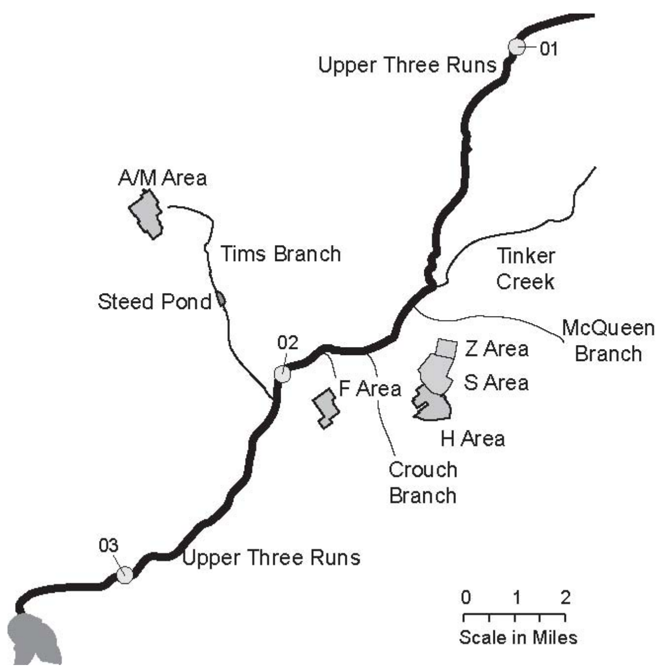


Figure 4-2. Flow Measurement Sampling Stations for Upper Three Runs

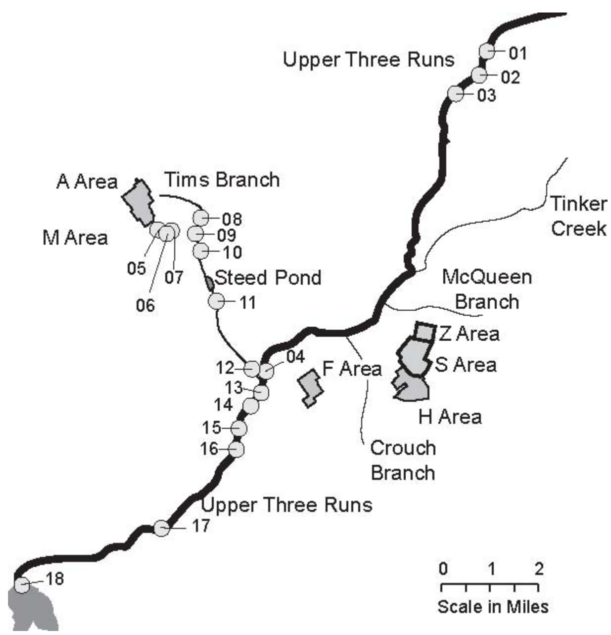
4.2.2 Water Chemistry and Quality

4.2.2.1 Studies and Monitoring

4.2.2.1.1 Water Quality Monitoring

WSRC Environmental Monitoring Section has monitored the water quality of Upper Three Runs since 1973. During routine monitoring, three sampling locations have been established on Upper Three Runs. These locations - Upper Three Runs at U.S. Highway 278, Tims Branch 5, and Upper Three Runs at Road A - are sampled monthly for physical and biological water quality parameters and for metals (Figure 4-3). Samples also are collected annually and analyzed for pesticides, herbicides, and PCBs. In 1990, the Upper Three Runs at Highway 278 sampling location was moved approximately 1.6 km (1 mi) downstream and closer to the SRS boundary to provide a better indication of contaminants originating above SRS; this new sampling location is designated Upper Three Runs 1A.

All routine water quality monitoring data reported in the following sections can be found in the annual SRS Environmental Reports.



01 Upper Three Runs (U3R) at U.S. Highway 278
02 U3R at Road 8-1
03 U3R-1A
04 upstream Road C, Tims Branch (TB)-5, Site 1 (F/H)
05 A-014
06 A-015
07 M out
08 TB-2
09 TB-0
10 TB-1
11 TB-3
12 TB-4, Tim Branch upstream of Upper Three Runs, Tims Branch (F/H), and Tims Branch 5 (water quality monitoring)
13 TB-6, Site 2 (F/H)
14 Site 3 (F/H)
15 Site 4 (F/H)
16 Site 5 (F/H)
17 U3R at Road A
18 confluence with Savannah River

Figure 4-3. Water Chemistry and Quality Sampling Stations for Upper Three Runs

4.2.2.1.2 Comprehensive Cooling Water Study (CCWS)

From 1983 to 1985, Upper Three Runs and Tims Branch were studied as part of the CCWS. This study was designed to assess the impact of current and proposed SRS activities on water quality. The CCWS included the following four locations on Upper Three Runs and Tims Branch (Figure 4-3):

- Upper Three Runs at Road 8-1 - upstream of SRS point source effluents and upstream of Tinker Creek (02 on map)
- Upper Three Runs at Road C - primarily consists of headwater conditions, but also reflects point-source effluents to tributaries of Upper Three Runs from 200-F and 200-H Separations Areas, as well as construction impacts from 200-S Area (13 on map).
- Upper Three Runs upstream of confluence with Savannah River - consists of all upstream point-source and runoff conditions, as well as temporal flooding from high water conditions of the Savannah River (18 on map).
- Tims Branch - cumulative effects of point-source effluents discharged to this stream from 300-M Area, the Savannah River National Laboratory, and the Savannah River Ecology Laboratory (12 on map).

Comprehensive results and discussion of CCWS data can be found in Newman et al. (1986) and Lower (1987). Gladden et al. (1985) present a synopsis of Upper Three Runs and Tims Branch water quality data prior to the CCWS.

4.2.2.1.3 Priority Pollutants Survey

In 1984, an instream survey of priority pollutants was conducted to determine the levels of volatile, acid, base and neutral compounds in Upper Three Runs. This study sampled four locations: Upper Three Runs at Highway 278 (01), Tims Branch near Road C (12), Upper Three Runs upstream of Road C (04), and Upper Three Runs at Road A (17). Potential sources for organics in Upper Three Runs included process sewer outfalls, local outcropping of groundwater, and the M-Area settling basin. The results of this study are presented in the sections that follow and in Lower (1987).

4.2.2.1.4 Chemical Assessment Studies

From 1985 to 1993, four studies were conducted on the waters of Tims Branch and Upper Three Runs to determine impacts from specific SRS operations. In addition, a toxicity study was done on Upper Three Runs waters upstream of all SRS discharges. These studies (summarized later in this chapter) included:

- Effect of changes in M-Area effluent on Tims Branch (June 1985-December 1986)
- Effect of M-Area Liquid Effluent Treatment Facility on Tims Branch (September 1988-March 1990)
- Effect of F/H-Area Effluent Treatment Facility on Upper Three Runs (July 1987-February 1990)
- Effect of contaminants from Mixed Waste Management Facility on Upper Three Runs wetlands (1993)
- Effect of Upper Three Runs water on *Ceriodaphnia dubia* (1994)

4.2.2.2 Field Data

4.2.2.2.1 Water Temperature

The mean water temperature at sampling locations on Tims Branch and Upper Three Runs ranged from 15.2 to 17.3°C (59 to 63°F) during the CCWS and routine monitoring program. These temperatures are reflective of the nonthermal nature of this stream.

4.2.2.2.2 pH Measurements

The mean pH in the Upper Three Runs watershed is slightly acidic, with means ranging from 6.03 near Road 8-1 to 6.65 at the stream confluence with the Savannah River. Throughout the CCWS and during routine monitoring, waters at all Upper Three Runs and tributary sites displayed wide pH variations (3.1-8.3).

4.2.2.3 Physical Characteristics and General Chemistry

4.2.2.3.1 Dissolved Oxygen

Mean dissolved oxygen concentrations ranged from 7.8 to 8.1 mg/l throughout Upper Three Runs during the CCWS. Dissolved oxygen concentrations measured since the CCWS have been slightly higher, with ranges from 5.0 to 15.1 mg/l. Dissolved oxygen in McQueen Branch and Crouch Branch fluctuates from 1.2 to 13.5 mg/l.

4.2.2.3.2 Suspended Solids and Turbidity

Mean concentrations of suspended solids and turbidity were highest and most variable during the CCWS (Table 5-3). The range in maximum suspended solids concentrations varied considerably (46.8 mg/l - 892 mg/l) throughout the watershed. Maximum turbidities ranged from 32 to 352 NTU (Nephelometric Turbidity Units). Suspended solids and turbidity concentrations have been lower since the CCWS. From 1987 to 1991, maximum suspended solids concentrations ranged from 6.0 to 97 mg/l, and turbidities have ranged from 3.9 to 120 NTU. From 1992 to 1995, maximum suspended solids concentrations ranged from 31 to 89 mg/l and turbidities ranged from 1.0 to 200 NTU in Upper Three Runs and its tributaries.

Water quality in tributaries to Upper Three Runs that drain the Defense Waste Processing Facility (DWPF) site was monitored from 1983 to 1995 to determine the effect of construction activities on the tributaries and Upper Three Runs. In both McQueen Branch and Crouch Branch, total suspended solids and turbidity increased over baseline and reference stream concentrations. During the period of construction mean total suspended solids ranged from 18.3 to 182.3 mg/l in McQueen Branch and from 50.1 to 99.6 mg/l in Crouch Branch. After construction means ranged from 5.6 to 135.8 mg/l and 26.13 to 157.0 mg/l in McQueen and Crouch Branch, respectively (Bodie and Scott 1995).

Turbidity ranged from 25.6 to 236.1 NTUs in McQueen Branch during construction and from 1.9 to 158.9 NTUs since construction. In Crouch Branch the values were 98.67 to 187.33 NTUs during construction and 30.6 to 237.4 NTUs after construction. The higher suspended solid loads and turbidity values occurred after periods of heavy rain and may be the result of poorly functioning sedimentation basins (Bodie and Scott 1995).

4.2.2.3.3 Conductivity

Statistically, it appears that construction activities had no significant adverse impact on Upper Three Runs.

During the CCWS, specific conductance in Upper Three Runs and Tims Branch was low compared to other onsite streams and the Savannah River (Newman et al. 1986). Specific conductance ranged from 1.4 to 20.1 µS/cm at the headmost waters of Upper Three Runs and increased in range from 20.6 to 68.9 µS/cm near the confluence with the Savannah River. Specific conductance measured from 1987 to 1991 was highest at Tims Branch 5 (mean 51.2 µS/cm) and lowest at the upstream location, Upper Three Runs 1A (mean 21.5 µS/cm). Between 1992 and 1995, mean conductivity at Tims Branch was 64.5 µS/cm, 76.75 µS/cm at Crouch Branch, 45.5 µS/cm at McQueen Branch, and 26.25 µS/cm and 24 at the two Upper Three Runs locations.

Conductivity values were monitored in McQueen Branch, Crouch Branch, and Upper Three Runs during and since construction of DWPF to determine the impact of construction activities on the tributaries' water quality and the effects of tributary water quality on Upper Three Runs water quality. During construction, mean conductivity ranged from 55.93 to 66.80 µS/cm in McQueen Branch and from 90.0 to 108.3 µS/cm in Crouch Branch. After construction conductivity ranged from 28.3 to 60.6 µS/cm in McQueen Branch and from 87.3 to 95.0 µS/cm in Crouch Branch (Bodie and Scott 1995).

4.2.2.4 Major Anions and Cations

4.2.2.4.1 Alkalinity, Chloride, and Sulfate

Alkalinity, chloride, and sulfate concentrations in Upper Three Runs increased with distance downstream during the CCWS. The waters near the confluence with the Savannah River had mean alkalinity and sulfate concentrations of 5.1 mg $CaCO_3$/l, chloride concentrations of 2.1 mg/l, and sulfate concentrations of 1.2 mg/l. Except for alkalinity and sulfate in Tims Branch, similar concentrations of alkalinity, chloride, and sulfate have been measured in Upper Three Runs in the years following the CCWS. Alkalinity in Tims Branch has averaged 14.3 mg $CaCO_3$/l since the study.

4.2.2.4.2 Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, sodium, and potassium in Upper Three Runs waters during the CCWS and as part of routine monitoring are given in the data. The CCWS determined that most of the calcium, magnesium, and sodium was in the dissolved phase (Newman et al. 1986). Mean potassium concentrations were below detection limits during CCWS and were not measured during routine monitoring. All monitoring data indicate that concentrations of these cations are low, but increase with distance downstream. Tims Branch tended to have slightly higher concentrations of these cations relative to the mainstream Upper Three Runs.

4.2.2.4.3 Aluminum, Iron, and Manganese

The highest concentrations of these cations were measured during the CCWS where most of the aluminum (91%) and iron (90%) was transported in the solid phase. Solid phase-associated manganese accounted for 34% of the concentrations measured at the farthest upstream site and increased to 47% near the stream mouth (Newman et al. 1986). Concentrations of aluminum, manganese, and iron have been lower since the CCWS.

4.2.2.5 Nutrients

4.2.2.5.1 Phosphorus

Concentrations of nutrients in Upper Three Runs were low relative to the Savannah River despite the influx of nutrients from offsite agricultural areas (Lower 1987). Mean total phosphorus ranged from 0.034 mg/l to 0.052 mg/l during the CCWS. Since 1987, mean total phosphorus has ranged from not detected to 0.072 mg /l.

4.2.2.5.2 Nitrogen

The major nitrogen species in Upper Three Runs waters during the CCWS were nitrate-nitrogen (40%) and total Kjeldahl nitrogen (50%). Concentrations of nitrogen (as NO_2-NO_3) measured during routine monitoring have been higher than concentrations measured during the CCWS; this difference is probably the result of changes in 300-M Area effluent (see section 4.2.2.10**)**. The maximum mean nitrogen concentration measured during routine monitoring (1.04 mg NO_3/l) was in Tims Branch.

4.2.2.6 Trace Elements

The CCWS measured relatively low levels of trace elements. Routine monitoring report detection limits that were higher than the concentrations measured during the CCWS; therefore, only CCWS data is discussed in this section. Mean total concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc in Upper Three Runs and Tims Branch during the CCWS reflected the ambient and largely undisturbed nature of these waters and the lack of significant quantities of these materials discharged from SRS operations. Mean concentrations ranged between the watershed headwaters and the creek mouth as follows: arsenic 0.4-1.3 µg/l; cadmium, 0.54-0.32 µg/l; chromium, 8.1-6.1 µg/l; copper, 1.9-2.1 µg/l; lead, 2.2-2.1 µg/l; nickel, 2.7-3.8 µg/l; and zinc, 4.5-4.6 µg/l. CCWS did not detect mercury or uranium in Upper Three Runs or Tims Branch.

4.2.2.7 Organic Carbon

During the CCWS, mean total organic carbon concentrations ranged from 5.56 to 6.59 mg/l, with approximately 55-75% of the organic carbon present in the dissolved phase. Total organic carbon was routinely measured only at Tims Branch sampling point 5 and at Upper Three Runs near Road A during routine monitoring. Total organic concentrations at these locations ranged from <1.0 to 12 mg/l.

4.2.2.8 Priority Pollutants

Concentrations of all 88 tested volatile, acid, and base/neutral organics were below detection limits in waters in Upper Three Runs at each of the sampling locations. The 1984 study indicated that the natural quality of these streams was low in detectable synthetic organics and that potential groundwater outcropping of chlorinated hydrocarbons from the 300-M Area to the Upper Three Runs watershed was not occurring in detectable quantities at the time of the study (Lower 1987).

4.2.2.9 Pesticides, Herbicides, PCBs, and Volatile Organic Compounds

Water samples also are collected annually from Tims Branch and Upper Three Runs during routine monitoring and analyzed for pesticides, herbicides, PCBs, and volatile organic compounds (VOCs). From 1987 to 1994, no analytes were detected in Upper Three Runs or Tims Branch. In 1995, pesticides and VOCs were detected in Tims Branch. VOCs and herbicides also were detected in Upper Three Runs (Arnett and Mamatey 1996).

Lower (1987) reports the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985, and results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations were also near or below detection limits at all locations.

4.2.2.10 Chemical, Including Radionuclide, and Toxicity Assessment Studies

4.2.2.10.1 Changes in M-Area Effluent

A chemical and biological study was conducted in Tims Branch from September 1988 to March 1990 to determine if changes to the discharges of the A-014 and A-015 outfalls had an adverse effect on communities in Tims Branch. Seven locations (Figure 4-3) were sampled semimonthly for chemical parameters. ECS (1990) documented the results.

During the study, a noticeable difference in water chemistry was observed along Tims Branch at TB-1 and TB-11. With the exception of total Kjeldahl nitrogen at Site 1 and temperature at Site 3, all other chemical parameters at the sites were significantly higher than the control site. The A-015 discharge increased the phosphate content of Tims Branch; however, the phosphate value for Site 4 had recovered to the level of control Site 2. The A-014 discharge was the primary source for nitrates in Tims Branch. The most noticeable effect of nitrates was at Site 4, which was significantly different from the control site only during release of the effluent.

Overall, the discharge from M-Area did appear to impact the water quality of Tims Branch. A comparison of preoperational and postoperational data for Tims Branch and the outfall channels indicated that total suspended solids, phosphate, dissolved oxygen, and temperature were significantly higher during 1988-1990. The nitrate values for Site 1 and Site 3 were lower than in 1985-1986, due to the modifications of effluents discharged to A-014 and A-015. Post-operational phosphate values increased for all sites along Tims Branch.

4.2.2.10.2 M-Area Liquid Effluent Treatment Facility

A chemical and biological assessment was conducted to address the effects of the M-Area Liquid ETF on the chemistry and biota of Tims Branch and Upper Three Runs. The discharge point and eight locations (Figure 4-3) along Tims Branch and Upper Three Runs were sampled monthly for chemical parameters. The results of this study are documented in ECS (1987).

The study indicated that a beaver pond immediately upstream greatly influenced the water chemistry at site TB-2 (Figure 4-3). High organic-matter concentrations in the waters of upstream sites TB-2, TB-0, and TB-1 created low dissolved oxygen conditions. Sites TB-3, TB-4, TB-5, and TB-6 had much higher mean dissolved oxygen concentrations.

Nitrate concentrations were highest at M-Out (maximum 47 mg/l), and decreased as the discharge peak moved downstream to TB-4 (maximum 2.7 mg/l). Background nitrate concentrations at Tims Branch sites increased by a factor of three between 1985 and 1986. Nitrite concentrations had trends similar to the nitrate, but were one or two orders of magnitude lower. Ammonium and total Kjeldahl nitrogen levels did not appear to be related to the M-Area Liquid ETF discharges.

Uranium was detected two times in water samples at M-Out and at some upstream Tims Branch sites, and once in Upper Three Runs (TB-6). Zinc levels originally were elevated at M-Out and TB-1.

Traces of trichloroethylene were observed frequently at M-Out, with an overall mean concentration of 2.9 µg/l. No detectable levels of tetrachloroethene or 1,1,1-trichloroethylene were measured.

4.2.2.10.3 F-/H-Area Effluent Treatment Facility

In June 1987, a 4-year biological study was initiated in anticipation of the fall 1988 startup of effluent discharges into Upper Three Runs by SRS F-/H-Area ETF. Using Hester-Dendy multiplate samplers, six sites were sampled quarterly for macroinvertebrates. Sampling locations included one site upstream of the Road C bridge, four sites downstream of the Road C bridge, and one site on Tims Branch (Figure 4-3). The discharge point for the ETF effluent (H-016) is at Road C. The results of this study are documented in Enwright Environmental (1990) and Chem-Nuclear Laboratory Services (1991).

Thirty-one parameters were analyzed monthly on water samples collected from the five sites on Upper Three Runs. Six parameters were analyzed monthly on water samples from the mouth of Tims Branch. Of the 31 water chemistry parameters analyzed, only two parameters were measured at higher levels at downstream sites than at the control site: nitrate-nitrogen and uranium. Nitrate-nitrogen levels also were found to be elevated in Tims Branch, which suggests that tributary, as being the source of elevated nitrate at downstream Upper Three Runs sites, not the F-/H-Area ETF. Uranium was not sampled in Tims Branch. All other measured parameters exhibited similar concentrations upstream and downstream, with no observed impact by the F-/H-Area ETF.

In 1993, sampling was conducted to characterize Upper Three Runs wetland waters near the Mixed Waste Management Facility to determine if contaminants from the facility were outcropping into the Upper Three Runs floodplain, and to determine if cesium from beneath the H-Area Tank Farm had migrated to the Upper Three Runs outcrops. The results indicate that tritium, but not cesium, is outcropping into the Upper Three Runs wetlands. In the spring and fall, tritium was detected in concentrations above the maximum contaminant level at 13 (9 wetland and 4 stream) and 18 (13 wetland and 5 stream) locations, respectively.

During spring, cadmium, gross alpha, nonvolatile beta, potassium-40, ruthenium-106, and trichloroethylene also were detected above the maximum contaminant levels from at least one location. Cadmium was detected above the maximum contaminant levels at four wetland locations. Gross alpha was detected above the maximum contaminant levels at two wetland locations, one of which was a background location. Nonvolatile beta was detected above the maximum contaminant level at three wetland locations, two of which were background locations. Trichloroethylene was detected at one wetland location at 5.09 µg/l, which is slightly above the method detection limit and maximum contaminant levels of 5 µg/l. None of these contaminants was detected above the maximum contaminant levels in the fall.

Results did not suggest that the wetlands were being impacted by leaks from Tank 16 in the H-Area tank farm. (Dixon and Cummins 1994).

4.2.2.10.4 Toxicity Study

In 1994, a study was conducted to determine if Upper Three Runs water could support the cladoceran *Ceriodaphnia dubia.* The objectives of the study were to determine if *Ceriodaphnia dubia* is adversely affected by the Upper Three Runs water that does not receive National Pollutant Discharge Eliminations System (NPDES) discharges; if *Ceriodaphnia* can be cultured for extended times in Upper Three Runs water; and if *Ceriodaphnia* cultured in Upper Three Runs water are sensitive to a reference toxicant. SRS surface waters are extremely soft, with hardnesses ranging from approximately 2 to 30 mg/l. Waters this soft may not have adequate calcium or trace minerals to support long-term survival of *Ceriodaphnia* (Specht 1994a).

Upper Three Runs water was acutely toxic (measured as percent survival) to *Ceriodaphnia dubia* in 6 of 11 monthly tests and was chronically toxic (measured as reproductive success) in 10 of 10 monthly tests. Reference toxicant (sodium chloride) tests on Upper Three Runs water indicated that the test organisms in that water were severely stressed and extremely sensitive to the reference toxicant (See Chapter 6 for detail). Additional studies are needed to determine if the toxicity is due to low pH, the presence of toxicants introduced upstream of the SRS boundary, or the lack of essential trace minerals.

4.2.3 Algae

Although the type locality for several diatom species have their origin in Upper Three Runs (Patrick and Reimer 1966), the algae of this stream have not been quantitatively sampled except for three sampling stations that were sampled for periphyton ash-free dry weight and chlorophyll content between 1983 and 1985 (Specht 1987). These measurements were primarily used for pooled data comparisons of thermal versus nonthermal streams on SRS. When extracted from this context, the data revealed limited descriptive information about the periphyson community of Upper Three Runs.

4.2.4 Macrophytes

4.2.4.1 Introduction

Aquatic macrophytes provide stream structure, substrate for periphyton development, cover and substrate for smaller animals, and a source of carbon for the stream system. Although aquatic macrophytes are an important component to the function of many aquatic systems, they tend to be less important in flowing waters. Streams such as Upper Three Runs tend to have little macrophyte colonization because of the closed canopy above the stream channel. The reduction in available sunlight falling directly upon the water limits macrophyte colonization to the few open areas of the channel such as those found at road bridges and power-line crossings.

4.2.4.2 Comprehensive Cooling Water Study (CCWS)

The only data dealing with aquatic macrophytes in Upper Three Runs comes from the CCWS (Specht 1987) and was collected during 1984-1985. The data are from one sample at one station in the creek near a bridge and show limited macrophyte development. A survey of the entire stream to document the extent of this important component of the lower food chain would provide valuable information on the structure and condition of this SRS watershed.

4.2.5 Zooplankton

To date, no studies have been conducted on the zooplankton in Upper Three Runs.

4.2.6 Macroinvertebrates

4.2.6.1 Sampling Locations and Methods

4.2.6.1.1 Aquatic Insects Survey

From September 1976 through August 1977, Morse et al. (1980) conducted an extensive sampling program for aquatic insects at six locations adjacent in the Upper Three Runs drainage basin. Sampling was conducted at Upper Three Runs at Roads 8-1 and F, Tinker Creek at Road 8-1, Mill Creek at Road E-2, Mill Creek at an unnamed fork 2.75 km (1.75 mi) upstream from Road E-2, and Boggy Gut at U.S. Forest Service at Road 781-4 (Figure 4-4). At each station, aquatic insects were collected biweekly from natural substrates and by light trapping. Details of sampling methods can be found in Morse et al. (1980).

01 TB-2
02 TB-0
03 TB-1
04 TB-3
05 CCWS1, F/H1, TB-5
06 TB-4
07 F/H2, TB-6
08 F/H3
09 F/H4
10 F/H5
11 CCWS3

Sampling locations for Morse et al. (1980) indicated with a rectangle.

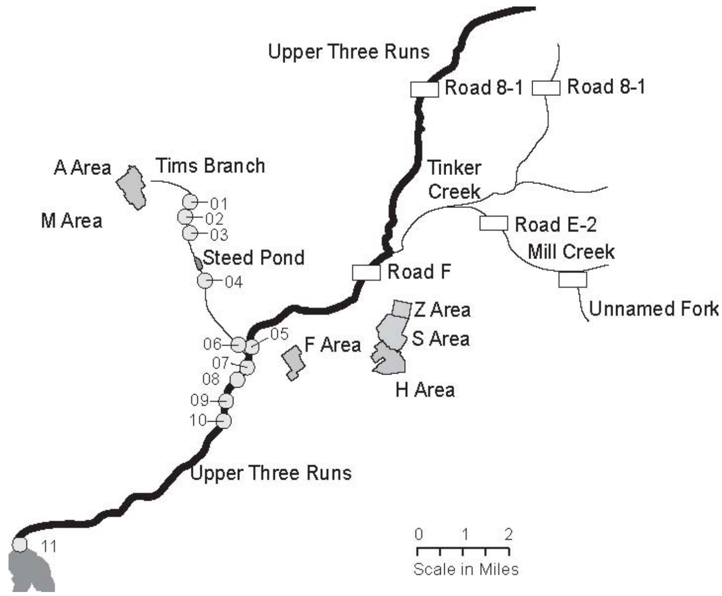


Figure 4-4. Macroinvertebrate Sampling Stations for Upper Three Runs

4.2.6.1.2 Comprehensive Cooling Water Study (CCWS)

During the CCWS, macroinvertebrates were collected monthly from November 1984 through September 1985 at two locations in Upper Three Runs (just above Road C and in the creek mouth) using Hester-Dendy multiplate samplers and drift nets (Chimney and Cody 1986; Firth et al. 1986). In the creek mouth, macroinvertebrates also were sampled quarterly from March 1982 through September 1984 using drift nets and Hester-Dendy multiplate samplers (Specht et al. 1984; O'Hop et al. 1985). Details of sampling methods can be found in Specht et al. (1984) and Firth et al. (1986). These results are summarized in Specht (1987).

4.2.6.1.3 F-/H-Area Effluent Treatment Facility Monitoring Program

Macroinvertebrates were sampled quarterly from July 1987 through July 1991 using Hester-Dendy multiplate samplers and semiannually by qualitative sampling of natural substrates at five locations in Upper Three Runs in the vicinity of Road C. These samples were taken to determine if the F-/H-Area ETF effluent was adversely impacting the macroinvertebrate community of the stream. Beginning in March 1990 and continuing through July 1991, this sampling program was continued at three of the five stations.

4.2.6.1.4 Tims Branch Monitoring Program

Macroinvertebrates were sampled from June 1985 through December 1986 at five stations in the Tims Branch tributary of Upper Three Runs and at two locations in Upper Three Runs to determine if effluents from M Area and the A-/M-Area sanitary wastewater treatment plant were adversely affecting the Tims Branch macroinvertebrate community. Additional sampling was conducted at four locations in Tims Branch from September 1988 through March 1990 using Hester-Dendy multiplate samplers.

4.2.6.1.5 Other Sampling Programs

Macroinvertebrates were sampled during the summer of 1993 at six locations in Upper Three Runs and in eight tributaries: Cedar Creek, Boggy Gut, Tinker Creek, Reedy Branch, Mill Creek, McQueen Branch, Crouch Branch, and Tims Branch. This one-month sample identified streams with great variability in populations among locations as a first step in developing a long-term sampling program. Hester-Dendy muliplate samplers were used to collect macroinvertebrates. Parameters measured included total number of taxa collected at each station, mean number of taxa per sampler, density of organisms, biomass, relative abundance of functional feeding groups, and relative abundance of major taxonomic groups (Specht 1994b).

Macroinvertebrates also were sampled in September 1994 to develop a biotic index for southeastern streams using Hester-Dendy multiplate samplers. While not specifically designed to characterize SRS streams, these data contribute to a better understanding of the streams. Upper Three Runs at Road C and its tributaries, Tinker Creek and Mill Creek, were 3 of the 16 sampled locations (Specht and Paller 1995).

Past investigators collected from SRS locations and described a “peculiar” species of a bivalve in the genus *Elliptio* (Britton and Fuller 1979). In 1989, *Elliptio* specimens were collected from seven locations on the SRS: the Savannah River, Upper Three Runs drainage (four sites), Pen Branch, and Lower Three Runs. The mussels’ morphology was described and compared with known specimens. In addition, electrophoresis was used to elicit differences in enzyme structures as further evidence of he unique status of these bivalves.

4.2.6.2 Results

4.2.6.2.1 Aquatic Insects Survey

Table 4-1 lists macroinvertebrates from all recent studies by subdrainage. A total of 34,206 aquatic insects were collected during the one-year study (Morse et al. 1980, 1983). The study identified at least 551 species of aquatic insects, including at least 52 species and 2 genera new to science. Several other species were collected from Upper Three Runs that are either rarely collected or were not reported in South Carolina before this study. The species list that Morse et al. (1980, 1983) compiled for Upper Three Runs contains more species than have been reported for any other North American streams of comparable size.

Morse et al. (1980) concluded: “It is clear that the aquatic insect fauna of the Upper Three Runs drainage is unusual. It not only includes many rare species, but also, because of its special combination of ecological characteristics, contains species not often found living together in the same freshwater system. This spring-fed stream is colder and generally clearer than most surface waters at its low elevation, reminiscent of unpolluted streams in northern North America or high in the Appalachian Mountains. On the other hand, its shifting sandy bottom and somewhat tea-colored water are visibly indistinguishable from those of other lowland southeastern streams. As a result, many typically northern and mountain species co-exist here with southern lowland species. In consideration of the many rare insect species in the Upper Three Runs drainage and of the several “typically northern” species co-existing here with an endemic southern fauna, it is probably safe to say that this stream has persisted for a very long time without appreciable alteration. It is therefore appropriate to regard the system as an outstanding example of an unpolluted, spring-fed, Sandhills waterway.”

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Oligocheata	*Naididae sp.*											X	
	Nais communis								X				
	Tubificidae sp.							X					
Hirudinea	*Macrobdella/Haemopsis*		X		X		X	X	X		X		X
Gastropoda	*Amnicola limosa*								X				
	Amnicola sp.												X
	Campeloma decisum				X								X
	Laevapex sp.				X		X				X		X
	Physella sp.												X
	Pseudosuccinea columella						X						
Pelycepoda	*Corbicula fluminea*												X
	Sphaerium sp.				X				X				
Arachnida	*Hydracarina sp.*								X		X		
Crustacea	*Caecidotea sp.*				X								
	Cambarinae sp.				X						X		
	Cambarus latimanus		X		X		X				X		X
	Crangonyx sp.		X										X
	Hyallela azteca				X								X
	Palaemonetes paludosus						X	X	X		X		
	Procambarus sp.		X		X		X				X		X

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage- continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Ephemeroptera	*Acentrella ampla*												X
	Acerpenna pygmaea											X	
	Baetis dubium											X	X
	Baetis ephippiatus												X
	Baetis frondalis												X
	Baetis intercalaris											X	X
	Baetis nr. punctiventris			X	X		X				X	X	
	Baetis propinquus											X	
	Baetis sp.												X
	Caenis diminuta							X					
	Ephemerella nr. catawba			X	X			X	X		X		X
	Eurylophella (immature / damaged)							X					
	Eurylophella sp.			X								X	
	Habrophlebia vibrans			X	X							X	X
	Heptagenia sp.											X	
	Hexagenia limbata											X	
	Hexagenia sp.				X						X		X
	Isonychia sp.				X								X
	Leptophlebia sp.												X
	Neoephemera youngi			X			X				X		X
	Paraleptophlebia sp.												X
	Plauditus nr. dubius			X	X						X		X
	Stenonema modestum												X
	Stenonema modestum/smithae		X		X		X				X		X
	Tricorythodes sp.			X	X	X	X	X				X	X

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Odonata	*Anax junius*				X		X				X		X
	Argia sedula												X
	Argia sp	X	X										X
	Boyeria vinosa			X									X
	Calopteryx dimidiata		X	X	X		X				X	X	X
	Cordulegaster maculata		X		X		X		X		X		X
	Cordulegaster sp.		X		X		X						
	Dromogomphus armatus		X		X		X						
	Enallagma divagans										X		X
	Enallagma sp.				X				X		X		X
	Enallagma traviatum	X			X				X				X
	Gomphus (Stylurus) notatus				X								
	Gomphus lividus						X						X
	Gomphus parvidens				X		X		X		X		X
	Gomphus rogersi										X		X
	Hagenius brevistylus				X						X		
	Helocordulia selysi												X
	Lanthus vernalis						X						
	Libellula sp.				X								
	Libellulidae sp.								X				X
	Macromia allagheniensis				X								
	Macromia georgina / illinoiensis				X						X		
	Macromia sp.				X				X				X
	Neurocordulia virginiensis				X								X
	Ophiogomphus mainensis												X
	Plathemis lydia						X						
	Progomphus obscurus		X										
	Progomphus sp.						X						
	Tetragoneuria semiaquea/cynosura				X		X						X

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Heteroptera	*Metrobates hesperius*								X				
	Neogerris sp.				X								
	Ranatra sp.												X
	Rhagovelia obesa								X				X
	Sigara nr. scabra		X				X				X		X
	Sigara virginiensis												X
	Trepobates sp.										X		
	Trichocorixa				X								X
Megaloptera	*Chauliodes pectinicornis*												X
	Corydalus cornutus								X				X
	Nigronia serricornis		X	X	X	X			X		X		X
	Sialis sp.			X	X	X	X	X			X	X	X
Plecoptera	*Acroneuria abnormis*				X				X		X		X
	Acroneuria lycorias										X	X	X
	Acroneuria mela											X	X
	Allocapnia sp.				X		X				X	X	
	Clioperla clio			X		X	X					X	X
	Eccoptura xanthenes			X	X		X						X
	Helopicus subvarians			X	X								
	Isoperla dicala											X	
	Leuctra sp.			X	X							X	X
	Neoperla sp.				X		X				X		X
	Paragnetina fumosa										X		X
	Perlesta placida										X	X	X
	Perlidae sp.			X	X	X					X	X	X
	Pteronarcys sp.											X	X
	Taeniopteryx metequi										X	X	X
	Taeniopteryx sp.				X		X					X	X

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Trichoptera	*Agarodes libalis*			X	X							X	X
	Anisocentropus pyraloides												X
	Brachycentrus chelatus				X		X						X
	Brachycentrus nigrosoma											X	X
	Brachycentrus numerosus											X	X
	Ceraclea nr. resurgens											X	X
	Cernotina sp.			X									
	Cernotina spicata				X						X		X
	Cheumatopsyche sp.												X
	Chimarra aterrima		X	X	X	X	X	X	X		X	X	X
	Diplectrona modesta			X	X								X
	Heteroplectron americanum		X		X		X					X	X
	Hydropsyche betteni				X								
	Hydropsyche elissoma						X	X	X		X		
	Hydroptila sp.										X	X	X
	Lepidostoma sp.												X
	Lype diversa		X									X	X
	Macrostemum carolina			X		X							
	Micrasema nr. rusticum												X
	Micrasema rusticum											X	X
	Micrasema wataga												X
	Nectopsyche sp.												X
	Neureclipsis sp.				X								
	Oecetis georgia												X
	Oecetis morsei/sphyra						X				X		X
	Oecetis sp.												X
	Oecetis sp. 2				X								
	Oxyethira sp.										X		

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Trichoptera (cont)	*Paranyctiophylax sp.*			X									
	Phylocentropus			X									X
	Psilotreta sp.				X		X				X	X	X
	Pycnopsyche guttifer						X						X
	Pycnopsyche sp.						X				X		
	Triaenodes ssp.												X
Lepidoptera	*Parapoynx obscuralis*		X		X						X		X
	Pyralidae sp.				X						X		X
Coleoptera	*Agabus/Ilybius*				X								X
	Anacaena limbata							X					
	Anchytarsus bicolor												X
	Ancyronyx variegatus		X				X						
	Berosus sp.			X	X		X		X		X	X	X
	Bidessonotus								X				
	Coptotomus interrogatus								X				
	Dineutus ciliatus								X				X
	Dineutus discolor						X		X				
	Dineutus sp.		X								X	X	X
	Dubiraphia bivittata				X				X		X		X
	Dubiraphia sp.				X						X		
	Ectopria nervosa				X						X		X
	Ectopria sp.				X								
	Gonielmis dietrichi			X							X		X
	Gyrinus sp.										X		X
	Helichus sp.				X						X		X
	Hydrocanthus oblongus		X										
	Hydrochus inequalis				X				X				X
	Hydroporus nr. pilatei						X						

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Coleoptera (cont)	*Hydroporus nr. rufilabris*								X				
	Hydroporus sp.								X				
	Hydroporus sp. 2			X	X				X				
	Hygrotus sp.												X
	Liodessus fuscatus								X				
	Macronychus glabratus												X
	Microcylloepus pusillus		X	X	X		X		X		X	X	X
	Neoporus nr. undulatus				X								
	Neoporus vittatipennis								X				
	Optioservus sp.								X				
	Oulimnius sp.			X								X	X
	Peltodytes sp.												X
	Sperchopsis tessellatus	X							X				X
	Stenelmis crenata												X
	Stenelmis sinuata											X	X
	Stenelmis sp.		X		X						X	X	X
Diptera	*(Diamesinae)-Potthastia longimana*		X		X	X	X		X		X	X	X
	Ablabesmyia janta gp.						X						
	Ablabesmyia mallochi	X											
	Antocha sp.			X	X				X		X		X
	Apsectrocladius johnsoni							X					
	Atherix lantha				X								
	Bezzia sp.											X	
	Bittacomorpha clavipes				X				X				X
	Brillia flavifrons								X				
	Chelifera sp.		X		X							X	X
	Chironomus sp.											X	
	Cladotanytarsus sp.	X	X			X		X	X				

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Diptera (cont)	*Clinotanypus pinguis*			X			X						X
	Conchapelopia sp.								X		X	X	X
	Conchapelopia/Meropelopia	X	X	X	X		X	X	X		X	X	X
	Corynoneura lobata	X	X	X	X							X	X
	Corynoneura nr. taris										X		
	Corynoneura sp.				X	X	X	X				X	
	Corynoneura sp. 2				X			X	X			X	
	Cricotopus / Orthocladius annectens	X	X	X									
	Cricotopus bicinctus												X
	Cricotopus vierriensis	X	X					X			X	X	
	Cryptochironomus fulvus gp.												X
	Cryptolabis sp.		X		X		X		X		X		X
	Crysops sp.						X						
	Culex sp.				X				X		X		X
	Diamesinae - Potthastia longimana												X
	Ectemnia invenusta												X
	Einfeldia sp.											X	X
	Ephydridae sp.								X				
	Eukiefferiella claripennis gp.							X					X
	Hemerodromia sp.											X	
	Hexatoma sp.	X		X	X		X	X			X		X
	Krenosmittia sp.				X		X						X
	Labrundinia becki/virescens						X						
	Labrundinia pilosella												X
	Larsia sp.	X	X	X	X				X		X		X
	Lauterborniella agrayloides		X										X
	Meropelopia sp.												X
	Microtendipes nr. rydalensis												X

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Diptera (cont)	*Microtendipes nr. rydalesis*											X	X
	Microtendipes pedellus												X
	Nanocladius sp.			X	X						X		X
	Natarsia sp.			X		X	X		X				X
	Nilothauma sp.												X
	Orthocladius nr. carlatus												X
	Pagastiella ostansa											X	X
	Palpomyia lineata										X		
	Palpomyia sp.		X								X		X
	Palpomyia sp. 2				X				X				X
	Parakiefferriella sp.												X
	Paralauterborniella nigrohalteralis			X								X	X
	Paramerina sp.												X
	Parametriocnemus lundbecki	X		X	X		X					X	
	Paratanytarsus sp.	X		X	X	X	X	X	X		X	X	X
	Phaenopsectra flavipes											X	
	Pilaria sp.	X	X	X	X							X	
	Polypedilum aviceps												X
	Polypedilum fallax			X	X		X		X		X	X	X
	Polypedilum flavum	X	X			X						X	X
	Polypedilum halterale												X
	Polypedilum illinoense												X
	Polypedilum scalaenum		X	X	X	X			X		X	X	X
	Procladius sp.								X		X		
	Rheocricotopus robacki		X						X		X		X
	Rheocricotopus tuberculatus		X	X	X	X	X	X				X	X
	Rheosmittia sp.								X				
	Rheotanytarsus distinctissimus gp.						X						

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Diptera (cont)	*Rheotanytarsus exiguus gp.*			X	X	X	X	X	X			X	X
	Saetheria tylus						X				X		X
	Simulium jonesi						X						
	Simulium nr. podostemi			X									X
	Simulium nr. tuberosum												X
	Simulium nr. venustum			X	X		X	X	X		X	X	X
	Simulium nr. verecundum			X								X	X
	Simulium sp.							X					
	Simulium venustum		X										X
	Simulium vittatum complex								X				
	Stempellinella sp.								X				
	Stenochironomus sp.												X
	Stilobezzia nr. lutea				X		X		X				
	Synorthocladius semivirens				X				X		X		X
	Tanytarsus sp.											X	X
	Tanytarsus sp. 3			X	X		X	X	X			X	X
	Tanytarsus sp. 4										X		X
	Thienemanniella fusca gp.										X		
	Thienemanniella lobopodema				X		X					X	X
	Thienemanniella xena gp.						X				X		X
	Tipula (Pupa)			X	X	X	X	X	X			X	X
	Tipula (Nippotipula)				X								
	Tipula (Nippotipula) nr. abdominalis					X	X						
	Tipula (Yamatotipula)				X								
	Tipula sp.		X		X				X				
	Tipula sp. 2		X				X		X				X
	Tribelos jucundum				X		X						
	Tvetenia bavarica			X	X	X	X	X	X		X		X

Table 4-1. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Upper Three Runs Drainage - continued

		Crouch Branch		Mill Creek		McQueens Branch		Tims Branch		Tinker Creek		Upper Three Runs	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**	**HD**	**NS**
Diptera (cont)	*Tvetenia discoloripes gp.*						X						
	Tvetenia paucunca gp.			X								X	X
	Tvetenia vitracies						X					X	X
	Unniella multivirga												X
	Zavrelimyia				X								X

More recent studies of the aquatic insects in Upper Three Runs identified more than 650 species, including 104 species of caddisflies (Trichoptera) (Floyd et al. 1993). Ninety-three species of caddisflies, representing 14 families, were identified during biweekly collections over a one-year period at two locations on Upper Three Runs downstream of all SRS discharges. Three species (*Oxyethira setosa*, *Triaenodes smithi, and Nyctiophylax seratus*) are new distributional records for South Carolina. Two species of *Triaenodes* are new to science. Other species considered endemic to the Upper Three Runs drainage, rare outside the drainage, or of limited distribution included *Cheumatopsyche richardsoni, Oxyethira dunbartonensis, Protoptila morettii, Hydrophysche elissoma, Triaenodes ochraceus, Neotrichia falca, Oecetis morsei, and Pycnopsyche virginica* (Floyd et al. 1993).

4.2.6.2.2 Comprehensive Cooling Water Study (CCWS)

4.2.6.2.2.1 Introduction

Macroinvertebrate drift and Hester-Dendy multiplate data are summarized in this section. More detailed information can be found in Specht et al. (1984), O'Hop et al. (1985), Firth et al. (1986), Chimney and Cody (1986), and Specht (1987).

4.2.6.2.2.2 Taxa Collected

Sixty-two macroinvertebrate taxa were collected from multiplate samplers near Road C during the 1984-1985 program. With comparable numbers of species per sampler, the Road C station had larger, but fewer organisms per sampler. However, these data are not directly comparable to the data collected by Morse et al. (1980, 1983) or to data from the F-/H-Area ETF monitoring program since there were differences in the level of taxonomic resolution among the studies.

4.2.6.2.2.3 Densities

The mean density of organisms on the multiplate samplers near Road C was 582.7 organisms/m^2 in 1984-1985, while densities in the creek mouth were much higher, averaging 2839.5 organisms/m^2. However, biomass was higher at Road C (0.500 g/m^2) than in the creek mouth (0.190 g/m^2). The number of taxa collected per sampler was similar at the two stations, averaging 15.1 taxa/sampler at Road C and 16.1 taxa/sampler in the creek mouth. The macroinvertebrate collections from multiplate samplers at Road C were overwhelmingly dominated by tanytarsine chironomids (70.1%; Firth et al. 1986).

Other abundant taxa included unidentified chironomids (21.6%) and the mayfly, *Stenonema modestum* (1.6%). Dominant taxa in the creek mouth were orthoclad chironomids (28.0%), chironomini chironomids (16.7%), tanytarsine chironomids (8.5%), brachycentrid and hydropsychid caddisflies (3.1% for each taxa; Chimney and Cody 1986).

Macroinvertebrate drift densities were much higher at Road C (6848.9 organisms/1000 m^3; Firth et al. 1986) than in the creek mouth (377.6 organisms/1000 m^3; Chimney and Cody 1986). Abundant taxa in the drift at Road C included chironomids (21.0%), hydropsychid caddisflies (10.5%), baetid mayflies (8.7%), blackfly larvae (6.7%), and the stonefly *Taeniopteryx longicera* (6.5%; Firth et al. 1986). The composition of drift in the creek mouth was dominated more by chironomids (52.9%) but also included relatively high abundances of baetid mayflies (12.3%), hydropsychid caddisflies (3.4%) and blackfly larvae (7.4%; Chimney and Cody 1986).

4.2.6.2.3 Effluent Treatment Facility Monitoring Program

Taxa Collected During the five-year monitoring program, 292 macroinvertebrate taxa were collected from Upper Three Runs from quantitative sampling (Hester-Dendy multiplate samplers) and sampling of natural substrates combined. Of these taxa, 96 were collected exclusively from natural substrates.

4.2.6.2.3.1 Taxa Collected

During the five-year monitoring program, 292 macroinvertebrate taxa were collected from Upper Three Runs from quantitative sampling (Hester-Dendy multiplate samplers) and sampling of natural substrates combined. Of these taxa, 96 were collected exclusively from natural substrates.

4.2.6.2.3.2 Dominant Taxa

Chironomids
At all stations, chironomids were the most common group of macroinvertebrates collected, ranging from 49.9 to 55.3% of the total number of organisms collected from the multiplate samplers. Most of the chironomids were in the subfamilies Orthocladiinae and Chironominae. Dominant species of chironomids collected from the multiplate samplers included *Rheocricotopus robacki*, *Polypedilum convictum*, *Tvetenia discoloripes*, and *Corynoneura* sp.. *Rheotanytarsus* sp., Conchopelopia sp., *Cladotanytarsus* sp., and *Rheosmittia* sp., and *Parametriocnemus lunbecki* also were abundant on natural substrates. The most common nonchironomid species of dipteran was the blackfly, *Simulium jonesi*.

Trichoptera
Trichoptera (caddisflies) composed 11.0-13.4% of the organisms collected from the multi-plate samplers. The most abundant caddisflies on the multiplates were *Hydropsyche elissoma* and *Cheumatopsyche* sp. These two taxa and *Brachycentrus numerosus* were the most commonly collected caddisflies on natural substrates.

Plecoptera
Plecoptera (stoneflies) were much more common in Upper Three Runs than in any other SRS streams, where they made up 11.4-13.2% of the macroinvertebrates collected from the multiplate samplers. Stoneflies prefer cool water, which is provided in Upper Three Runs by naturally occurring flows of groundwater into the stream. The most common stoneflies were *Perlesta placida*, *Acroneuria abnormis*, and *Isoperla* sp.

Ephemeroptera and Coleoptera
Ephemeroptera (mayflies; 7.2-9.4%) and Coleoptera (beetles; 5.6-10.7%) accounted for most of the remaining organisms collected from the multiplate samplers. *Stenonema modestum/smithae*, *Heptagenia flavescens*, and *Paraleptophlebia guttata* were the dominant mayflies, while *Stenelmis crenata* and several other elmid beetles were the most common beetles in the stream.

4.2.6.2.3.3 Mean Number of Taxa and Density of Organisms

The mean number of taxa collected from multiplate samplers at a given station (all multiplates combined) ranged from 27.0 to 45.0 during the five year study, while the mean number of taxa per sampler ranged from 12.3 to 22.9. Mean densities of organisms ranged from 213.9 to 799.2 organisms/m^2, which is lower than the densities reported for most other SRS streams. However, macroinvertebrate biomass (ash-free dry weight) was comparable to most other streams, ranging from 0.1399 to 0.6860 g/m^2. Distinct seasonal variations in biomass were observed, with biomass peaking in the spring as organisms reached their maximum size and declining over summer, just after the period of peak emergence.

Macroinvertebrate diversity, as calculated by the Shannon diversity index was high at all stations, ranging from 3.90 to 4.59. Generally, for this geographic area, diversity values above 3 are indicative of unimpacted streams.

4.2.6.2.3.4 Temporal Trends

During the course of the five-year study, declines in the mean number of taxa per station, mean number of taxa per sampler, mean density of organisms, and diversity were observed at all stations. The decline in density of organisms was the most dramatic, with mean density for all stations combined declining from 667.5 organisms/m^2 in 1987 to 273.8 organisms/m^2 in 1990. In 1991, densities increased somewhat to an average of 427.0 organisms/m^2. Taxa that exhibited the greatest declines in abundance were primarily chironomids, such as the orthoclads, *Rheocricotopus robacki*, *Thienemanniella* spp., *Tvetenia discoloripes*, *Orthocladius* spp., and *Cricotopus* spp.; the Chironomini midge, *Polypedilum convictum*; and the tanytarsine midge, *Rheotanytarsus* spp. Species richness among Ephemeroptera, Plecoptera, and Trichoptera, which are generally considered to be pollution-intolerant organisms, did not decrease significantly, and the relative abundance of Plecoptera and Trichoptera actually increased, although overall densities of these orders remained relatively constant. Although the densities declined, the total biomass of the macroinvertebrate community did not decrease over time, which indicates that larger organisms were being collected.

The observed changes in the macroinvertebrate community are not attributable to effects from the F-/H-Area ETF effluent since they occurred at the upstream reference station (Station 1 [05]) as well as the stations located downstream from the F-/H-Area ETF. At this time, there is no explanation for the observed changes, but data from 1991 indicate that the stream appears to be recovering somewhat from the unknown perturbation. Possible perturbations included increased siltation from the Defense Waste Processing Facility construction area and/or toxic inputs to the stream from areas upstream from SRS.

4.2.6.2.4 <u>Tims Branch Monitoring Program</u>

4.2.6.2.4.1 1985-1986 Sampling Program

The 1985-1986 sampling program collected 147 macroinvertebrate taxa in Tims Branch, including 97 taxa from multiplate samplers and 50 taxa collected exclusively from natural substrates during qualitative sampling efforts. The fewest total number of taxa (23) was collected from multiplate samplers at Station TB-2, which was upstream from the M-Area effluent discharge but just downstream from a stagnant pond. Outflow from the pond often had no detectable levels of dissolved oxygen, and the macroinvertebrate community of this station was typical of streams with high organic loading. The mean number of taxa collected per sampler was also lowest at Station TB-2 (5 taxa/sampler) and increased in a downstream direction to 12.8 taxa per sampler in the mouth of the creek (Station TB-4). Dominant groups of macroinvertebrates at Station TB-2 included oligochaetes (66.4%) and chironomids from the tribe Chironomini (23.1%). The macroinvertebrate community downstream from the M-Area effluent discharge gradually improved to a community more typical of less impacted streams, with the oligochaetes and Chironomini being replaced by orthoclad and tanytarsine chironomids, as well as Coleoptera (beetles), Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). At Station TB-4, 57 taxa were collected from multiplate samplers. Mayflies composed 19.5% of the total organisms collected; stoneflies 3.6%; caddisflies, 4.8%; beetles, 5.5%; orthoclads, 30.9%; and tanytarsine chironomids 16.6%.

The total density of organisms in 1985-1986 was highest at Station TB-2 (3679.1 organisms/m^2) and generally declined in a downstream direction to 584.0 organisms/m^2 at Station TB-4. Total biomass was also highest at Station TB-2 (0.253 g/m^2), declined to 0.072 g/m^2 at Station TB-1, and then increased to 0.123 and 0.207 g/m^2 at Stations TB-3 and TB-4, respectively.

4.2.6.2.4.2 1988-1990 Sampling Program

Macroinvertebrate identification during the 1988-1990 study generally was performed only to the family level; therefore direct comparisons of taxa richness with the 1985-1986 study are not possible. Also, no taxa list is presented for the 1988-1990 program since all of the families identified were present in the 1985-1986 study.

The macroinvertebrate community in Tims Branch in 1988-1990 differed somewhat from that of 1985-1986. Station TB-2 still was dominated by pollution-tolerant taxa, but had shifted from a community dominated by oligochaetes to one dominated by pollution-tolerant chironomids of the tribe Chironomini, which constituted 90.7% of the organisms collected from multiplate samplers at this station.

At the most downstream station (Station TB-4), mayflies and caddisflies were less abundant than in 1985-1986, composing 14.5% and 1.2%, respectively, of the macroinvertebrates on the multiplate samplers, while stoneflies were more abundant, making up 14.3% of the organisms collected in 1988-1990, as compared to just 3.6% in 1985-1986.

The density of organisms was much lower at Station TB-2 in 1988-1990 (421.1 organisms/m^2 as compared to 3679.1 in 1985-1986). Densities at Stations 1 and 3 were also somewhat lower, while mean densities at Station 4 were higher (763.5 organisms/m^2 as compared to 584.0 in 1985-1986). At present, there is no explanation for the observed declines. The decline in density of organisms is of particular concern since densities were observed to decline steadily during the last year of the sampling program.

In contrast to the decline in macroinvertebrate densities, macroinvertebrate biomass was higher at three of the four sampling stations in 1988-1990 than in 1985-1986. The increased biomass with decreased densities indicates that the relative size of the organisms has increased, possibly due to shifts in species composition.

4.2.6.2.4.3 1993-1994 Sampling Program

Table 4-1 is a list of species taken in the Upper Three Runs drainage, separated by subdrainage. Upper Three Runs and three of its tributaries (Tims Branch, McQueen Branch, and Crouch Branch) received effluent from 25 NPDES outfalls in A, B, F, H, M, and S Areas and the Flowing Streams Facility at Road C. The new NPDES permit issued in 1996, eliminated 10 of theses outfalls by deletion or consolidation of several outfalls into one. Upper Three Runs supports a reasonably rich macroinvertebrate community. Total number of taxa collected per station in 1993 ranged from 42 at Road F to 52 at Road C. Thirty-six taxa were collected at Road C in 1994. The mean number of taxa per sampler in 1993 ranged from 20.0 at Banks Mill Road (offsite) to 26.8 at Road C. In 1994, the mean number of taxa per sampler at Road C was 20.8. Density ranged from 444.7 organisms/m^2 at Road F to 1378.8 organisms/m^2 at the railroad bridge upstream of Road C in the 1993 study and was 765.4 organisms/m^2 in 1994 at Road C. Biomass in 1993 ranged from 0.0296 g/m^2 at Road A to 0.8470 g/m^2 at Road 8-1. Biomass was 0.0390 g/m^2 at Road C in 1994. The most abundant group of macroinvertebrates collected at all of the stations in 1993 were the orthoclad chironomids (33.7-57.0%). In 1994, the most abundant group was the Chironomini (31.4%). Other abundant groups were Tanytarsini chironomids, Chironomini chironomids, Trichoptera, and Coleoptera in 1993 and Orthocladiinae, Tanytarsini, other Diptera, and Ephemeroptera in 1994. Collector-gatherers was the most abundant functional feeding group at any station in either year. No longitudinal trends were observed for any measured population parameter.

Sampled tributaries of Upper Three Runs included Cedar Creek and Boggy Gut (both upstream of the SRS boundary), Tinker Creek, Reedy Branch, Mill Creek, McQueen Branch, Tims Branch, and Crouch Branch. The data indicate that the three tributaries that receive NPDES discharges (Tims Branch, McQueen Branch, and Crouch Branch) are perturbed to some extent as evidenced by fewer total taxa, fewer mean taxa per sampler, and lower densities.

Crouch Branch was the most disturbed of the tributaries sampled in 1993 with only 19 taxa collected, none of which was of the more sensitive Ephemeroptera-Plecoptera-Trichorptera taxa. Chironomini chironomids dominated its community, generally an indication of perturbed conditions. Crouch Branch had relatively low oxygen concentrations, which may be responsible, at least in part, for the observed perturbation. In addition, Crouch and McQueen Branches had high suspended solids loads during the construction of the Defense Waste Processing Facility which also may have had some effect on the streams' macroinvertebrate communities. Crouch Branch was also the most disturbed stream sampled in 1994. It had 25 taxa and was dominated by Chironomini and oligochaetes.

The remainder of the sampled tributaries showed no evidence of perturbation in 1993. Mill Creek had the highest number of taxa (63), and Tinker Creek had the fewest (46). Dominant taxa in most streams included the orthoclad chironomids, the Tanytarsine chironomids, a Tanypodinae chironomid, and a Chironomini chironomid. As in Upper Three Runs proper, the most abundant functional group was the collector-gatherers. Based on the Hester-Dendy data from 1994, Tims Branch showed evidence of some disturbance (Specht 1994b; Specht and Paller 1995).

4.2.7 Bivalve Mollusks

Mill Creek is a tributary of Upper Three Runs. Recent research indicates that the taxonomy of the bivalve population in the Upper Three Runs' drainage is more complex than was previously suspected.

Based on conchology and electrophoresis it is apparent that while mollusks in the Savannah River are *Elliptio icterina*, the traditional classification scheme for Upper Three Runs *Elliptio* needs to be modified. The Mill Creek *Elliptio* population, formerly considered *E. icterina*, contains two discrete species, *E. compeanata* and one whose shells match the holotype of *E. hepatica* (Davis and Mulvey 1993).

4.2.8 Fish

4.2.8.1 Introduction

Upper Three Runs was sampled in 1984-1985, 1992, and 1993. The 1984-1985 samples were taken as part of the CCWS. Table 4-2 summarizes fish species found in Upper Three Runs. These samples included ichthyoplankton collections from the lower reaches of the stream. The 1992 samples were taken as a dual effort to characterize stream fish assemblages on SRS and assess possible impacts from the outcropping of contaminated groundwater from F and H Areas into Upper Three Runs.

4.2.8.2 Comprehensive Cooling Water Study (CCWS)

4.2.8.2.1 <u>Introduction</u>

Most of the sampling in Upper Three Runs during the CCWS was devoted to the collection of ichthyoplankton from sample stations at Road C, Road A, and in the creek mouth (Figure 4-5). Samples were collected with 0.505-mm mesh nets weekly during daylight from February through July during 1984 and 1985 (Paller 1985; Paller et al. 1986).

Table 4-2. Fish Collected from Streams within the Upper Three Runs Drainage

Family	Common Name	Scientific Name	CrouchBranch	Mill Creek	Reedy Branch	McQueen Branch	Tims Branch	Tinker Creek	Upper Three Runs
Lepisosteidae	Longnose Gar	*Lepisosteus osseus*							X
Amiidae	Bowfin	*Amia calva*					X		X
Anguillidae	American Eel	*Anguilla rostrata*	X	X	X	X		X	X
Clupeidae	American Shad	*Alosa sapidissima*							X
Cyprinidae	Eastern Silvery Minnow	*Hybognathus regius*							X
	Bluehead Chub	*Nocomis leptocephalus*	X	X	X	X	X	X	X
	Golden Shiner	*Notemigonus crysoleucas*					X	X	X
	Ironcolor Shiner	*Notropis chalybaeus*					X	X	X
	Dusky Shiner	*Notropis cummingsae*	X	X			X	X	X
	Spottail Shiner	*Notropis hudsonius*			X			X	X
	Yellowfin Shiner	*Notropis lutipinnis*	X	X	X	X	X	X	X
	Coastal Shiner	*Notropis petersoni*						X	X
	Pugnose Minnow	*Opsopoeodus emiliae*							X
	Lowland Shiner	*Pteronotropis hypselopterus*		X				X	X
	Creek Chub	*Semotilus atromaculatus*	X	X	X	X	X	X	X
Catostomidae	Creek Chubsucker	*Erimyzon oblongus*	X	X	X	X	X	X	X
	Lake Chubsucker	*Erimyzon sucetta*						X	X
	Northern Hogsucker	*Hypentilium nigricans*		X				X	X
	Spotted Sucker	*Minytrema melanops*		X				X	X
	Notchlip Redhorse	*Moxostoma collapsum*						X	X

Table 4-2. Fish Collected from Streams within the Upper Three Runs Drainage - continued

Family	Common Name	Scientific Name	CrouchBranch	Mill Creek	Reedy Branch	McQueen Branch	Tims Branch	Tinker Creek	Upper Three Runs
Ictaluridae	Snail Bullhead	*Ameiurus brunneus*						X	
	White Catfish	*Ameiurus catus*							X
	Yellow Bullhead	*Ameiurus natalis*	X	X	X	X	X	X	X
	Brown Bullhead	*Ameiurus nebulosus*						X	X
	Flat Bullhead	*Ameiurus platycephalus*		X	X			X	X
	Channel Catfish	*Ictalurus punctatus*							X
	Tadpole Madtom	*Noturus gyrinus*	X	X	X	X		X	X
	Margined Madtom	*Noturus insignis*	X	X	X	X		X	X
	Speckled Madtom	*Noturus leptacanthus*	X	X	X			X	X
Esocidae	Redfin Pickerel	*Esox americanus*		X	X	X	X	X	X
	Chain Pickerel	*Esox niger*						X	X
Umbridae	Eastern Mudminnow	*Umbra pygmaea*					X		
Aphredoderidae	Pirate Perch	*Aphredoderus sayanus*	X	X	X	X	X	X	X
Fundulidae									
	Lined Topminnow	*Fundulus lineolatus*						X	X
Poeciliidae	Eastern Mosquitofish	*Gambusia holbrooki*		X	X		X	X	X
Atherinopsidae	Brook Silverside	*Labidesthes sicculus*							X
Moronidae	Striped Bass	*Morone saxatilis*							X
Elassomatidae	Banded Pygmy Sunfish	*Elassoma zonatum*	X						X

Table 4-2. Fish Collected from Streams within the Upper Three Runs Drainage - continued

Family	Common name	Scientific name	CrouchBranch	Mill Creek	Reedy Branch	McQueen Branch	Tims Branch	Tinker Creek	Upper Three Runs
Centrarchidae	mud sunfish	Acantharcus pomotis		X	X		X	X	
	flier	Centrarchus macropterus						X	
	blackbanded sunfish	Enneacanthus chaetodon							X
	bluespotted sunfish	Enneacanthus gloriosus							X
	redbreast sunfish	Lepomis auritus	X	X	X		X	X	X
	warmouth	Lepomis gulosus		X			X	X	X
	bluegill	Lepomis macrochirus		X				X	X
	dollar sunfish	Lepomis marginatus		X	X	X	X	X	X
	redear sunfish	Lepomis microlophus	X					X	X
	spotted sunfish	Lepomis punctatus		X	X		X	X	X
	largemouth bass	Micropterus salmoides		X		X		X	X
	white crappie	Pomoxis annularis							X
	black crappie	Pomoxis nigomaculatus						X	X
Percidae	Savannah darter	Etheostoma fricksium		X				X	X
	swamp darter	Etheostoma fusiforme						X	
	Christmas darter	Etheostoma hopkinsi		X				X	
	tesselated darter	Etheostoma olmstedi	X	X	X	X		X	X
	yellow perch	Perca flavescens						X	X
	blackbanded darter	Percina nigrofasciata		X	X			X	X

4.2.8.2.2 Ichthyoplankton Taxa Collected

Paller (1985) collected 358 ichthyoplankters from Upper Three Runs during 1984, and Paller et al. (1986) collected 217 during 1985. Table 4-3 lists the fish taxa found while sampling Upper Three Runs. The dominant taxon during both years was spotted sucker (*Minytrema melanops*). Other relatively abundant taxa were darters (*Etheostoma* spp.), black crappie (*Pomoxis nigromaculatus*), minnows (primarily *Notropis* spp.), blueback herring (*Alosa aestivalis*), and American shad (*Alosa sapidissima*). The occurrence of American shad in Upper Three Runs reflects the relatively large size and substantial flow of this creek that make it a suitable spawning area for this species. Perhaps the most unusual feature of the ichthyoplankton assemblage in Upper Three Runs was the relatively high abundance of spotted sucker larvae. Larvae of this species were not found in such numbers in any of the other SRS creeks, suggesting that Upper Three Runs is an important spawning site for spotted sucker.

Table 4-3. Taxa of Ichthyoplankters Found in Upper Three Runs

Family	**Taxa**
Clupeidae	*Alosa aestivalis*, blueback herring
	Alosa sapidissima, American shad
	Dorosoma sp., gizzard or threadfin shad
Cyprinidae	*Cyprinus carpio*, common carp
	Unidentified minnows
Catostomidae	*Minytrema melanops*, spotted sucker
	Unidentified sucker
Esocidae	*Esox* spp., pickerel
Aphredoderidae	*Aphredoderus sayanus*, pirate perch
Centrarchidae	*Lepomis* spp., bream
	Unidentified sunfish
	Pomoxis sp., crappie
Percidae	*Perca flavescens*, yellow perch
	Unidentified darters

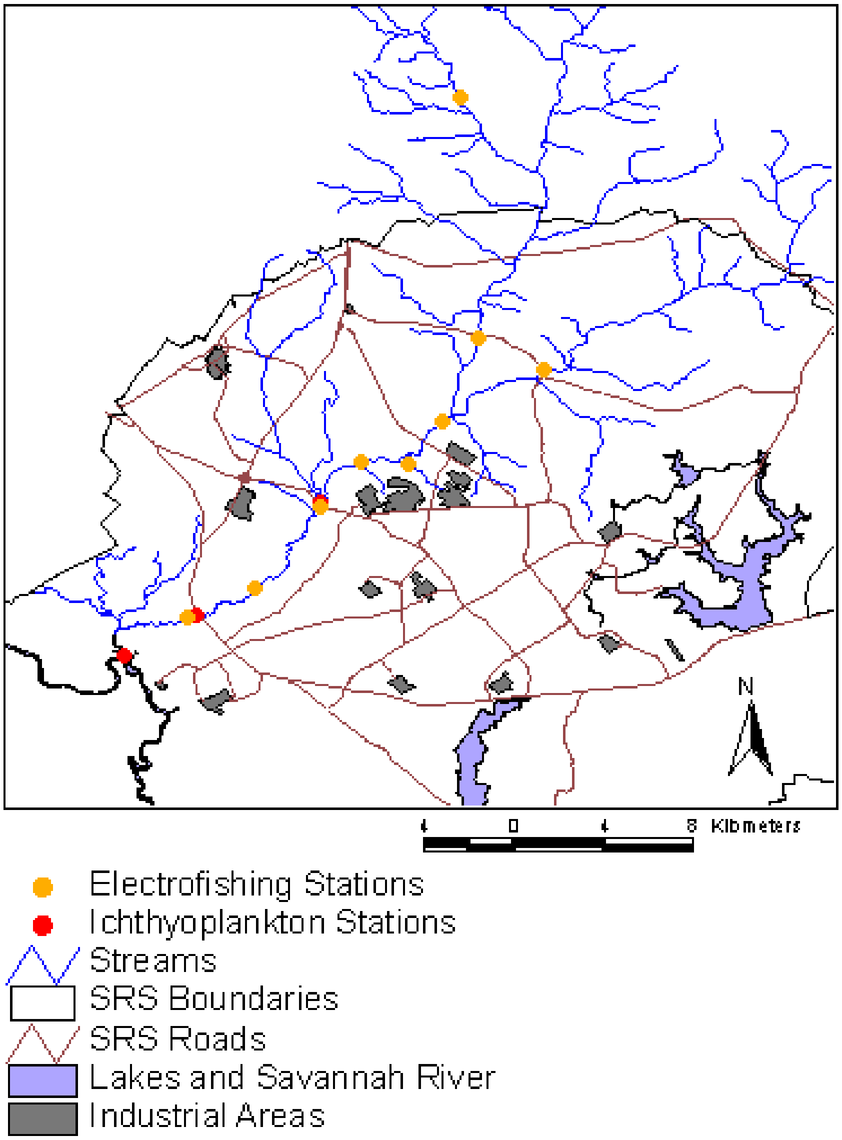


Figure 4-5. Fish Sampling Stations in Upper Three Runs

4.2.8.2.3 <u>Ichthyoplankton Densities</u>

Mean ichthyoplankton densities at the three sample stations in Upper Three Runs ranged from 29/1000 m^3 to 69/1000 m^3 during 1984. Mean densities during 1985 ranged from 21/1000 m^3 to 41/1000 m^3. These densities were low to moderate compared with densities in the other unimpacted creeks sampled during the CCWS (Paller 1985; Paller et al. 1986). There were few consistent differences among sample stations except that the sample station in the creek mouth supported more taxa, partly because of the accessibility of this sample station to riverine taxa such as the anadromous American shad and blueback herring.

4.2.8.3 Studies to Assess Impacts from F and H Areas

4.2.8.3.1 Introduction

Paller (1992) electrofished sample sites on Upper Three Runs, several tributary streams, and a control stream, Hollow Creek, to assess possible impacts of the F- and H- Area seepage basins on fish assemblages in Upper Three Runs. The tributaries include two third-order streams: Cedar Creek, north of the SRS; and Tinker Creek, which joins Upper Three Runs upstream from the F- and H- Area seepage basins. The third tributary was Crouch Branch, a small first-order tributary of Upper Three Runs that drains F and H Areas. The control stream, Hollow Creek, was selected because of its proximity to Upper Three Runs and its generally similar size, bottom substrate, channel morphometry, and water quality.

Eight sample stations were located on Upper Three Runs (Figure 4-5), four (Stations 4-8) downstream from and four upstream from F and H Areas. One sample station was located on Cedar Creek (Station 9), one sample station on Tinker Creek (Station 10), one sample station on Crouch Branch (Station 11), and three sample stations (Stations 12-14) on Hollow Creek. Each sample station consisted of three 100-m stream reaches. Repeated electrofishing passes (usually seven) were made through each reach until no or few fish were collected. Habitat data also were collected, consisting of stream width, and depth, current velocity, number of logs and stumps, substrate type, dissolved oxygen concentration, pH, temperature, and conductivity. Percentages of stream bottom area covered or overhung by submerged debris (leaves, twigs, and wood fragments), submerged brush/snags, submerged root masses, and aquatic macrophytes. Low-growing riparian vegetation were estimated visually.

4.2.8.3.2 Comparison to Other SRS Streams

In general, the fish assemblages in Upper Three Runs were typical of those in third- and higher-order streams on SRS (Paller 1992). Shiners (Cyprinidae) and sunfishes (Centrarchidae) numerically dominated the fish assemblages at most Upper Three Runs sample stations. Larger predatory and benthic insectivorous species were present, as is typically the case in larger streams. The smaller tributary sample stations were strongly dominated by shiners, followed by pirate perch, madtoms, and darters. This pattern, too, is typical of unimpacted streams on the SRS (Paller 1992).

4.2.8.3.3 Differences Among Sample Stations

Differences in number of species and number of individuals among sample stations did not indicate degradation of the fish assemblages downstream from the waste management areas. Three of the five highest mean species numbers were observed at sample stations that were downstream from F and H Areas. The lowest mean species numbers were observed upstream from the confluence of Upper Three Runs and Tinker Creek, possibly reflecting smaller stream size, other habitat factors, or offsite impacts. There were no significant differences in total number of fish per sample station; densities at the stations downstream from F and H Areas were within the range or higher than numbers at the stations upstream of F and H Areas.

Canonical discriminant analysis was used to assess differences among sample stations based on the numbers of the 10 most abundant species. Sample stations were divided into three groups: Upper Three Runs upstream from the waste management areas, Upper Three Runs downstream from the waste management areas, and Hollow Creek. Differences among the three station groups were significant at $P<0.05$. Upper Three Runs stations downstream from the waste management areas differed from Upper Three Runs sample stations upstream from the waste management areas in that they had higher numbers of many species and from Hollow Creek sample stations in that they had lower densities of coastal shiner (*Notropis petersoni*), dusky shiner (*Notropis cummingsae*) and redbreast sunfish (*Lepomis auritus*).

4.2.8.3.4 Differences Among Different Habitats

Canonical discriminant analysis was used to assess habitat differences that could be responsible for the observed differences in fish assemblage structure among station groups. Habitat differences among the three station groups were significant at $P<0.05$. Upper Three Runs stations downstream from the waste management area were wider, deeper, and had faster currents than both Upper Three Runs sample stations upstream from the waste management area and Hollow Creek sample stations. The sample station groups also differed in macrophyte coverage, coverage by brush, and other factors. These and related habitat differences can exert strong influences on fish assemblage structure and fish-capture probability and were probably responsible for the observed differences among station groups.

4.2.8.3.5 Effects of F- and H-Area Operations

Paller (1993) observed that natural changes in species composition resulting from increases in stream size and other longitudinal habitat changes would be expected to be gradual and continuous. In contrast, changes caused by the introduction of toxicants from a point source could be abrupt, with the greatest change occurring near the discharge point. However, indices of similarity in species composition between adjacent station pairs indicated less differences between the sample station just upstream from the F and H Areas and the sample station just downstream from F and H Areas than between the putatively unimpacted sample stations farther upstream. Thus, this analysis also supported the conclusion of no measurable community level impacts associated with contaminants outcropping from F and H Areas. Further conclusions about the impacts of F and H Areas on fish in Upper Three Runs must remain tentative until additional data are available, including the analyses of contaminant levels in fish from potentially polluted sites.

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4.3 BEAVER DAM CREEK

4.3.1 Drainage Description and Surface Hydrology

4.3.1.1 General Description

Beaver Dam Creek, which is approximately 5 km (3 mi) long and drains an area of approximately 2.2 km^2 (0.85 mi^2), originates at the effluent outfall canal of D Area and flows south, parallel to Fourmile Branch, to the Savannah River (Figure 4-6). The discharge of Beaver Dam Creek mixes with a portion of Fourmile Branch discharge in the Savannah River floodplain swamp before entering the Savannah River. Beaver Dam Creek is deep, narrow, and channelized in its headwaters and near its mouth and opens into a slough-like channel in its midreaches (Firth et al. 1986).

4.3.1.2 Effluents Contribution

Before SRS operations, Beaver Dam Creek probably had only intermittent or very low flow. Beaver Dam Creek has received thermal effluents since 1952 as a result of cooling water discharges from combined heavy water production (shut down in 1982) and operation of a coal-fired power plant in 400-D Area. In fall 1988, extended reactor outages decreased site electrical and steam demands, thus reducing the operations and thermal effluent of 400-D Area. Currently, Beaver Dam Creek receives condenser cooling water from the coal-fired power plant, neutralization waste water, sanitary waste water, ash basin effluent waters, and various laboratory waste waters.

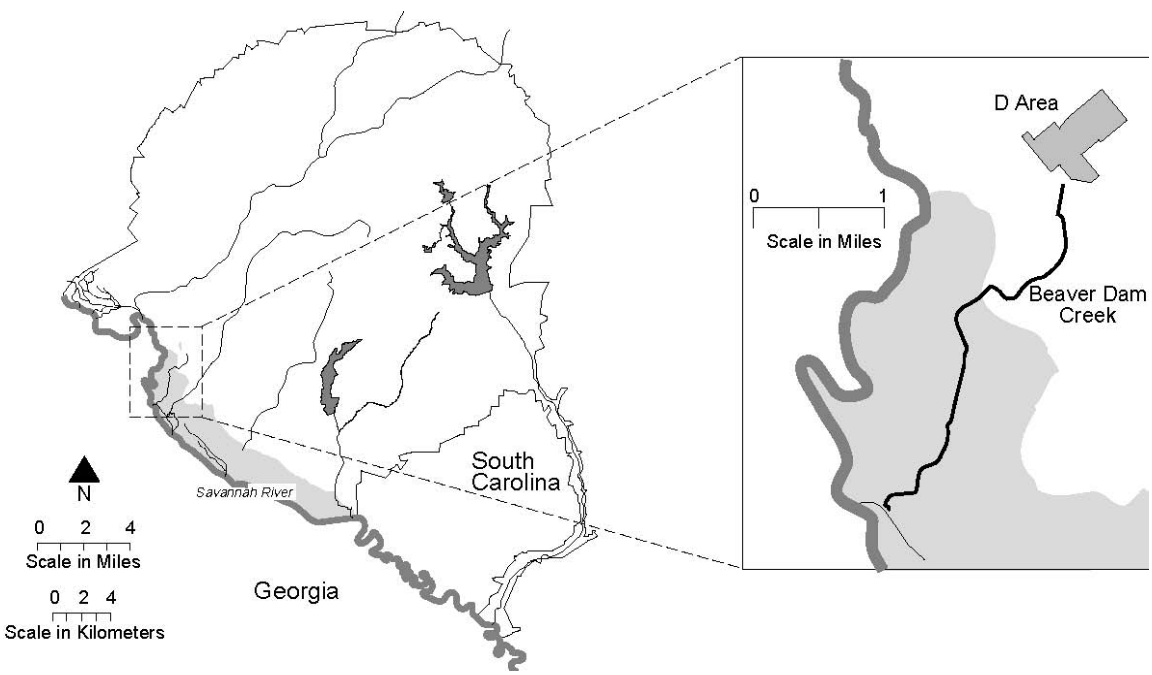

Figure 4-6. Location of Beaver Dam Creek on SRS

4.3.1.3 Flow Measurements

The U. S. Geological Survey measures flow at 400-D (Figure 4-7). Records for the station at 400-D begin in June 1974. Over the period of water years 1974-1995 at 400-D, the mean flow was 2.3 m^3/s (82 ft^3/s), the 7-day low flow was 0.45 m^3/s (16 ft^3/s), and the 7Q10 was 0.0003 m^3/s (0.01 ft^3/s). This is one of the few flow monitoring stations still monitored at the writing of this document.

01 at 400-D

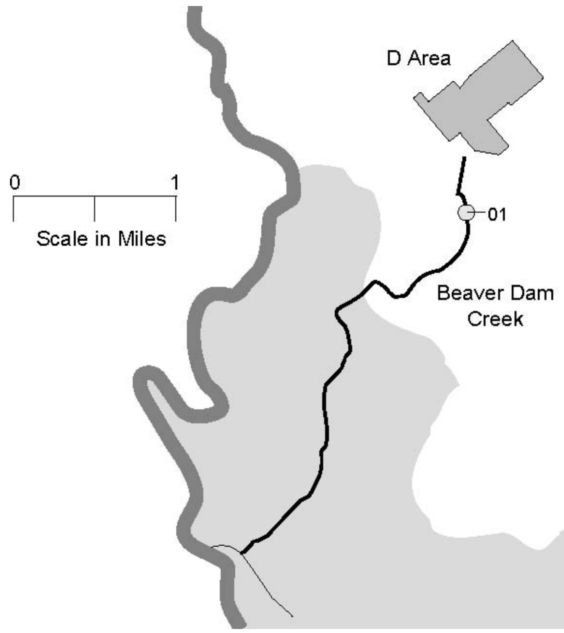

Figure 4-7. Flow Sampling Station on Beaver Dam Creek

4.3.2 Water Chemistry and Quality

4.3.2.1 Studies and Monitoring

4.3.2.1.1 <u>Water Quality Monitoring</u>

WSRC Environmental Monitoring Section (EMS) conducted routine water-quality monitoring of Beaver Dam Creek from 1973 to 1986. EMS monitored one location on Beaver Dam Creek near the Savannah River Swamp (Figure 4-8; location 08 on map) monthly for physical and biological water quality indicators and quarterly for metals. Since 1986, water-quality measurements consisting of water temperature, pH, dissolved oxygen concentration, conductivity, and oxidation/reduction potential have been taken hourly downstream of D-Area discharge. Lower (1987) summarizes water quality monitoring results for Beaver Dam Creek from 1983-1985. All routine water quality monitoring data reported in the following sections can be found in the annual SRS Environmental Reports.

4.3.2.1.2 Comprehensive Cooling-Water Study (CCWS)

From 1983 to 1985, three locations on Beaver Dam Creek were studied as part of the CCWS. This study was designed to assess the impact of current and proposed SRS activities on water quality. The Beaver Dam Creek sampling locations (Figure 4-8) included:

- Beaver Dam Creek at 400-D outfall prior to ash basin effluent (01 on map)
- Beaver Dam Creek downstream of 400-D ash basin effluent (02 on map)
- Beaver Dam Creek near confluence with Savannah River (09 on map)

A synopsis of historical water quality monitoring of Beaver Dam Creek prior to the CCWS can be found in Gladden et al. (1985).

Comprehensive results and discussion of CCWS data can be found in Lower (1987).

01 Prior to ash basin effluent
02 Downstream of ash basin effluent; downstream of outfall
03 1A -316(a) Demonstration (see p. 4-35)
04 1 - 316(a) Demonstration
05 2 - 316(a) Demonstration
06 3 -316(a) Demonstration
07 4 - 316(a) Demonstration
08 5 - 316(a) Demonstration
09 6 - confluence with Savannah River

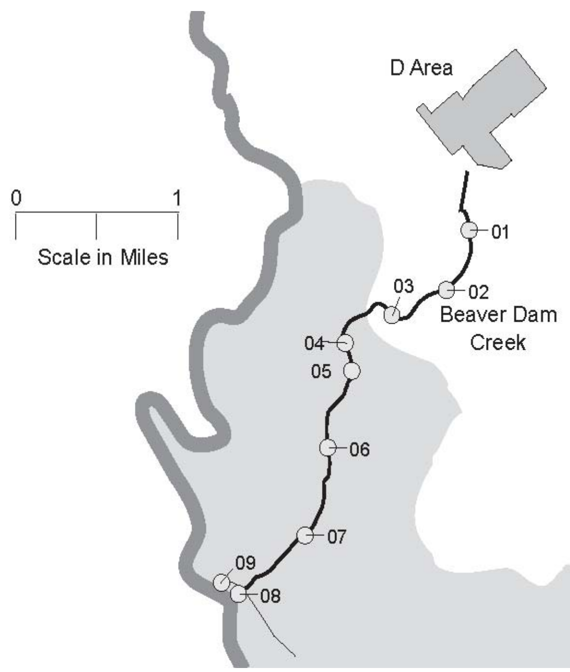

Figure 4-8. Water Chemistry and Quality Sampling Stations for Beaver Dam Creek

4.3.2.1.3 Priority Pollutants Survey

In 1984, a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral organic compounds in Beaver Dam Creek. One location in Beaver Dam Creek, downstream of 400-D effluent, was sampled (Figure 4-8; 02 on map). The "Comprehensive Cooling Water Study Final Report, Volume II: Water Quality" (Lower 1987) documented these results. This document also reports the results of analyses for pesticides and PCBs in Beaver Dam Creek.

4.3.2.1.4 <u>Chemical Assessment Studies</u>

A Clean Water Act Section 316(a) Demonstration special study was conducted in 1988 on the waters of Beaver Dam Creek to determine impacts from specific SRS operations. The data collected during the 316(a) Demonstration are reflective of the thermal flow regimes that exist when D Area is operating at a reduced power level and are most reflective of current conditions in Beaver Dam Creek. This study, documented in "Compliance of the Savannah River Site D-Area Cooling System with Environmental Regulations" (Specht et al. 1990), is discussed later in this chapter. Stations 03 to 09 on Figure 4-8 correspond to the stations sampled during this monitoring program (1A-6).

4.3.2.2 Field Data

4.3.2.2.1 <u>Water Temperature</u>

Stream water temperatures at the mainstream Beaver Dam Creek sites during the CCWS ranged from 11.2 to 34°C (52.2 to 93.2°F), with an average temperature of 25.5°C. These temperatures reflected the moderate thermal effluent associated with the stream. In Beaver Dam Creek near the confluence with the Savannah River, the temperatures were slightly lower than at the upstream sites. However, the range of temperatures was greater, reflecting river water inputs during high water conditions in the winter and the input of thermal effluents from Four Mile Creek during the spring and summer (Lower 1987). Routine monitoring on Beaver Dam Creek near the Savannah River Swamp from 1987 to 1991 indicated temperatures were comparable to those measured during the CCWS at the same location. Hourly temperature measurements ranged from 5 to 32°C (41 to 89.6°F), with a mean temperature of 22°C (71.6°F).

4.3.2.2.2 <u>pH Measurements</u>

The pH measurements at all locations during the CCWS ranged from 6.0 to 7.7, with an average near 7.0. These values reflected Savannah River source water concentrations. From 1987 to 1991, hourly pH measurements ranged from 4.9 to 10.9.

4.3.2.3 Physical Characteristics and General Chemistry

4.3.2.3.1 <u>Dissolved Oxygen</u>

The mean dissolved oxygen concentration in the mainstream waters of Beaver Dam Creek was 7.3 mg O_2/l, with ranges of 5.4 to 10.0 mg O_2/l during the CCWS. Near the confluence with the Savannah River (swamp), the mean dissolved oxygen concentration was much lower (5.5 mg O_2/l). The lower dissolved oxygen concentration in the swamp was likely the result of thermal input from Fourmile Branch. From 1987 to 1991, concentrations of dissolved oxygen (mean 7.9 mg O_2/l) have continued to reflect concentrations measured during the CCWS.

4.3.2.3.2 Suspended Solids and Turbidity

Mean turbidity and total suspended solids concentrations measured during the CCWS were elevated compared to Savannah River source water concentrations (Newman et al. 1986). Newman et al. (1986) documented that the source water contributions and the mainstream velocity regime contributed to the conditions in Beaver Dam Creek. The routine monitoring program does not measure suspended solids and turbidity.

4.3.2.3.3 Conductivity

Mean specific conductance in Beaver Dam Creek ranged from 79.1 to 91.1 µS/cm during the CCWS. These values are reflective of the specific conductance of Savannah River source water. Hourly specific conductance measurements from 1987 to 1991 ranged from 44 to 302 µS/cm, with a mean of 107 µS/cm.

4.3.2.4 Major Anions and Cations

4.3.2.4.1 Alkalinity, Chloride and Sulfate

Total alkalinity and chloride concentrations measured during the CCWS reflected concentrations of Savannah River water. Mean total alkalinity concentrations in Beaver Dam Creek ranged from 16.7 to 18.1 mg $CaCO_3$/l; Savannah River concentrations ranged from 16.5 to 19.6 mg $CaCO_3$/l (Lower 1987). Mean chloride concentrations in Beaver Dam Creek ranged from 5.7 to 6.4 mg/l; while Savannah River concentrations ranged from 5.5 to 6.3 mg/l (Lower 1987). Sulfate concentrations during the CCWS were higher downstream (mean 11.3 mg/l) than at the upstream location (mean 6.8 mg/l). Sulfate concentrations in the Beaver Dam Creek swamp waters (mean 8.4 mg/l) were slightly reduced from the downstream location, but were elevated compared to the upstream location and were attributed to ash basin effluent entering Beaver Dam Creek. The routine monitoring program does not measure total alkalinity, chloride, and sulfate.

4.3.2.4.2 Calcium, Magnesium, Sodium, and Potassium

Data collected during the CCWS indicated that the transport of these cations in Beaver Dam Creek was almost entirely in the dissolved phase (Newman et al. 1986). Calcium, magnesium, sodium, and potassium are not measured during routine monitoring.

4.3.2.4.3 Aluminum, Iron, and Manganese

Approximately 94% of the aluminum was associated with the solid phase, 86% of the iron was in the solid phase, and about 25-40% of the manganese was in the solid phase (Newman et al. 1986). The concentrations of these elements were reflective of Savannah River source water. The routine monitoring program does not measure aluminum, manganese, and iron.

4.3.2.5 Nutrients

4.3.2.5.1 <u>Phosphorus</u>

During the CCWS, all phosphorus species in Beaver Dam Creek waters were found in concentrations similar to those of its source water, the Savannah River (Table 5-39). Mean concentrations of total phosphorus and total orthophosphate in the mainstream waters during the CCWS were 0.13 mg P/l and 0.10 mg P/l, respectively. In the Beaver Dam Creek swamp waters, mean concentrations of total phosphorus (0.092 mg P/l) and total orthophosphate (0.064 mg P/l) were slightly lower than at the mainstream locations. The routine monitoring program does not measure phosphorus species.

4.3.2.5.2 <u>Nitrogen</u>

During the CCWS, all nitrogen species in Beaver Dam Creek waters were found in concentrations similar to those of its source water, the Savannah River. Concentrations of nitrite and ammonia were lowest at the Beaver Dam Creek swamp location. Mean concentrations of nitrate were similar at all three locations, with a range of 0.310-0.325mg/l. Newman et al. (1986) documented that at the mainstream locations, mean percentages of total nitrogen and nitrate, ammonia, and organic nitrogen were 40%, 20%, and 40%, respectively. The routine monitoring program does not measure nitrogen species.

4.3.2.6 Trace Elements

Total trace elemental concentrations measured in Beaver Dam Creek during the CCWS largely reflected Savannah River source water concentrations. During the CCWS, mean total arsenic concentrations ranged from 2.7 to 3.7 µg/l; total cadmium ranged from 0.55 to 0.77 µg/l; total chromium ranged from 7.7 to 11.8 µg/l; total copper ranged from 2.8 to 5.4 µg/l; total lead ranged from 2.1 to 3.1 µg/l; and total zinc ranged from 4.8 to 5.3 µg/l.

Total nickel concentrations sometimes were elevated during the CCWS, with ranges from 3.2 to 4.6 µg/l. The elevated nickel concentrations may have been the result of the 400-D Area powerhouse and ash sluicing operations (Lower 1987).

Total mercury and uranium concentrations were consistently below the analytical detection limits for those elements during the CCWS. The routine monitoring program does not measure trace elements.

4.3.2.7 Organic Carbon

Total organic carbon concentrations in Beaver Dam Creek were similar to concentrations in the Savannah River. Mean total organic carbon concentrations ranged from 5.65 to 6.75 mg/l in Beaver Dam Creek, while the Savannah River average was 6.10 mg/l. Approximately 72-84% of the organic carbon was present in the dissolved phase (Newman et al. 1986).

4.3.2.8 Priority Pollutants

Concentrations of all 88 volatile, acid, and base/neutral organics tested in Beaver Dam Creek during the 1984 instream survey were below the associated analytical detection limits (Lower 1987). These results confirmed the 1981 point source data for outfall D-001 and indicated that the input of Savannah River water for various operations in 400-D Area had no adverse impact on levels of organics in Beaver Dam Creek.

4.3.2.9 Pesticides, Herbicides, and PCBs

Pesticides, herbicides, and PCBs are not measured in Beaver Dam Creek during routine water quality monitoring. Lower (1987) reports the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985; results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations were also near or below detection limits at all locations.

4.3.2.10 Chemical, Including Radionuclide, and Toxicity Assessment Studies

In 1988, a Clean Water Act Section 316(a) Demonstration was initiated to determine whether Beaver Dam Creek could support a balanced indigenous biological community because water temperature during D-Area operations exceeded limits set forth in the NPDES permit. Seven sampling locations were selected on Beaver Dam Creek to represent different habitats of the stream (Figure 4-8; locations 03-09).

Forty water quality parameters were assessed monthly at the sampling stations in Beaver Dam Creek. The data show that 400-D Area operations greatly influence the water quality of Beaver Dam Creek. Generally, water quality parameters at Station 1A show that the 400-D Area operations greatly influence the water quality of Beaver Dam Creek. Station 1A was in the original intermittent stream channel above the confluenceof the 400-D Area discharge canal. However, this station was usually dry, except after periods of heavy rainfall, and the water collected was reflective of rainwater runoff.

Station 1A had the lowest mean values for pH, conductivity, dissolved oxygen, temperature, orthophosphorus, sulfate, nitrate, total phosphorus, and dissolved and total strontium. Means for total hardness, total suspended solids, turbidity, dissolved and total aluminum, dissolved and total barium, dissolved and total iron, total lead, dissolved and total manganese, and total zinc were higher at Station 1A than at the other stations. Excluding Station 1A, means for the study period were generally similar among stations on Beaver Dam Creek.

This study indicated that there were no characteristics of the Beaver Dam Creek water quality measurements that represented obvious indicators of stress to the biological communities. Water temperatures never exceeded the maximum NPDES limit of 32.2°C (90°F). However, the water temperatures below the thermal discharge from the D-Area power plant were often more than 2.8°C (5°F) higher than the water temperatures at the 5G pumphouse at the Savannah River or the upstream station (1A).

No radionuclide or toxicity data have been collected from Beaver Dam Creek.

4.3.3 Algae

No studies of the algae of Beaver Dam Creek have been completed with the exception of three stations that were sampled for periphyton from 1983 to 1985 (Specht 1987) as part of the CCWS. Periphyton biomass values for the Beaver Dam Creek sampling stations were statistically similar to each other and to the values of the other SRS streams. There was no evidence that pollutants discharged to Beaver Dam Creek via D-Area effluents had an adverse impact on the periphyton community of this stream system.

4.3.4 Macrophytes

4.3.4.1 Introduction

Aquatic macrophytes provide stream structure, substrate for periphyton development, cover and substrate for smaller animals, and a source of carbon for the stream system. Although aquatic macrophytes are an important component of the function of many aquatic systems, they tend to be less important in flowing than still waters.

4.3.4.2 Comprehensive Cooling Water Study (CCWS)

The CCWS examined the Beaver Dam Creek aquatic macrophyte community (Specht 1987). Data from the single station sampled for macrophytes in 1983-1984 show a total of 28 taxa; of the 28 taxa, only 4 were found growing in the stream channel, and the remainder were found growing in the riparian area. Macrophyte data from a different single station were collected from October 1984-September 1985. Eight taxa were found in measurable quantities. Differences were found between spring-summer values and those of fall-winter sampling periods. Most aquatic macrophyte growth was in backwaters and along the creek margins (Specht 1987). The number of taxa and population parameters compare favorably with those for at least one nonthermal stream location surveyed during the same sampling period.

4.3.4.3 Effects of Reduced Power Plant Operation

Normal successional patterns and development of macrophyte beds would be expected to continue in suitable sections of Beaver Dam Creek with the reduced operation of the D-Area power plant.

4.3.5 Zooplankton

4.3.5.1 Comprehensive Cooling Water Study (CCWS)

Chimney and Cody (1986a) studied the zooplankton in Beaver Dam Creek for regulatory compliance issues covered by the Clean Water Act Section 316(a). The study documented the temporal and spatial characteristics of zooplankton species based on quarterly sampling from December 1984 to August 1985. Surface-water grab samples were collected at two stations approximately one-third of the distance down the channel. Species richness comprised 7 Protozoa, 15 Rotifera, 14 Cladocera, 4 Copepoda, and 1 Ostracoda; Steel Creek was the only SRS stream with a higher species richness. The greatest densities occurred during March 1985 and May 1985. During March 1985, Cladocera dominated the assemblage; during May 1985, Protozoa and Copepods were most abundant.

4.3.5.2 Regulatory Compliance Study

Specht et al. (1990) performed a study in Beaver Dam Creek from September 1988 to February 1990 to meet regulatory compliance of the D-Area cooling system. Results were based on seven sampling stations distributed throughout the length of the stream at approximately equal intervals. Species richness during these years averaged 26 Protozoa, 27 Rotifera, 7 Cladocera, 8 Copepoda, and 1 Ostracoda. Zoo plankton densities vary sporadically and the 1988 to 1990 data do not show a clear seasonal pattern. Seasonal patterns were different from the results in 1985, probably due to sampling differences and large natural variability in abundances. Large and typical standard errors are associated with this variation. These results are representative of most zooplankton populations in flowing water habitats.

4.3.6 Macroinvertebrates

4.3.6.1 Sampling Locations and Methods

4.3.6.1.1 Comprehensive Cooling Water Study (CCWS)

From September 1982 through August 1983, macroinvertebrates were sampled quarterly in the mouth of Beaver Dam Creek using Hester-Dendy multiplate samplers and drift nets (Specht and Painter 1983).

From November 1983 through September 1985, as part of the CCWS, macroinvertebrates were sampled monthly at five stations in Beaver Dam Creek (Figure 4-9) using Hester-Dendy multiplate samplers, leaf bags, and drift nets; at three of these five stations, macroinvertebrates also were collected from aquatic macrophytes (Kondratieff and Kondratieff 1984, 1985; Firth et al. 1986). The CCWS macroinvertebrate data were summarized by Specht (1987).

4.3.6.1.2 Clean Water Act Compliance Study

In support of a Clean Water Act Section 316(a) Demonstration, macroinvertebrate sampling also was conducted monthly at six stations in Beaver Dam Creek (Figure 4-9) from September 1988 through February 1990 using Hester-Dendy multiplate samplers and quarterly using drift nets and dip nets (Specht et al. 1990). Detailed sampling methods for the 1988-1990 program can be found in Nagle et al. (1990). Stream temperatures in Beaver Dam Creek averaged several degrees cooler during the 1988-1990 study than during the 1983-1985 study, due to reduced power production at the D-Area power house.

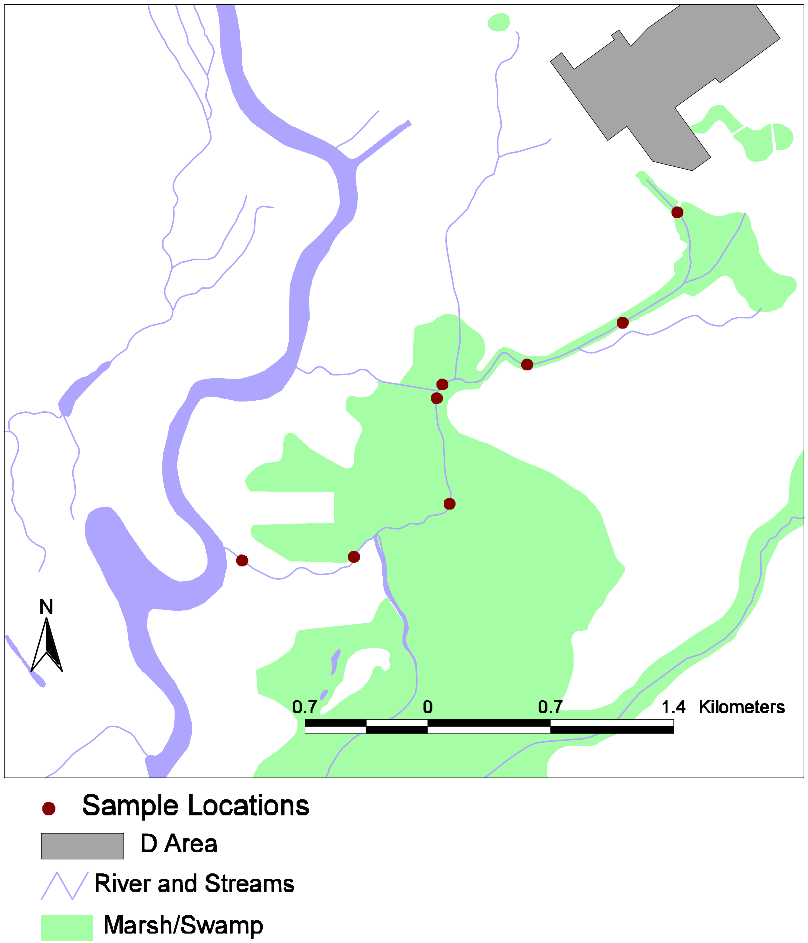

Figure 4-9. Macrointertebrate Sampling Stations for Beaver Dam Creek

4.3.6.1.3 <u>Additional Study</u>

A program to develop a biotic index for southeastern streams using Hester-Dendy multi- plate samplers sampled macroinvertebrates in the upstream portion of Beaver Dam Creek in September 1994. While not specifically designed to characterize SRS streams, these data contribute to a better understanding of the streams (Specht and Paller 1995).

4.3.6.2 Results

4.3.6.2.1 <u>Introduction</u>

The thermal regime in 1988-1990 is similar to 1997 conditions; therefore, the macroinvertebrate data from 1988-1990 should be representative of present conditions. Most of the data presented and discussed in this section are Hester-Dendy data from the1984-1985 and 1988-1990 sampling programs because these are the most comparable data sets, with respect to sampling methods and stations. Table 4-4 summarizes the macroinvertebrate taxa collected from Beaver Dam Creek.

Table 4-4. Macroinvertebrates taken from Beaver Dam Creek in 1994

Class or Order	Lowest Practical Taxon	Class or Order	Lowest Practical Taxon
Nemertea	*Nemertea*	Coleoptera	*Ancyronyx variegatus*
Oligochaeta	*Oligochaeta*		*Ectopria nervosa*
Gastropoda	*Ferrissia sp.*		*Macronychus glabratus*
	Hydrobiidae		*Stenelmis humerosa*
Pelycypoda	*Sphaerium spp.*		*Stenelmis spp.*
Arachnida	*Hydracarina*	Diptera	*Ablabesmyia spp.*
Crustacea	*Amphipoda*		*Atherix lantha*
	Cambaridae		*Brilla flavifrons*
Ephemeroptera	*Acerpenna pygmaeus*		*Ceratopogonidae*
	Baetis spp.		*Chironomus spp.*
	Caenis spp.		*Conchapelopia spp.*
	Callibaetis spp.		*Corynoneura spp.*
	Eurylophella spp.		*Cricotopus/Ortho spp.*
	Heptagenia spp.		*Cryptochironomus spp.*
	Hexagenia spp.		*Cryptotendipes spp.*
	Isonychia spp.		*Dicrotendipes spp.*
	Neoephemera youngi		*Eukiefferiella spp.*
	Paraleptophlebia spp.		*Hemerodromia spp.*
	Stenonema spp.		*Labrundinia spp.*
	Tricorythodes spp.		*Lopescladius spp.*
Odonata	*Boyeria vinosa*		*Microtendipes rydalensis*
	Enallagma spp.		*Microtendipes spp.*
	Neurocordulia spp.		*Nanocladius spp.*
	Progomphus spp.		*Nilotanypus spp.*
Megaloptera	*Corydalus cornutus*		*Nilothauma babiyi*
	Nigronia serricornis		*Parakiefferiella sp.1*
	Sialis spp.		*Paramerina sp.*
Plecoptera	*Acroneuria abnormis*		*Parametriocnemus sp.*
	Acroneuria spp.		*Pentaneura inconspicua*
	Allocapnia spp.		*Phaenopsectra flavipes*
	Paragentina kansensis		*Polypedilum fallax*
	Paragentina spp.		*Polypedilum spp.*
	Perlesta spp.		*Potthastia longmana*
	Perlinella ephyre		*Procladius sp.*
	Perlinella spp.		*Rheocricotopus spp.*
	Pteronarcys dorsata		*Rheotanytarsus spp.*
	Taeniopteryx sp.		*Simulium spp.*
Trichoptera	*Brachycentrus numerosus*		*Stelechomyia perpulchra*
	Cheumatopsyche spp.		*Stenochironomus sp.*
	Chimarra spp.		*Synorthocladius semivirens*
	Diplectrona modesta		*Tanytarsus spp.*
	Hydropsyche spp.		*Thienemanniella spp.*
	Hydroptila spp.		*Tribelos jucundum*
	Lype diversa		*Tvetenia spp.*
	Micrasema spp.		
	Nectopsyche exquisita		
	Nectopsyche spp.		
	Neureclipsis spp.		
	Nyctiophylax spp.		
	Oecetis spp.		
	Polycentropus spp.		

4.3.6.2.2 Number of Taxa

In 1984-1985, the total number of macroinvertebrate taxa collected on Hester-Dendy multiplate samplers at each of the five sampling stations ranged from 36 to 61, while in 1988-1990, excluding chironomid genera, the number of taxa collected at the six sampling stations was slightly higher, ranging from 41 to 64. In both sampling programs, the most upstream station had the fewest taxa, while the slough-like area (Station 7 in 1984-1985; Station 04 in 1988-1990) had the most taxa. Total number of taxa collected in September 1994 at one station was 27.

The 1988-1990 sampling program including all sampling methods, collected 163 macroinvertebrate taxa from Beaver Dam Creek. Of these taxa, 124 were collected on the multiplate samplers, and 39 were collected exclusively by the supplemental sampling methods. Taxa that were most likely to be missed or under-represented by the multiplate samplers included some species of mollusks (Gastropoda and Pelecypoda), dragonflies and damselflies (Odonata), most aquatic bugs (Hemiptera), and many aquatic beetles(Coleoptera). Many of these taxa are exclusively benthic and do not readily colonize artificial substrates that are above the stream bottom. Taxa that are likely to be over-represented on the multiplate samplers include many species of chironomids, at least one of which (*Stenochironomus*) actively burrowed into the plates of the multiplate samplers in large numbers but was rarely collected on natural substrates in Beaver Dam Creek.

4.3.6.2.3 Densities

The mean density of macroinvertebrates collected on multiplate samplers ranged from 921.2 to 1776.5 organisms/m^2 in 1984-1985 and from 773.7 to 2348.0 organisms/m^2 in1988-1990. Mean density in September 1994 at Station 5 (Figure 4-9) was 502.8 organisms/m^2. Densities at upstream stations (01, 02, and 03) were generally higher than at downstream stations (04, 05, and 06) throughout the sampling programs. Densities were fairly comparable between studies for any given station. The mean biomass of macroinvertebrates ranged from 0.076 to 0.220 g ash-free dry-weight (AFDW)/m^2 in 1984-1985, while biomass in 1988-1990 was substantially higher at most stations, ranging from 0.185 to 0.394 g AFDW/m^2. Biomass in September 1994 was 0.442 g AFDW/m^2.

4.3.6.2.4 Dominant Species

As a group, Chironomidae were by far the most common macroinvertebrates in Beaver Dam Creek in 1988-1990, comprising from 51.8% (Station 05) to 75.9% (Station 01) of the organisms collected from the multiplate samplers. At Stations 01 through 04, the chironomid subfamily Orthocladiinae was the most abundant macroinvertebrate taxon, accounting for 22.4-29.6% of the organisms collected, while at Stations 05 and 06, chironomids of the tribe Chironomini were most abundant (20.6 and 25.0%, respectively). Tanytarsini chironomids were also abundant at all stations, comprising 8.4-19.9% of the organisms collected. Other groups of macroinvertebrates that contributed at least 5% to the total density at one or more stations included mayflies (Ephemeroptera; 0.8-26.5%), caddisflies (Trichoptera; 2.1-11.8%), beetles (Coleoptera; 1.0-11.9%), oligochaete worms (1.4- 6.6%), and non-chironomid dipterans (0.8-5.6%). Groups that contributed at least 5% to the total density at Station 5 in 1994 were Ephemeroptera (73%) and Trichoptera (12%).

4.3.6.2.5 Differences Among Sampling Stations

In 1988-1990, Station 01 had fewer macroinvertebrate taxa and slightly lower biomass than the other sampling stations, but was similar to the other sampling stations with respect to densities of organisms and mean number of taxa. There were some indications of longitudinal changes in the relative abundances of macroinvertebrate taxonomic groups in Beaver Dam Creek. Station 01 had the lowest relative abundance of mayflies (0.8%) and the highest relative abundance of chironomids (75.9%) of all of the stations. In general, the relative abundance of mayflies increased in a downstream direction and beetles (Coleoptera) were much more abundant at Stations 05 and 06 (11.9% and 5.1%, respectively) than at the four upstream stations (1.0- 2.1%). Conversely, trichopterans were more abundant at the three upstream stations (5.9-11.8%) than at the three downstream stations (2.1-4.8%).

4.3.6.2.6 Taxonomic Composition Changes Since 1984-1985

The taxonomic composition of Beaver Dam Creek has changed substantially between 1984-1985 and 1988-1990, with most stations exhibiting increases in the relative abundance of mayflies (Ephemeroptera), snails (Gastropoda), beetles (Coleoptera), caddisflies (Trichoptera) and Tanytarsini chironomids, and an overall decline in the relative abundance of Chironomini chironomids. Many species of Chironomini generally are considered to be pollution-tolerant (Beck 1977), while most species of mayflies and caddisflies are intolerant of poor water quality (Hynes 1970). Although Ephemeroptera were common in 1994 (73% of the total number of macroinvertebrates), the group comprised almost exclusively *Baetis*. Some species of this genus have been reported to be very tolerant of heavy metals (Heliovaara and Vaisanen 1993), which are present in the coal ash, the ash basins, and the run-off to the creek from these areas. However, it appears that, with respect to taxonomic composition, the macroinvertebrate community of Beaver Dam Creek has undergone substantial improvement since 1984-1985.

4.3.7 Fish

4.3.7.1 Introduction

Three fisheries sampling programs have been conducted on Beaver Dam Creek. The most extensive was the D-Area Clean Water Act Section 316(a) Demonstration, which was conducted from September 1988 through February 1990 to evaluate the effects of heated cooling water discharged to Beaver Dam Creek from the D-Area power plant. Fisheries sampling in Beaver Dam Creek also was conducted in conjunction with the CCWS (1983-1985) and the Comprehensive Cooling Water Quarterly Study (1984-1985). The results of all three programs will be presented in this discussion, although the 316(a) study will be emphasized because it is more recent and comprehensive than the earlier studies.

4.3.7.2 D-Area 316(a) Demonstration

4.3.7.2.1 Introduction

Six stations from the upper reaches to the mouth of Beaver Dam Creek were electrofished monthly from September 1988 through February 1990 (Figure 4-10) (Specht et al. 1990). These stations encompassed a range of habitats from wide, deep, slow-flowing areas near the creek mouth (Station 06) to narrower, more swiftly flowing channels (Stations 01, 02, and 03). Some portions of the creek were heavily overgrown with aquatic vegetation, particularly the slough-like habitat represented by Station 04. Initially, all stations also were sampled monthly by hoopnetting. However, hoopnet sampling was discontinued at Stations 02, 03, and 04 to prevent the accidental trapping of alligators. Hoopnet sampling also was suspended at all sample stations during April and May, the months of maximum alligator movement.

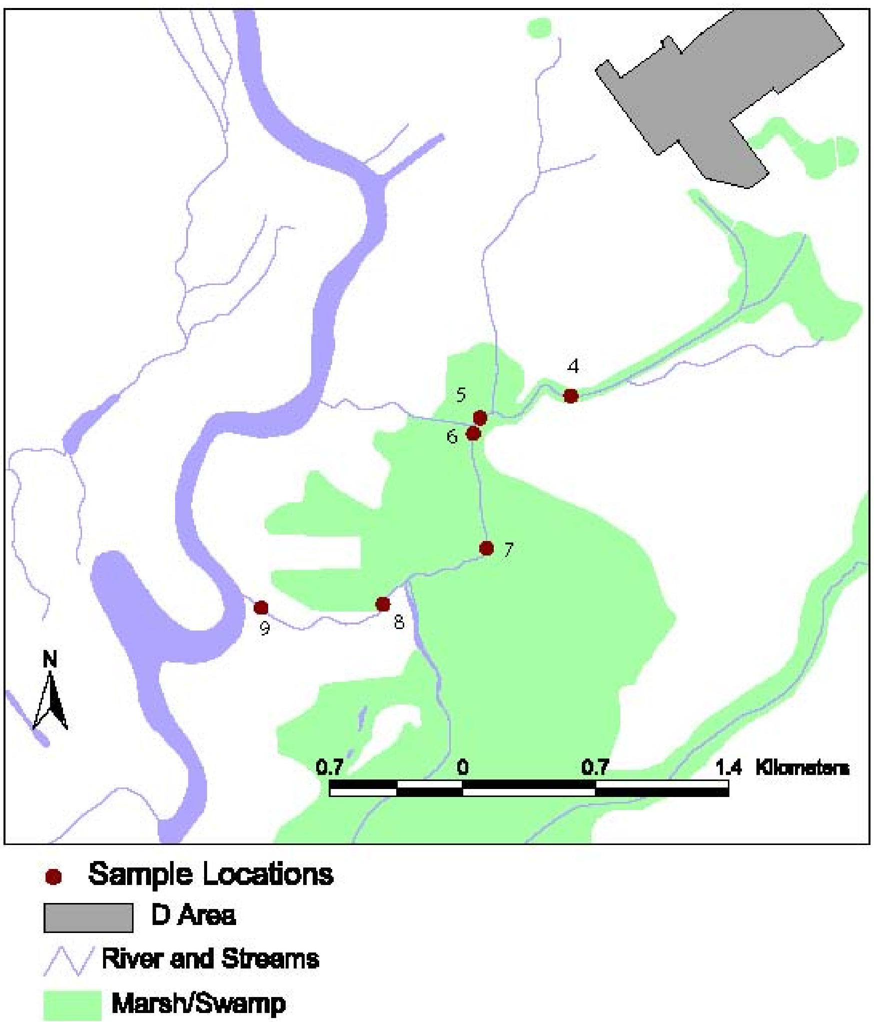

Figure 4-10. Fish Sampling Stations for Beaver Dam Creek

4.3.7.2.2 Adult Fish

Forty-five species were collected by electrofishing and hoopnetting during the 18-month study (Specht et al. 1990). Table 4-5 lists fish species taken by each collecting method. The number of fish collected by electrofishing ranged from 561 at Station 02 and 532 at Station 05 to 167 at Station 01 (Figure 4-10). The number of species collected from each station was less variable, ranging from 25-32. Electrofishing catches varied monthly, and long-term patterns were not evident.

Table 4-5. Fish Collected from Beaver Dam Creek

Family	Common Name	Scientific Name	Electrofishing	Hoop Net
Lepisosteidae	Longnose gar	*Lepisosteus osseus*		X
	Florida gar	*Lepisosteus platyrhincus*		X
Amiidae	Bowfin	*Amia calva*	X	X
Anguillidae	American eel	*Anguilla rostrata*	X	X
Clupeidae	Blueback herring	*Alosa aestivalis*	X	
	Gizzard shad	*Dorosoma cepedianum*	X	
Cyprinidae	Whitefin shiner	*Cyprinella leedsi*	X	
	Coastal shiner	*Notropis petersoni*	X	
Catostomidae	Quillback	*Carpiodes cyprinus*		X
	Spotted sucker	*Minytrema melanops*	X	
Ictaluridae	White catfish	*Ameiurus catus*		X
	Yellow bullhead	*Ameiurus natalis*	X	
	Flat bullhead	*Ameiurus platycephalus*	X	X
	Channel catfish	*Ictalurus punctatus*	X	X
Poeciliidae	Eastern mosquitofish	*Gambusia holbrookii*	X	
Atherinopsidae	Brook silverside	*Labidesthes sicculus*	X	
Centrarchidae	Mud sunfish	*Acantharchus pomotis*		X
	Flier	*Centrarchus macropterus*		X
	Redbreast sunfish	*Lepomis auritus*	X	X
	Warmouth	*Lepomis gulosus*		X
	Bluegill	*Lepomis macrochirus*		X
	Dollar sunfish	*Lepomis marginatus*		X
	Redear sunfish	*Lepomis microlophus*	X	X
	Spotted sunfish	*Lepomis punctatus*	X	X
	Largemouth bass	*Micropterus salmoides*	X	
	Black crappie	*Pomoxis nigromaculatus*	X	X
Percidae	Blackbanded darter	*Percina nigrofasciata*	X	
Mugilidae	Striped mullet	*Mugil cephalus*	X	

Fewer fish were collected at Station 01 than at the other stations. Station 01 was closest to the D-Area outfall and had higher flow rates than the other sample stations. A major portion of the sample area at Station 01 was strongly channelized with little vegetation or instream structure to serve as foraging or refuge areas for fish. Stations 02, 04, and 05, in contrast, generally had open canopies with abundant aquatic and shoreline vegetation.

The electrofishing data were converted to catch per unit effort (CPUE, expressed as number caught per 100 m [328 ft]) by dividing the number caught in each transect by the transect length. Total (all species) mean CPUE ranged from approximately 10.4 fish/100 m at Station 02 to approximately 3.1 fish/100 m at Station 01. CPUE fluctuated widely monthly. Low CPUE occurred when Savannah River flood waters inundated Stations 03, 04, 05, and 06. Flooding greatly increased water depth at these stations and allowed fish to disperse into the surrounding floodplain.

Statistical testing indicated that CPUE was significantly lower at Station 01 than at the other stations. The low CPUE at Station 01 was probably a result of high current velocities and relatively poor habitat. Other differences were likely the result of local variations in instream structure, vegetation, substrate, current velocity, flooding, and other factors that influenced habitat quality and sampling efficiency.

The most abundant species (by number) collected by electrofishing were spotted sucker (*Minytrema melanops*), coastal shiner (*Notropis petersoni*), redbreast sunfish (*Lepomis auritus*), largemouth bass (*Micropterus salmoides*), and spotted sunfish (*Lepomis punctatus*). Sunfish (Centrarchidae) were the most abundant family, composing nearly 40% of the fish collected from Beaver Dam Creek. Minnows and shiners (Cyprinidae) (26%) and suckers (Catostomidae) (17.3%) were also abundant. Several taxa, including the bannerfin shiner (*Cyprinella leedsi*), blackbanded darter (*Percina nigrofasciata*), and channel catfish (*Ictalurus punctatu*s), exhibited a distinct longitudinal zonation, being more abundant either towards the headwaters or towards the stream mouth. Most of the more common species, however, were abundant throughout the stream.

Seventeen species were collected by hoopnetting. The greatest number of fish (96) and greatest number of species (13) were collected from Station 06, at the mouth of Beaver Dam Creek. While Stations 02, 03, and 04 were sampled for only four months due to the high potential for alligator mortality by drowning in the hoopnets, they yielded a total of 11 species and 99 individuals, indicating that fish were abundant at these stations.

For further analysis, the hoopnetting data were converted to CPUE (expressed as number caught per net per day). Mean CPUE was highly variable. However, catch rates were generally higher during the warmer months. Zero catch rates occurred most often during the fall and winter of 1988-1989, especially at Station 01, probably because of seasonal reductions in fish activity and movement.

Channel catfish constituted 60% of the total hoopnetting catch, followed by redbreast sunfish (10.5%), bluegill (*Lepomis macrochirus*) (5.1%), and flat bullhead (*Ameiurul platycephalus*) (4.2%). In addition, white catfish (*Ameiurus catus*) were abundant at Stations 05 and 06, perhaps because this species entered the lower reaches of Beaver Dam Creek from the Savannah River.

One objective of the 316(a) Demonstration was to determine the health of the Beaver Dam Creek fish community. This was done by comparing fish communities in Beaver Dam Creek to fish communities in relatively unimpacted streams. These included several nonthermal streams on the SRS and several other southeastern streams described in the literature (summarized in Paller et al. 1988).

Total number of species ranged from 21 in Upper Three Runs Creek to 59 in Steel Creek. The total in Beaver Dam Creek, 46, was near the maximum. The high species number in Beaver Dam Creek was partly a function of sampling effort, but it also reflects the habitat diversity of this stream, which contains swamp, slough, and stream environments.

Sunfishes and black bass dominated the fish assemblage in Beaver Dam Creek (38% of the collections), followed by minnows (23%), suckers (15%), and catfishes (11%). The relative abundance of minnows and sunfishes was within the range of the other southeastern streams, but the relative abundance of suckers and catfishes was greater. The high relative abundance of catfishes in Beaver Dam Creek was partly due to the intensive hoopnet sampling effort in this stream but also indicates the abundance of these fish. Catfishes and spotted sucker may enter Beaver Dam Creek from the Savannah River, where both are common (Paller and Saul 1986). Comparisons of CPUE were restricted to the onsite streams where sampling methods were relatively consistent and similar to those in the 316(a) Demonstration. Electrofishing CPUE in Upper Three Runs Creek, Steel Creek, and Lower Three Runs Creek ranged from 0.3-26.7/100 m. CPUE in Beaver Dam Creek (0.7-16.6 fish/100 m) fell within this range. Mean quarterly hoopnetting CPUE ranged from 0.43 fish/net day in Upper Three Runs to 0.75 fish/net day in Lower Three Runs. Mean hoopnetting CPUE in Beaver Dam Creek was somewhat higher (1.38 fish/net day), reflecting the abundance of catfishes in Beaver Dam Creek.

In summary, the fish assemblage in Beaver Dam Creek compared favorably with the fish assemblages in other southeastern streams. Taxa richness, relative abundance of major taxa, densities, and catch rates in Beaver Dam Creek were within the ranges measured in the other streams.

4.3.7.2.3 Ichthyoplankton

Plankton nets (0.505-mm mesh) were used to collect ichthyoplankton (drifting fish larvae and eggs) weekly. Only one complete spawning season (February through July 1989) was surveyed. Table 4-6 summarizes taxa taken during the study.

Table 4-6. Ichthyoplankter Taxa Taken in Beaver Dam Creek

Family	Taxa
Clupeidae	*Alosa aestivalis*, blueback herring
	Alosa sapidissima, American shad
Cyprinidae	Unidentified minnows
Catostomidae	*Minytrema melanops*, spotted sucker
Ictaluridae	Unidentified catfish
Esocidae	*Esox* spp., pickerel
Aphredoderidae	*Aphredoderus sayanus*, pirate perch
Fundulidae	*Fundulus* spp., topminnows
Atherinopsidae	*Labidesthes sicculus*, brook silverside
Moronidae	*Morone saxatilis*, striped bass
Elasommatidae	*Elassoma* sp. (probably zonata)
Centrarchidae	*Lepomis* spp., bream
	Unidentified sunfish
	Pomoxis sp., crappie
Percidae	*Perca flavescens*, yellow perch
	Unidentified darters

A total of 82 larval fish and 15 fish eggs, representing at least 9 taxa, were collected from Beaver Dam Creek during February through July 1989. Station 06 had the most ichthyoplankton and the most taxa, followed by Station 05. Stations 01 and 03 had only five specimens each. The greatest ichthyoplankton catches were in April (55 specimens) and May (17 specimens). Centrarchids (primarily *Lepomis* spp., bluegill and other sunfishes) and elassomatids or pygmy sunfish [*Elassoma* spp.] were the most abundant groups, composing together approximately 53% of the total number of larvae and eggs. Other relatively abundant taxa were percids (19.0%) and suckers (12.4%).

Mean ichthyoplankton densities ranged from 1.7/1000 m^3 at Station 03 to 15.8/1000 m^3 at Station 06. The highest average monthly density for the creek as a whole was in April (21.4/1000 m^3). Average densities for the other months ranged from 1.6/1000 m^3 in July to 6.4/1000 m^3 in May.

As with the adult fish, the ichthyoplankton assemblage in Beaver Dam Creek was compared to ichthyoplankton assemblages in other creeks. The nonthermal streams included in this comparison were Steel Creek, Upper Three Runs, and Lower Three Runs. The number of taxa collected from these streams during 1984 and 1985 ranged from 8-15 compared with the 9 taxa collected from Beaver Dam Creek in 1989. Relative abundance in Beaver Dam Creek during 1989 was similar to relative abundance in the other streams during 1984 (dominant taxa were sunfishes, darters, and suckers), but not 1985. However, all streams exhibited high interannual variability in species composition and numbers, making it difficult to evaluate the significance of differences among streams.

4.3.7.3 Comprehensive Cooling Water Study (CCWS)

4.3.7.3.1 Adult and Juvenile Fish

The CCWS involved two adult/juvenile fish sampling programs on Beaver Dam Creek: one quarterly and one reporting on the distribution of fish during the winter (Paller and Osteen 1985; Paller and Saul 1986). Table 4-5 lists fish species taken by each collecting method. For the quarterly study, two hoopnets were placed in the mouth of Beaver Dam Creek and five sites were electrofished four times a year. Four of the electrofishing sites corresponded to Stations 03-06 of the 316(a) Demonstration. The overwintering study included one electrofishing sample station in the mouth of Beaver Dam Creek during 1984 and three during 1985 in the mouth (Station 06), lower reaches of the floodplain swamp (roughly analogous to Station 05), and upper reaches of the floodplain (roughly analogous to Station 02). In addition, hoopnets were set in the mouth of the creek during the 1985 overwintering study.

Electrofishing CPUE near the mouth of Beaver Dam Creek was considerably lower during the quarterly (1.6/100 m) and overwintering (1.4/100 m) studies than during the 316(a) Demonstration (7.1/100 m). Similar trends also were observed at Stations 02, 03, 04, 05, and 06. The studies used the same sampling methods and equipment, suggesting that differences in sampling efficiency were not responsible for the differences in CPUE.

Electrofishing data from the overwintering study indicated that the dominant species, in rank order, at Stations 02, 05, and 06 were spotted sunfish, redbreast sunfish, largemouth bass, bowfin, (*Amia calva*) gizzard shad (*Dorosoma cepedianum)* and bluegill. Dominant species at the same stations during the 316(a) Demonstration were spotted sucker, redbreast sunfish, largemouth bass, spotted sunfish, striped mullet (*Mugil cephalus*), and bluegill. Definite reasons for these differences are unknown, but interannual variations in recruitment and changes in habitat between studies (e.g., aquatic plant growth) are possible causes for sampling variation.

Mean overall hoopnetting CPUE for the overwintering study (1.2 fish/net day) was approximately the same as for the 316(a) Demonstration (1.0 fish/net day); CPUE during both studies was higher than during the quarterly study (0.6 fish/net day). Channel catfish were dominant during the overwintering program, but flat bullhead (*Ameiurus platycephalus*), black crappie (*Pomoxis nigromaculatus*), redear sunfish (*Lepomis microlophus*), and blueback herring (*Alosa aestivalis*) constituted substantial proportions of the catch (Table 5-62). Channel catfish were also strongly dominant during the 316(a) Demonstration. In general, all these studies revealed the presence of diverse fish assemblages in Beaver Dam Creek over time.

4.3.7.3.2 Ichthyoplankton

Larval fish and fish eggs were collected from five sample stations in Beaver Dam Creek during the 1984-1985 CCWS. Four of these sample stations were analogous to the stations sampled in the 316(a) demonstration in 1989 (Stations 03, 04, 05, and 06). Sampling methodology and effort was similar for both studies.

More ichthyoplankton were collected in 1984 (334 individuals) and 1985 (253 individuals) than in 1989 (97 individuals). This may be an effect of low water levels during the 1989 spawning season since many species spawn most successfully when floodwaters inundate terrestrial areas (Martin et al. 1981). Relative abundance also differed among years. While sunfishes (Centrarchidae) were dominant during 1984 and 1989, they constituted a comparatively small proportion of the total catch in 1985 (11.4%). Similarly, the relative abundance of clupeids (herring and shad), suckers, darters, and brook silversides varied substantially among years.

Mean ichthyoplankton densities in 1984, 1985, and 1989 were highest in the creek mouth and the stations (04 and 05) in the lower reaches of Beaver Dam Creek. The lowest densities occurred in the upper reaches of Beaver Dam Creek during all years.

The preceding comparisons indicate considerable annual variability in ichthyoplankton density and species composition. Some of this variability stems from sampling error, but some probably reflects real differences in ichthyoplankton abundance. Water level is known to strongly influence the attractiveness of tributary streams to spawning anadromous fish such as blueback herring (Frankensteen 1976) and the spawning success of other species that require coves, backwaters, shallows, and inundated vegetation where larvae and eggs are sheltered and protected from currents (Martin et al. 1981). A noteworthy trend that was consistent across all years was greater densities and species richness in the lower reaches of Beaver Dam Creek reflecting the relative importance of this portion of the stream as a spawning area for some species.

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4.4 FOURMILE BRANCH

4.4.1 Drainage Description and Surface Hydrology

4.4.1.1 General Description

Fourmile Branch originates near the center of SRS and flows southwesterly for approximately 24 km (15 mi) (Figure 4-11). The watershed, which drains about 57 km^2 (22 mi^2), includes several SRS facilities: C Area (reactor), F and H Areas (separations facilities, tank farms, and seepage basins), and the Solid Waste Disposal Facility (SWDF). At its headwaters, Fourmile Branch is a small blackwater stream that is relatively unimpacted by SRS operations (Specht 1987).

In its lower reaches, Fourmile Branch broadens and flows through a delta that has been formed by the deposition of sediments. Although most of the flow through the delta is in one main channel, the delta has numerous standing dead trees, logs, stumps, and cypress trees, which provide structure and reduce water velocity in some areas. Downstream of the delta the creek flows in one main channel; the majority of the flow discharges into the Savannah River at river kilometer 244.7 (river mile 152.1), while a small portion of the creek flows west and enters Beaver Dam Creek. When the Savannah River floods, water from Fourmile Branch flows along the northern boundary of the floodplain swamp and joins with Pen Branch and Steel Creek instead of flowing directly into the river (Specht 1987).

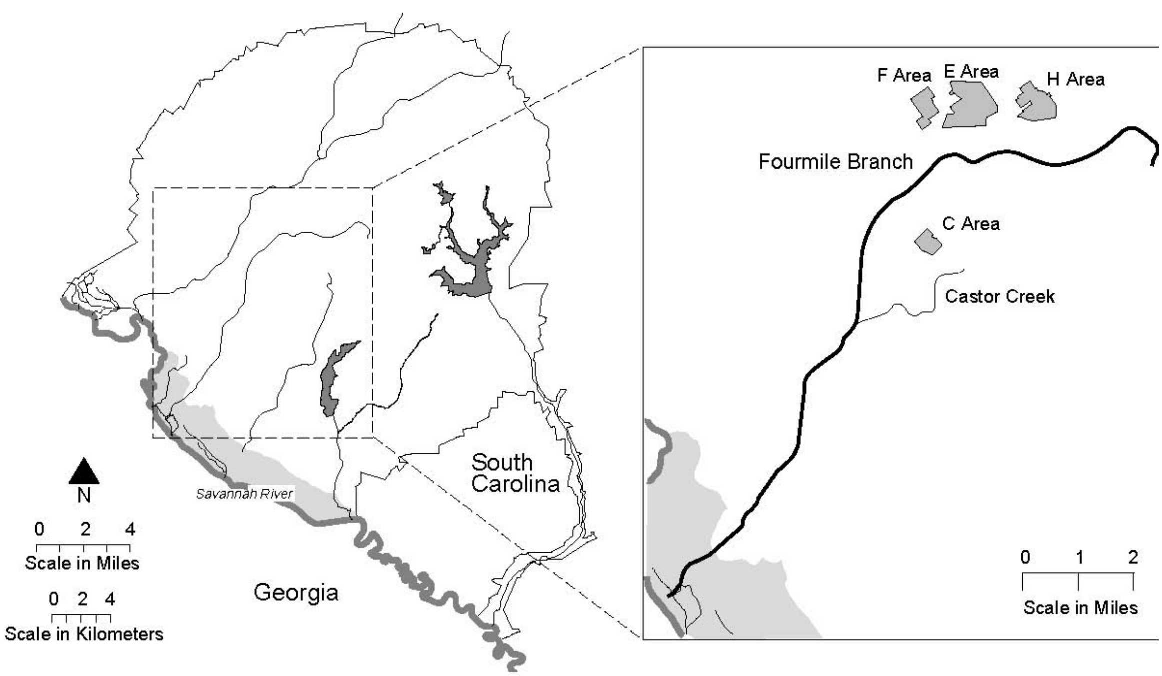

Figure 4-11. Location of Fourmile Branch on SRS

4.4.1.2 Effluent Contributions

Fourmile Branch receives effluents from F, H, and C Areas. Before C-Reactor shutdown in 1985 the reactor discharged heated Savannah River water (as hot as 70°C [158°F]) into Fourmile Branch via Castor Creek. Resulting water temperatures were in excess of 60°C (140°F) in Fourmile Branch just downstream of its confluence with Castor Creek.

With the contribution of C-Reactor cooling water, the flow in Fourmile Branch measured about 11.3 m^3/s (400 ft^3/s) (Murphy et al. 1991). The flows and temperatures associated with C-Reactor operations no longer occur since June 1985.

Prior to 1996, Fourmile Branch received effluents from 16 National Pollutant Discharge Elimination System (NPDES) outfalls in C, F, and H Areas, and Central Shops as well as groundwater from beneath F and H Areas. Until 1985, Fourmile Branch also received thermal effluents from C Reactor. With the new NPDES permit issued in 1996, outfalls were reduced from 16 to 5 due to deletions of waste streams and the consolidation of the outfalls. Effluent from the new 1.05-million gallon per day Centralized Sanitary Wastewater Treatment Facility began discharging to Fourmile Branch in 1995.

Fourmile Branch, either directly or via tributaries, receives the following NPDES-permitted discharges: 186 basin overflows, cooling water, floor drains, steam condensate, process wastewater, laundry effluent, stormwater, sanitary treatment wastewater, ash basin runoff, and lab drains.

4.4.1.3 Flow Measurements

The U.S. Geological Survey measured flow at several locations on Fourmile Branch (Figure 4-12). Records for the most downstream station (Fourmile Branch at Road A-13.2) date back to November 1976. In water year 1995, the mean flow of Fourmile Branch at Road A-13.2 was 1.1 m^3/s (37.3 ft^3/s). Over the period of water years 1977-1995 at Road A-13.2, the mean flow was 3.2 m^3/s (113 ft^3/s), the 7-day low flow was 0.22m^3/s (7.6 ft^3/s), and the 7Q10 was 0.23 m^3/s (8.2 ft^3/s). Neither station is currently monitored and no data are available after September 2002.

4.4.2 Water Chemistry and Quality

4.4.2.1 Studies and Monitoring

4.4.2.1.1 <u>Water Quality Monitoring</u>

Westinghouse Savannah River Company's Environmental Monitoring Section has conducted routine water-quality monitoring in Fourmile Branch since 1973. It samples locations on Fourmile Branch - near Road A-7 and near Road A-13.2 - monthly for physical and biological parameters and quarterly for metals (Figure 4-13; 08 and 10). The Environmental Monitoring Section also collects a sample annually from the same locations and analyzes it for pesticides, herbicides, and PCBs. All routine water quality monitoring data reported in the following sections can be found in the annual SRS Environmental Reports.

01 Site No. 7 at SRS
02 At Road A-13.2 at SRS

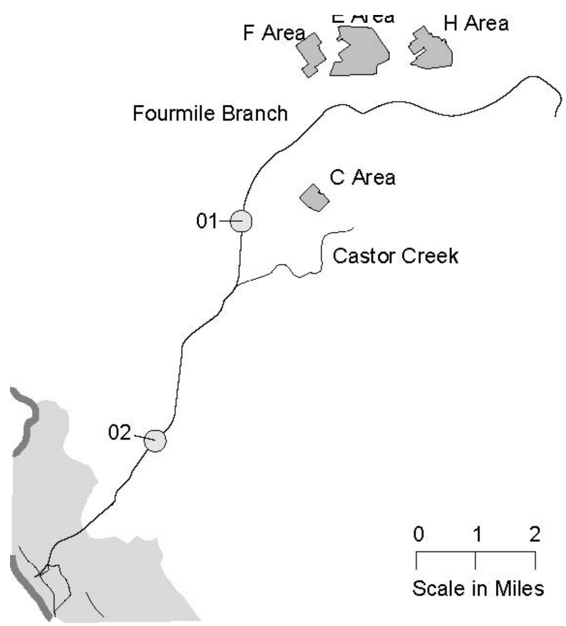

Figure 4-12. Flow Measurement Stations for Fourmile Branch

01 Upstream H(I)
02 Road E-1, CW3, HW7
03 Road C1
04 Downstream H (III)
05 Road C
06 Upstream F (IV), CW2 & HW2
07 115 TransLine and Downstream F (VI) and CW1, FW4
08 Road A-7
09 Road 3
10 Road A
11 Road A-13.2

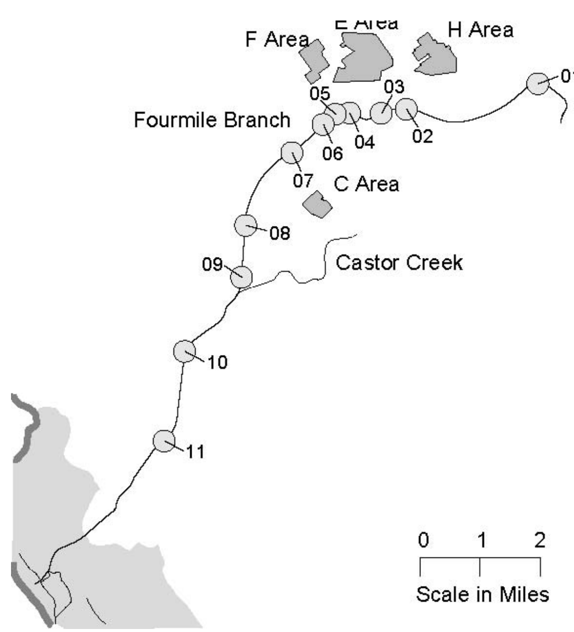

Figure 4-13. Water Quality Monitoring Stations on Fourmile Branch

4.4.2.1.2 Comprehensive Cooling Water Study (CCWS)

From 1983 to 1985, the Savannah River Ecology Laboratory (SREL) studied Fourmile Branch as part of the CCWS. The study was to provide "an assessment of the potential effects of present and proposed SRS activities on the quality of waters used for cooling at the SRS" (Newman et al. 1986). The study included sampling the following four locations on Fourmile Branch (Figure 4-13):

- Fourmile Branch at Road E-1 (02)
- Fourmile Branch at Road 3, near Fourmile Branch at Road A-7 (08)
- Fourmile Branch at Castor Creek (09)
- Fourmile Branch at Road A-13.2, near Fourmile Branch at Road A (11)

The data collected from the thermal portions of Fourmile Branch reflect impacts associated with reactor operation and are not relevant to the current conditions of Fourmile Branch. However, because a limited amount of monitoring data are available, portions of the CCWS data will be presented.

Gladden et al. (1985) presented a synopsis of historical water quality monitoring of the Fourmile Branch system prior to the CCWS. Comprehensive results and discussion of CCWS data can be found in Lower (1987).

4.4.2.2 Priority Pollutant Study

In 1984, a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral compounds in Fourmile Branch. The sample locations were Fourmile Branch at Road C (05 on map), Road A-7 (08 on map), and Road A (10 on map). Potential sources for organics into Fourmile Branch were discharges from F and H Areas, shallow groundwater outcropping, runoff from precipitation, and input of Savannah River water. The results of this study are in the following sections and in Lower (1987).

4.4.2.3 Chemical Assessment Studies

Since 1985, three special studies have been conducted on Fourmile Branch to determine the impacts of groundwater contamination on Fourmile Branch. The Savannah River National Laboratory (SRNL) conducted two studies in 1988 and 1989 aimed at characterizing the shallow groundwater outcropping into Fourmile Branch and its associated seepline (Looney et al. 1988; Haselow et al. 1990). The third study, (Dixon et al. 1994) which began in 1991, is a continuation of the 1988 and 1989 studies and is aimed at determining whether annual rainfall and natural groundwater flow will dilute and flush the remaining contaminant plume out of the shallow groundwater and Fourmile Branch wetland. The Chemical Assessment Studies later in this section summarize the results of the SRNL studies.

4.4.2.4 Field Data

4.4.2.4.1 Water Temperature

When C-Reactor was operating (from the 1950s to 1985), temperatures in Castor Creek reached in excess of 70°C (158°F), while temperatures in the nonthermal portions of Fourmile Branch averaged 16.9°C (62.4°F) at Fourmile Branch near Road 3. After the thermal and nonthermal waters of this system blended, the mean temperature was 39.4°C (102.9°F) (Fourmile Branch at Road A-13.2), and then dropped to 28°C (82.4°F) near the confluence with the Savannah River.

Between C-Reactor's shutdown in 1985 and 1991, temperatures in Fourmile Branch at Road A ranged from 4.2°C to 31°C (39.5 to 87.8°F) with means ranging from 16.8 to 18.5°C (62.2 to 65.3°F) and averaged 18.5°C (65.3°F). Since 1992, the temperatures have ranged from 4.5°C to 25.5°C (40.1 to 77.9°F) and averaged 17°C (62.6°F). The wide fluctuations in temperature reflect seasonal temperature differences. Temperatures upstream at Road A-7 reflect a similar range of 6.4°C to 27°C (43.5 to 80.6°F) and an average of 17°C (62°F).

4.4.2.4.2 pH Measurements

Since 1987, the pH in Fourmile Branch has varied from 5.4 to 8.1 at Road A-7 and from 3.1 to 8.5 at Road A. The pH measurements from the CCWS also fell within these $\pm$ ranges. The change in the ionization constant (K_w = [H][OH]) associated with the change in water temperature is responsible, in part, for the changes in pH (Newman et al. 1986).

4.4.2.5 Physical Characteristics and General Chemistry

4.4.2.5.1 Dissolved Oxygen

Concentrations of dissolved oxygen are strongly correlated to water temperature. Because there was no thermal input near Road A-7, dissolved oxygen concentrations measured between 1987 and 1991 (mean 8.4 mg/l) were similar to those measured during the CCWS (mean 7.8 mg/l). During the CCWS, the mean dissolved oxygen concentration upstream of Road 3 at the swampy headwater pool (Road E-1) was 6.8 mg/l. Dissolved oxygen concentrations near Road A-13.2 (mean 6.0 mg/l) were lower during the CCWS than during the period following cessation of reactor operations (mean 7.9 mg/l; at Road A), due to the thermal input to the system. Mean dissolved oxygen concentrations between 1992 and 1995 were 8.9 mg O_2/l at Road A and 8.22 mg O_2/l at Road A-7.

4.4.2.5.2 Turbidity and Suspended Solids

Turbidity and suspended solids have been lower in Fourmile Branch since the cessation of C Reactor operations. Mean turbidities and suspended solids near Road A-7 between 1987 and 1991 were 8.2 NTU and 5.1 mg/l, respectively. However, during the CCWS, the mean turbidity near Road 3 was 20.8 NTU, and the mean suspended solids concentration was 7.82 mg/l. Between 1987 and 1991, mean turbidities and suspended solids have been 5.2 NTU and 3.1 mg/l, respectively, near Road A. During the CCWS, the mean turbidity near Road A-13.2 was 18.5 NTU, and the mean suspended solids concentration was 9.31 mg/l. Between 1992 and 1995, mean turbidity was 4.5 NTU and Road A and 7.5 NTU at Road A-7.

4.4.2.5.3 Conductivity

Specific conductivity in Fourmile Branch between 1987 and 1991 averaged 56.5 µS/cm at Fourmile Branch near Road A-7 and 44.3 µS/cm at Fourmile Branch near Road A. Between 1992 and 1995, specific conductivity averaged 60 µS/cm at Road A and 70.75 µS/cm at Road A-7. During the CCWS, mean conductivity in Fourmile Branch near Road A-13.2 was 66 µS/cm. Discharging Savannah River water to Fourmile Branch resulted in this higher conductivity.

4.4.2.6 Major Anions and Cations

4.4.2.6.1 Alkalinity, Chloride, and Sulfate

Monitoring data from 1987-1991 indicate that mean concentrations of total alkalinity are similar in waters near Road A-7 (9.7 mg $CaCO_3$/l) and near Road A (10.3 mg $CaCO_3$/l). These mean concentrations are also similar to those measured during the CCWS (8.52 mg $CaCO_3$/l at Road 3 and 14.14 mg $CaCO_3$/l near Road A-13.2). Mean chloride concentrations between 1987 and 1991 were higher at Road A-7 (5.7 mg/l) than at Road A (3.2 mg/l), which may reflect groundwater outcroppings from the F-and H-Area seepage basins. Mean sulfate concentrations were highest near Road A-7, also reflecting groundwater input from the F- and H-Area seepage basins. Higher sulfate and chloride concentrations also were observed during the CCWS. Between 1992 and 1995, mean chloride concentrations in Fourmile Branch ranged from 3.58 to 4.22 mg/l; mean sulfate concentrations ranged from 4.75 to 6.5 mg/l; and mean alkalinity ranged from 8.25 to 11.75 mg $CaCO_3$/l.

4.4.2.6.2 Calcium, Magnesium, Sodium, and Potassium

Concentrations of calcium, magnesium, sodium, and potassium near Road A-7 and Road A remain similar to the concentrations measured during the CCWS. As in other onsite aquatic systems, calcium, magnesium, and sodium are transported almost entirely in the dissolved phase throughout Fourmile Branch (Newman et al. 1986). Mean concentrations of potassium were generally below the detection limits in the nonthermal portion of Fourmile Branch, but increased to about 1 mg/l in downstream thermal waters, reflecting Savannah River source waters. Potassium is not measured during routine SRS water quality monitoring.

4.4.2.6.3 Aluminum, Iron, and Manganese

During the CCWS, concentrations of aluminum were highest near Road A-13.2, reflecting concentrations in the Savannah River. Concentrations of manganese and iron were highest at the upstream location (Road E-1). The high concentrations of iron (mean 3.59 mg/l) measured at the upstream Fourmile Branch location were attributed to a large amount of iron oxide deposition in the marshy area.

From 1987-1991, the maximum aluminum (0.37 mg/l) and manganese (0.21 mg/l) concentrations were measured near Road A-7. The maximum iron concentration, 1.7 mg/l, was measured near Road A. From 1992 to 1995, the maximum aluminum (0.865 mf/l), iron (1.51 mg/l), and manganese (0.16 mg/l) concentrations were all at Road A-7.

4.4.2.7 Nutrients

4.4.2.7.1 Phosphorus

The mean concentrations of phosphorus species in Fourmile Branch waters during the CCWS were higher near Road-A 13.2 (0.089 mg/l) than the concentrations near Road 3 (0.023 mg/l). Analyses determined that the larger percentage of the phosphorus was dissolved orthophosphate. From 1987-1991, mean concentrations of phosphorus have been lower near Road A than near Road A-7 (0.075 mg/l near Road A-7 and 0.028 mg/l near Road A). Between 1992 and 1995, the concentrations were almost the same (mean of 0.038 mg/l at Road A and 0.03 mg/l at Road A-7).

4.4.2.7.2 Nitrogen

Organic nitrogen and nitrite concentrations during the CCWS were similar at all Fourmile Branch sites. Nitrite is not measured in routine water-quality monitoring, and organic nitrogen was measured only near Road A-7 between 1987 and 1995. The concentrations of organic nitrogen measured near Road A-7 were similar to those measured in the CCWS. Ammonia concentrations were highest in the most upstream location (Road E-1) and decreased with distance downstream.

The CCWS measured extremely high concentrations of nitrate (2.3 mg NO_3/l) near Road 3 during the CCWS. These elevated concentrations can be attributed to the outcropping of water from the F-and H-Area seepage basins (Fenimore and Horton 1972). Nitric acid was added to the seepage basins during that time. Ammonia and nitrate concentrations measured since 1992 are similar to prior measurements.

4.4.2.8 Trace Elements

SREL measured low levels of trace elements in Fourmile Branch during the CCWS. The detection limits reported for routine monitoring are higher than the concentrations measured during the CCWS; therefore, only the CCWS data is discussed. The CCWS measured the highest mean concentrations of arsenic (2.5 µg/l), cadmium (0.45 µg/l), copper (3.8 µg/l), and nickel (3.6 µg/l) in Fourmile Branch at Road A. Fourmile Branch near Road A-7 had the highest mean concentration of chromium (9.1 µg/l), while the most upstream location, Road E-1, had the highest mean concentrations of lead (2.2 µg/l) and zinc (8.2 µg/l).

4.4.2.9 Organic Carbon

During the CCWS, mean total organic carbon concentrations in nonthermal waters ranged from 4.3 to 8.0 mg/l, while the thermal waters had total organic carbon concentrations of 6.4-7.3 mg/l. Between 1987 and 1991, total organic carbon concentrations ranged from 0.06 to 9.04 mg/l.

4.4.2.10 Priority Pollutants

Lower (1987) reports the results of an instream study to determine the levels of volatile, acid, and base/neutral organics in Fourmile Branch. Concentrations of all 88 tested organics were below the detection limits at each of the three sampling locations.

In 1984, an instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral compounds in Fourmile Branch. Three locations - Fourmile Branch at Road C, Road A-7, and Road A - were sampled for this study. Potential sources for organics into Fourmile Branch were discharges from F and H Areas, shallow groundwater outcropping, runoff from precipitation, and input of Savannah River water. The results of this study are in the sections that follow and in Lower (1987).

4.4.2.11 Pesticides, Herbicides, PCBs, and Volatile Organic Compounds

Pesticides, herbicides, PCBs, and volatile organic compounds also are measured during routine water quality monitoring. No pesticides, herbicides, PCBs, or volatile organic compounds have been detected in Fourmile Branch.

Lower (1987) reports the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985; results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations were also near or below detection limits at all locations.

4.4.2.12 Chemical, Including Radionuclide, and Toxicity Assessment Studies

4.4.2.12.1 Seepline Metals

In 1987, SRNL initiated a sampling and analysis program in the vicinity of the F-and H-Area seepage basins because observations of the basins suggested that water outcropping along the seepline was impacting a small area of the terrestrial/wetlands environment along Fourmile Branch. SRNL collected samples upstream and downstream from both F and H Areas (Figure 4-13) and analyzed for selected metals, inorganic constituents, pH, conductivity, nitrate, and nitrite.

Results from the analysis of the water from Fourmile Branch suggested that the input of sodium nitrate from the seep areas or area outfalls was measurable in the stream. The remaining constituents did not measurably impact the stream (Looney et al. 1988).

Haselow et al. (1990) collected soil cores, stream, and seepline water samples from Four-mile Branch in 1988 and 1989 as a follow-up to the Looney et al. (1988) study. These samples also were analyzed for selected metals, inorganic constituents, pH, conductivity, nitrate, and nitrite.

Metals analyses showed that all concentrations in Fourmile Branch were below the proposed drinking water standards for those analytes. Aluminum and sodium concentrations were elevated, but no standards exist for these constituents. The high sodium concentrations are probably from the caustic discharged to the basins, and the aluminum is probably being leached from the soil matrix. Nitrate was elevated at both the F-and H-Area seeplines but was no more than half the concentration in the stream at all sampling locations. The concentration of chloride apparently was unaffected by the basins because upstream samples were about the same as the concentrations along the seepline and in Fourmile Branch.

Discharges to the seepage basins were discontinued in 1988, and the basins were capped and sealed in 1990 to minimize the release of contaminants to the environment. Scientists hypothesized that after eliminating the contaminant source, annual rainfall and natural groundwater flow would dilute and flush the remaining contaminant plume out of the shallow groundwater and Fourmile Branch wetland system. After the contaminant plume in the shallow groundwater is diluted and flushed, the Fourmile Branch wetland systems below the basins will begin to recover.

To investigate this hypothesis and to monitor the postbasin-closure temporal changes in the contaminant levels outcropping along the Fourmile Branch seepline, a semiannual program was initiated to monitor Title 40 CFR Part 264 Appendix IX metals and various inorganics. Samples were collected from five seepline locations in F Area, five seepline locations in H Area, and three stream locations on Fourmile Branch. Analytical results for the seepline sampling locations are in Dixon and Rogers (1994), Chappell et al. (1995), Koch and Dixon (1997). The sampling indicates that as of 1996 the seepline and Fourmile Branch still were influenced by contaminants migrating from the F- and H-Area seepage basins. However, when compared to 1989 concentrations (Haselow et al. 1990), the concentrations of most constituents have declined.

4.4.2.12.2 <u>Seepline Tritium</u>

The Savannah River National Laboratory established a monitoring program to track changes in tritium, pH, and specific conductivity at the Fourmile Branch seepline down-gradient from the F- and H-Area seepage basins.

Measurements from the September 1993 survey indicated higher tritium concentrations, conductivity measurements, and pH values than in recent previous surveys, but lower than measurements recorded in 1990. Decreased rainfall prior to the sampling event contributed to the increased tritium concentrations and conductivity values during this survey.

September 1993 tritium values in the F-Area seepline ranged from 12 to 17,800 pCi/ml (Figure 4-14). Six of twenty-one locations sampled had above-background tritium activities that exceeded 1989 measurements by 10%. The tritium activity of 17,800 pCi/ml exceeded the maximum value recorded in 1989 (14,000 pCi/ml [Dixon et al. 1994])

Tritium values in the H-Area seepline ranged from 124 to 15,500 pCi/ml (Figure 4-15). Four of twenty-one sampling locations had above-background tritium activities that exceeded 1989 measurements by more than 10%. No tritium activity exceeded the maximum activity of 24,000 pCi/ml measured in 1989.

Below-average rainfall prior to the September 1993 sampling event caused the tritium plume to move upward through the soil profile, while the toe of the plume moved back toward the seepage basins and the seepline intercept. Therefore, tritium concentrations at most locations increased considerably. With increased rainfall, the plume should move deeper into the soil profile and outcrop closer to Fourmile Branch. Tritium concentrations at the seepline should return to levels typically measured in the past. It is important to note that total tritium fluxes to the wetlands and Fourmile Branch have steadily declined since basin closure. Overall results suggest that the tritium plume is flushing from the Fourmile Branch system (Dixon et al. 1994).

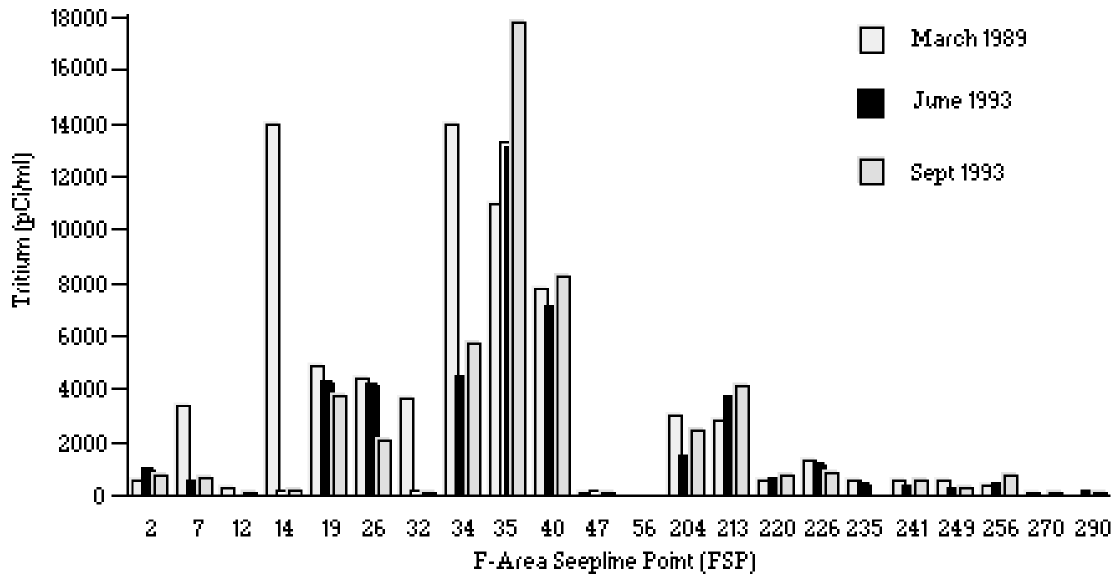

Figure 4-14. Comparison of March 1989, June 1993, and September 1993 Tritium Concentrations for Selected F-Area Seepline Locations

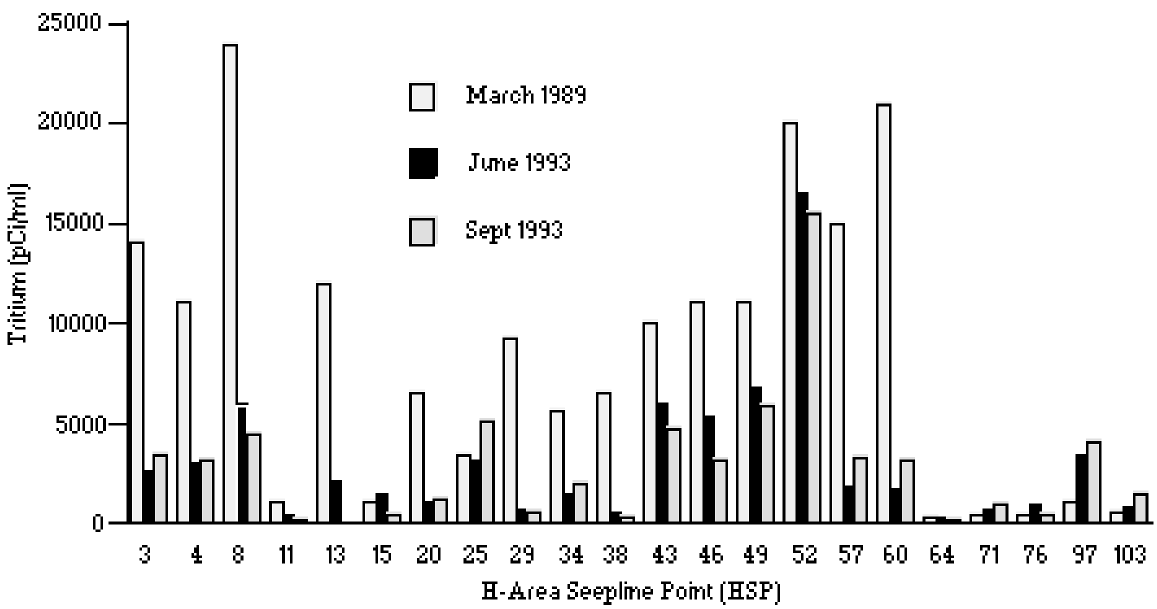

Figure 4-15. Comparison of March 1989, June 1993, and September 1993 Tritium Concentrations for Selected H-Area Seepline Locations

In September 1996, tritium concentrations ranged from 7-7150 pCi/ml at the F-Area seepline, from 20-1980 pCi/ml at the H-Area seepline and from 16-19,100 pCi/ml in the drainage below 643-E (a decommissioned area of the Solid Waste Management Facility).

The following conclusions are based on trends in measured concentrations from 1986 to 1996:

- tritium concentrations measured at most locations in September 1996 are relatively unchanged compared to the previous sampling events, but are significantly lower than the 1986 baseline tritium concentration
- total tritium fluxes to Fourmile Branch and its associated wetlands have steadily declined since basin closure, supporting the hypothesis that the tritium plumes are being flushed from shallow groundwater
- most of the tritium detected along the F-Area seepline is localized in two areas (8 of 22 sample locations)
- most of the tritium detected along the seepline below 643-E (a decommissioned area of the Solid Waste Management Facility) is on the west side of the drainage
- differences in tritium concentrations measured from one sampling event to the next represent seasonal variability and the effects of rainfall

4.4.2.12.3 Radiocesium

Over the history of the Site, Fourmile Creek has received an estimated 2.8 TBq (77 Ci) of radiocesium with 99% of this being ^{137}Cs (Garten et al. 2000).

4.4.2.12.4 Toxicity

In 1994, a study was done to determine if the cladoceran *Ceriodaphnia dubia* is adversely affected by Fourmile Branch water that does not receive NPDES discharges, if *Ceriodaphnia* can be cultured for extended times in Fourmile Branch water, and if *Ceriodaphnia* cultured in Fourmile Branch water are sensitive to a reference toxicant. SRS surface waters are extremely soft, with hardnesses ranging from approximately 2 to 30 mg/l. Waters this soft may not have adequate calcium or trace minerals to support long-term survival of *Ceriodaphnia*. Detailed results of this study are presented in Specht (1994a).

Fourmile Branch water was acutely toxic (measured as percent survival) to *Ceriodaphnia dubia* in three of five monthly tests and was chronically toxic (measured as reproductive success) in five of five monthly tests. The reference toxicant (sodium chloride) tests on Fourmile Branch water indicated test organisms in that water were severely stressed and extremely sensitive to the reference toxicant. Water from Fourmile Branch above any SRS NPDES outfall is not capable of sustaining cultures of *Ceriodaphnia dubia*.

In order to determine the source of the observed toxicity in Fourmile Branch, a Toxicity Identification Evaluation (TIE) was performed in 1995 on water collected from Fourmile Branch at Road F following U.S. Environmental Protection Agency protocols (Durhan et al. 1993; Norberg-King et al. 1991). The results of the TIE indicate that naturally occurring iron is responsible for the toxicity to *Ceriodaphnia dubia* (ETT Environmental 1995a, b).

4.4.3 Algae

4.4.3.1 Phytoplankton

The former C-Reactor cooling water effluent system, which includes Fourmile Branch and its principal tributary Castor Creek, is a low-potential impact area for phytoplankton. The food base throughout this system is composed of detrital material and attached algae (periphyton), rather than phytoplankton, as is typical in lotic systems (Wetzel 1983). Primary producers in the Fourmile Branch system consist mainly of periphyton and macrophytes (Specht 1987).

4.4.3.2 Periphyton

The periphyton of Fourmile Branch were studied from 1983-1985 as part of the CCWS. Methods and sampling locations can be found in Specht (1987).

4.4.4 Macrophytes

Aquatic macrophytes provide stream structure, substrate for periphyton development, cover and substrate for smaller animals, and a source of carbon for the stream system. Although aquatic macrophytes are an important component of the function of many aquatic systems, they tend to be less important in flowing waters. Macrophytes could not colonize the channels of systems such as Fourmile Branch during the large thermal and flow impacts from reactor operations. Colonization of the stream has occurred since the cessation of C-Reactor operations in 1985; unfortunately, there are no data dealing with the invasion of submerged macrophytes in Fourmile Branch. However, there is some research, started in 1987 (Sharitz et al. 1993), addressing vegetational succession in the Fourmile Branch corridor that does deal with the emergent and wetland species colonizing the stream banks.

4.4.4.1 Comprehensive Cooling Water Study (CCWS)

The 1984-1985 data collected during the CCWS (Specht 1987) were the only data dealing with aquatic macrophytes in Fourmile Branch. The CCWS data are not representative of the current status of aquatic macrophytes in the Fourmile Branch system because they were collected at only two stations, both of which had been impacted by reactor operations. The data showed fewer total number of taxa than post-thermal and reference streams and had no taxa growing in the stream channel.

4.4.4.2 Expectations Since the Cessation of C-Reactor Operation

Normal successional patterns and development of macrophyte beds would likely have occurred in suitable sections of Fourmile Branch since the cessation of C-Reactor operation. This probability cannot, however, be supported or refuted because of the lack of observations and data. There may be adequate justification for either resampling of the areas studied during the CCWS, or a survey of the entire stream to document the invasion of this important component of the lower food chain.

4.4.5 Zooplankton

Chimney and Cody (1986) performed the only systematic study of the zooplankton in Fourmile Branch which documented the temporal and spatial characteristics of zooplankton species based on quarterly sampling from December 1984 to August 1985. Surface water grab samples were collected adjacent to macrophyte beds at a single station where the stream enters the Savannah River swamp. Due to thermal discharges, mean temperature was greater than 32°(89.6 F). Species richness consisted of 8 Protozoa, 21 Rotifera, 6 Cladocera, 2 Copepoda, and 1 Ostracoda.

The data indicate that the greatest densities occurred during March 1985. With the exception of December 1984, Protozoa and Rotifera made up more than 80% of the monthly total densities. This result is typical of zooplankton populations, which are warm-water, summer species (Hutchinson 1967).

4.4.6 Macroinvertebrates

4.4.6.1 Sampling Locations and Methods

4.4.6.1.1 <u>Locations</u>

Macroinvertebrates were sampled monthly from September 1982 to August 1983 in the mouth of Fourmile Branch (Specht et al. 1984), monthly from November 1983 through September 1984 at three locations in Fourmile Branch (Kondratieff and Kondratieff 1984, 1985; O'Hop et al. 1985), and monthly from October 1984 through September 1985 at six locations in Fourmile Branch (Figure 4-16) (Specht 1987). Because C Reactor, which discharged to Fourmile Branch, was placed on cold standby in June 1985, these data primarily represent the macroinvertebrate community that existed when C Reactor was operating at full power; however, the data also document early recovery of thermal stations between June and September 1985. After C Reactor shut down in June 1985, Lauritsen and Starkel (1989) collected macroinvertebrate samples at one location in Fourmile Branch from June 1985 to September 1987 to document macroinvertebrate recolonization. During the recolonization study, they collected samples at time intervals ranging from one day to two weeks from June through August 1985 and monthly from October 1985 to September 1987.

Macroinvertebrates were sampled during the summer of 1993 at six locations in Fourmile Branch using Hester-Dendy multiplate macroinvertebrate samplers (Specht 1994b). Macro-invertebrates also were sampled in September 1994 using Hester-Dendy multiplate samplers to develop a biotic index for southeastern streams. While not specifically designed to characterize SRS streams, these data contribute to a better understanding of them. Fourmile Branch was sampled at Road C and Road A-13.2 (Specht and Paller 1995).

01 12 (Road A-7)
02 14 (Road A-13.2)
03 15
04 16
05 17
06 18

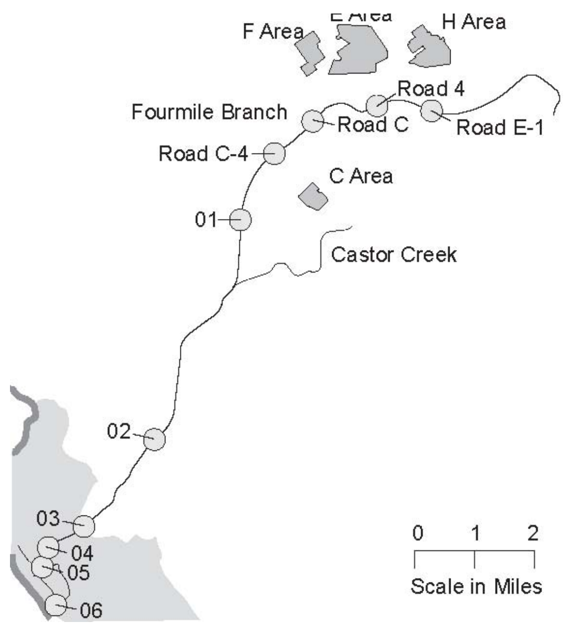

Figure 4-16. Location of the Fourmile Branch Macroinvertebrate Sampling Stations

4.4.6.1.2 <u>Methods</u>

A majority of the Fourmile Branch macroinvertebrate sampling was conducted with Hester-Dendy multiplate samplers. However, macroinvertebrates also were collected from leaf bags, artificial snags, macrophytes, natural substrates, and drift at some stations. Details of sampling methods can be found in Specht et al. (1984), Kondratieff and Kondratieff (1984, 1985), Firth et al. (1986), Lauritsen and Starkel (1989), Specht (1994b), and Specht and Paller (1995). Most of the data in this summary is from the 1984-1985 sampling period because fewer stations were sampled in the other years.

4.4.6.2 Results

4.4.6.2.1 <u>Introduction</u>

From the onset of macroinvertebrate sampling in 1982 until C-Reactor was shut down in June 1985, Fourmile Branch was subject to severe thermal stress, with temperatures as high as 51.7°C (125°F) recorded at some macroinvertebrate sampling stations. However, during reactor outages, which sometimes lasted for several weeks or longer, stream temperatures were near ambient. Many species of macroinvertebrates were able to colonize the stream quickly during reactor outages. In addition, it is likely that some of the organisms collected in the severely thermal areas drifted downstream from portions of the stream where temperatures were ambient and that the organisms were no longer alive when collected. Therefore, the macroinvertebrate data collected from Fourmile Branch between 1982 and June 1985 must be interpreted cautiously to prevent erroneous conclusions. Table 4-7 lists Fourmile Branch macroinvertebrates by time period.

Table 4-7. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Fourmile Branch

Class or order	Lowest practical taxa	HD	NS
Oligocheata	*Lumbriculidae sp.*	X	
	Nais sp.	X	
	Tubificidae sp.		X
	Uncinais uncinata	X	
Hirudinea	*Placobdella sp.*		X
Gastropoda	*Amnicola limosa*	X	X
	Campeloma decisum		X
	Ferrissia sp.	X	
	Gyraulis parvulus	X	
	Physella heterostropha	X	X
	Physella sp.	X	X
	Planorbella sp.		X
	Somatogyrus sp.		X
Pelycepoda	*Corbicula fluminea*	X	X
	Sphaerium sp.		X
Arachnida	*Hydracarina sp.*	X	X
Crustacea	*Cambarinae sp.*	X	X
	Crangonyx obliquus/richmondensis		X
	Hyallela azteca	X	X
	Palaemonetes paludosus		X
	Procambarus sp.		X
Ephemeroptera	*Baetis ephippiatus*		X
	Baetis frondalis		X
	Baetis intercalaris	X	X
	Baetis nr. punctiventris		X
	Caenis diminuta		X
	Callibaetis		X
	Ephemerella nr. doris	X	
	Eurylophella doris	X	X
	Eurylophella sp.	X	
	Isonychia sp.	X	X
	Leptophlebia sp.	X	
	Neoephemera youngi		X
	Paraleptophlebia sp.	X	X
	Plauditus nr. dubius		X
	Stenonema modestum		X
	Stenonema modestum/smithae	X	X
	Tricorythodes sp.		X

Table 4-7. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Fourmile Branch - continued

Class or order	Lowest practical taxa	HD	NS
Odonata	*Aeshna umbrosa*		X
	Anax longipes		X
	Argia sedula		X
	Argia sp	X	X
	Boyeria vinosa		X
	Calopteryx dimidiata	X	X
	Cordulegaster sp.		X
	Dromogomphus armatus		X
	Enallagma divagans	X	X
	Enallagma nr. dubium		X
	Enallagma sp.	X	X
	Enallagma vesperum		X
	Enallagma weewa		X
	Erythemis simplicicollis		X
	Gomphus lividus		X
	Gomphus vastus		X
	Ischnura posita		X
	Libellula nr. auripennis		X
	Libellula sp.		X
	Libellulidae sp.		X
	Macromia sp.		X
	Neurocordulia virginiensis	X	
	Plathemis lydia		X
	Tetragoneuria semiaquea/cynosura		X
Heteroptera	*Mesovelia mulsanti*		X
	Metrobates hesperius		X
	Neogerris sp.		X
	Pelocoris sp.		X
	Rhagovelia obesa		X
	Trichocorixa macroceps		X
Megaloptera	*Corydalus cornutus*	X	X
	Nigronia serricornis	X	
	Sialis sp.		X
Plecoptera	*Allocapnia sp.*	X	
	Haploperla brevis	X	
	Paragnetina fumosa	X	
	Paraleuctra sara	X	
	Taeniopteryx metequi	X	X
	Taeniopteryx sp.	X	

Table 4-7. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Fourmile Branch - continued

Class or order	Lowest practical taxa	HD	NS
Trichoptera	*Anisocentropus pyraloides*		X
	Cernotina sp.	X	X
	Cernotina spicata	X	
	Cheumatopsyche sp.	X	X
	Chimarra aterrima	X	
	Hydropsyche betteni	X	X
	Hydropsyche venularis	X	
	Limnephilidae sp.	X	
	Lype diversa	X	
	Micrasema wataga		X
	Molanna uniophila		X
	Oecetis georgia		X
	Oecetis sp.	X	X
	Oxyethira sp.	X	X
	Phylocentropus		X
	Ptilostomis sp.	X	X
	Triaenodes ssp.	X	X
Lepidoptera	*Parapoynx obscuralis*		X
Coleoptera	*Agabus/Ilybius*	X	
	Ancyronyx variegatus	X	X
	Berosus nr. exiguus		X
	Berosus sp.		X
	Celina		X
	Coptotomus sp.	X	
	Dineutus discolor		X
	Dineutus sp.		X
	Dubiraphia bivittata		X
	Dubiraphia sp.		X
	Ectopria sp.		X
	Hydroporus sp.	X	X
	Macronychus glabratus	X	X
	Microcylloepus pusillus		X
	Peltodytes sp.		X
	Stenelmis crenata	X	
	Stenelmis sinuata		X
	Stenelmis sp.	X	X

Table 4-7. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Fourmile Branch - continued

Class or order	Lowest practical taxa	HD	NS
Diptera	*Ablabesmyia mallochi*	X	X
	Ablabesmyia nr. peleensis		X
	Ablabesmyis peleensis		X
	Chironomus sp.	X	X
	Clinotanypus pinguis		X
	Conchapelopia sp.	X	X
	Conchapelopia/Meropelopia	X	
	Corynoneura nr. taris	X	X
	Corynoneura sp.	X	
	Corynoneura sp. 2	X	
	Cricotopus bicinctus	X	X
	Cricotopus fugax		X
	Cricotopus tremulus gp.		X
	Cryptochironomus fulvus gp.	X	
	Crysops sp.	X	X
	Culex sp.	X	X
	Dicrotendipes nr. neomodestus	X	X
	Hemerodromia sp.	X	
	Hydrobaenus sp.	X	
	Kiefferulus dux	X	
	Labrundinia pilosella	X	
	Limoninae sp.	X	
	Microtendipes pedellus	X	
	Nanocladius sp.		X
	Nanocladius sp.	X	
	Orthocladius (Euorthocladius)		X
	Orthocladius annectens		X
	Orthocladius nr. carlatus		X
	Orthocladius obumbratus		X
	Orthocladius sp.	X	
	Palpomyia lineata		X
	Parachironomus monochromus		X
	Parakiefferriella sp.	X	X
	Paramerina sp.		X
	Parametriocnemus lundbecki	X	
	Paratanytarsus sp.	X	X
	Phaenopsectra flavipes	X	X
	Pilaria sp.		X
	Polypedilum aviceps	X	X

Table 4-7. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Fourmile Branch - continued

Class or order	Lowest practical taxa	HD	NS
Diptera – (cont)	*Polypedilum fallax*	X	X
	Polypedilum halterale	X	X
	Polypedilum illinoense	X	X
	Procladius sp.		X
	Psectrocladius elatus		X
	Pseudochironomus sp.		X
	Pseudorthocladius sp.		X
	Rheocricotopus robacki	X	X
	Rheotanytarsus distinctissimus gp.	X	X
	Rheotanytarsus exiguus gp.		X
	Simulium nr. tuberosum	X	X
	Simulium nr. venustum	X	X
	Simulium nr. verecundum	X	X
	Simulium sp.	X	
	Simulium vittatum complex	X	
	Stenochironomus sp.		X
	Tanypus punctipennis		X
	Tanytarsus sp.	X	X
	Tanytarsus sp. 3		X
	Thienemanniella fusca gp.	X	
	Thienemanniella lobopodema		X
	Thienemanniella xena gp.	X	X
	Tipula (Yamatotipula)		X
	Tipula sp.		X
	Tribelos jucundum		X
	Tvetenia discoloripes gp.	X	X
	Tvetenia vitracies		X
	Zavrelimyia	X	X

4.4.6.2.2 Macroinvertebrate Community During Operation of C-Reactor

4.4.6.2.2.1 Nonthermal Areas

Station 12 was located at Road A-7 upstream from the discharge of thermal effluent into Fourmile Branch. Macroinvertebrate data collected from Hester-Dendy multiplate samplers indicate that this station was similar to other nonthermal SRS streams with respect to density of organisms, biomass, average number of taxa, and total number of taxa collected. Dominant taxa at Road A-7 included leeches (Hirudinea), the mayfly *Stenonema modestum*, blackflies, tanytarsine and orthoclad chironomids, and several species of hydropsychid caddisflies. The taxonomic composition of the Station at Road A-7 differed from most other nonthermal stream stations sampled during the CCWS in that it was overwhelmingly dominated by filter-feeders. The domination of filter-feeders makes Station 12 most similar to the macroinvertebrate communities found downstream from L Lake and Par Pond. Fourmile Branch receives nutrient inputs from several small sanitary wastewater treatment plants and nitrogen inputs from the F- and H-Area seeplines. The creek also supports numerous beavers, which dam the creek. It is likely that ponding from beaver activity occurred upstream from Station 12 and that the nutrient inputs from SRS sources stimulated algal production, which resulted in an abundant source of food for filter-feeding macroinvertebrates.

4.4.6.2.2.2 Thermal Areas

During reactor operation, few macroinvertebrates were found in the water column of Fourmile Branch. Only a few species of oligochaetes, nematodes, and chironomids survived deep in the sediments. During reactor outages, the thermal portion of the stream quickly was colonized by several species of mayflies, caddisflies, and beetles. Gastropods also were collected at the thermal stations during reactor outages. The gastropods probably moved into the main channels of the creek from cooler side channels. Thus, the resident number of taxa, density of organisms, and biomass during reactor operation were much lower than suggested.

4.4.6.2.2.3 Creek Mouth

During reactor operation, water temperatures in the mouth of Fourmile Branch were always at least several degrees warmer than the Savannah River, except when the creek was flooded by high river levels. During reactor operation, water temperatures in the creek mouth exceeded 35°C (95°F) beginning in May and approached 40°C (104°F) in July. The macro-invertebrate community in the mouth of Fourmile Branch was far more diverse than that of the delta, but still exhibited strong evidence of thermal perturbation. The community was dominated by dipterans (primarily chironomids). Some species, such as *Hyalella azteca* (Amphipoda) and *Caenis* spp. (Ephemeroptera), were abundant during the winter and spring. *Physella heterostropha* (Gastropoda) was abundant from January to April, especially on the multiplate samplers positioned near the creek bottom. From June to October, densities of all macroinvertebrates were low and the fauna consisted mostly of *Cheumatopsyche* spp. (Trichoptera), *Simulium* spp. (Diptera), and Nematoda. When river levels were high and the Savannah River swamp was flooded, the number of taxa and densities increased on multiplate samplers in the mouth of Fourmile Branch. When compared to the mouths of the other four creeks that drain SRS, Fourmile Branch had far lower mean densities, taxa richness, and biomass.

4.4.6.2.3 Recovery of Macroinvertebrate Community After Shutdown of C Reactor

4.4.6.2.3.1 Introduction

A smaller mesh size (#106) was used in the recovery study than in the CCWS (#600 mesh size). Therefore, density estimates from the recovery study are not directly comparable to density estimates from the CCWS. The smaller mesh size was used to collect very early instars of macroinvertebrates that might otherwise be missed by conventional sampling.

4.4.6.2.3.2 Recolonization

Following the shutdown of C Reactor in June 1985, macroinvertebrates rapidly colonized the stream. Within two months of shutdown, macroinvertebrate taxa richness in Fourmile Branch (mean of 20 taxa/sampler) was comparable to that of nonthermal SRS streams sampled during the CCWS (19.7-25.9 taxa/sampler). In subsequent months, the number of taxa collected was variable, but increased slightly over time, to about 23 taxa/sampler when sampling ended in September 1987. Mean densities of macroinvertebrates were low during the first few weeks after reactor shutdown. However, in July 1985 densities increased sharply and peaked at 23,631 organisms/m^2, which was the highest density reported during the recolonization study.

4.4.6.2.3.3 Taxa Collected

The dominant organisms found during the first months of recovery were Orthocladiinae, Tanytarsini, and other chironomid early instar larvae, which accounted for up to 98.8% of the macroinvertebrates collected. Chironomids are often among the first colonizers of aquatic habitats that have been severely stressed. These data indicate that recolonization of Fourmile Branch following reactor shutdown was rapid for certain groups of aquatic insects. Other insects, such as caddisflies and mayflies, were somewhat slower to colonize, but still were present in relatively large numbers within two months of reactor shutdown. Mean macroinvertebrate biomass was similar to nonthermal streams within a month of reactor shutdown, and the distribution of biomass in functional groups was similar to most nonthermal streams at SRS.

4.4.6.2.4 Macroinvertebrate Community After Long-Term Shutdown of C Reactor

4.4.6.2.4.1 1993

Three of the six stations sampled in 1993, (at Roads 4, A-7, and A-13.2) had relatively high numbers of taxa (ranging from 46 to 52) and high mean numbers of taxa per sampler (ranging from 20.2 to 32.2). Two of the remaining stations (at Road E-1 and C-4) had somewhat lower values for these parameters, while the macroinvertebrate community at Road C was extremely depauperate with only five taxa collected. The macroinvertebrate community was dominated by chironomids at most stations. Ephemeroptera (mayflies) were the most abundant group at the Road A-13.2 station, which is downstream of all the outfalls and in the section of the stream that received thermal effluent. Collector-filterers, which feed on suspended organic matter were common at both Road A-13.2 (29.7% of the functional groups) and Road A-7 (35.7%) stations.

The source of perturbation at Road C appears to be low dissolved oxygen concentrations. Dissolved oxygen levels at that station were extremely low at the time of sample collection (0.8mg/l) and are probably responsible for the poor macroinvertebrate community at this location. Contrast these data with data from 1994, when dissolved oxygen concentration at the time of collection was 4.7 mg/l, still the lowest from all the creeks sampled, but not so low as to preclude the survival of macroinvertebrates. The macroinvertebrate data from 1993 indicate that the quality of the stream appears to improve with downstream distance (Specht 1994b).

4.4.6.2.4.2 1994

In 1994, 55 taxa were collected in Fourmile Branch at Road C and 48 taxa at Road A-13.2. Mean number of taxa per sampler was 27.6 at Road C and 30.6 at Road A-13.2. Biomass was 0.0904 g/m^2 at Road C and 0.3176 g/m^2 at Road A-13.2. Tanytarsii (41%), oligochaetes (13%), Tanypodinae (14%), and Chironomini (11%) dominated the macroinvertebrate community at Road C. At Road A-13.2, Ephemeroptera (45%), Tanytarsini (20%), and Trichoptera (13%) were the most common organisms. Collector-gatherer was the most common functional feeding group at both locations. The macroinvertebrate community at Road C underwent substantial recovery between 1993 and 1994 (Specht and Paller 1995).

4.4.7 Fish

4.4.7.1 Introduction

4.4.7.1.1 Classifying Studies

Fish studies in Fourmile Branch can be classified temporally into three phases. The earliest phase (prior to 1980) was descriptive and nonquantitative. Results of this work are summarized in a list of species and their relative abundances in Fourmile Branch and other riverine ecosystems (Bennett and McFarlane 1983), which is not discussed further.

4.4.7.1.2 Assessment of Thermal Impacts

The second and most extensive phase (1983-1985) concentrated on the assessment of impacts caused by the thermal discharges from C Reactor. Fourmile Branch was sampled at various locations, including the ambient temperature section of the stream above C Reactor, the section below C Reactor, and the section that flowed through the Savannah River floodplain swamp (Figure 4-17). These studies focused on distribution and relative abundance, reproduction, and habitat use.

4.4.7.1.3 Assessment of Potential Impacts from Contaminants

The third phase of work (performed in 1990) was undertaken to assess potential impacts to fish communities associated with contaminants outcropping from the waste disposal sites in F and H Areas. The latter work also documented the changes that have occurred in the Fourmile Branch fish community since C Reactor operations were terminated in 1985. The following discussion summarizes the second and third phases of fisheries work.

01 headwaters
02 Road 4
03 Road C
04 Road A-7
05 Road 3
06 Road A
07 Road A-13.2
08 Delta
09 swap
10 swamp
11 swamp
12 creekmouth

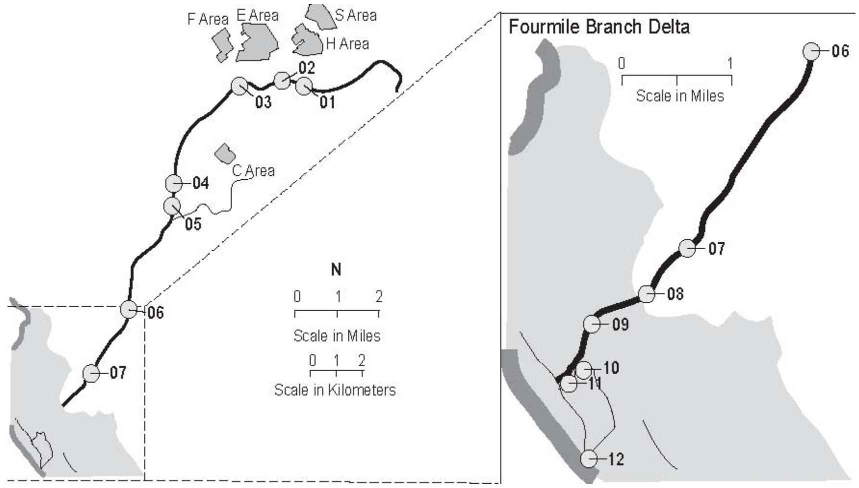

Figure 4-17. Fish Sampling Stations on Fourmile Branch

4.4.7.2 C-Reactor Operations

4.4.7.2.1 <u>Fish Movements in Relation to Reactor Operation</u>

4.4.7.2.1.1 Introduction

Fish were observed to enter the lower reaches of Fourmile Branch (i.e., the portion of Fourmile Branch that runs through the SRS Savannah River floodplain swamp) during reactor outages. These movements were studied by Aho et al. (1986) in Fourmile Branch and a similar section of Pen Branch. This work was conducted from September 1983 to December 1985 and involved collections made with fyke nets near the mouths and in the lower swamp reaches of both creeks. The sampling periods encompassed 3 and 16 outages of C and K Reactors, respectively.

4.4.7.2.1.2 Methods

Fyke nets were placed in the stream channels one to two days before the outage. Thereafter, the nets were checked daily for the presence of fish until reactor restart. During periods when heated effluents were being released into either Fourmile Branch or Pen Branch, fish use was minimal. Fish never were captured in the fyke nets, and the resident fish assemblage was depauperate, dominated by the eastern mosquitofish (>90% numerical abundance). Following a cessation in reactor production activities and a return to seasonally ambient water temperatures, fish were observed moving upstream from the Savannah River swamp system into both streams.

4.4.7.2.1.3 Seasonal Variation

The use of these upstream swamp habitats by fish varied seasonally. Timing of fish movement was comparable among years with the least upstream movement during the winter. Greatest movement occurred during spring and early summer, and intermediate levels of stream use occurred during summer and fall. Fish moved into the creeks predominantly along the streambank, but high catches occurred in mid-channel nets on several occasions during the summer and fall. Declining water levels and a return to ambient temperatures across the width of the stream associated with a reactor outage reduced the importance of the streambank route to upstream migrants.

4.4.7.2.1.4 Reactor Shutdown

Reinvasion of fish into the stream channels was rapid, with individuals captured within 12 hours of the cessation of reactor operations. There was no single pulse of upstream movement after the streams returned to ambient water temperatures and reduced discharge rates. Recolonization was variable for the duration of the shutdown.

4.4.7.2.1.5 Movement

Fish released following capture and later recaptured showed that several species made movements of 3-5 km (1.8-3.1 mi) within a week of their release. Fish that moved away from the original point of capture moved downstream, made local movements, or shifted laterally within the stream. Local movement was defined as recapture of the same fish at the same net within the same reactor cycle.

4.4.7.2.1.6 Upstream Migration

A dam approximately 1 km (0.6 mi) above the nets limited upstream migration within Fourmile Branch. Additionally, a nearby backwater served as a limited refuge area when water temperatures were high (McFarlane 1976). Observations during reactor outages revealed that the dam provides a barrier to the upstream migration of fish independent of reactor operation.

4.4.7.2.1.7 Species Collected

Totals of 39 and 29 species of fish were collected from the Fourmile Branch and Pen Branch channels (Aho et al. 1986), respectively. Table 4-8 lists species of fish taken in surveys of Fourmile Branch. Centrarchids (sunfishes and basses) were the most abundant taxa, more than 30% of the species. Four species (spotted sunfish [*Lepomis punctatus*], lake chubsucker [*Erimyzon sucetta*], golden shiner [*Notemigonus crysoleucas*], and redbreast sunfish [*Lepomis auritus*]) accounted for more than 50% of the fish entering the stream channels. Individuals caught moving into the stream included both juveniles and adults. Cyprinids, principally the coastal shiner *(Notropis petersoni*), and eastern mosquitofish *(Gambusia holbrooki*), frequently were observed in the streams during periods of ambient conditions. Their absence from the collection reflects a sampling bias of the nets against small fishes.

4.4.7.2.1.8 Effects of Reactor Restart

The number of fish killed when thermal conditions were reestablished was low compared to the cumulative number that moved upstream during ambient water temperature conditions. Visual observations suggested that fish responded to the increased flow rates and release of heated effluents associated with a reactor restart by moving downstream into the Savannah River floodplain swamp. Some potential refuge areas existed along the stream margin (e.g., marshes and isolated groundwater seepage zones), but were either ephemeral or too small to provide sufficient shelter for the number of fish that migrated upstream during reactor outages.

Table 4-8. Fish Collected from Fourmile Branch

Family	Common Name	Scientific Name
Anguillidae	American Eel	*Anguilla rostrata*
Cyprinidae	Whitefin Shiner	*Cyprinella nivea*
	Rosyface Chub	*Hybopsis rubifrons*
	Bluehead Chub	*Nocomis leptocephalus*
	Golden Shiner	*Notemigonus crysoleucas*
	Ironcolor Shiner	*Notropis chalybaeus*
	Dusky Shiner	*Notropis cummingsae*
	Spottail Shiner	*Notropis hudsonius*
	Yellowfin Shiner	*Notropis lutipinnis*
	Coastal Shiner	*Notropis petersoni*
	Lowland Shiner	*Pteronotropis hypselopterus*
	Creek Chub	*Notropis atromaculatus*
Catostomidae	Creek Chubsucker	*Erimyzon oblongus*
	Lake Chubsucker	*Erimyzon sucetta*
	Spotted Sucker	*Minytrema melanops*
Ictaluridae	Yellow Bullhead	*Ameiurus natalis*
	Brown Bullhead	*Ictalurus nebulosus*
	Flat Bullhead	*Ameiurus platycephalus*
	Tadpole Madtom	*Noturus gyrinus*
	Margined Madtom	*Noturus insignis*
	Speckled Madtom	*Noturus leptacanthus*
Esocidae	Redfin Pickerel	*Esox americanus*
	Chain Pickerel	*Esox niger*
Umbridae	Eastern Mudminnow	*Umbra pygmaea*
Aphredoderidae	Pirate Perch	*Aphredoderus sayanus*
Fundulidae	Lined Topminnow	*Fundulus lineolatus*
Poeciliidae	Eastern Mosquitofish	*Gambusia holbrooki*
Atherinopsidae	Brook Silverside	*Labidesthes sicculus*
Centrarchidae	Mud Sunfish	*Acantharcus pomotis*
	Bluespotted Sunfish	*Enneacanthus gloriosus*
	Redbreast Sunfish	*Lepomis auritus*
	Green Sunfish	*Lepomis cyanellus*
	Warmouth	*Lepomis gulosus*
	Bluegill	*Lepomis macrochirus*
	Dollar Sunfish	*Lepomis marginatus*
	Spotted Sunfish	*Lepomis punctatus*
	Largemouth Bass	*Micropterus salmoides*
Percidae	Savannah Darter	*Etheostoma fricksium*
	Tesselated Darter	*Etheostoma olmstedi*
	Sawcheek Darter	*Etheostoma serrifer*
	Blackbanded Darter	*Percina nigrofasciata*

4.4.7.2.2 Fish Assemblages at Thermal Swamp Sites

4.4.7.2.2.1 Introduction

Aho et al. (1986) also studied the fish assemblage structure within the Savannah River swamp system. Four sites (FMl, FM2, FM3, and FM4) were in or near the flow path of Fourmile Branch (original text has descriptions of locations). A total of 11,996 individuals representing 51 species were collected by electrofishing during the study. The vast majority of species were categorized as year-round residents. However, two species (hickory shad [*Alosa mediocris*] and striped mullet [*Mugil cephalus*]) were migratory. Centrarchids and cyprinids represented more than 40% of the taxa and individuals.

4.4.7.2.2.2 Faunal Groups

Although the more common species occurred throughout the Savannah River swamp system, a cluster analysis based on relative abundance provided evidence of spatial variation (Figure 4-18). Eight major faunal group clusters were formed. The four sites within Four-mile Branch grouped together, along with the three sites associated with Stave Island (downstream of Fourmile Branch in the Savannah River Swamp) and one site in Steel Creek. Temporal variability in assemblage composition was minor compared to spatial differentiation of the groupings. In the majority of cases (>70%), the seasonal censuses from the same site (spring, summer, and fall) fell within the same cluster.

4.4.7.2.2.3 Dominant Species in Faunal Groups

While no cluster had a unique fish fauna, cross classifying the clusters with the dominant fish species (those contributing at least 5% of the numerical size of a faunal group) highlighted basic compositional differences between the different groups. Large-bodied species, such as the bowfin (*Amia calva*), gizzard shad (*Dorosoma cepedianum*), longnose gar (*Lepisosteus osseus*), and largemouth bass (*Micropterus salmoides*) were the dominant species of the depauperate Group A assemblage, which included the Fourmile Branch sites. Largemouth bass, brook silversides (*Labidesthes sicculus*), longnose gar, and cyprinids also were identified as common species. For the remaining faunal clusters, the species assemblage had greater representation by minnows and centrarchids. Groups C through E represented a shift in general body shape from large-bodied to an assemblage dominated by small-bodied fishes.

4.4.7.2.2.4 Spatial Differentiation

The spatial differentiation in assemblage structure corresponded to two major habitat gradients within the Savannah River swamp system. Faunal cluster A was most closely linked with sites that had high water temperatures. Areas experiencing high levels of thermal loading had depauperate assemblages dominated by eastern mosquitofish when water temperatures were elevated, but were rapidly reinvaded when ambient temperature conditions returned. The second gradient involved different degrees of canopy closure.

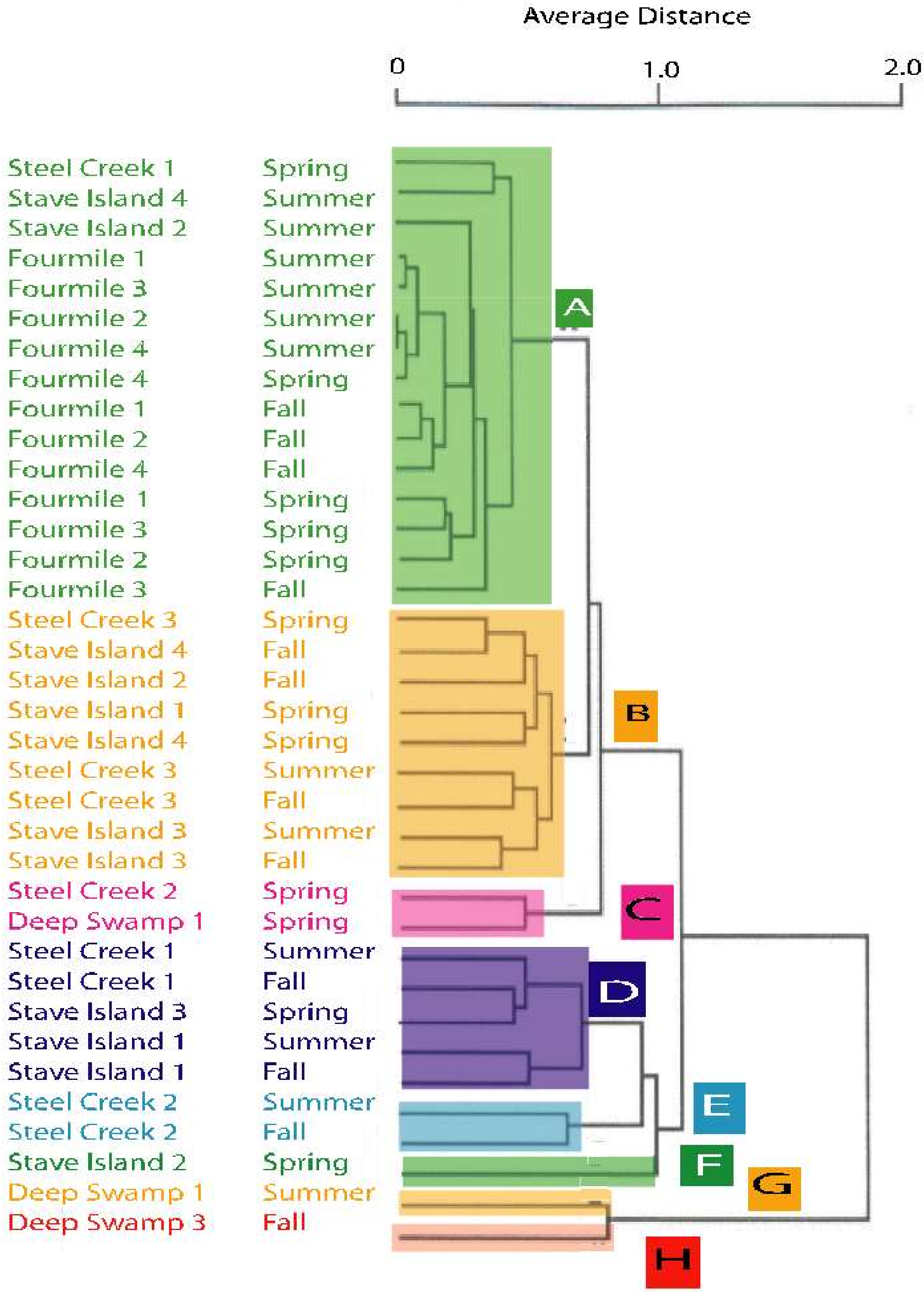

Figure 4-18. Average Linkage Cluster Analysis of the Fish Assemblage Structure from Collections from Twelve Sites During Three Seasons in the Savannah River Swamp System (Data from Aho et al. 1986)

Faunal Cluster B was associated with sites characterized as having a predominantly closed overstory of cypress and tupelo, limited emergent macrophyte growth, and low habitat complexity; open water and standing tree buttresses were the dominant habitat features. The number of species was moderate compared to other groups, but abundance was low and dominated by taxa commonly associated with less structured habitats. Open canopy, braided water courses with periodically high flow rates, and high habitat diversity with extensive macrophyte growth and downed timber characterized faunal clusters C through H and included sites where the canopy had been lost as a result of prior disturbances. Species associated with structurally complex habitats dominated these groups. Subtle elevations in water temperature at sites near Stave Island (SI2, SI3, and SI4) did not appear to additionally influence assemblage structure for either open or closed canopy groups.

4.4.7.2.2.5 Effects of Canopy Cover

Several factors may have contributed to the difference in species richness and abundance between open- and closed-canopy areas. The occurrence of macrophyte growth can affect fish-assemblage dynamics by providing a refuge from predators (Werner and Hall 1979; Werner et al. 1983; Keast 1978). Macrophytes also may influence the availability of food resources by increasing the amount of substrate for secondary productivity of aquatic invertebrates, the dominant prey category for most of the fishes in the Savannah River swamp system.

4.4.7.2.3 <u>Fish Assemblages at Thermal Swamp Sites</u>

4.4.7.2.3.1 Upstream of C Reactor

Paller et al. (1986) electrofished Fourmile Branch above C Reactor (at SRS Road A-7) on six dates and identified 20 taxa. Minnows were the most numerically abundant taxon followed by redbreast sunfish, spotted sunfish (*Lepomis punctatus*), and pirate perch (*Aphredoderus sayanus*). These taxa were also among the most numerous species in the undisturbed upper coastal plain streams of South Carolina as determined by Meffe and Sheldon (1988).

4.4.7.2.3.2 Downstream of C Reactor

No attempts were made to collect adult or juvenile fish in the portion of Fourmile Branch immediately below C Reactor. It is assumed that this area was devoid of fish when C Reactor was operating (except for some possible short-term migration of fish into this area during reactor outages) because average monthly temperatures during C-Reactor operation exceeded 50°C (122°F) throughout the year.

Paller and Saul (1986) studied fish communities in SRS streams between November 1984 and August 1985. Sampling stations for this study included sites near Road A and Road A-13.2, where electrofishing was scheduled quarterly. The observations from the study by Paller and Saul (1986) indicate that only eastern mosquitofish inhabited the portion of Fourmile Branch below the C Reactor outfall during reactor operation. However, when C Reactor shut down, sunfish migrated into the area according to the findings of Aho et al. (1986) discussed earlier.

4.4.7.2.3.3 Effects of Cool Water

Paller and Saul (1986) collected additional samples in the lower reaches of Fourmile Branch (February 21, 1985). They sampled fish on one occasion (February 21, 1985) in the Fourmile Branch delta using a backpack electroshocker. Collections were taken from relatively cool backwater areas during a period of reactor operation. Only one specimen, a brook silverside, was captured. Eastern mosquitofish were observed in the cooler portions of the Fourmile Branch delta on numerous occasions when C Reactor was operating. Thus, eastern mosquitofish were undoubtedly year-round residents of portions of the delta.

4.4.7.2.3.4 Effects of Reactor Operation

Paller and Saul (1986) electrofished the mouth of Fourmile Branch on 15 occasions. Eleven taxa were represented. They found that few or no fish were present when C Reactor was operating and water temperatures were elevated, but that fish rapidly reinvaded the area during reactor outages.

4.4.7.2.4 Ichthyoplankton Distribution

4.4.7.2.4.1 Introduction

Paller and Saul (1986) also collected ichthyoplankton from seven sampling stations on Fourmile Branch during 1984 and 1985. One station was situated near Road A-7 in the undisturbed headwaters upstream from the confluence with the reactor cooling water effluent. One station was at Road A, approximately 8 km (5 mi) downstream from C Reactor, one at the inflow into the delta, three in the thermal swamp downstream from the delta, and one in the creek mouth (Figure 4-17). The three thermal swamp stations were grouped together in the following analysis because they had similar habitats and temperatures. Table 4-9 summarizes taxa taken during surveys of icthyoplankton with stream and swamp data separated.

4.4.7.2.4.2 Effects of Reactor Operation

A total of 206 ichthyoplankton was collected from Fourmile Branch between March 14 and July 31, 1984. Centrarchids were the most abundant taxa, although brook silverside and blueback herring (*Alosa aestivalis*) were also well-represented.

C Reactor was operating at full power throughout April and May 1984, and operation was intermittent during March. As a result, temperatures at Road A ranged from 33.9 to 40.l°C (93-104°F), and temperatures at the inflow into the delta ranged from 30.1 to 44.8°C (86.1-112.6°F) during the spring spawning season of 1984. Ichthyoplankton were absent from these sites with the exception of some brook silverside eggs and unidentifiable eggs collected from the Road A sample site in May 1984. These eggs probably drifted into the channel of Fourmile Branch from cooler side-channel waters (Paller 1985).

4.4.7.2.4.3 Thermal Variation in Swamp

Temperatures in the Fourmile Branch thermal swamp and creek mouth ranged from 18 to 42°C (64.4 to 107.6°F), and were lower and much more variable than at the inflow into the Fourmile Branch delta and at the Road A sample stations. The temperature variability in the thermal swamp was due to the intermittent intrusion of relatively cool river water during periods of high water in the Savannah River. During these periods, the river water displaced the thermal plume and created suitable habitats for fishes in normally hot areas. Most of the larvae collected from the Fourmile Branch thermal swamp during April and May 1984 were spawned during periods of high river water levels when the swamp was inundated with cool river water. These larvae were principally centrarchids, but also included blueback herring and threadfin or gizzard shad (*Dorosoma* spp.). Some larvae also were collected when temperatures were relatively high (37°C [98.6°F]) in mid-April 1984. These larvae may have drifted into the main swamp channels from the cooler backwater areas (Paller 1985).

A total of 174 ichthyoplankton was collected from Fourmile Branch between February and July 1985. Unidentified ichthyoplankton (primarily eggs) were most common. Mean densities of ichthyoplankton upstream from C Reactor were generally low (<15/ 1000 m^3), and most of the organisms collected were minnows or centrarchids. Throughout the sampling, ichthyoplankton were largely absent from the sample station near Road A, where water temperatures sometimes exceeded 40°C (104°F) when C Reactor was operating. Farther downstream in the delta, some cooling had occurred, but temperatures still remained near 40°C (104°F) during much of the sampling.

Table 4-9. Ichthyoplankton Taxa Found in Fourmile Branch

Family	Taxa
Clupeidae	*Alosa aestivalis*, blueback herring
	Alosa sapidissima, American shad
Cyprinidae	Unidentified minnows
Catostomidae	*Minytrema melanops*, spotted sucker
Atherinopsidae	*Labidesthes sicculus*, brook silverside
Centrarchidae	*Lepomis* spp., bream
	Unidentified sunfish
	Pomoxis sp., crappie
Percidae	Unidentified darters

4.4.7.2.4.4 Mouth of Fourmile Branch

No larvae or eggs were collected from the mouth of Fourmile Branch except in February, March, and May 1984. The ichthyoplankton densities in the mouth of Fourmile Branch were greatest in May. All of the ichthyoplankton collected during May were unidentifiable eggs. They were taken on a single sample date when C Reactor was briefly shutdown and the water temperature was 27°C (80.6°F). These data suggest that fish began spawning in the creek mouth as soon as temperatures became tolerable (Paller 1985).

4.4.7.2.4.5 Comparison of 1984 and 1985 Data

Except for the densities at the creek mouth, ichthyoplankton were less abundant in Fourmile Branch during 1985 than during 1984. The differences in the swamp and creek mouth ichthyoplankton densities probably were due to differences in the level of the Savannah River during those years. During the spring of 1984, the swamp was intermittently flooded by cool river water (Paller 1985). Most of the larvae taken from the swamp during 1984 were collected when the swamp was flooded. Conversely, the Savannah River generally remained below flood stage during 1985, and relatively few ichthyoplankton were collected from Fourmile Branch.

4.4.7.2.4.6 Effects of Temperature on Ichthyoplankton

Introduction - Aho et al. (1986) studied larval fish assemblages at nine sampling locations in the Savannah River swamp system during 1985. Five stations spanned a wide range of temperatures (temperatures elevated 2-19°C [7.2-34°F] above ambient) along the plumes from Fourmile Branch and Pen Branch. These were numbered 1 through 5, from hottest to coolest. The other four stations near the mouth of Steel Creek were at ambient temperatures (Aho [1986] has a description of station locations). Each sampling station was an area roughly 50 m (164 ft) in diameter and included both channels and adjacent shallows (except two stations that had no distinct channels).

Effect of Reactor Operation - At stations within the thermal plumes, water temperatures changed suddenly when reactors stopped and started. During these reactor cycles, recording thermometers showed temperatures fell to ambient levels (and subsequently rose) at about 1°C (1.8°F)/hr at the Fourmile Branch stations. Stations 4 and 5 had more gradual temperature changes due to their distances from the main flow from Pen Branch. The most extreme fluctuations among the nonthermal sites occurred at the station in a shallow disturbed area that lacked canopy vegetation, where temperatures changed 20°C (36°F) over two weeks in February.

No larvae were collected in the first week of January at any location, although water temperatures exceeded l5°C (59°F) in the hottest thermal areas. Densities began to rise at thermal Stations 1 through 3 by the end of January. In the ambient temperature areas, density peaks occurred later in the year.

Densities - The timing of peak ichthyoplankton densities differed by as much as eight weeks between the hottest thermal area and the ambient temperature stations. Seasonal patterns were advanced, even at Station 5, where temperatures were only about two degrees warmer than in the natural or previously disturbed habitats.

Maximum densities occurred two to four weeks earlier in the previously disturbed areas, where canopy trees had been killed, than in the natural areas; although water temperatures were similar.

4.4.7.3 F-and H-Area Impacts

4.4.7.3.1 Introduction

Paller and Storey (1990) electrofished Fourmile Branch during June 26-July 2, 1990, to assess the impacts of outcropping groundwater from the F-and H-Area seepage basins on fish abundance and distribution. Effluents formerly discharged to the basins contained sodium hydroxide, nitric acid, low levels of radionuclides (mostly tritiated water), and dissolved metals (Looney et al. 1988, Haselow et al. 1990). These effluents seeped into the ground, migrated through the subsurface strata, and outcropped into Fourmile Branch and adjacent wetlands. Seepage basin discharge appeared to cause elevated conductivity, total dissolved solids, nitrate, phosphate, sodium, potassium, and, possibly, cadmium levels in Fourmile Branch downstream from the seepage basins (Looney et al. 1988). In addition, gross beta and tritium levels were above either the proposed or established drinking water standards at one or more points in Fourmile Branch (Haselow et al. 1990).

4.4.7.3.2 Effects of Seepage Basin Constituents on Fish

The occurrence of elevated levels of several seepage basin constituents in Fourmile Branch water raised concerns about possible impacts to aquatic organisms. Gladden et al. (1985) reviewed the historical data from the upper reaches of Fourmile Branch to determine if outcropping effluent from the seepage basins was adversely affecting the instream communities. They concluded that there was no clear evidence of adverse impacts due to the seepage basin effluent, but said the data were insufficient to evaluate possible local effects. To provide more information, a sampling program was designed to assess the abundance, distribution, and tissue contaminant levels of Fourmile Branch fish upstream and downstream from the seepage basins. This program included seven sample stations: six in Fourmile Branch, including locations upstream from (Stations 1 and 2) and downstream from (Stations 3 - 6) the seepage basins, and one in Pen Branch (Figure 4-17). The sample station in Pen Branch was included primarily to serve as a source of uncontaminated fish to establish background levels of potential tissue contaminants. Three 100-m (328 ft) stream segments were electrofished at each sample station.

4.4.7.3.3 Sampling Program

Fish assemblage structure differed among sample stations. Pirate perch, redbreast sunfish, and creek chubsuckers (*Erimyzon oblongus*) dominated Station 1. Several types of shiners (*Notropis* spp.) (dusky, yellowfin, or taillight) and sunfishes (*Lepomis* spp.) (dollar, spotted, or redbreast) dominated Stations 2-4. Eastern mosquitofish, redbreast sunfish, spotted sunfish, and yellow bullhead dominated Stations 5 and 6. The number of fish collected per 100 m (catch per unit effort or CPUE) also differed among stations. The lowest CPUE in Fourmile Branch occurred at Station 2 (44.7 fish/100 m) and the highest occurred at station 4 (149.7 fish/100 m). However, a comparison of collections at Stations 1 and 2 (above the outcropping zone) with Stations 3 and 4 (below the outcropping zone) indicated that species number and total (i.e., all species summed) CPUE were higher below the outcropping zone than above (Figure 4-19). On an individual species basis, four species decreased below the outcropping zone, while nine increased. These differences were not indicative of adverse impacts due to seepage basin outcropping and were more likely from habitat differences among stations.

4.4.7.3.4 Changes in Fish Assemblage with Habitat Alterations

While not a consequence of seepage basin operation, species number and total CPUE decreased downstream from Station 4. Eastern mosquitofish, a species commonly associated with thermal and post-thermal sites on the SRS (Aho et al. 1986), increased in abundance below Station 4. These changes are likely from habitat alterations associated with past thermal discharge from C Reactor. Decreases in species number and CPUE at these stations indicate that recovery from C Reactor operation was not yet complete at the time of this study.

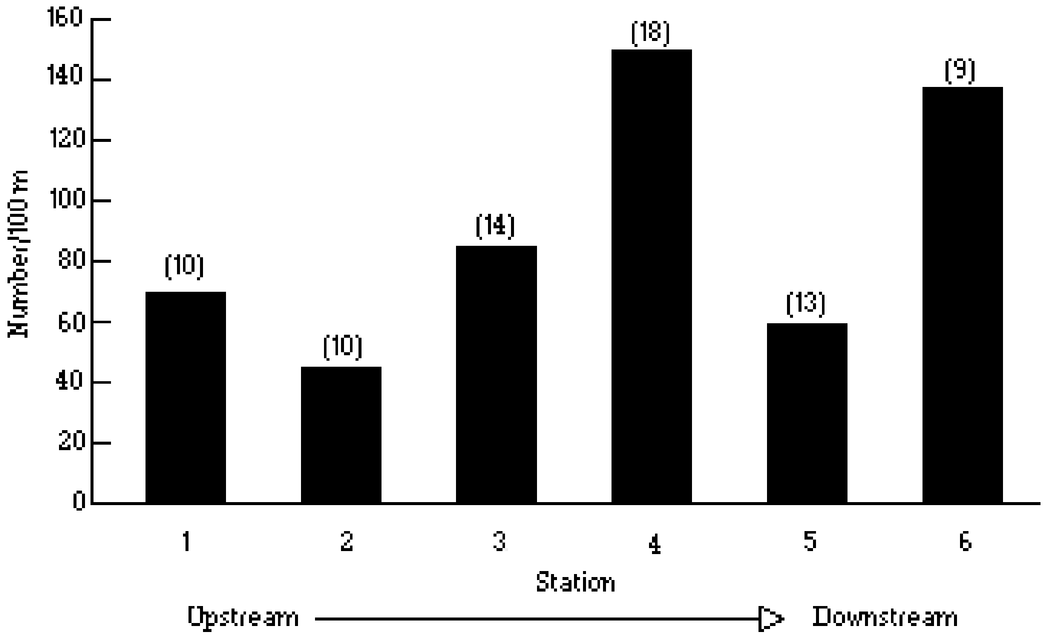

Figure 4-19. Mean Electrofishing Catch per Unit Effort at Sample Stations in Fourmile Branch (Number of species collected is in parentheses)

4.4.7.3.5 Fish Communities Comparison with Unimpacted Streams

The fish community below the outcropping zone, but above the former point of C Reactor cooling water entry, also was evaluated by comparing it to the fish communities in nearby unimpacted streams of similar size and generally similar habitat. Three unimpacted stream reaches (upper Meyers Branch, upper Steel Creek, and upper Pen Branch [Station 7]) were used in this comparison. Species number at Stations 3 and 4 in Fourmile Branch was comparable to species number in the other streams. Relative abundance at Stations 3 and 4 was generally similar to that in the other streams, except that sunfishes constituted a slightly higher percentage of the community and minnows a slightly lower percentage.

4.4.7.3.6 Fish Analysis for RCRA Trace Metals

Fish collected from Fourmile Branch and Pen Branch were analyzed for Resource Conservation and Recovery Act (RCRA) trace metals using standard U.S. Environmental Protection Agency methods. Loehle and Paller (1990) report the results of the analyses. Silver, arsenic, beryllium, cadmium, copper, nickel, lead, antimony, and thallium were all either undetectable or had only a few detectable values. Mercury values were all well below 1 µg/l. For the total group of fish analyzed, there were no differences among sampling sites for aluminum, chromium, or zinc. Selenium concentrations differed among sites; fish collected near the H-Area and two control sites had the highest concentrations. When the analysis was restricted to sunfishes only, the seepage basin site was shown to be slightly elevated. Among species, yellowfin shiners had higher aluminum and zinc concentrations than sunfishes and bottom fish.

4.4.7.3.7 Summary of Studies

These studies provided no indication that outcropping groundwater from the F- and H-Area seepage basins adversely affected the fish community in Fourmile Branch. Because there was an absence of adverse changes in community structure below the outcropping zone, community structure in this region generally was comparable to community structure in other relatively unimpacted SRS streams, and there was no indication of significant accumulation of heavy metals in the fish. However, they do indicate that habitat alterations from past C Reactor operations still were influencing fish community structure in Fourmile Branch at the time of the study.

4.4.7.3.8 Radionuclides in Fish

Paller et al. (1999) examined historical trends in ^{137}Cs in fishes of the SRS. The half-life of ^{137}Cs in fish was much shorter than the radioactive half-life indicating that removal is occurring rather than simple radioactive decay. Ecological half-lives of ^{137}Cs in sunfishes (*Lepomis* spp.) and largemouth bass (*Micropterus salmoides*) in Fourmile Creek are 4.95 (4.63-5.32) years and 4.65 (4.31-5.05) years respectively which is similar to most other sites on SRS for which this information has been calculated.

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4.5 PEN BRANCH

4.5.1 General Description

Pen Branch drains an area of about 55 km^2 (21 mi^2) and is approximately 24 km (15 mi) long. The creek flows southwesterly, from its headwaters about 3.2 km (2 mi) east of K Area to the Savannah River swamp (Figure 4-20). After entering the swamp, the creek flows parallel to the Savannah River for about 8 km (5 mi) before it enters and mixes with the waters of Steel Creek about 0.4 km (0.2 mi) from the mouth of Steel Creek on the Savannah River. In its headwaters, Pen Branch is a largely unperturbed blackwater stream, similar to the headwater reaches of Fourmile Branch. Indian Grave Branch is the principal tributary of Pen Branch.

Pen Branch discharges into the Savannah River floodplain swamp rather than flowing directly into the Savannah River. The discharge of Pen Branch into the swamp formed a delta where water temperatures typically ranged from 25 to 40°C (45 to 72°F) above ambient during reactor operations. The flow from Pen Branch spreads over the delta and continues through the swamp as shallow sheet flow until entering the lower reaches of Steel Creek; from there it travels to the Savannah River. When the Savannah River inundates the floodplain swamp, Pen Branch flows along the northern border of the swamp and crosses the Steel Creek delta. When the Savannah River is not flooding, the Pen Branch flow enters the Steel Creek channel downstream from the swamp. By the time Pen Branch discharged into Steel Creek during reactor operation, its temperature was near ambient, due to dilution and cooling in the swamp.

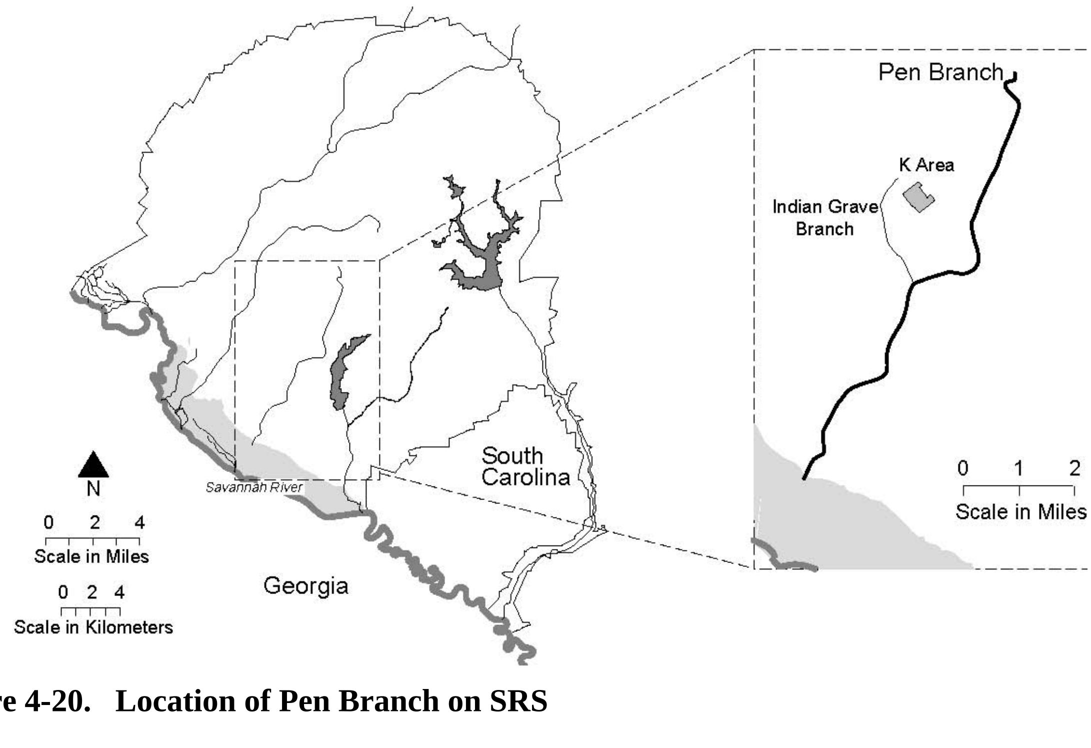


Figure 4-20. Location of Pen Branch on SRS

4.5.2 Effluents Contribution

Until K Reactor shut down in 1988, Indian Grave Branch received thermal effluent from K Reactor. With K-Reactor discharge, the natural flow of about 0.3 m^3/s (10 ft^3/s) was increased to about 11.3 m^3/s (400 ft^3/s). K Reactor cooling water discharges, which originated from the Savannah River, changed the water quality and temperature and flow regimes in Pen Branch (Firth et al. 1986). Currently, the Pen Branch system receives nonthermal effluents (i.e., nonprocess cooling water, ash basin effluent waters, powerhouse waste water, and sanitary waste water) from K Area and sanitary effluent from the Central Shops Area. K Reactor has been placed on permanent shutdown; therefore, flow and temperature will no longer affect the stream.

Pen Branch, via Indian Grave Branch, receives the following National Pollutant Discharge Elimination System (NPDES) permitted discharges: cooling water, blowdown, powerhouse wastewater, stormwater, 186 basin overflow, and sanitary wastewater.

4.5.3 Flow Measurements

The U.S. Geological Survey measured flow at several locations on Pen Branch (Figure 4-21). Records at SRS Road A-13.2 date back to November 1976 (no records from February 1983 through April 1983). In water-year 1995, the mean flow of Pen Branch at Road A-13.2 was 1.6 m^3/s (55.8 ft^3/s). Over the period water-years 1977-1995 at Road A-13.2, the mean flow was 5.9 m^3/s (210 ft^3/s), the 7-day low flow was 0.25 m^3/s (8.8 ft^3/s), and the 7Q10 was 0.15 m^3/s (5.46 ft^3/s). Neither monitoring station is active; the station at Road B has no dta since September 1996 and the one a Road A-13.2 has no data since September 2002.

01 at SRS Road B
02 at SRS Road A-13.2

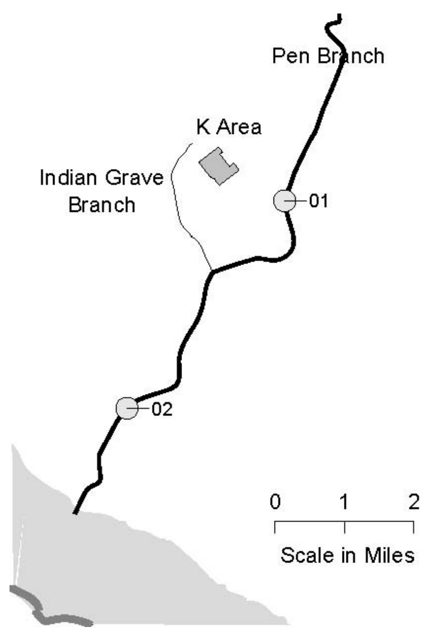


Figure 4-21. Flow Measurement Sampling Stations for Pen Branch

4.5.4 Water Chemistry and Quality

4.5.4.1 Studies and Monitoring

4.5.4.1.1 Water Quality Monitoring

The WSRC Environmental Monitoring Section (EMS) has conducted routine water quality monitoring of the Pen Branch system since 1973. EMS monitors one location on Pen Branch near Road A-17 (Figure 4-22; location 04) monthly for physical and biological water quality indicators and quarterly for metals. EMS also collects an additional sample annually and analyzes it for pesticides, herbicides, and PCBs. All routine water quality monitoring data reported in the following sections can be found in the annual SRS Environmental Reports.

4.5.4.1.2 Comprehensive Cooling Water Study (CCWS)

Five locations on the Pen Branch system were studied from 1983 to 1985 as part of the CCWS. This study was designed to assess present and proposed SRS activities on water quality. The Pen Branch sampling locations (Figure 4-22) include the following:

- Pen Branch at Road B (01) - measured the effects of the effluent from the Central Shops Area
- Indian Grave Branch downstream of K-Reactor Effluent (02) - measured the effects of the thermal effluent
- Pen Branch at Road A-13 (03) - downstream of confluence of Indian Grave Branch and Pen Branch
- Pen Branch at Road A-17 (04) - measured concentrations after release to the Savannah River Swamp
- Pen Branch upstream of Steel Creek confluence (05) - measured thermal effluents and upriver waters during periods of high river water, which overflows into the Savannah River Swamp

The data collected downstream of K-Reactor effluent during the CCWS reflect impacts associated with reactor operation and are not relevant to the current conditions of the stream. However, because limited monitoring data are available for the Pen Branch system, all data will be presented.

Comprehensive results and discussion of CCWS data can be found in Newman et al. (1986) and Lower (1987).

4.5.4.1.3 Priority Pollutants Survey

In 1984, a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral organic compounds in the Pen Branch system. Three stations - near Road C, Road B, and Road A - were established in Pen Branch. Newman et al. (1986) and Lower (1987) documented these results. Lower (1987) also reported the results of analyses for pesticides and PCBs in the Pen Branch system.

01 Road B
02 Downstream of K Reactor effluent
03 Road A-13
04 Road A-17
05 Pen Branch upstream of confluence with Steel Creek
06 Road C
07 Road A

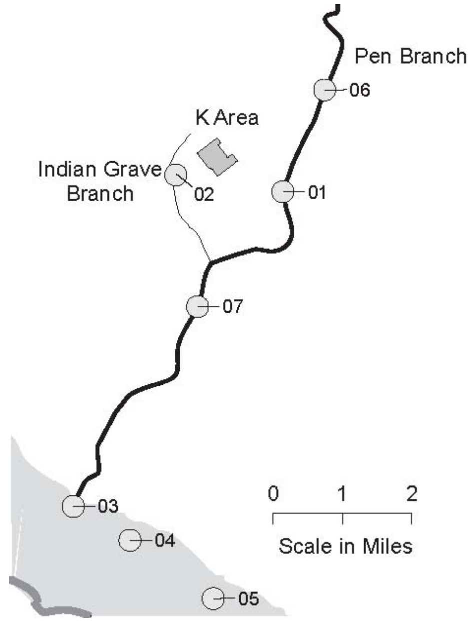


Figure 4-22. Water Chemistry and Quality Sampling Stations for Pen Branch

4.5.4.2 Field Data

4.5.4.2.1 Water Temperature

During reactor operation, mean temperatures in thermal portions of the Pen Branch watershed (33.5 - 48.1°C [95.9 - 118.5°F]) ranged from 18 to 33°C (32 to 59°F) above those of the upstream nonthermal waters (17.4°C [63.3°F]). The temperatures at the thermal sites fluctuated more widely than those of the nonthermal site due to the reactor cycle. The shutdown of K Reactor in 1987 decreased temperatures to an average of 22°C (71.6°F) in the Pen Branch system.

4.5.4.2.2 pH Measurements

The pH values for the thermal sites (mean 7.46) were higher than those of the nonthermal site (mean 6.89), reflecting Savannah River source-water pH levels. Over the past 9 years, the pH near Road A-17 has ranged from 5.7-8.6.

4.5.4.3 Physical Characteristics and General Chemistry

4.5.4.3.1 Dissolved Oxygen

The dissolved oxygen concentration is inversely related to water temperature, reflected in the data the CCWS generated. The mean dissolved oxygen concentrations in the thermal waters were much lower (5.3-7.5 mg/l or 87-90% saturation) than those at the nonthermal site. Mean dissolved oxygen concentration was 8.12 mg/l at the Pen Branch nonthermal site. Because there has been no thermal input to the Pen Branch system since 1987, the mean dissolved oxygen concentrations (8.5 mg/l between 1987 and 1991 and 9.1 mg/l between 1992 and 1995 at Road A-17 have been similar to the concentrations measured at the nonthermal site during the CCWS.

4.5.4.3.2 Suspended Solids and Turbidity

The CCWS measured a wide range of total suspended solids concentrations (mean 3.14-13.9 mg/l). At locations with slower water velocities, the total suspended solids concentrations were lower than at locations with higher water velocities. Data collected from 1987 to 1991 at Road A-17 indicate slightly higher total suspended solids concentrations (mean 7.7 mg/l). Between 1992 and 1995, total suspended solids concentrations were even higher (8.25 mg/l). Turbidity between 1992 and 1995 was about half of what it was during the CCWS (7.08 NTU).

4.5.4.3.3 Conductivity

Mean specific conductivity increased from 45.6 µS/cm at the nonthermal sites to 73.4 µS/cm at the thermal sites. This change was linked to the specific conductance of Savannah River source water (Lower 1987). Routine water quality monitoring since the CCWS has measured a wide range of specific conductance (13-171 µS/cm), with a mean of 77 µS/cm.

4.5.4.4 Major Anions and Cations

4.5.4.4.1 Alkalinity, Chloride, and Sulfate

During the CCWS, mean concentrations of total alkalinity, chloride, and sulfate ranged from 13.8 to 17.9 mg/l, 2.48 to 6.02 mg/l, and 2.53 to 5.26 mg/l, respectively. The maximum total alkalinity, chloride, and sulfate concentrations were measured at the thermal sites and likely reflected the chemistry of the Savannah River water used to cool the reactor. Mean concentrations of total alkalinity (18.2 mg/l), chloride (7.1 mg/l), and sulfate (7.4 mg/l) from 1987 to 1991 have been slightly higher than the ranges measured during the CCWS. Between 1992 and 1995, mean values of chloride, alkalinity, and sulfate were lower still.

4.5.4.4.2 Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, and sodium measured from 1987 to 1991 near Road A-17 are similar to those concentrations measured during the CCWS. The CCWS determined that nearly all of the calcium, magnesium, sodium, and potassium in Pen Branch waters were in the dissolved fraction (Newman et al. 1986). The mean concentration of calcium was slightly higher at the nonthermal site than at the thermal sites. Magnesium, sodium and potassium, however, were higher at the thermal sites than at the nonthermal sites. SRS does not measure potassium during routine water quality monitoring. Calcium, magnesium, and sodium values between 1992 and 1995 were similar to those measured during the CCWS.

4.5.4.4.3 Aluminum, Iron, and Manganese

Concentrations of total and dissolved aluminum measured during the CCWS were higher in the waters of the thermal sites than in those of the nonthermal site. Approximately 92% of the aluminum was associated with the solid phase at the nonthermal site and 92-93% was associated with the solid phase at the thermal sites. Total and dissolved iron concentrations were higher at the nonthermal site than those at the thermal sites. Approximately 83-86% of the iron was in the solid phase. Mean total manganese concentrations ranged from 0.071 to 0.104 mg/l. Roughly 20-28% of the manganese was in the solid phase (Newman et al. 1986). From 1987 to 1995, concentrations of total aluminum, iron, and manganese were slightly lower than those measured during the CCWS. The higher concentrations during the CCWS reflected Savannah River source water concentrations.

4.5.4.5 Nutrients

4.5.4.5.1 <u>Phosphorus</u>

All measured forms of phosphorus were higher in the thermal portions of this system than at the nonthermal site during the CCWS. Whereas 13% of the phosphorus was present as dissolved orthophosphate at the nonthermal site, 49-59% at the thermal site was dissolved orthophosphate. At the nonthermal site, 62% of the phosphorus was not orthophosphate, and 27-38% of the phosphorus at the thermal sites was not orthophosphate. The speciation and concentrations of phosphorus in the thermal sites reflected, at least partially, the phosphorus speciation and concentrations in the Savannah River (Newman et al. 1986). Only total phosphorus is measured during the routine monitoring, but concentrations of total phosphorus near Road A-17 were similar to those measured at Road A-17 during the CCWS.

4.5.4.5.2 <u>Nitrogen</u>

Although the mean concentrations of organic nitrogen did not differ greatly between the thermal and nonthermal sites, the percentage of nitrogen in the organic form was 73% in the nonthermal waters and only 23-26% in the thermal waters (Newman et al. 1986). Routine monitoring does not measure for organic nitrogen in Pen Branch. During the CCWS, mean ammonia, nitrite, and nitrate concentrations were higher at the thermal sites than at the nonthermal site, reflecting the nitrogen species and concentrations in the Savannah River. Since 1987, concentrations of ammonia and nitrate have remained similar to those concentrations measured during the CCWS. Nitrite has not been measured since the CCWS.

4.5.4.6 Trace Elements

Newman et al. (1986) measured low levels of trace elements during the CCWS. Routine monitoring detection limits are higher than the concentrations measured during the CCWS; therefore, only CCWS data are discussed in this section. Mean total arsenic concentrations were similar in the nonthermal waters (1.6 µg/l) and the thermal waters (1.3 to 2.8 µg/l) of Pen Branch. Mean total cadmium concentrations ranged from 0.29 µg/l upstream of the Steel Creek confluence to 0.99 µg/l at Road A-13. Although mean total chromium concentrations were as high as 10.4 µg/l, mean dissolved chromium concentrations were below the detection limit at all sites (Newman et al. 1986). Mean total copper concentrations were approximately 2.1-3.2 µg/l. The highest mean concentration of total nickel (4.3 µg/l) was found near Road A-13 (4.3 µg/l). Mean total zinc concentrations ranged from 4.7-6.2 µg/l. Mercury and uranium concentrations were below the detection limit in Pen Branch waters (Newman et al. 1986).

4.5.4.7 Organic Carbon

Total organic carbon concentrations were similar for thermal and nonthermal sites in Pen Branch. However, the nonthermal site had slightly more organic carbon in the dissolved phase (77%) relative to those of the thermal sites (68-69%) (Newman et al. 1986).

4.5.4.8 Priority Pollutants

The Pen Branch system had below detectable concentrations of all 88 tested volatile, acid, and base/neutral organics. The 1984 study also confirmed the lack of variability between thermal and nonthermal waters (Lower 1987).

4.5.4.9 Pesticides, Herbicides, and PCBs

Water samples collected annually during routine monitoring are analyzed for pesticides, herbicides, and PCBs. None of the analytes has been detected in the Pen Branch system.

Lower (1987) reports the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985; results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations also were near or below detection limits at all locations.

4.5.4.10 Chemical, Including Radionuclide, and Toxicity Assessment Studies

In 1994, a study was done to determine if the macroinvertebrate *Ceriodaphnia* is adversely affected by Pen Branch water that does not receive National Pollutant Discharge Elimination System (NPDES) discharges; if *Ceriodaphnia* can be cultured for extended times in Pen Branch water; and if *Ceriodaphnia* cultured in Pen Branch water are sensitive to a reference toxicant. SRS surface waters are extremely soft, with hardness ranging from approximately 2 to 30 mg/l. Waters this soft may not have adequate calcium or trace minerals to support long-term survival of *Ceriodaphnia*. Detailed results of this study are in Specht (1994a) and in Chapter 6 of this document.

Pen Branch water was never acutely toxic (measured as percent survival) to *Ceriodaphnia dubia* in 11 monthly tests. However, it was chronically toxic (measured as reproductive success) in 5 of 11 monthly tests. Results of the acute reference toxicant (sodium chloride) tests on Pen Branch water indicated that the test organisms in that water were slightly more sensitive to the reference toxicant than other organisms cultured in standard dilute mineral water. Reproduction in Pen Branch waters in the presence of the reference toxicant was more successful than reproduction in the control population in the presence of the reference toxicant. These results suggest that water from Pen Branch may be superior to dilute mineral water as dilution and control water for chronic toxicity testing of SRS waters (Specht 1994a).

Little information on chemical or radionuclide contaminants is available for Pen Branch. Over the history of the Site, Pen Branch has received an estimated 0.90 TBq (24 Ci) of radiocesium with 99% of this being ^{137}Cs (Garten et al. 2000).

4.5.5 Algae

4.5.5.1 Phytoplankton

Phytoplankton has not been studied in the Pen Branch drainage system. The potential for activities to impact the phytoplankton is low. Phytoplankton contribute insignificantly to the food chain base in this and other shallow streams.

4.5.5.2 Periphyton

Studies of the ecology of the thermal and nonthermal streams of SRS that were conducted between 1983 and 1985 (Firth et al. 1986; Specht 1987) included the periphyton community of Pen Branch. The analyses of the periphyton communities in these studies included taxonomic identifications, chlorophyll analyses, and measurement of ash-free dry weight.

Reactor operations undoubtedly affected periphyton species composition and abundance. Periphyton differed in type between thermal and nonthermal sites. Green algae and diatoms characterized the nonthermal sites, while thick mats of blue-green algae were unevenly distributed at the thermal sites (Specht 1987). Also, variations in periphyton biomass values were higher at the thermal stream sites than at the nonthermal sites. The densely canopied Pen Branch swamp station had a significantly lower periphyton biomass than the Pen Branch delta station. Biomass at the Pen Branch swamp station did not appear to be affected by the status of K Reactor (Firth et al. 1986)

4.5.6 Macrophytes

4.5.6.1 Introduction

Aquatic macrophytes provide stream structure, substrate for periphyton development, cover and substrate for smaller animals, and a source of carbon for the stream system. Although aquatic macrophytes are an important component of the function of many aquatic systems, they tend to be less important in flowing waters. Macrophytes could not colonize channels during the large thermal and flow impacts from reactor operations. Because K-Reactor operation ceased in 1988, recolonization of the slower reaches and backwaters of the stream would be expected.

4.5.6.2 Comprehensive Cooling Water Stud (CCWS)y

4.5.6.2.1 Introduction

The only data dealing with aquatic macrophytes in Pen Branch comes from the CCWS (Specht 1987) and was collected from 1983 to 1985. The CCWS data do not represent the current status of aquatic macrophytes in the system because they were collected at only four stations, all of which were impacted by reactor operations. Only one of the sampled stations was in the stream itself; two were in the thermal delta; and one was in the river swamp.

4.5.6.2.2 Number of Taxa Collected

The total number of taxa at the thermal stream station and the thermal swamp stations were similar; the stream, however, had no taxa growing in the channel. The delta stations had approximately one-third of their taxa in the water channels and a similar number (<50%) growing on the floodplain. The channel and floodplain accounted for slightly more than three-quarters of the total taxa found in the two delta stations. Little additional information is available from the CCWS except the observation of greater biomass in the thermal delta during the winter of 1983-1984 and the presence of little or no vegetation in the thermal stream and delta channels or the nonthermal swamp during the 1984-1985 sampling period (Specht 1987).

4.5.6.2.3 Expectations Since the Cessation of K-Reactor Operations

Normal successional patterns and development of macrophyte beds would be likely to occur in suitable sections of Pen Branch with the cessation of K-Reactor operation. However, baseline data have not been collected on this component of the ecosystem. Analyses of remote sensing data (Chapter 6 - Wetlands and Carolina Bays of the SRS) suggest that macrophyte recolonization of the stream and delta have been substantial.

4.5.7 Zooplankton

Chimney and Cody (1986) documented the temporal and spatial characteristics of zooplankton species based on quarterly sampling from December 1984 to August 1985 in Pen Branch. This study evaluated populations with regard to regulatory compliance issues covered by the Clean Water Act, Section 316(a) Demonstration. Surface-water grab samples were collected adjacent to macrophyte beds at two stations: the first approximately one-third of the distance downstream from the headwaters and a second approximately another third downstream. Because of thermal discharges, mean temperature was greater than 32°C (89°F). Species richness consisted of 7 Protozoa, 15 Rotifera, 14 Cladocera, 4 Copepoda, and 1 Ostracoda.

For this data set the greatest densities occurred during April 1985. Eighty percent of the monthly total densities comprised Protozoa and Rotifera. As with other SRS streams, this result is representative of zooplankton populations, which are warm-water, summer species (Hutchinson 1967).

4.5.8 Macroinvertebrates

4.5.8.1 Sampling Locations and Methods

4.5.8.1.1 Comprehensive Cooling Water Study (CCWS)

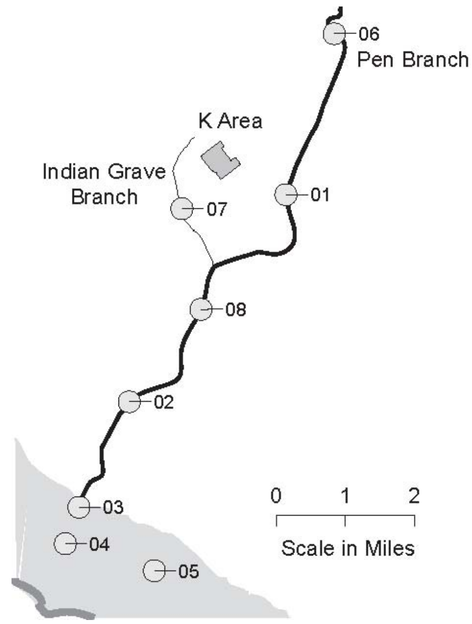
Macroinvertebrates were sampled monthly at three locations in Pen Branch from November 1983 through September 1984 using Hester-Dendy multiplate samplers, leaf bags, artificial snags, sediment coring and at five locations in Pen Branch from October 1984 through September 1985 (Figure 4-23) using Hester-Dendy multiplate samplers, leaf bags, and drift sampling. Data from 1983 through 1985 were collected as part of the CCWS when K Reactor was discharging thermal effluent to Pen Branch; these data are representative of the conditions that would exist if K Reactor were to be operated at full power. Details of sampling methodology can be found in Kondratieff and Kondratieff (1984, 1985) and Firth et al. (1986).

4.5.8.1.2 Pen Branch Recovery Studies

Subsequent to K-Reactor shutdown in April 1988, the macroinvertebrate community of Pen Branch was sampled with Hester-Dendy multiplate samplers at seven locations in December 1988 and February and May 1989 (Enwright Laboratories 1989a, b, and c) to document the recovery of the macroinvertebrate community.

Macroinvertebrates were sampled during the summer of 1993 at five locations in Pen Branch and at one site on Indian Grave Branch. Hester-Dendy multiplate macroinvertebrate samplers were deployed for 1 month (Specht 1994b).

	1983-1984[a]	1988-1989	1993-1994
01	20	Road B	Road B
02	21	Road A-13.2	Road A-13.2
03	22	Boardwalk	Boardwalk
04	23	Swamp	
05	24	Stave Island	
06		Road C	Road C
07		Indian Grave at Road B	Indian Grave at Road B
08		Road A	Road A



[a]Station designations are as in Firth et al. 1986.

Figure 4-23. Macroinvertebrate Sampling Stations for Pen Branch

Macroinvertebrates also were sampled in September 1994 using Hester-Dendy multiplate samplers in order to develop a biotic index for southeastern streams. While not specifically designed to characterize SRS streams, these data contribute to a better understanding of the streams. Pen Branch was sampled at Roads A, B, and C. Indian Grave Branch was sampled at Road B (Specht and Paller 1995).

4.5.8.2 Results

4.5.8.2.1 <u>Introduction</u>

Pen Branch and its tributary, Indian Grave Branch, receive effluents from seven NPDES outfalls in K Area and Central Shops. Until 1989, Indian Grave Branch also received thermal effluents directly from K Reactor. Indian Grave Branch and Pen Branch, downstream from its confluence with Indian Grave Branch, were subject to extremely high water temperatures and flows.

The data presented in this summary are primarily Hester-Dendy multiplate data because this was the only sampling method used consistently in the 1984-1985, 1988-1989, 1993, and 1994 sampling periods. Macroinvertebrate data from the other sampling methods can be found in Kondratieff and Kondratieff (1984, 1985) and in Firth et al. (1986). Table 4-10 lists the taxa captured during and following K Reactor operation.

Table 4-10. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Pen Branch Drainage

		Indian Grave Branch		Pen Branch	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**
Oligocheata	*Nais sp.*	X			
	Stylaria fossularis	X			
	Tubificidae sp.		X		X
Gastropoda	*Amnicola limosa*			X	X
	Campeloma decisum	X	X	X	X
	Elimia sp.				X
	Helisoma anceps		X		X
	Physella heterostropha	X			
	Planorbella trivolvis		X		
Pelycepoda	*Corbicula fluminea*		X	X	X
	Elliptio sp.				X
	Sphaerium sp.		X	X	X
Arachnida	*Hydracarina sp.*		X		X
Crustacea	*Caecidotea sp.*			X	X
	Cambarinae sp.	X	X	X	X
	Crangonyx sp.		X		
	Hyallela azteca	X	X	X	X
	Palaemonetes paludosus				X
	Procambarus sp.		X		X
Ephemeroptera	*Ameletus lineatus*				X
	Baetis ephippiatus				X
	Baetis frondalis				X
	Baetis intercalaris	X	X	X	X
	Baetis nr. punctiventris			X	
	Baetis propinquus		X		X
	Baetis sp.			X	
	Caenis diminuta	X	X		
	Callibaetis		X		
	Dannella simplex			X	
	Ephemerella nr. catawba			X	
	Ephemerella sp.			X	X
	Heptagenia sp.				X
	Isonychia sp.				X
	Leptophlebia sp.			X	X
	Neoephemera youngi				X
	Paraleptophlebia sp.	X	X		X
	Stenacron interpunctatum			X	X
	Stenonema modestum		X		X
	Stenonema modestum/smithae	X	X	X	X
	Tricorythodes sp.		X		X

Table 4-10. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Pen Branch Drainage - continued

		Indian Grave Branch		Pen Branch	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**
Odonata	*Argia sedula*		X		
	Argia sp		X	X	X
	Argia tibialis			X	X
	Boyeria vinosa		X	X	X
	Calopteryx dimidiata		X		X
	Cordulegaster maculata				X
	Cordulegaster sp.				X
	Dromogomphus armatus				X
	Enallagma divagans	X	X		X
	Enallagma nr. dubium		X		
	Enallagma sp.			X	X
	Epitheca (Epicordulia) sp.	X			
	Erythrodiplax connata	X			
	Gomphus lividus				X
	Ischnura posita		X		
	Lanthus vernalis				X
	Libellula sp.		X		X
	Libellulidae sp.				X
	Macromia georgina / illinoiensis				X
	Macromia sp.				X
	Ophiogomphus mainensis				X
	Progomphus obscurus				X
	Progomphus sp.				X
Heteroptera	*Belostoma lutarium*		X		
	Mesovelia mulsanti				X
	Mesovelia sp.				X
	Neogerris sp.				X
	Rhagovelia obesa		X		
	Trepobates sp.				X
	Trichocorixa				X
Megaloptera	*Corydalus cornutus*		X	X	X
	Nigronia serricornis				X
	Sialis sp.				X
Plecoptera	*Acroneuria abnormis*			X	
	Acroneuria mela				X
	Allocapnia sp.	X		X	X
	Clioperla clio			X	X
	Isoperla dicala			X	X

Table 4-10. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Pen Branch Drainage - continued

		Indian Grave Branch		**Pen Branch**	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**
Plecoptera (cont)	*Leuctra sp.*				X
	Paragnetina fumosa				X
	Perlesta placida			X	X
	Perlinella ephyre			X	
	Taeniopteryx metequi			X	X
	Taeniopteryx nr. metequi			X	X
	Taeniopteryx sp.	X		X	
Trichoptera	*Anisocentropus pyraloides*				X
	Brachycentrus nigrosoma			X	
	Cernotina sp.	X			X
	Cernotina spicata	X			
	Cheumatopsyche sp.	X	X	X	X
	Chimarra aterrima		X		
	Chimarra socia				X
	Heteroplectron americanum				X
	Hydropsyche betteni		X		X
	Hydropsyche nr. venularis			X	X
	Hydroptila sp.	X	X		
	Hydrospyche sp.				X
	Lype diversa		X	X	
	Oxyethira janella			X	
	Oxyethira sp.	X	X		
	Phylocentropus				X
	Psilotreta sp.				X
	Pycnopsyche sp.				X
	Triaenodes ssp.				X
Lepidoptera	*Parapoynx obscuralis*				X
Coleoptera	*Anchytarsus bicolor*			X	
	Ancyronyx variegatus			X	X
	Curculionidae		X		
	Dineutus ciliatus				X
	Dineutus sp.				X
	Dubiraphia bivittata				X
	Dubiraphia sp.				X
	Ectopria nervosa			X	
	Helichus fastigiatus				X
	Helichus lithophilus				X
	Helichus sp.				X
	Helocombus sp.	X			

Table 4-10. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Pen Branch Drainage - continued

		Indian Grave Branch		Pen Branch	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**
Coleoptera (cont)	*Hydrochus sp.*				X
	Hydroporus sp.			X	X
	Hydroporus vittatipennis				X
	Macronychus glabratus			X	X
	Microcylloepus pusillus				X
	Neoporus nr. undulatus				X
	Optioservus sp.				X
	Peltodytes sexmaculatus		X		
	Peltodytes sp.				X
	Stenelmis sinuata				X
	Stenelmis sp.	X		X	X
Diptera	*(Diamesinae)-Potthastia longimana*	X			
	Ablabesmyia janta gp.			X	
	Ablabesmyia mallochi	X	X	X	X
	Ablabesmyis nr. monilis	X	X		
	Antocha sp.		X		X
	Apsectrocladius johnsoni				X
	Bezzia sp.				X
	Brillia flavifrons			X	
	Chironomus sp.			X	
	Cladotanytarsus sp.				X
	Clinotanypus pinguis		X		X
	Conchapelopia sp.	X		X	X
	Conchapelopia/Meropelopia			X	X
	Corynoneura nr. taris			X	X
	Corynoneura sp.	X	X	X	X
	Corynoneura sp. 2	X	X	X	X
	Cricotopus bicinctus	X	X	X	X
	Cryptochironomus fulvus gp.				X
	Diamesinae - Potthastia longimana	X		X	
	Dicrotendipes nr. neomodestus	X	X	X	X
	Dicrotendipes simpsoni			X	
	Eukiefferiella sp.				X
	Hemerodromia sp.				X
	Heterotrissocladius marcidus gp.				X
	Hydrobaenus sp.			X	
	Labrundinia pilosella		X		X
	Meropelopia sp.		X		
	Microtendipes pedellus	X	X	X	X

Table 4-10. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Pen Branch Drainage - continued

		Indian Grave Branch		Pen Branch	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**
Diptera (cont)	*Nanocladius sp.*		X		X
	Natarsia sp.				X
	Orthocladius (Eudactylocladius)				X
	Orthocladius (Euorthocladius)		X		
	Orthocladius (Symposiocladius) lignicola			X	
	Orthocladius annectens			X	X
	Orthocladius obumbratus			X	X
	Orthocladius sp.				X
	Pagastiella sp.				X
	Palpomyia sp.				X
	Parachaetocldius sp.				X
	Paracladius sp.				X
	Parakiefferriella sp.	X	X	X	X
	Paramerina sp.				X
	Parametriocnemus lundbecki	X	X	X	X
	Phaenopsectra flavipes			X	X
	Pilaria sp.				X
	Polypedilum aviceps	X	X	X	X
	Polypedilum fallax			X	X
	Polypedilum flavum				X
	Polypedilum halterale	X		X	
	Polypedilum illinoense			X	X
	Procladius sp.				X
	Prosimulium sp.	X			
	Psectrocladius sp.	X			
	Rheocricotopus robacki	X	X	X	X
	Rheocricotopus tuberculatus			X	
	Rheotanytarsus distinctissimus gp.	X	X	X	X
	Rheotanytarsus exiguus gp.				X
	Simulium nr. tuberosum		X	X	X
	Simulium nr. venustum		X	X	
	Stenochironomus sp.				X
	Synorthocladius semivirens	X	X		
	Tanytarsus sp.	X	X	X	X
	Tanytarsus sp. 3		X		X
	Tanytarsus sp. 4				X
	Thienemanniella fusca gp.			X	X
	Thienemanniella xena gp.		X	X	X

Table 4-10. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Pen Branch Drainage - continued

		Indian Grave Branch		Pen Branch	
Class or order	**Lowest practical taxa**	**HD**	**NS**	**HD**	**NS**
Diptera (cont)	*Tipula (Nippotipula)*				X
	Tipula (Yamatotipula)		X		X
	Tipula sp.		X		X
	Tipula sp. 2		X		
	Tipulidae sp.				X
	Tribelos jucundum	X	X	X	X
	Tvetenia discoloripes gp.		X	X	X
	Tvetenia paucunca gp.			X	X
	Tvetenia vitracies		X		
	Unniella multivirga			X	X
	Zavrelimyia	X	X	X	X

4.5.8.2.2 Macroinvertebrate Community of Pen Branch During the Operation of K Reactor

4.5.8.2.2.1 Introduction

From the onset of macroinvertebrate sampling in 1983 until K Reactor shut down in 1988, Pen Branch was subject to severe thermal stress, with temperatures greater than 60°C (140°F) recorded at Station 21. However, during reactor outages, which sometimes lasted several weeks or longer, stream temperatures were near ambient. Because the multiplate samplers were collected monthly, some collections followed periods of reactor outages when stream temperatures were ambient. Therefore, the macroinvertebrate data must be interpreted cautiously to prevent erroneous conclusions.

4.5.8.2.2.2 Nonthermal Station

Station 20, which is at Road B, upstream from all thermal discharges, was similar to other nonthermal SRS streams during 1984-1985 with respect to density of organisms, biomass, and average number of taxa. Total taxa richness (70 taxa) was higher than at all but one of the stations that were sampled during the CCWS. Dominant taxa included orthoclad, tanytarsine, and chironomini chironomids; the mayfly *Stenonema modestum*; the beetle *Macronychus glabratus*; and several species of caddisflies. Macroinvertebrate biomass (ash-free dry weight) was higher at Station 20 (0.187 g/m^2) than at the thermally impacted delta stations (0.003 to 0.078 g/m^2), but lower than at Station 24, which was the mildly impacted swamp station. At Station 20, large numbers of mayflies (primarily *Stenonema modestum*) and fewer numbers of large predatory stoneflies (*Perlesta*) and dobsonflies (*Corydalus*) made up the majority of the biomass.

4.5.8.2.2.3 Thermally Impacted Delta and Swamp Stations

Number of Taxa Collected - During reactor operation, 51 taxa were collected from the thermally impacted stations in Pen Branch. Taxonomic richness below the reactor outfall was lowest at the station closest to the reactor outfall (Station 21; 28 taxa) and gradually increased farther downstream to 33 taxa at Station 22 and 38 taxa at Station 23. At Station 24, where temperatures were near ambient, 55 taxa were collected.

Dominant Species - At all of the thermally impacted stations, except Station 23, Diptera was by far the most common insect order collected, ranging from 43.3 to 77.7% of the organisms collected, Chironominae and Tanytarsini predominated at the thermally impacted stations. Nematode worms were the dominant taxon at Station 23 (71.5%) and were also abundant at the other thermally impacted stations. Nematodes are often an important component of the fauna at thermally stressed sites because of their tolerance for heated water. Oligochaete worms also were collected commonly at all of the stations, with abundances ranging from 1.6 to 7.7%.

Mayflies (Ephemerotera) were abundant in the swamp, at Station 24, accounting for 22.5% of the macroinvertebrates collected. *Stenonema modestum, Caenis*, and *Stenocron interpunctatum* were the most common species of mayflies collected at Station 24. Gastropods (primarily *Physella heterostropha*, *Helisoma trivolvis*, and *Gyralus parvus*) were abundant at Stations 23 and 24, accounting for 5.5 and 5.1% of the organisms collected. Beetles (Coleoptera) and caddisflies (Trichoptera) were abundant at Station 20, above the outfall, but less abundant farther downstream. Turbellaria, Arachnida, Odonata, and Plecoptera each generally accounted for less than 3% of the organisms collected at any station.

Densities - Mean densities of macroinvertebrates on the multiplate samplers ranged from 55.6/m^2 at the most thermally impacted station (Station 21) to 2144.9/m^2 in the delta (Station 23). The high density at Station 23 was due primarily to large numbers of nematodes.

Biomass - Macroinvertebrate biomass (ash-free dry weight) was low at the thermally impacted stations (0.003-0.078 g/m^2) and much higher (0.320 g/m^2) at Station 24, which was mildly thermal. At Station 24, mayflies and gastropods accounted for most of the biomass. Although Station 23 had by far the greatest mean density of organisms (2144.g/m ^{2}), biomass was relatively low at this station (0.070 g/m^2) due to a preponderance of small nematodes.

4.5.8.2.3 Recovery of Macroinvertebrate Community Subsequent to K-Reactor Shutdown

4.5.8.2.3.1 Introduction

The macroinvertebrate data collected subsequent to K-Reactor shutdown differ from the data collected during reactor operation in that data were collected for 3 months in the 1988-1989 program rather than 12 months and the level of taxonomic resolution was better in the 1988-1989 study, particularly for chironomids. Macroinvertebrates were sampled only from July to August 1993 and in September 1994. Any comparisons of species richness or taxonomic composition should take these important differences into consideration.

4.5.8.2.3.2 Number of Taxa Collected

During the sampling conducted during three months in 1988 and 1989, 132 taxa of macroinvertebrates were collected in Pen Branch and Indian Grave Branch. Of these taxa, 86 were collected from the portions of the creeks that had been thermally impacted. It is likely that more taxa would have been collected if sampling had been conducted over an entire year because some species occur seasonally, and some rare species are collected infrequently. The total number of taxa collected was highest at Road C (58 taxa). Fewer taxa were collected at the other five stations in Pen Branch, ranging from 48 at the boardwalk to 53 at Road B and Stave Island. In Indian Grave Branch, substantially fewer taxa were collected (35).

The station in Indian Grave Branch and three of the five stations in Pen Branch in 1993 all had relatively high numbers of taxa present (40-62). Macroinvertebrate communities at the two remaining stations in Pen Branch, at Road C and in the river swamp, differed from the others, with fewer total taxa (12 and 4, respectively). Results from the 1994 sampling indicate that the macroinvertebrate community improved downstream. The total number of taxa collected at the Pen Branch stations ranged from 37-51, and total taxa at the Indian Grave Branch Station was 38.

4.5.8.2.3.3 Taxa Richness

Taxa richness (mean number of taxa collected per multiplate sampler) ranged from 8.9 in Indian Grave Branch to 19.6 at Road B in 1988-1989. In general, fewer taxa were collected from the portions of the creek that had been thermally perturbed (Indian Grave Branch, Road A, Road A-13.2, and the boardwalk, in order of increasing distance from the reactor outfall) than from unperturbed areas of the creek (Road C, Road B, and Stave Island). However, in the Pen Branch delta (the boardwalk) species richness was relatively high (16.1), probably due to the increasing habitat diversity that resulted from recolonization by aquatic macrophytes. These data indicate that although the macroinvertebrate community of Pen Branch had undergone some recovery subsequent to reactor shutdown in April 1988, taxonomic richness was still somewhat depressed and it is likely that the macroinvertebrate community had not completely recovered and was still undergoing succession.

In 1993, the stations in Indian Grave Branch and three of the five Pen Branch stations had taxa richness values from 22.0 to 34.2. However, taxa richness at the swamp station and at Road C was low (1.0 and 5.2, respectively). Data from 1994 remained essentially unchanged from the higher 1993 taxa richness numbers, with taxa richness from 20.2 to 35.0 at the three Pen Branch stations. In Indian Grave Branch, there was a mean of 18 taxa per sampler.

4.5.8.2.3.4 Dominant Species

For all stations combined, chironomid dipterans were by far the most common group of macroinvertebrates on the 1988-1989 multiplate samplers, making up 68.4-91.8% of the organisms collected. Orthoclad midges were the most abundant chironomids (36.5-71.2%) at all but the boardwalk, where tanytarsine midges were more common (46.9%). Nonchironomid dipterans (mostly blackflies or danceflies) were abundant at some stations, comprising 0.4-26.6% of the collections. Trichoptera (caddisflies) and Ephemeroptera (mayflies) were also abundant at most stations, accounting for 0.4-11.2% and 0-8.4%, respectively, of the organisms collected on the multiplate samplers. Plecoptera (stoneflies) and Coleoptera (beetles) were abundant locally at Road B (7.8 and 9.3%, respectively), but accounted for less than 1% of the macroinvertebrates collected at each of the other stations.

Dominant taxa included several species of orthoclad midges (*Corynoneura* nr. *tarsis*, *Cricotopus* spp., *Orthocladius* spp., and *Tvetenia discoloripes* gr.), chironomini midges (*Microtendipes pedellus*, and *Polypedilum* spp.), tanytarsine midges (*Rheotanytarsus distinctissimus* and *Tanytarsus* spp.), and blackflies (*Simulium tuberosum* and *S. vittatum*). Other species that were abundant locally at at least one station included the mayflies, *Caenis* sp. and *Stenonema modestum/smithae*; the stonefly, *Perlesta placida*; the caddisflies, *Cheumatopsyche* spp. and *Hydropsyche* spp.; the beetle, *Macronychus glabratus*; and danceflies (*Empidae*).

Station 7, in Indian Grave Branch just downstream from the reactor outfall, differed from the other stations in that the community was composed almost exclusively of dipterans (99.57%). Dominant dipterans at this station included the chironomids, *Cricotopus* and *Orthocladius*, blackflies, and empidid danceflies. This difference is probably due, at least in part, to differences in substrate composition. Station 7 contains rock rip-rap, which provides stable substrate for attachment by blackflies and other species that prefer rock substrate. However, the conspicuous absence of clinging mayflies, such as *Stenonema*, and the overall low taxonomic richness suggest that Station 7 still was perturbed at the time of sampling.

In 1993, the macroinvertebrate community in Indian Grave Branch and Road B, Road A, and Road A-13.2 in Pen Branch was dominated by Ephemeroptera (23.57-38.74%) or Trichoptera (2.77-39.70%) and by collector-gatherers or collector-filterers. The macroinvertebrate community at Road C was composed mostly of Chironomini chironomids. Both the Road C and the swamp stations were perturbed at the time of sampling with very low concentrations of dissolved oxygen, which was probably responsible for the observed poor community structure (Specht 1994b). Orthoclad chironomids and Coleoptera also were abundant in Pen Branch but not Indian Grave Branch. Gastropods accounted for 24.65% of the organisms collected in Indian Grave Branch.

Common Pen Branch taxa in 1994 included Tanytarsini and Ephemeroptera at Roads B and C; Chironomini, and Orthocladiinae at Road B and oligochaetes, Trichoptera, Ephemeroptera, and Orthocladiinae at Road A. Oligochaetes dominated the Indian Grave station (72%). The dominant functional group at all stations in 1994 was collector-gatherer (56.62-88.7%). Road A also had a good number of collector-filterers (27.39%).

4.5.8.2.3.5 Densities

Macroinvertebrate densities on the multiplate samplers in 1988-1989 ranged from 534.7/m^2 at Road B to 988.3/m^2 at the Boardwalk. Densities were variable from month to month (Enwright 1989a, b, and c), and no relationship between density and thermal history was apparent.

Densities ranged from 1106.1 to 2765.4 organisms/m^2 in Indian Grave and at Roads A, B, and C in 1993. Densities at the Pen Branch Road C and swamp station were low, 157.8 and 5.59 organisms/m^2, respectively. In 1994, the mean numbers of organisms at the three Pen Branch sample locations ranged from 1194.1 to 2235.8 organisms/m^2, similar to the higher 1993 values. Density at the Indian Grave Branch location in 1994 was 2520.7 organisms/m^2.

Macroinvertebrate biomass was exceptionally low at all stations in 1988-1989, ranging from 0.029 g/m^2 at Station 7 to 0.089 g/m^2 at Station 4. The low biomass was due primarily to the predominance of small chironomids on the multiplate samplers.

Biomass was also high in 1993, ranging from 0.1339 to 0.4648 g AFDW/m^2 in Indian Grave Branch and the three stations in Pen Branch. The two remaining stations in Pen Branch had low biomass values (0.0118 g AFDW/m^2 at Road C and 0.0008 g AFDW/m^2 in the swamp). At the 1994 sample locations, biomass ranged from 0.0336 to 0.5365 g AFDW/m^2 in Pen Branch and was 0.3462 g AFDW/m^2 in Indian Grave Branch.

4.5.9 Fish

4.5.9.1 Introduction

Fisheries studies have been conducted at Pen Branch. Apart from an early survey by Bennett and McFarlane (1983) and later studies by Meffe and Sheldon (1989a and b), these studies generally have been motivated by concern about possible impacts to Pen Branch and its tributary, Indian Grave Branch, as a result of SRS operations. The objective of studies conducted prior to 1988 (Aho et al. 1986; Paller and Saul 1987) generally was to assess the impacts of water temperature elevations caused by the discharge of cooling water from K Reactor in Indian Grave Branch and hence to Pen Branch.

In 1988, K Reactor was shut down for maintenance and safety upgrades. The objectives of studies conducted during and after 1988 (Mealing and Paller 1989; Mealing and Heuer 1989a, b, c, and d; Paller et al. 1992) were to monitor the recovery of the fish community in Indian Grave Branch and Pen Branch and assess possible impacts caused by flow perturbations from tests of the K Reactor pumping system. Fisheries data collected from the Pen Branch system are summarized in Paller et al. (1989). Lists of species captured during and following K Reactor operation are given in Table 4-11.

Table 4-11. Fish Collected from Streams within the Pen Branch Drainage

Family	Common name	Scientific name	Indian Grave Branch	Pen Branch
Lepisosteidae	longnose gar	*Lepisosteus osseus*	X	X
	Florida gar	*Lepisosteus platyrhincus*		X
Amiidae	bowfin	*Amia calva*		X
Anguillidae	American eel	*Anguilla rostrata*	X	X
Cyprinidae	whitefin shiner	*Cyprinella nivea*		X
	eastern silvery minnow	*Hybognathus regius*		X
	rosyface chub	*Hybopsis rubifrons*		X
	bluehead chub	*Nocomis leptocephalus*	X	X
	golden shiner	*Notemigonus crysoleucas*	X	X
	ironcolor shiner	*Notropis chalybaeus*	X	X
	dusky shiner	*Notropis cummingsae*	X	X
	spottail shiner	*Notropis hudsonius*	X	X
	yellowfin shiner	*Notropis lutipinnis*	X	X
	coastal shiner	*Notropis petersoni*	X	X
	creek chub	*Notropis atromaculatus*		X
Catostomidae	creek chubsucker	*Erimyzon oblongus*	X	X
	lake chubsucker	*Erimyzon sucetta*	X	X
	northern hogsucker	*Hypentilium nigricans*		X
	spotted sucker	*Minytrema melanops*	X	X
	notchlip redhorse	*Moxostoma collapsum*		X
Ictaluridae	white catfish	*Ameiurus catus*		X
	yellow bullhead	*Ameiurus natalis*	X	X
	brown bullhead	*Ictalurus nebulosus*		X
	flat bullhead	*Ameiurus platycephalus*	X	X
	channel catfish	*Ictalurus punctatus*		X
	tadpole madtom	*Noturus gyrinus*		X
	margined madtom	*Noturus insignis*	X	X
	speckled madtom	*Noturus leptacanthus*	X	X
Esocidae	redfin pickerel	*Esox americanus*	X	X
	chain pickerel	*Esox niger*		X
Umbridae	eastern mudminnow	*Umbra pygmaea*		X
Aphredoderidae	pirate perch	*Aphredoderus sayanus*	X	X
Fundulidae	golden topminnow	*Fundulus chrysotus*		X
	lined topminnow	*Fundulus lineolatus*		X
Poeciliidae	eastern mosquitofish	*Gambusia holbrooki*	X	X
Atherinopsidae	brook silverside	*Labidesthes sicculus*	X	X

Table 4-11. Fish Collected from Streams within the Pen Branch Drainage - continued

Family	Common name	Scientific name	Indian Grave Branch	Pen Branch
Centrarchidae	mud sunfish	*Acantharcus pomotis*	X	X
	flier	*Centrarchus macropterus*		X
	bluespotted sunfish	*Enneacanthus gloriosus*		X
	redbreast sunfish	*Lepomis auritus*	X	X
	warmouth	*Lepomis gulosus*	X	X
	dollar sunfish	*Lepomis marginatus*	X	X
	redear sunfish	*Lepomis microlophus*		X
	spotted sunfish	*Lepomis punctatus*	X	X
	largemouth bass	*Micropterus salmoides*	X	X
	black crappie	*Pomoxis nigomaculatus*		X
Percidae	Savannah darter	*Etheostoma fricksium*	X	X
	swamp darter	*Etheostoma fusiforme*		X
	christmas darter	*Etheostoma hopkinsi*		X
	tesselated darter	*Etheostoma olmstedi*	X	X
	sawcheek darter	*Etheostoma serrifer*		X
	blackbanded darter	*Percina nigrofasciata*	X	X

4.5.9.2 K-Reactor Operations

4.5.9.2.1 <u>Adult Fish</u>

Aho et al. (1986) used multiple-pass electrofishing to sample the fish assemblages in 100-m (328-ft) sample sites in the headwaters of Pen Branch, a relatively unperturbed reach above the confluence of Pen Branch and Indian Grave Branch. Samples also were taken from Steel Creek and Meyers Branch. They found that species richness and community structure were generally comparable among streams with the exception of one relatively depauperate sample site in Pen Branch that had low habitat diversity.

Paller and Saul (1987) sampled the midreach of Pen Branch (i.e., the reach between the Indian Grave Branch/Pen Branch confluence and the delta) during 1984 and 1985. Their sampling was restricted to side channels and pools connected to the main channel because the main channel was too hot to safely electrofish during periods of reactor operation. They found eastern mosquitofish in these relatively cool refugia when the reactor was operating. During outages dollar sunfish (*Lepomis marginatus*) and unidentified juvenile sunfish (*Lepomis* spp.) also were collected from these areas, suggesting recolonization by immigrating fish. During periods of reactor operation, fish were presumably absent from the main channel of the midreach because of extremely high temperatures (>40°C [104°F]).

Aho et al. (1986) studied the fish assemblages in Pen Branch just above the delta and in a similar section of Fourmile Branch in relation to the operating cycles of K and C Reactors, respectively. Their work involved collections made with fyke nets placed in the stream channels during outage periods to monitor the upstream and downstream movements of fish. Few fish were collected from the midreach when heated effluents were being released. However, when water temperatures returned to ambient levels during outages, fish moved upstream into the creek from the Savannah River swamp. Both juveniles and adults rapidly reinvaded the stream channels; individuals were captured within 12 hours of the cessation of reactor operations. In total, 29 species were collected from the midreach of Pen Branch during reactor outages; the most abundant species were spotted sunfish (*L. punctatus*) and lake chubsucker (*Erimyzon oblongus*). Additional information on this study is in Section 4.3 - Fourmile Branch.

The delta/swamp of Pen Branch included both disturbed, open-canopy areas where water temperatures elevated to high levels (>40°C [104°F] in some places), and comparatively undisturbed, closed canopy areas deeper in the swamp where water temperatures remained near ambient even during reactor operation.

Paller and Saul (1987) used backpack electrofishing to sample fish during periods of K-Reactor operation in the highly disturbed open-canopy delta of Pen Branch. Eastern mosquitofish (*Gambusia holbrooki*) dominated the community at this location and were observed in high densities in cooler areas of the delta. Small numbers of spotted sunfish and dollar sunfish also were collected.

Aho et al. (1986) collected fish by electrofishing at 12 sites in the SRS Savannah River floodplain swamp, including three in the comparatively undisturbed area near Stave Island, which lies in the flowpath of Pen Branch. They collected 51 species from the Stave Island area, all of which were year-round residents with the exception of two migratory species: hickory shad (*Alosa mediocris*) and striped mullet *(Mugil cephalus*). Sunfishes and minnows were the dominant taxa in the swamp. Based on habitat analysis and multivariate analyses of fish community structure, Aho et al. (1986) hypothesized that two major habitat gradients influenced fish community structure in the Savannah River swamp. The first corresponded to the degree of habitat disturbance caused by elevated water temperatures, and the second corresponded to the amount of shading by the cypress/tupelo overstory. (This study is discussed more extensively in Section 4.3 - Fourmile Branch).

4.5.9.2.2 Larval Fish

While not sampled as extensively as the adult fish, larval fish assemblages in Pen Branch have been studied by Paller et al. (1986) and Aho et al. (1986). Larval fish were collected by Paller et al. (1987) from three sampling stations on Pen Branch during 1984 and 1985 (Paller et al. 1986). One station was near Road B in the undisturbed headwaters. The second was located at Road A-13.2 (approximately 7.0 km (4.3 mi) downstream from K Reactor) where water temperatures were well above ambient. The third sample station was among the braided channels, dead cypress and tupelo, and emergent vegetation in the Pen Branch delta; this station was also highly thermal.

Fifty-three fish larvae and eggs were collected from Pen Branch between March and July 1984. Most were collected upstream from K Reactor (primarily minnow and darters). However, juvenile eastern mosquitofish and sunfish larvae were collected from the delta and a small number of unidentified eggs were collected from the sampling station near Road A-13.2. The latter probably drifted into the sampling area from relatively cool pools and side channels rather than being produced in the main channel where temperatures often exceeded 40°C (104°F). Similar patterns were observed during 1985 (Paller et al. 1986). Taxa of fish larvae and eggs taken from Pen Branch are listed in Table 4-12.

4.5.9.2.3 Ichthyoplankton

Aho et al. (1986) collected ichthyoplankton from two sample stations in the Stave Island area of Pen Branch as part of a study of the effects of varying temperature elevations on fish reproduction. At least 10 taxa were collected from the Stave Island sample stations; dominant taxa were darters, sunfishes, and minnows. Aho et al. (1986) found that spawning occurred earlier than usual at thermal sample sites, and that spawning was advanced even near Stave Island where temperatures were only one to two degrees warmer than ambient.

Table 4-12. Ichthyoplankter Taxa Found in Pen Branch

Family	**Taxa**
Clupeidae	*Alosa sapidissima*, American shad
Cyprinidae	*Notropis chalybaeus*, ironcolor shiner
	Notropis cummingsae, dusky shiner
	Notropis petersoni, coastal shinier
	Unidentified minnows
Catostomidae	*Erimyzon* spp., chubsuckers
	Moxostoma spp., redhorse
	Unidentified suckers
Aphredoderidae	*Aphredodereus sayanus*, pirate perch
Fundulidae	*Fundulus* spp., topminnow
Poeciliidae	*Gambusia holbrooki*, eastern mosquitofish
Centrarchidae	*Lepomis* spp., bream
	Lepomis punctatus, spotted sunfish
	Centrarchus macropterus, flier
	Unidentified sunfish
	Pomoxis sp., crappie
Percidae	Unidentified darters
	Perca flavescens, yellow perch

4.5.9.3 Shutdown of K Reactor

4.5.9.3.1 <u>Recolonization of Pen Branch and Indian Grave Branch</u>

Fish recolonized Pen Branch and Indian Grave Branch following the shutdown of K Reactor in April 1988 (Mealing and Paller 1989; Mealing and Heuer 1989a, b, c, and d). Sixteen species were collected from the midreaches of Pen Branch (sample station 3) and eleven species were collected from Indian Grave Branch (sample station 7) between November 1988 and January 1989. However, the average number of species (4.8) and the average catch per 100-m stream segment (9.3) were low. Samples collected by Paller et al. (1992) (February-May 1991) yielded significantly greater numbers of species (average of 9.9) and numbers of individuals per 100-m stream segment (average of 78.0), demonstrating further recovery of the fish assemblages in the midreach of Pen Branch.

The Pen Branch delta also was recolonized after K-Reactor shutdown. Mealing and Paller (1989) and Mealing and Heuer (1989a, b, c, and d) collected 14 species from the delta between November 1988 and January 1989; dominant species included spotted sunfish, coastal shiner (*Notropis petersoni*), lake chubsucker, eastern mosquitofish, and dollar sunfish. The relatively shallow water in the delta was probably responsible for the predominance of small species in this habitat. Mealing and Paller (1989) and Mealing and Heuer (1989a, b, c, and d) also electrofished three transects farther downstream near Stave Island in the closed canopy swamp (sample Station 6). They collected 17 species; large fish such as longnose gar (*Lepisosteus osseus*) and largemouth bass (*Micropterus salmoides*) were well represented in deeper channels. Other relatively abundant species included brook silversides (*Labidesthes sicculus*) and coastal shiners.

4.5.9.3.2 <u>Effects of Artificial Flow Perturbations</u>

During the years following K-Reactor shutdown, high volumes of unheated water were twice pumped into Indian Grave Branch and Pen Branch during tests of the cooling-water pumps. High stream flows can result in the downstream displacement of fishes and marked reductions in the abundance of species that lack the physical and behavioral adaptations necessary to orient in fast waters (Minckley and Meffe 1987; Bain et al. 1988). Electrofishing samples collected before and after a one-week, nine-fold increase in discharge during January 1989 demonstrated a significant reduction in species number and abundance (Paller et al. 1992).

A second period of increased discharge, from February to May 1991, had more limited effects consisting of reductions in shiners, spotted sucker, and largemouth bass. Species number, total fish abundance, and condition did not decline or declined only moderately. Differences between 1989 and 1991 may have been related to the extent of fish-assemblage recovery from previous thermal impacts. In 1989, recovery was in its early stages; many species were represented by only a few transient individuals, and flow-sensitive species comprised a relatively high percentage of the community (Paller et al. 1992).

In summary, fish-assemblage structure varied throughout the Pen Branch system, both as a result of the former influence of K-Reactor discharge and from natural changes in habitat and gradient that accompany the spatial transition along Pen Branch from a small headwater stream to a part of the Savannah River swamp. When K Reactor operated, water temperature exerted a controlling influence on community structure. Fish essentially were eliminated from Indian Grave Branch and the mid-reaches of Pen Branch, with the exception of a few species in relatively cool refugia off the main channel. Fish began to recolonize formerly thermal areas after K Reactor was shut down, and considerable recovery had occurred, although habitat degradation resulting from former cooling-water discharges undoubtedly influenced community structure in some areas. In the absence of elevated temperatures, habitat is the primary determinant of community structure with small stream species such as yellowfin shiner (*Notropis lutipinnis*) and bluehead chub (*Nocomis leptocephalus*) inhabiting the upper reaches; sunfishes, chubsuckers, and largemouth bass predominating in the midreaches; and a typical southeastern swamp community including longnose gar, brook silverside, largemouth bass, coastal shiner, and chain pickerel (*Esox niger*) inhabiting the deep swamp reaches.

4.5.10 References

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4.6 STEEL CREEK

4.6.1 Drainage Description and Surface Hydrology

4.6.1.1 General Description

The headwaters of Steel Creek originate near P Reactor, southwest of Par Pond (Figure 4-24). The creek flows southwesterly about 3 km (1.8 mi) before it enters the headwaters of L Lake. The lake is 6.5 km (4.0 mi) long and relatively narrow, with an area of about 418 ha (1034 acres). Flow from the outfall of L-Lake dam travels about 5 km (3 mi) before entering the SRS Savannah River swamp and then another 3 km (1.8 mi) before entering the Savannah River. Meyers Branch, the main tributary of Steel Creek, flows approximately 10 km (6.2 mi) before entering Steel Creek. Meyers Branch is a small blackwater stream that has remained relatively unperturbed by SRS operations. The confluence of Steel Creek and Meyers Branch is downstream from the L-Lake dam and upstream from SRS Road A. The total area drained by the Steel Creek-Meyers Branch system is about 91 km^2 (35 mi^2) (Specht 1987).

From 1954 to 1968, when Steel Creek was receiving thermal discharge and increased flow, an extensive delta developed where the creek entered the Savannah River floodplain swamp. The delta is drained by numerous braided channels that eventually coalesce and continue for approximately 1.6 km (1 mi) before entering the Savannah River. Just before it enters the river, the flow from Steel Creek is joined by the flow from Pen Branch and part of the flow from the Fourmile Branch-Beaver Dam Creek system (Specht 1987).

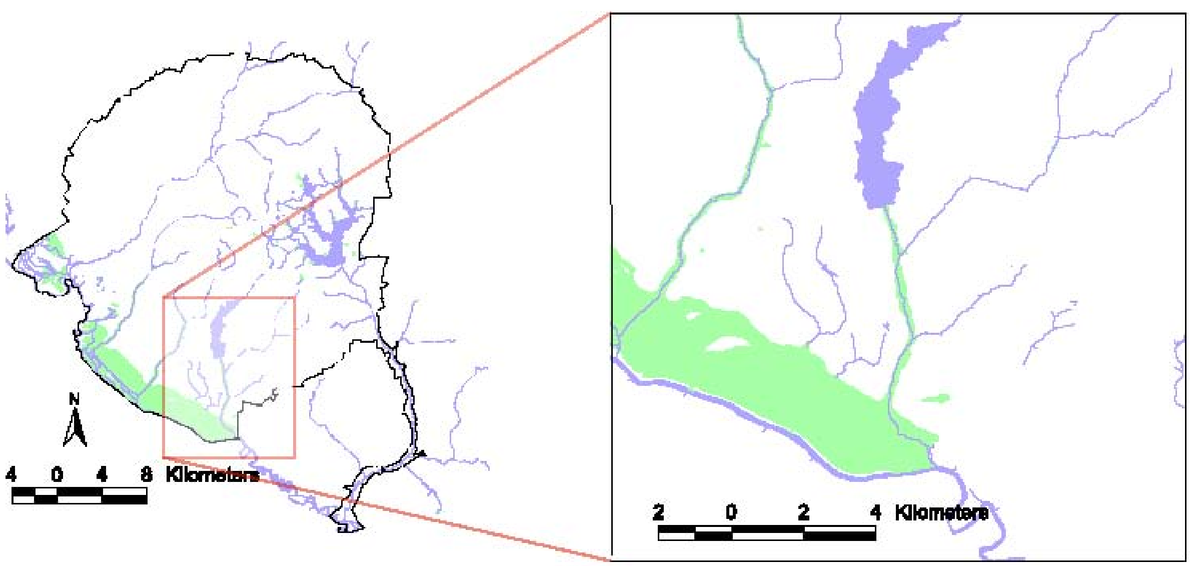

Figure 4-24. Location of Steel Creek on SRS

4.6.1.2 Effluents Contribution

In 1954, Steel Creek began receiving thermal effluents from P and L Reactors. By 1961, both reactors released a total of 24 m^3/sec (850 ft^3/sec) of thermal effluent into Steel Creek. From 1961 to 1964 P Reactor partially used the Par Pond recirculating system. In 1964, all P-Reactor effluent was diverted to Par Pond, and in 1968 L Reactor was put on standby. From 1968 until early 1985, Steel Creek recovered from the impacts of early SRS operations. In 1981, the U.S. Department of Energy (DOE) initiated activities to restart L Reactor. Based on an Environmental Impact Statement (DOE/EIS-0108 1984), various thermal mitigation alternatives, L Lake was constructed in 1985 along the upper reaches of Steel Creek to receive and cool the heated effluents from L Reactor (restarted in 1985) prior to their release into Steel Creek (Firth et al. 1986). L Reactor was shut down in 1988. Steel Creek also has received nonthermal effluents, including ash basin drainage, nonprocess cooling water, powerhouse waste water, reactor process effluents, sanitary treatment plant effluents, and vehicle wash waters.

4.6.1.3 Flow Measurements

The U.S. Geological Survey (USGS) measured flow at several locations on Steel Creek (Figure 4-25). Records for the station at SRS Road A date back to March 1985. Prior to March 1985, this USGS station was farther downstream at the Old Hattiesville Bridge. Flow records at Old Hattiesville Bridge date back to March 1974. In water year 1995, the mean flow of Steel Creek at Road A was 2.4 m^3/s (86.2 ft^3/s). Over the period water years 1985 - 1995 at Road A, the mean flow was 4.5 m^3/s (160 ft^3/s), the 7-day low flow was 0.33 m^3/s (12.0 ft^3/s), and the 7Q10 was 0.37 m^3/s (12.9 ft^3/s). Flows in Steel Creek below L Lake were influenced by the flow requirements mandated by the L-Reactor Operation Final EIS (DOE 1984). The EIS mandated that reactor outages during the spring spawning season had to maintain flow in Steel Creek at Road A at a rate of about 3.0 m^3/sec (106 ft^3/sec). During the remainder of the year, flow would be maintained at a rate of about 1.5 m^3/sec (53 ft^3/sec) at times of reactor outage. No flow monitoring station within Steel Creek is currently active; the most recent data are for the station at Road A, where data exists until the end of September 2002.

4.6.2 Water Chemistry and Quality

4.6.2.1 Studies and Monitoring

4.6.2.1.1 <u>Water Quality Monitoring</u>

The Westinghouse Savannah River Company Environmental Monitoring Section (EMS) has conducted routine water-quality monitoring of Steel Creek since 1973. One location (Steel Creek at Road A) has been monitored monthly for physical and biological properties and for metals (Figure 4-26). Temperature and dissolved oxygen measurements have also been taken hourly at Road A as part of SCDHEC Consent Order 84-4-W with DOE. The EMS also collects an additional sample annually and analyzes it for pesticides, herbicides, and PCBs.

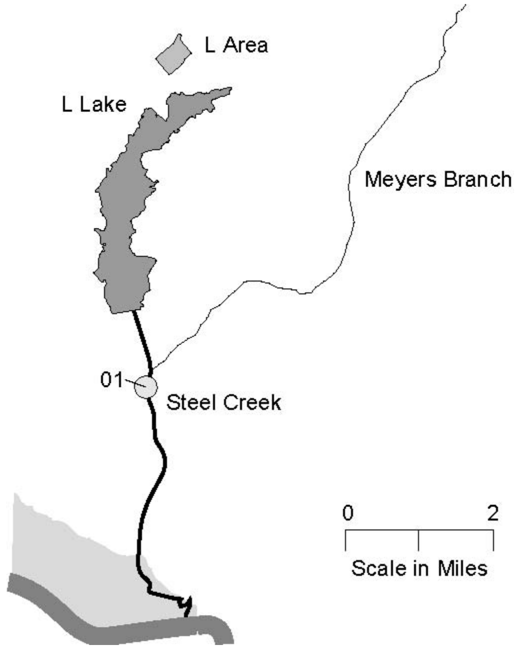

Figure 4-25. Flow Measurement Sampling Station for Steel Creek at Road A

01 Road B
02 Road A-14
03 Upstream of confluence with Meyers Branch
04 Meyers Branch at Road B-6.2
05 Meyers Branch at Road 9
06 Meyers Branch upstream of confluence with Steel Creek
07 Road A
08 Old Hattiesville Bridge
09 Steel Creek Delta
10 Confluence with Savannah River

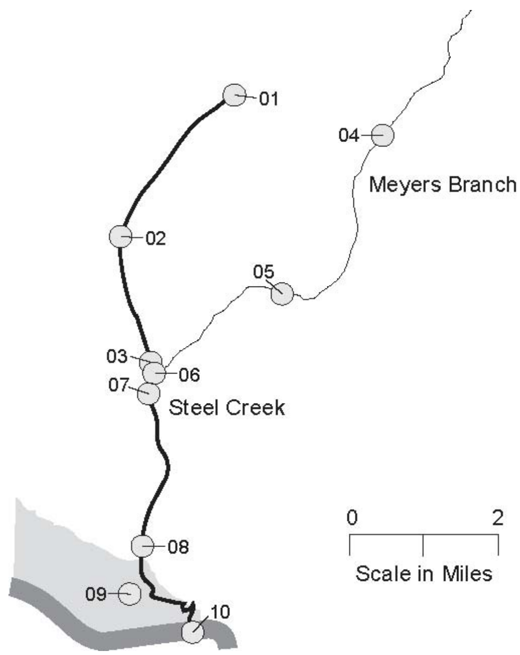

Figure 4-26. Water Quality Monitoring Stations for Steel Creek prior to construction of L Lake, 1983-1985

4.6.2.1.2 Comprehensive Cooling Water Study (CCWS)

Ten locations on Steel Creek (01, 02, 03, 07, and 08), Meyers Branch (04, 05, and 06), and in the Steel Creek swamp (09 and 10) were studied from 1983 to 1985 as part of the CCWS. This study was designed to assess present and proposed SRS activities on water quality. Because the CCWS was conducted prior to construction of L Lake, data collected from this study are not representative of conditions in Steel Creek after L Lake construction. However, these data are presented in the following subsections for comparison purposes. Lower (1987) should be referenced for a synopsis of CCWS data for Steel Creek.

4.6.2.1.3 Priority Pollutants Survey

In 1984, a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral compounds in Steel Creek. Two locations - Steel Creek at Road B (01) and at Road A (07) - were sampled for this study. The results of this study are discussed later in this chapter and documented in Lower (1987).

4.6.2.1.4 Chemical Assessment Studies

In 1985, the L Lake/Steel Creek Biological Monitoring Program was initiated to assess various components of the system and identify any changes due to the operation of L Reactor or discharge from L Lake. The study was designed to meet environmental regulatory requirements associated with the restart of L Reactor and was driven primarily by Section 316(a) of the Clean Water Act. Kretchmer and Chimney (1992) reports the results of Steel Creek water quality over the six years of the study. A summary of their report is provided later in this chapter.

4.6.2.2 Field Data

4.6.2.2.1 Water Temperature

Water temperatures measured in Steel Creek since construction of L Lake have been similar to preconstruction conditions, with a range of 7.1-30°C (44.7-86°F), and an average of 19°C (66.2°F).

4.6.2.2.2 pH Measurements

The pH of Steel Creek at Road A ranged from 5.1-8.3 between 1987 and 1995. Similar pHs were measured prior to the construction of L Lake with pH ranges from 6 to 8.4.

4.6.2.3 Physical Characteristics and General Chemistry

4.6.2.3.1 Dissolved Oxygen

Concentrations of dissolved oxygen in Steel Creek at Road A reflect the lack of thermal input to the creek (range 5.0-14.8 mg/l; mean 8.1 mg/l). These concentrations, measured from 1987 to 1991, are similar to concentrations measured during the CCWS.

4.6.2.3.2 Suspended Solids and Turbidity

Mean total suspended solids and turbidity levels in Steel Creek were 5.3 mg/l and 3.7 NTU, respectively, from 1987 to 1991 and 3.75 mg/l and 2.56 NTU, respectively from 1992 to 1995. These levels are within the ranges measured prior to the construction of L Lake.

4.6.2.3.3 Conductivity

From 1987 to 1995, specific conductivity in Steel Creek at Road A ranged from 10 to 92 µS/cm. These measurements are similar to those measured during the CCWS.

4.6.2.4 Major Anions and Cations

4.6.2.4.1 Alkalinity, Chloride, and Sulfate

Alkalinity concentrations in Steel Creek at Road A ranged from 1.0 to 21 mg $CaCO_3$/l from 1987 to 1995, which was slightly lower than the range of measurements taken during the CCWS. Chloride and sulfate concentrations measured during the same period were higher than data collected during the CCWS. Mean chloride and sulfate concentrations at Road A from 1987 to 1991 were 6.7 mg/l and 6.9 mg/l, respectively, and from 1992 to 1995 were 6.64 mg/l and 6.12 mg/l, respectively.

4.6.2.4.2 Calcium, Magnesium, Sodium, and Potassium

From 1987 to 1991, calcium concentrations ranged from 1.8 to 3.8 mg/l, and sodium concentrations ranged from 5.4 to 11.7 mg/l. These concentrations are slightly lower than the concentrations measured during the CCWS. Magnesium concentrations ranged from 0.76 mg/l to 1.4 mg/l, which is in the range measured during the CCWS. Potassium is not measured during routine water quality monitoring.

4.6.2.4.3 Aluminum, Manganese, and Iron

Concentrations of aluminum, iron, and manganese have been much lower since the construction of L Lake. From 1987 to 1991, aluminum ranged from <0.01 to 0.16 mg/l; iron ranged from <0.02 to 0.26 mg/l; and manganese ranged from <0.01 to 0.17 mg/l. Between 1992 and 1995, aluminum ranged from <0.01 to 0.28 mg/l, iron ranged from 0.05 to 0.59 mg/l, and manganese ranged from <0.01 to 0.10 mg/l.

4.6.2.5 Nutrients

4.6.2.5.1 Phosphorus

Total phosphorus is the only form of phosphorus measured during routine water quality monitoring. From 1987 to 1991, the mean total phosphorus concentration in Steel Creek at Road A was 0.032 mg/l, which is similar to the mean measured during the CCWS. From 1992 to 1995, the mean total phosphorus concentration in Steel Creek at Road A was 0.02 mg/l.

4.6.2.5.2 Nitrogen

Organic nitrogen, ammonia, and nitrate are the only forms of nitrogen measured during the Steel Creek routine water quality monitoring program. All forms of nitrogen have been higher in Steel Creek at Road A since the construction of L Lake. The means for these forms of nitrogen were as follows between 1987 and 1991: 0.37 mg/l organic nitrogen; 0.076 mg/l ammonia; and 1.00 mg/l nitrate. From 1992 to 1995, means were: 0.33 mg/l Kjeldahl nitrogen; 0.08 mg/l ammonia; and 0.18 mg/l nitrate.

4.6.2.6 Trace Elements

Maximum concentrations of trace elements detected in Steel Creek at Road A ranged from 5 µg/l of cadmium to 46 µg/l of chromium. Nickel had a maximum concentration of 70 µg/l. Lead and zinc were detected at 30 µg/l and 50 µg/l, respectively.

4.6.2.7 Organic Carbon

Organic carbon is not measured during routine water quality monitoring.

4.6.2.8 Priority Pollutants

Lower (1987) reported the results of a special study to determine the levels of volatile, acid, base, and neutral organics in Steel Creek. Concentrations of all 88 tested organics were below detection limits at both the Steel Creek Road B and Road A sampling locations.

4.6.2.9 Pesticides, Herbicides, PCBs, and Volatile Organic Compounds

Water samples are collected annually from Steel Creek at Road A during routine water quality monitoring and analyzed for pesticides, herbicides, PCBs and volatile organic compounds. From 1987 to 1994, no analytes were detected in Steel Creek. In 1995, pesticides were detected (Arnett and Mamatey 1996).

Lower (1987) reported the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985; results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations were also near or below detection limits at all locations.

4.6.2.10 L-Lake/Steel Creek Biological Monitoring Program

The L-Lake/Steel Creek Biological Monitoring Program was an extensive water quality monitoring study initiated after the construction of L Lake. This study was designed to assess various components of the Steel Creek system and identify changes due to the operation of L Reactor or discharge from L Lake. Thirteen sampling stations were located throughout the Steel Creek corridor, marsh, swamp, and channel (Figure 4-27).

Steel Creek water quality during the Steel Creek Biological Monitoring Program was found to be similar to the range of values reported for other regional lotic systems and judged to be typical of southeastern waters in general (Kretchmer and Chimney 1992).

During parts of the study downstream gradients were observed between corridor Stations 275 (just below the L-Lake dam) and 290 (Old Hattiesville Bridge) for temperature, dissolved oxygen, pH total organic and inorganic carbon, ortho- and total phosphorus, nitrite-nitrogen, nitrate-nitrogen, and ammonia-nitrogen, total inorganic nitrogen, silica, total aluminum, total and dissolved iron, total and dissolved sodium, chloride, total and dissolved magnesium, total and dissolved potassium, and total and dissolved calcium. These differences were attributed to natural conditions such as cooling, metabolic activity of stream organisms, or chemical reactions (Kretchmer and Chimney 1992).

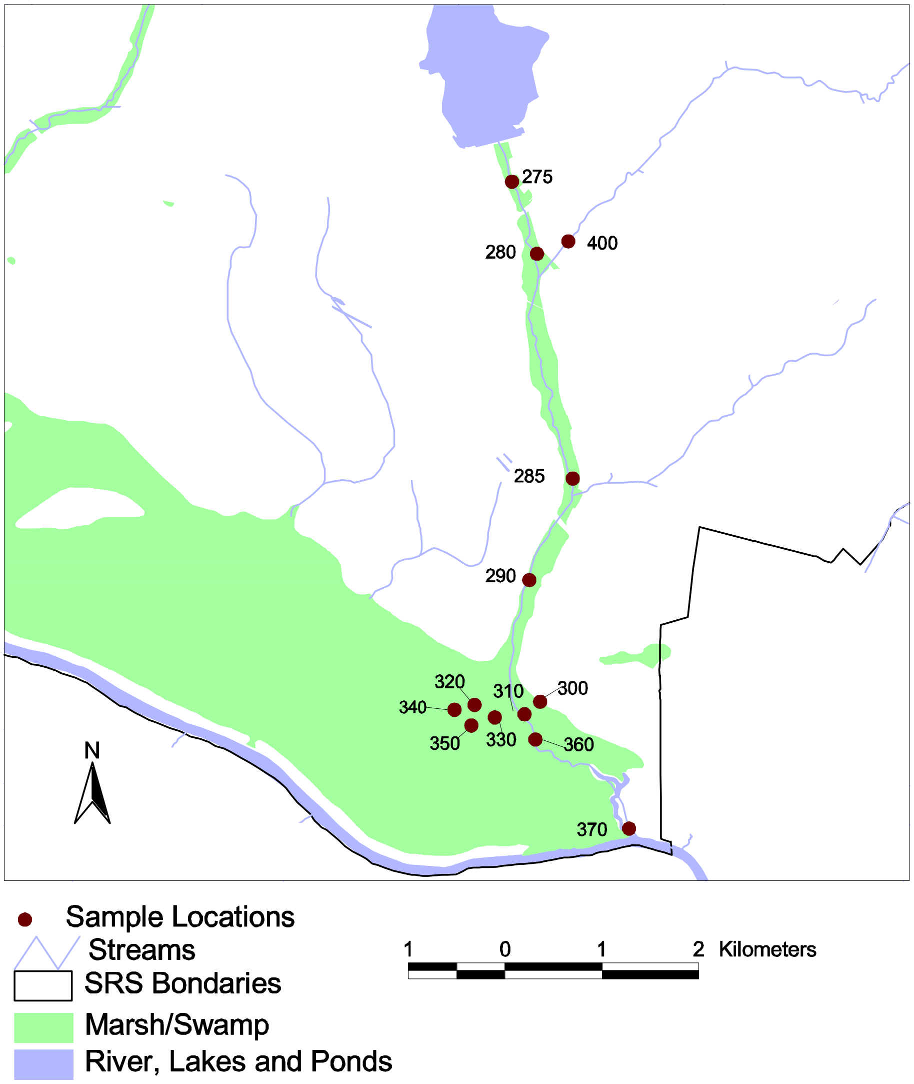

Figure 4-27. Sampling Stations used during the Steel Creek Biological Monitoring Program, 1985-1992

Differences between swamp (closed canopy) and marsh (open canopy) stations were noted during at least a portion of the study for temperature, ortho- and total phosphorus, nitrate-nitrogen, total inorganic nitrogen, total and dissolved sodium, and sulfate. However, no consistent differences were evident. Such variation would not be unexpected between stations in different habitat types (Kretchmer and Chimney 1992).

Inspection of pre-and post-impoundment data for the years 1985-1989 indicated that increases in temperature, conductivity, total phosphorus, nitrate-nitrogen, ammonia-nitrogen, total and dissolved sodium, and chloride, and decreases in pH have occurred relative to preimpoundment conditions documented during the CCWS. These changes reflected differences between water being released from L Lake (dominated by Savannah River water) and the natural drainage of the Steel Creek basin (Kretchmer and Chimney 1992).

Higher levels were measured at Station 300 (Steel Creek marsh) for conductivity, total dissolved solids, total inorganic carbon, alkalinity, ammonia-nitrogen, total and dissolved calcium, total iron, total and dissolved magnesium, total and dissolved manganese, and total and dissolved potassium; and lower concentrations were found at Station 300 for orthophosphate and sulfate during the summers of 1986-1988. Reduced flow velocities due to the abundance of macrophytes were thought to have impeded water exchange with the rest of the swamp and marsh. Water quality differences were much reduced compared to previous years (Kretchmer and Chimney 1992).

4.6.2.11 Chemical, Including Radionuclide, and Toxicity Assessment Studies

No chemical, radionuclide or toxicity studies have been done on the waters of Steel Creek

4.6.3 Algae

4.6.3.1 Phytoplankton

Primary producers in Steel Creek consist of macrophytes and periphyton. Phytoplankton are believed to contribute insignificantly to the food base, as is typically the case in shallow stream systems (Wetzel 1983) and, therefore, were not included in biological monitoring programs.

4.6.3.2 Periphyton

The abundance and community structure of periphyton assemblages in the Steel Creek system were studied from 1986-1991 as part of an extensive biological monitoring program initiated to assess the ecological impacts of L-Reactor operations. Sampling locations are shown in Figure 4-28. Detailed methods and results can be found in reports by Hooker (1990) and Toole and van Duyn (1992). Data from 1986-1987 have been previously summarized in compliance documents by Gladden et. al. (1988) and Wike et. al. (1989).

4.6.3.2.1 Biomass Quantities

Periphyton biomass values, measured as organisms per millimeter of glass slide surface, did not reveal consistent seasonal patterns. The highest quantities were obtained from the corridor stations with successively lower quantities in the marsh, channel, and swamp locations, respectively. The largest quantities reported from the study were from the upper corridor during reactor operations (1986-1988). Periphyton biomass values measured as chlorophyll a and ash free dry weight were also generally higher in the corridor than at the other sampling locations throughout the study.

Diatoms (Bacillariophyta) were the dominant algal group in most samples from all stations and dates. One exception was at Station 275 in the upper corridor of the creek where blue-green algae (Cyanophyta) made up 80.1% of the total periphyton during 1987.

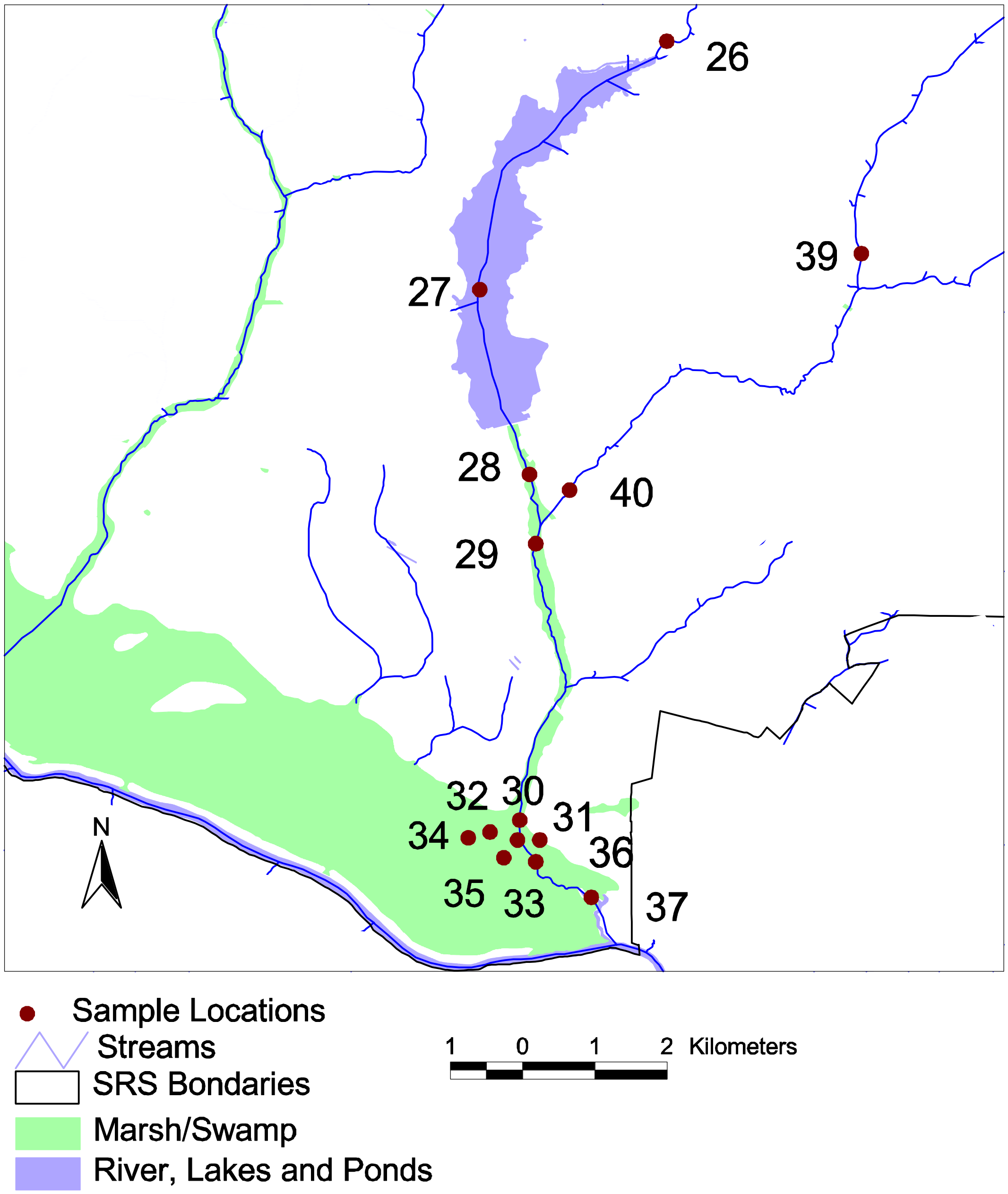

Figure 4-28. Steel Creek Sampling Locations Used in the Comprehensive Cooling Water Study (CCWS)

4.6.4 Macrophytes

4.6.4.1 Comprehensive Cooling Water Study (CCWS)

Between the shutdown of L Reactor in 1968 and the construction of L Lake in 1984-1985, Steel Creek went through vegetation community successional recovery from the impacts of high flows and temperatures caused by previous L-Reactor discharges. During the CCWS in 1984-1985, four channel, one delta, and two Steel Creek swamp stations were sampled quarterly. Two stations on Meyers Branch, an unimpacted tributary of Steel Creek, also were sampled as controls (Figure 4-28).

Species diversity appears to be similar between the post-thermal and reference streams, but there are differences between the two swamp stations; these differences probably can be attributed to Station 33 being in the delta and having an open canopy while Station 35 is in the swamp and has a closed canopy. (These stations are at the same sites as stations used during the L Lake/ Steel Creek Biological Monitoring Program. The two sets of sites can be paired by adding a zero to the CCWS station designations. For example, Station 33 in the CCWS and Station 330 in the later Biological Monitoring Program are the same station. Several stations [26, 27] in the CCWS were in the area of the creek converted to L Lake.) The data demonstrate clear similarities between three (26, 27, 29) of the four stream corridor site macrophyte populations and those of the reference stream (39, 40). These are all in closed-canopy portions of the stream. Corridor station 28 is more similar to the delta and swamp stations, principally because it is in an open-canopy area. Diversity of plant communities is similar for the delta and swamp stations (33, 34, 35), but the greater macrophyte area, volume, biomass, and percent cover observed at Station 33 can be attributed to its open canopy as opposed to the closed canopy at the other swamp stations.

The CCWS also presented data describing the aquatic habitat of Steel Creek prior to the restart of L Reactor. This included channel morphometry; the volume and density of wood, logs, and sticks; the surface area of trailing vegetation; the volume of trailing roots; and the surface area of debris. This information was included and discussed in the L-Lake/Steel Creek Biological Monitoring Program reports.

4.6.4.2 L-Lake/Steel Creek Biological Monitoring Program

The L-Lake/Steel Creek Biological Monitoring Program monitored the effects of the restart of L Reactor on the macrophytes and aquatic habitat of Steel Creek. During the years 1986 through 1989, this program mapped reaches in the main channels at 12 locations between L-Lake dam and the Savannah River on a semiannual (8 stations) or quarterly (4 stations) basis (Figure 4-27) (Hooker 1990).

In the years 1990-1992, the program was reduced to four stations sampled annually (Westbury 1993). Variables reported by these studies include: width, depth, surface, and cross-sectional area of the main channel; the surface area, volume, density and importance values of living and non-living woody structures; and the total and species-specific percent cover and biomass of aquatic macrophytes.

The cross-sectional area of the main channel at Stations 290, 330, and 370 increased with the start of L Reactor operations in 1986. The channel at Station 350 is separated from the Steel Creek delta by two islands and is only indirectly affected by flow from Steel Creek. Station 350 was influenced by discharge into Pen Branch by K-Reactor operations.

In low-order flowing streams where the riparian canopy shades much of the channel, woody structures provide a major portion of the stable surface area for colonization by periphyton and microhabitat for aquatic organisms. The total surface area of woody structures was lowest at the marsh station (330) in all years of this study. The increase in surface area at Station 290 is the result of the exposure of previously buried woody structures due to scouring after the re-start of L Reactor. At Station 350, woody structure surface area was reduced after the shutdown due to increased aquatic macrophyte coverage.

The mean percent cover of aquatic vegetation generally increased throughout the study at all stations other than Station 370. The percent cover of aquatic plants at Station 370 was low due to the unstable substrate and canopy shading. Increased coverage at Station 290 after the shutdown was due to the increase in coontail (*Ceratophyllum demersum*). The percent cover at Stations 330 and 350 increased with the startup and continued after the shutdown due to the invasion of waterweed (*Egeria densa*). Waterweed was not found at Station 330 in 1985, and comprised less than 2 percent cover at Station 350 prior to the restart. At the end of the study waterweed covered 85.5% of Station 330 and 72% of Station 350. The percent cover at these stations generally increased after the shutdown due to decreased water depth and decreased boat traffic. The percent cover decreased at Station 370 after 1989 due to increased water depth and turbidity as the result of higher Savannah River water levels.

4.6.5 Zooplankton

4.6.5.1 Introduction

Chimney and Cody (1986) examined the zooplankton communities in several SRS stream systems (including Steel Creek) prior to the construction of L Lake. Bowers (1991) reported on zooplankton sampled at seven locations (Figure 4-27) in Steel Creek from 1986 to 1989, following the construction of L Lake.

4.6.5.2 Early Effects of L Lake on Steel Creek Zooplankton

During 1985, Rotifera and Cladocera constituted more than 75% of the total number of zooplankton species in the Steel Creek swamp and delta. By 1986, rotifer, cladocera, and copepod species had decreased by about 50%. By 1987, Rotifera was represented by 29 species, 5 more than in 1985. Based only on the number of species, the impoundment of Steel Creek during 1984 and 1985 and the subsequent L-Lake discharge significantly affected the zooplankton taxa in the Steel Creek swamp and delta regions during 1985 and 1986, but recovery by all groups, except cladocerans, as measured by taxa richness had occurred by 1987.

The littoral rotifers dominated the community during 1985 and suffered severe losses during 1986, following impoundment. Those littoral rotifers were replaced by planktonic rotifers from L Lake during 1986, but in 1987, littoral rotifer species returned. Many of the original littoral cladoceran species were lost by 1986 and replaced by a single cladoceran, *Chydorus brevilabris*, and several new species of copepods. By 1987, the Steel Creek swamp and delta appeared to be supporting a new, steady-state post-impoundment community structure. However, successional changes were probably not complete in this habitat and the community is expected to continue to change. The disappearance of limnetic zooplankton is common to reaches of streams below reservoirs. Ward's (1975) study on the South Platte River below a large reservoir is a good example. Relative abundances of cladocerans, copepods, and rotifers decreased 79%, 91%, and 61%, respectively, over an 8.5 km (5.2 mi) stretch downstream from the reservoir.

4.6.5.3 Effect of L Lake Releases on Steel Creek Zooplankton

The abundance, diversity, and turnover of zooplankton populations in Steel Creek reflect zooplankton community composition and population densities in L Lake and flow rates from the L-Lake dam. Whether or not L Reactor was operational, zooplankton were introduced continuously into the corridor of Steel Creek, above the delta and swamp. When L Reactor operated, populations of limnetic zooplankton were introduced into the corridor of Steel Creek at an accelerated rate.

4.6.5.4 Zooplankton Taxa Found in Steel Creek

A comprehensive list of taxa identified from monthly zooplankton collections in Steel Creek at corridor, swamp, and delta stations during 1984 and 1985 is given in Chimney and Cody (1986). These taxa represented three broad taxonomic categories, including the phylum Rotifera (33 taxa), and within the phylum Arthropoda, the order Cladocera (16 taxa), and the subclass Copepoda (9 taxa).

The most recent sampling has monitored zooplankton populations in Steel Creek and L Lake from 1986 through 1989. Results presented here were obtained by averaging the monthly results from all corridor (stations 275, 280, and 290) and swamp and delta (stations 310, 330, 350, and 370) stations from 1986 to 1989.

4.6.5.4.1 <u>Species Densities</u>

Cladoceran densities in the Steel Creek corridor reached their greatest concentrations during May and June for 1986, 1987, and 1988. Thereafter, densities remained low. Cladoceran densities in the corridor region most likely reflect populations originating from L Lake whose numbers significantly decreased after 1988 due to threadfin shad predation. Copepod populations also suffered, but to a lesser degree, from fish predation in L Lake. Copepod densities remained greater than 5 organisms/l throughout the study period. Greatest densities were observed during May 1986, May 1987, September 1987, and during the winter of 1988. Variation between years and within each season was considerable due to natural variations and differences in sampling methods. Rotifers also had no pronounced seasonal cycle in the corridor. These patterns reflect two features of Steel Creek between L Lake and the swamp. Zooplankton from L Lake are continuously being washed into the corridor, especially when flow rates (>11 m^3/sec) were greatest due to L-Reactor operations. Furthermore, thermal loading into L Lake altered species composition and seasonal population cycles.

Most of the zooplankton originating in L Lake are consumed by stream predators before reaching the delta and swamp. Significant zooplankton populations in the swamp and delta occur only in slow flowing sections. They do not play a significant role in community metabolism. Cladoceran populations at swamp stations were sporadic throughout the study period with low densities and no marked seasonal trend. Copepod densities also did not follow any seasonal pattern, having their greatest abundances several times in any given year. Rotifer populations in the swamp had their greatest densities during February through April 1987, a period when all zooplankton groups were abundant.

4.6.6 Macroinvertebrates

4.6.6.1 Sampling Locations and Methods

4.6.6.1.1 Comprehensive Cooling Water Study (CCWS)

Macroinvertebrates were collected at 11 stations in Steel Creek and 2 stations in Meyers Branch in 1983-1985 as part of the CCWS. CCWS data will not be discussed here, because the data collected subsequent to impoundment of Steel Creek are more representative of present conditions. A summary of the CCWS macroinvertebrate data for Steel Creek can be found in Specht (1987).

4.6.6.1.2 Clean Water Act Section 316(a) Demonstration and Miscellaneous Studies

From January 1986 through December 1991, macroinvertebrates were collected at up to 12 stations throughout the Steel Creek corridor, marsh and swamp, and lower channel regions and at 1 station in Meyers Branch, a tributary of Steel Creek (Figure 4-27).

Between 1986 and 1989, macroinvertebrates were sampled monthly with Hester-Dendy multiplate samplers at each of the 13 sampling stations. Macroinvertebrate drift and insect emergence were sampled monthly at seven stations. Macroinvertebrates were collected from natural substrates, including snags, macrophytes and sediment cores semiannually at 7 stations and qualitative sampling of natural substrates was conducted semiannually at 13 stations (Lauritsen and Hosey 1990).

In 1990 and 1991, the overall level of effort for macroinvertebrate sampling was reduced. All sampling was restricted to four stations. Hester-Dendy samples, drift, and qualitative dip net samples were collected quarterly at each of the four stations. Natural substrates were sampled semiannually. Emergence continued to be sampled monthly, but beginning in June 1990, a different type of emergence trap was used (Trapp and Hosey 1992). Due to the changes in sampling frequency for most parameters, data from 1990 to 1991 are not directly comparable to the 1986-1989 data. However, for summary purposes, annual means for the data for all six years will be presented.

Macroinvertebrates were sampled during the summer of 1993 at two locations in Steel Creek and at one site on a small tributary of Steel Creek. Hester-Dendy multiplate macroinvertebrate samplers were deployed for one month (Specht 1994).

Macroinvertebrates also were sampled in September 1994 using Hester-Dendy multiplate samplers to develop a biotic index for southeastern streams. While not specifically designed to characterize SRS streams, these data contribute to a better understanding of the streams. Meyers Branch was sampled during this study (Specht and Paller 1995).

4.6.6.2 Results

4.6.6.2.1 Introduction

The small tributary of Steel Creek that was sampled in 1993 receives no discharges from SRS operations. Results indicate that it is perturbed, probably because of low oxygen concentrations that may be due to beaver dams upstream of the sampling location (Specht 1994).

Until 1996, Steel Creek and its major tributary, Meyers Branch, received effluents from nine National Pollutant Discharge Elimination System (NPDES) outfalls in L and P Areas, and the Railroad Yard. In 1996, with the issuance of the new NPDES permit, outfalls were consolidated or eliminated. Presently, only five NPDES outfalls discharge to L Lake and Steel Creek (L-07, L-07A, L-08, P-13 and P-14). Until 1968, Steel Creek received thermal effluents directly from L Reactor and in 1985, L Lake was constructed on the upper reaches of Steel Creek to protect the downstream reaches from thermal effluent.

Steel Creek and Meyers Branch both support diverse and productive macroinvertebrate communities. Table 4-13 lists the macroinvertebrate taxa found in Steel Creek and Meyers Branch. Macroinvertebrate taxa richness, densities, and biomass in Steel Creek were generally similar to what has been observed in reference streams at SRS, as well as in other southeastern streams. The macroinvertebrate community in the stream corridor downstream from L Lake is strongly influenced by seston inputs from the reservoir. The corridor stations contain high densities and biomass of filter-feeding organisms. The macroinvertebrate communities of the delta and lower creek channel appear to be affected little by the impoundment of Steel Creek, although *Chaoborus* and other lentic species were collected at times, particularly in the drift samples.

The macroinvertebrate community at Road B was sampled in 1993 in a lotic area without flow just upstream from L Lake. It appeared perturbed when compared with the community sampled at Road A, downstream of the L-Lake dam. It had fewer total taxa (29 vs. 49), lower density (717.3 organisms/m^2 vs. 1124 organisms/m^2), and lower biomass (0.057 g AFDW/m^2 vs. 0.1153 g AFDW/m^2) (Specht 1994).

4.6.6.2.2 Taxa Richness

Taxa richness (mean number of macroinvertebrate taxa per station) on Hester-Dendy multi-plate samplers ranged, except at Road B, from 35 to 103. In general, taxa richness was lowest just downstream from L Lake (Stations 275 and 280) and at stream channel Station 360. Taxa richness in Meyers Branch, on the average, was a little higher than at most stations in Steel Creek.

Table 4-13. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Steel Creek Drainage

Class or Order	Lowest Practical Taxa	Meyers Branch		Steel Creek	
		HD	NS	HD	NS
Oligocheata	*Naididae sp.*		X		
	Tubificidae sp.	X	X		
Gastropoda	*Campeloma decisum*		X		
	Ferrissia sp.	X		X	
	Physella heterostropha		X	X	X
	Physella sp.				X
	Planorbella sp.		X		
Pelycepoda	*Corbicula fluminea*			X	X
	Sphaerium sp.		X		
Arachnida	*Hydracarina sp.*		X		
Crustacea	*Caecidotea sp.*		X		
	Cambarinae sp.	X	X		X
	Crangonyx sp.		X		
	Hyallela azteca		X		X
	Palaemonetes paludosus		X		
	Procambarus sp.		X		X
Collembola	*Collembola sp.*	X			
Ephemeroptera	*Baetis frondalis*		X		X
	Baetis intercalaris		X	X	
	Baetis propinquus		X		
	Caenis diminuta	X	X		
	Ephemerella nr. catawba/inconstans			X	
	Ephemerella sp.	X	X		
	Eurylophella (immature / damaged)		X		
	Eurylophella sp.				X
	Isonychia sp.			X	
	Paraleptophlebia sp.	X	X		
	Stenacron interpunctatum		X		
	Stenonema modestum				X
	Stenonema modestum/smithae	X	X	X	X
	Tricorythodes sp.				X
Odonata	*Argia sedula*		X		
	Boyeria vinosa		X	X	X
	Calopteryx dimidiata		X		X
	Cordulegaster maculata		X		X
	Cordulegaster sp.		X		X
	Enallagma divagans		X		X
	Enallagma sp.		X		X
	Erythrodiplax connata		X		

Table 4-13. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Steel Creek Drainage - continued

Class or Order	Lowest Practical Taxa	Meyers Branch		Steel Creek	
		HD	NS	HD	NS
Odonata (cont)	*Gomphus lividus*		X		X
	Hagenius brevistylus				X
	Ischnura posita		X		
	Libellula nr. incesta		X		
	Libellula sp.		X		
	Macromia sp.		X		X
	Pachydiplax longipennis		X		
	Progomphus obscurus		X		
	Progomphus sp.				X
	Tetragoneuria semiaquea/cynosura		X		
Heteroptera	*Corixidae sp.*		X		
	Mesovelia mulsanti		X		X
	Notonecta sp.		X		
	Ranatra sp.				X
	Rhagovelia obesa		X		X
Megaloptera	*Corydalus cornutus*			X	
	Sialis sp.		X		
Plecoptera	*Allocapnia sp.*	X	X	X	X
	Clioperla clio	X	X	X	X
	Isoperla bilineata			X	X
	Perlesta placida			X	X
	Pteronarcys sp.		X		
	Taeniopteryx metequi		X	X	
Trichoptera	*Anisocentropus pyraloides*				X
	Cernotina sp.	X			
	Cheumatopsyche sp.	X	X		X
	Chimarra aterrima		X	X	X
	Hydropsyche betteni		X	X	X
	Lepidostoma sp.				X
	Lype diversa	X		X	
	Micrasema rusticum	X			
	Nectopsyche sp.				X
	Oecetis sp.		X	X	
	Phylocentropus		X		
	Ptilostomis sp.		X		
	Pycnopsyche sp.		X		X
	Triaenodes ssp.		X		X
Lepidoptera	*Parapoynx obscuralis*				X

Table 4-13. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Steel Creek Drainage - continued

Class or Order	Lowest Practical Taxa	Meyers Branch		Steel Creek	
		HD	NS	HD	NS
Coleoptera	*Ancyronyx variegatus*		X		X
	Cybister fimbriolatus		X		
	Dineutus ciliatus		X		X
	Dineutus discolor				X
	Dineutus sp.		X		X
	Dubiraphia bivittata		X		
	Dubiraphia vittata		X		
	Helichus fastigiatus				X
	Hydroporus sp.	X			
	Macronychus glabratus		X		X
	Microcylloepus pusillus		X		
	Optioservus sp.				X
	Peltodytes sp.		X		
	Rhantus callidus		X		
	Stenelmis sp.		X		X
Diptera	*Ablabesmyia janta gp.*		X		
	Ablabesmyia mallochi	X	X	X	X
	Brillia flavifrons	X		X	X
	Chaoborus sp.			X	
	Chironomus sp.		X		X
	Cladopelma sp.		X		
	Clinotanypus pinguis		X		
	Conchapelopia sp.	X	X		
	Conchapelopia/Meropelopia	X	X		
	Corynoneura nr. taris	X		X	
	Corynoneura sp.				X
	Corynoneura sp. 2	X	X		X
	Cricotopus / Orthocladius annectens				X
	Cricotopus bicinctus		X	X	
	Cryptochironomus fulvus gp.		X		X
	Diamesinae - Potthastia longimana			X	X
	Dicrotendipes nr. neomodestus	X	X		
	Dixa sp.				X
	Eukiefferiella claripennis gp.				X
	Helopelopia sp.	X			
	Hemerodromia sp.	X			
	Hexatoma sp.	X			
	Labrundinia pilosella	X	X	X	X

Table 4-13. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Streams within the Steel Creek Drainage - continued

Class or Order	Lowest Practical Taxa	Meyers Branch		Steel Creek	
		HD	NS	HD	NS
Diptera (cont)	*Microtendipes pedellus*	X			
	Nanocladius sp.		X		X
	Orthocladius annectens		X		
	Orthocladius obumbratus		X		
	Orthocladius sp.			X	
	Parakiefferriella sp.	X		X	X
	Parametriocnemus lundbecki	X	X	X	X
	Phaenopsectra flavipes	X	X		
	Pilaria sp.		X		
	Polypedilum aviceps	X	X	X	X
	Polypedilum fallax	X			
	Polypedilum illinoense	X	X		X
	Probezzia sp.		X		X
	Psectrocladius sp.		X		
	Rheocricotopus robacki	X	X		X
	Rheosmittia sp.	X			
	Rheotanytarsus distinctissimus gp.	X	X	X	X
	Simulium nr. tuberosum		X	X	X
	Simulium nr. venustum		X		
	Simulium nr. verecundum		X		
	Tanytarsus sp.	X	X	X	X
	Tanytarsus sp. 2	X	X		
	Thienemanniella fusca gp.	X			
	Thienemanniella xena gp.	X	X	X	X
	Tipula sp.				X
	Tribelos jucundum				X
	Tvetenia discoloripes gp.		X		
	Tvetenia paucunca gp.			X	X
	Tvetenia vitracies		X		
	Unniella multivirga	X	X		X
	Zavrelia		X		X
	Zavrelimyia	X			

4.6.6.2.3 Dominant Taxa

During the six years of sampling between 1986 and 1991, dominant groups of taxa in Steel Creek and Meyers Branch included dipterans (13.0 to 94.2%), caddisflies (1.0 to 46.5%), oligochaetes (0.3 to 36.9%) and mayflies (<0.1 to 37.97%). Gastropods (snails), isopods, and amphipods were locally abundant in the delta (stations 300-350).

From 1986 to 1991, the relative abundance of dipterans decreased at most stations, while the relative abundance of oligochaetes, caddisflies, and mayflies increased (Lauritsen and Hosey 1990; Trapp and Hosey 1992).

Although species composition differed somewhat among stations and among years, the most common taxa collected on the multiplate samplers in the Steel Creek corridor included filter-feeding organisms such as *Simulium* (blackflies), tanytarsine and orthoclad chironomids, Coleoptera, mayflies, and net-spinning caddisflies such as *Cheumatopsyche* and *Hydropsyche*. In the delta, amphipods (*Hyalella azteca* and *Gammarus fasciatus*), oligochaetes, caddisflies (*Cheumatopsyche* and *Oxythira*), isopods (*Caecidotea*), gastropods (*Amnicola*, *Physella*, *Menetus*, and limpets), mayflies (*Baetis*, *Eurylophella*, and *Stenonema*) and the chironomid groups Tanypodinae, Orthocladiinae, Chironomini, and Tanytarsini were most abundant. Dominant taxa at the channel stations included oligochaetes; the mayfly, *Stenonema*; and orthoclad and tanytarsine chironomids. Chironomids (68.8%) and mayflies (104.4%) dominated the lotic station at Road B.

4.6.6.2.4 Densities

The mean annual density of organisms collected from the multiplate samplers ranged from 294.7 organisms/m^2 at delta Station 330 in 1990 to 41,080.3 organisms/m^2 at corridor Station 275 in 1988. Macroinvertebrate densities just downstream from the L-Lake dam at Station 275 were always much higher than at the other stations, due to the presence of numerous filter-feeding organisms that fed on the seston inputs flowing into the stream from L Lake. In general, macroinvertebrate densities were higher in the upper stream corridor than in the delta. In the stream channel downstream from the delta, densities were always lower at Station 360 than near the creek mouth (Station 370). In Meyers Branch, macroinvertebrate densities were usually fairly similar to densities in the Steel Creek delta. Although macroinvertebrate densities at all stations varied considerably among years, no distinct temporal trends were observed during the six-year study.

4.6.6.2.5 Biomass

Macroinvertebrate biomass on the multiplate samplers, as measured by ash-free dry weight/m^2, ranged from 0.001 g AFDW/m^2 at Station 370 in 1990 to 8.220 g AFDW/m^2 at Station 275 in 1988. In general, biomass followed the same patterns as density, with the highest biomass usually found at stations in the stream corridor just downstream from the L-Lake dam. No distinct temporal trends were observed.

4.6.6.2.6 Drift

4.6.6.2.6.1 Densities

Mean annual densities of macroinvertebrate drift in Steel Creek ranged from 1653.6 organisms/ 1000 m^3 at Station 330 in 1991 to 35,880.7 organisms/1000 m^3 at this same station in 1990. High drift densities were reported at delta Stations 330 and 350 during the spring of 1990. No obvious reason for the high drift densities was reported. Drift could not be collected at these two stations during the spring of 1991 due to low water levels (Trapp and Hosey 1992).

4.6.6.2.6.2 Dominant Species

Dominant taxa collected in the drift included oligochaetes; hydroptilid caddisflies (*Oxyethira and Hydroptila);* the mayflies *Baetis, Caenis, and Stenonema;* the amphipod, *Hyalella azteca;* water mites; blackflies *(Simulium);* the phantom midge, *Chaoborus punctipennis;* and the chironomids *Rheotanytarsus, Cricotopus and Orthocladius.* The taxonomic composition of the drift varied greatly seasonally.

4.6.7 Fish

4.6.7.1 Introduction

McFarlane (1976) first studied the fish assemblages of Steel Creek. However, extensive sampling began in 1983 and continued through 1985 (Paller et al. 1984, 1985, and 1986a). These studies emphasized ichthyoplankton but also included limited sampling of adult and juvenile fish. Their objective was to assess the importance of spawning habitats in Steel Creek that could be damaged by the planned restart of L Reactor in late 1985.

Fisheries studies were intensified during 1986-1991 to document the effects of thermal effluents released from L Reactor on the Steel Creek fish assemblages. These comparatively extensive studies included both juvenile and adult, and ichthyoplankton sample stations located throughout Steel Creek. Table 4-14 lists species of adult and juvenile fish taken in Steel Creek and Meyers Branch. The following discussion of fisheries studies in Steel Creek has been divided into two sections: before the L-Reactor restart and after the L-Reactor restart.

4.6.7.2 Studies Conducted Prior to the Restart of L Reactor

Thermal effluent from L Reactor was discharged directly into Steel Creek during 1954-1968, resulting in the destruction of the cypress-tupelo canopy in portions of the Steel Creek swamp and the stream corridor upstream from the swamp (Gladden et al. 1985). Loss of vegetation cover and high reactor flows also caused erosion in the stream corridor and the deposition of sediments where Steel Creek enters the Savannah River swamp. After reactor discharges ceased in 1968, areas of open-canopy swamp previously impacted by high temperatures and sediment deposition came to support a marsh habitat characterized by an abundance of submerged and emergent macrophytes and woody plants such as willow and buttonbush.

Table 4-14. Species of Fishes Taken from Steel Creek

Family	Scientific Name	Common Name	Electrofishing	Fyke Net
Lepisosteidae	*Lepisosteus osseus*	longnose gar	X	X
	Lepisosteus platyrhincus	Florida gar	X	X
Amiidae	*Amia calva*	bowfin	X	X
Anguillidae	*Anguilla rostrata*	American eel	X	X
Clupeidae	*Alosa aestivalis*	blueback herring	X	X
	Alosa sapidissima	American shad	X	X
	Dorosoma cepedianum	gizzard shad	X	X
Cyprinidae	*Cyprinella leedsi*	bannerfin shiner	X	
	Cyprinella nivea	whitefin shiner	X	
	Cyprinus carpio	common carp	X	
	Nocomis leptocephalus	bluehead chub	X	X
	Notemigonus crysoleucas	golden shiner	X	X
	Notropis chalybaeus	ironcolor shiner	X	
	Notropis cummingsae	dusky shiner	X	
	Notropis hudsonius	spottail shiner	X	
	Notropis lutipinnis	yellowfin shiner	X	
	Notropis petersoni	coastal shiner	X	
Catostomidae	*Erimyzon oblongus*	creek chubsucker	X	X
	Erimyzon sucetta	lake chubsucker	X	X
	Hypentelium nigricans	northern hog sucker	X	X
	Minytrema melanops	spotted sucker	X	X
	Moxostoma collapsum	notchlip redhorse	X	
	Scartomyzon sp.	brassy jumprock	X	
Ictaluridae	*Ameiurus brunneus*	snail bullhead	X	X
	Ameiurus catus	white catfish	X	X
	Ameiurus natalis	yellow bullhead	X	X
	Ameiurus nebulosus	brown bullhead	X	X
	Ameiurus platycephalus	flat bullhead	X	X
	Ictalurus punctatus	channel catfish	X	X
	Noturus gyrinus	tadpole madtom	X	
	Noturus insignis	margined madtom	X	
	Noturus leptacanthus	speckled madtom	X	
Esocidae	*Esox americanus*	redfin pickerel	X	X
	Esox niger	chain pickerel	X	X
Umbridae	*Umbra pygmaea*	eastern mudminnow	X	
Aphredoderidae	*Aphredoderus sayanus*	pirate perch	X	
Amblyopsidae	*Chologaster cornuta*	swampfish	X	
Belonidae	*Strongylura marina*	Atlantic needlefish	X	
Fundulidae	*Fundulus chrysotus*	golden topminnow	X	
	Fundulus lineolatus	lined topminnow	X	
Poeciliidae	*Gambusia holbrooki*	eastern mosquitofish	X	

Table 4-14. Species of Fishes Taken from Steel Creek - continued

Family	Scientific Name	Common Name	Electrofishing	Fyke Net
Atherinopsidae	*Labidesthes sicculus*	brook silverside	X	
Moronidae	*Morone saxatilis*	striped bass		X
Elassomatidae	*Elassoma evergladei*	Everglades pygmy sunfish	X	
	Elassoma zonatum	banded pygmy sunfish	X	
Centrarchidae	*Acantharchus pomotis*	mud sunfish	X	
	Centrarchus macropterus	flier		X
	Enneacanthus gloriosus	bluespotted sunfish	X	
	Lepomis auritus	redbreast sunfish	X	X
	Lepomis cyanellus	green sunfish	X	
	Lepomis gulosus	warmouth	X	X
	Lepomis macrochirus	bluegill	X	X
	Lepomis marginatus	dollar sunfish	X	
	Lepomis microlophus	redear sunfish	X	X
	Lepomis punctatus	spotted sunfish	X	X
	Micropterus salmoides	largemouth bass	X	X
	Pomoxis nigromaculatus	black crappie	X	X
Percidae	*Etheostoma fricksium*	Savannah darter	X	
	Etheostoma fusiforme	swamp darter	X	
	Etheostoma hopkinsi	Christmas darter	X	
	Etheostoma olmstedi	tessellated darter	X	
	Etheostoma serrifer	sawcheek darter	X	
	Perca flavescens	yellow perch	X	
Mugilidae	*Mugil cephalus*	striped mulet	X	

McFarlane (1976) studied the fish assemblage in Steel Creek to determine if it had recovered from previous thermal discharges from L-Reactor. He reported that recovery was "almost complete," based on comparisons of species richness between Steel Creek and nearby unimpacted streams.

Sampling efforts in Steel Creek during 1983-1985 were part of the CCWS, which evaluated the impacts of SRS operations on spawning activity and ichthyoplankton distribution at sites on SRS and in the Savannah River. Special emphasis was placed on Steel Creek because of concerns that it would be affected negatively by the restart of L Reactor after approximately 17 years of nonoperation (with the exception of a brief operational period in the mid-1970s). Ichthyoplankton sampling originally was confined to the mouth of Steel Creek to document the contribution of Steel Creek to the ichthyoplankton assemblages of the Savannah River, but was later expanded to include sample sites in the swamp, marsh, and channel habitats upstream from the stream mouth. A list of icthyoplankton taxa from Steel Creek is presented in Table 4-15.

Table 4-15. Taxa of Ichthyoplankters Taken in Steel Creek

Family	Taxa
Clupeidae	*Alosa aestivalis*, blueback herring
	Alosa sapidissima, American shad
	Dorosoma spp., gizzard or threadfin shad
Cyprinidae	Unidentified minnows
Catostomidae	*Minytrema melanops*, spotted sucker
	Unidentified suckers
Esocidae	*Esox* spp., pickerel
Aphredoderidae	*Aphredoderus sayanus*, pirate perch
Atherinopsidae	*Labidesthes sicculus*, brook silverside
Centrarchidae	*Lepomis* spp., bream
	Micropterus salmoides, largemouth bass
	Unidentified sunfish
	Pomoxis sp., crappie
Percidae	*Perca flavescens*, yellow perch
	Unidentified darters

Samples also were taken from the Savannah River and Savannah River tributaries to develop a basis for assessing the relative importance of Steel Creek compared with other spawning sites. Ichthyoplankton were collected weekly with paired 0.505-mm mesh nets during daylight from February through July. The number of samples collected was approximately equal among years.

Ichthyoplankton composition in Steel Creek near its confluence with the Savannah River varied among years. Larval minnows (Cyprinidae), larval yellow perch (*Perca flavescens*), larval sunfish/bass (Centrarchidae), and blueback herring (*Alosa aestivalis*) were the most abundant taxa in 1983. Species composition was fairly similar in 1984 except that darters replaced yellow perch. However, species composition changed in 1985 when American shad, blueback herring, and darters were the dominant species and minnows and sunfishes were comparatively rare (Paller et al. 1984, 1985, and 1986a).

Despite this variability, Steel Creek was consistently one of the most productive Savannah River tributaries in terms of its contribution to the river ichthyoplankton assemblage. This contribution was assessed by determining the number of ichthyoplankton transported from creek to river (Paller et al. 1984, 1985, and 1986a). In 1983, Steel Creek ranked ninth among the 33 major tributaries between river kilometers 47.6 and 301 (River mile 29.6 and 187.1), essentially from Savannah, Georgia, to Augusta, Georgia. (The only creeks with greater ichthyoplankton contributions were in lower reaches of the river.)

A similar pattern was observed during 1984 except that only three creeks transported more ichthyoplankton into the Savannah River than Steel Creek. In 1985, more ichthyoplankton were transported to the Savannah River from Steel Creek than from any other tributary under study. The number of ichthyoplankton transported from all creeks was much lower during 1985 than during 1984 or 1983, possibly due to decreased creek discharges (79% lower during 1985 than 1984) or decreased spawning resulting from comparatively low water levels.

Ichthyoplankton transported from Steel Creek raised Savannah River ichthyoplankton levels by an estimated 10% in 1983, 12.8% in 1984, and 2% in 1985 (Paller et al. 1984, 1985, and 1986a). All creeks made minimal contributions in 1985. While creek-to-river transport varied among years, Steel Creek consistently demonstrated high transport in relation to the other creeks in the mid-reaches of the Savannah River. Steel Creek also typically produced more American shad and blueback herring eggs and larvae than most of the other creeks. Relatively high ichthyoplankton transport from Steel Creek during three years with dissimilar hydrological patterns indicated that Steel Creek was an important spawning area compared with other Savannah River tributaries.

Identification of the importance of Steel Creek as a spawning area led to further interest in locating and assessing the spawning and nursery areas in Steel Creek. Fifteen ichthyoplankton sample stations were established throughout Steel Creek (Paller et al. 1986b); most were concentrated in the lower reaches of the creek, which consisted of three main habitats: creek mouth, a channel connecting the creek mouth to the marsh and swamp, and the marsh and swamp. The marsh and swamp consisted of open canopy marsh habitats where previous discharges from L Reactor killed the cypress-tupelo canopy and closed canopy cypress-tupelo swamp. Aquatic macrophytes were abundant in the open canopy areas.

Sampling was conducted weekly from February through July during 1984 and 1985 (Paller 1985, Paller et al. 1986b). Spawning generally began in March, peaked in April and May, then declined through June and July. In 1984, ichthyoplankton densities were approximately comparable in the swamp and marsh and creek mouth; densities further upstream in Steel Creek were relatively low (Paller et al. 1986b). In 1985, densities were highest in the creek mouth but also fairly high in the creek channel and at several locations upstream from the swamp and marsh. However, species composition differed among habitats with American shad, blueback herring, and darters predominating in the creek mouth and channel and minnows and darters predominating further upstream. These data indicated the importance of the creek mouth and creek channel habitats as spawning areas for anadromous fish.

Most of the ichthyoplankton sampling efforts in Steel Creek concentrated on assessing and comparing ichthyoplankton distribution among macrohabitats (i.e., creek mouth, marsh, swamp, upper creek). However, efforts also were made to assess the distribution of ichthyoplankton among microhabitats in portions of the Steel Creek marsh and swamp (Paller 1987). Three microhabitats (macrophyte beds, open channels, and macrophyte bed/open channel interface) were sampled by pumping water through a 0.505-mm mesh net with a trash pump.

Samples were taken in the day and at night. The results demonstrated high abundances of a number of taxa (suckers, minnows, pirate perch, and sunfishes) within the macrophyte beds, indicating the importance of this habitat as a spawning or nursery area. Larvae seldom were found in the open channels except at night. Larvae drifting in the open channels were invariably young and probably originated in the macrophyte beds. Many were undoubtedly transported out of Steel Creek into the Savannah River.

Aho et al. (1986) sampled adult and juvenile fishes by electrofishing in Steel Creek and two other streams to assess the persistence and stability of the fish assemblages in these streams. Steel Creek had slightly higher species richness and diversity than the other streams. Species richness was highest in the lower reaches of all streams. While limited temporal variability occurred at all sites, there were no consistent differences in degree of variability between sites on Steel Creek or between Steel Creek and the other streams under study.

Aho et al. (1986) also electrofished 12 sample sites in the Savannah River swamp system, three of which were in the Steel Creek marsh and swamp. The number of species and fish density were highest in the Steel Creek marsh where habitat diversity, structural complexity, and primary productivity were high as a result of abundant macrophyte growth and other factors related to the progression of secondary succession. Sites in the Steel Creek marsh were dominated by small-bodied species such as minnows and brook silversides, while larger species were more common in closed canopy areas with less macrophyte growth. While the fish assemblages in the Steel Creek marsh and swamp varied temporally and annually, assemblage stability and persistence of species were generally high with most species repeatedly found over census periods and the rank order of species abundance remaining relatively constant over time.

4.6.7.3 Studies Conducted Following the Restart of L Reactor

The ecological importance of the lower reaches of Steel Creek led to the decision to build a cooling reservoir that would reduce the temperature of L-Reactor cooling water to environmentally acceptable levels before it entered the lower reaches of Steel Creek. After the restart of L Reactor in late 1985, the emphasis of fisheries studies in Steel Creek was on assessing possible impacts caused by the presence of L Lake and the operation of L Reactor. These studies initially included 14 sample stations throughout Steel Creek, although this number was reduced to four in 1991. Adult and juvenile fish and ichthyoplankton were collected at each sample station.

There was a major change in reactor operations during the 1986-1992 study period that affected environmental conditions in Steel Creek. L Reactor was operated from 1986 to mid-1988, resulting in the discharge of large volumes of water to Steel Creek. However, L Reactor has not operated since July 1988. The shutdown of L Reactor coupled, in some instances, with decreases in natural runoff due to low rainfall, greatly diminished reservoir releases to Steel Creek. Resulting instream changes included diminished depths, current velocities, and habitat volumes.

The Steel Creek sample stations represented a variety of habitats: corridor (the stream reach between the L Lake dam and the marsh and swamp), marsh (the open canopy area in the marsh and swamp), swamp (the closed canopy area in the marsh and swamp) and channel (the stream channel between the marsh and swamp and the creek mouth) (Paller et al. 1987). Marked differences in species composition among sample sites were attributed to differences in habitat. In addition, the impacts of reactor operation differed markedly among sites.

Marsh sample stations supported a diverse fauna of primarily small species such as minnows (particularly coastal shiner), sunfishes, and pirate perch. Other species of importance were brook silversides, chubsuckers, and largemouth bass. Closed canopy swamp stations supported fewer small fishes and more large fishes such as largemouth bass and spotted sucker. Fish assemblages in the Steel Creek marsh and swamp showed little immediate change following the restart of L Reactor. Exceptions were a possible decrease in the abundance of brook silversides and an increase in the abundance of redbreast sunfish and bluegill. The latter species probably emigrated into the marsh from L Lake, where it was stocked in large numbers. By 1988, it was probable that a reproducing population of bluegill had become established in the Steel Creek marsh/swamp, although there was no sign that this species displaced indigenous swamp species (Heuer and Kissick 1989). Reductions in species richness and the abundance of some taxa in 1988 were associated with reductions in creek flow and depth from the shutdown of L Reactor. Decreases in fish species richness and abundance also could have partly resulted from reduced sampling effort due to program changes and the inaccessibility of some sample stations (Sayers and Mealing 1992).

The greatest impacts of the L-Reactor restart occurred in the stream corridor, the area of the creek closest to the dam. High densities of larvae and, in some cases, juveniles of species common in L Lake were observed immediately below the L-Lake dam. This influx of L-Lake species (in water discharged from L Lake) led to the temporary establishment of bluegill in the stream corridor and possibly permanent establishment of this species in the marsh and swamp as discussed. Other species observed to enter Steel Creek from L Lake were redbreast sunfish and gizzard shad (Heuer and Kissick 1989). While bluegill temporarily attained high numbers at several locations in the corridor and in Meyers Branch, a tributary of Steel Creek, they decreased over time and had no apparent effects on the stream's indigenous fish fauna. Meffe (1991) concluded that the failure of bluegill to establish permanent populations in Meyers Branch was the result of unfavorable habitat and the maintenance of natural flow regimes in this stream.

Additional impacts on the corridor fish assemblage resulted from large increases in current velocity and habitat volume due to the discharge of water from L Lake into Steel Creek. Before and after comparisons indicated a decrease in species typical of small streams, such as darters and some types of minnows (Paller et al. 1987). Species richness declined over time due to the loss of these species and the L-Lake species that colonized the corridor from L Lake as described above (Heuer and Kissick 1989). Fish assemblage structure continued to change following the shut-down of L-Reactor, with sunfishes and largemouth bass composing a larger proportion of the catch than in previous years. Fish abundance also appeared to decline, possibly reflecting lower habitat availability due to reduced flows (Sayers and Mealing 1992).

The channel below the marsh and swamp initially experienced increased flows as a result of the discharge of L-Reactor effluent. However, before and after comparisons demonstrated little measurable effect on fish assemblage structure (Paller et al. 1987). The ichthyofauna of the channel remained dominated by largemouth bass, catfish, spotted sunfish, and minnows, and icthyoplankton collections demonstrated continued use of the channel as a spawning area by the anadromous American shad and blueback herring. Flow reductions following the shutdown of L-Reactor were associated with a shift in dominance to largemouth bass and minnows and a reduction in species richness (Sayers and Mealing 1992). The latter could be the result of reduced habitat availability, but it also coincided with a reduction in sampling effort that could have come from the collection of fewer species.

4.6.7.4 Radionuclides in Fish

Paller et al. (1999) examined historical trends in ^{137}Cs in fishes of the SRS. Peak levels were found between 1960 and 1970 with highest levels occurring in Steel Creek (53.9 Bq/g). This was nearly an order of magnitude above the concentrations reported for Par Pond and Fourmile Creek. Between 1969 and 1973 concentrations of ^{137}Cs in Steel Creek fishes dropped from approximately 54 Bq/g to approximately 2 Bq/g. Rate of reduction of ^{137}Cs concentrations after 1973 was much slower. The half-life of ^{137}Cs in fish was much shorter than the radioactive half-life indicating that removal is occurring rather than simple radioactive decay. Paller et al. (2002) demonstrated that ^{137}Cs levels in Steel Creek fish have continued to drop (Figure 4-29). Peles et al. (2000) calculated ecological half-lives of ^{137}Cs for seven species of fish from Steel Creek. The half-live estimates ranged from 4.43 years for pirate perch (*Aphredoderus sayanus*), an insectivore, to 6.53 years for warmouth (*Lepomis gulosus*), a predator taking fish and crayfish.

Over Site history, Steel Creek has received an estimated 11 TBq (284 Ci) of radiocesium with 99% of this being ^{137}Cs (Garten et al. 2000). Burger et al. (2001) examined current levels of radiocesium (^{137}Cs) in the fishes of Steel Creek and the Savannah River. Fish collected from Steel Creek had significantly more ^{137}Cs (about an order of magnitude) than those captured in the Savannah River, however no fish from Steel Creek had ^{137}Cs levels above 0.6 Bq/g, the European Economic Community limit for fresh fish.

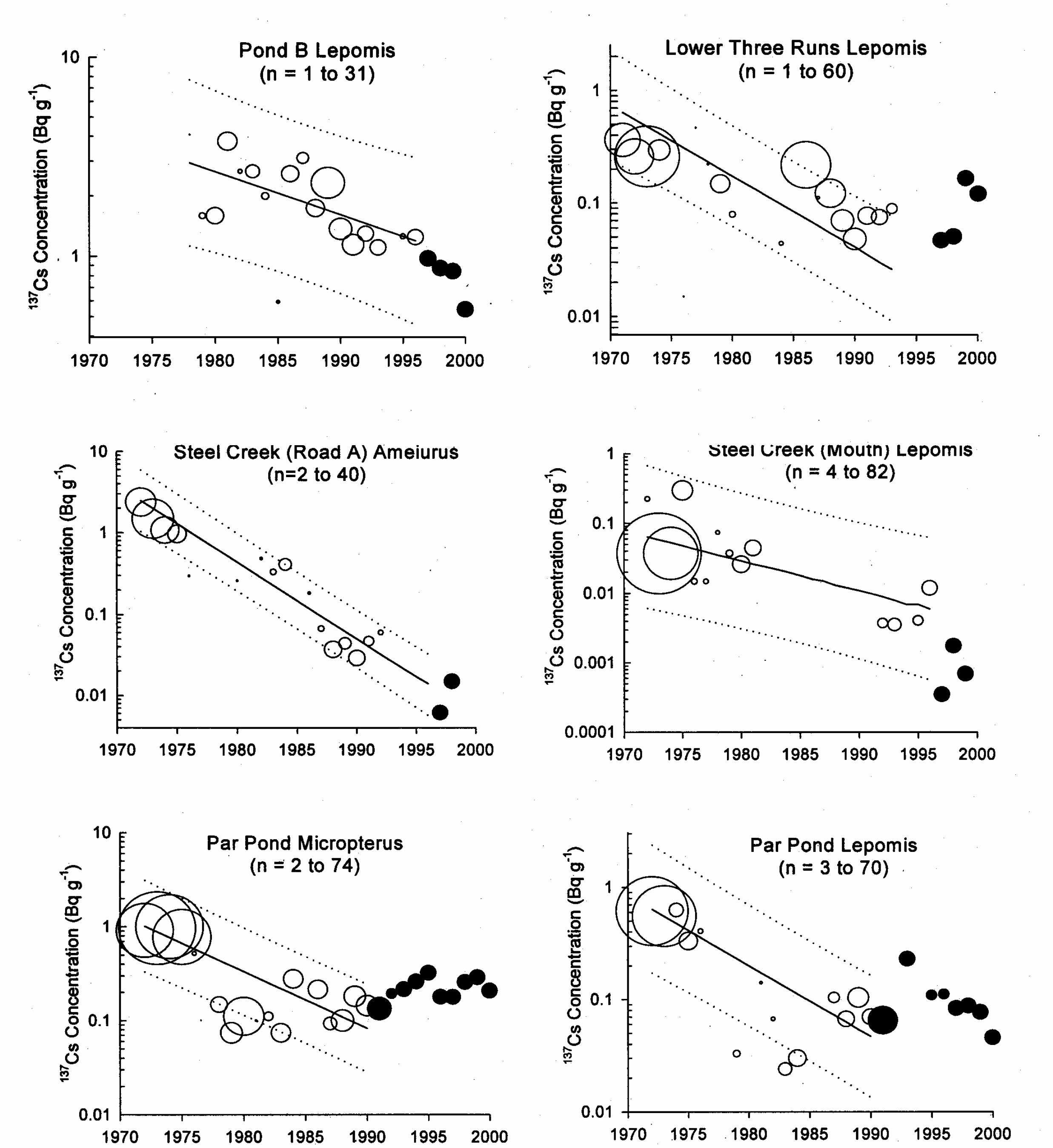

Figure 4-29. Changes in ^{137}Cs in Whole Fish Over Time

Circle size is proportional to sample size.
Solid circle represents samples measured in 1997-2001 time period.
Solid line is the regression line and dottel lines represent the 95% confidence limits.
Taken from Paller et al. (2002).

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4.7 LOWER THREE RUNS

4.7.1 Drainage Description and Surface Hydrology

4.7.1.1 General Description

Lower Three Runs is a large blackwater creek that drains about 460 km^2 (178 mi^2) and has a 1012-ha (2500-acre) mainstream impoundment (Section 5.8-Par Pond has a detailed description) on its headwaters (Figure 4-30). From the Par Pond dam, Lower Three Runs flows about 39 km (24 mi) before it enters the Savannah River. The SRS includes the floodplain of Lower Three Runs between the dam and the river. Several other ponds were constructed in the headwaters above Par Pond to improve cooling of the reactor effluent. Pond B, the largest, has an area of about 73 ha (180 acres).

4.7.1.2 Effluent Contribution

Before construction of Par Pond, effluent cooling water from R Reactor (about 5.66 m^3/sec [200 ft^3/sec]) was discharged through Joyce Branch to Lower Three Runs. In 1964, R Reactor was shut down, and all P-Reactor cooling water was diverted from Steel Creek to Par Pond. P Reactor was shut down in 1988. Historically, SRS operations caused large fluctuations in water volume in Lower Three Runs just downstream from the dam at Par Pond, but groundwater and tributary inputs were sufficient to dampen these fluctuations farther downstream (Firth et al. 1986).

4.7.1.3 Flow Measurements

The U.S. Geological Survey (USGS) measured flow at several locations on Lower Three Runs. Records for the most downstream station (Lower Three Runs near Snelling) date back to March 1974. In water year 1995, the mean flow of Lower Three Runs at Patterson Mill was 1.7 m^3/s (60 ft^3/s). Over the period of water years 1974-1995 at Patterson Mill, the mean flow was 2.4 m^3/s (85.8 ft^3/s); the 7-day low flow was 0.42 m^3/s (15 ft^3/s); and the 7Q10 was 0.45 m^3/s (16 ft^3/s). All flow monitoring stations in Lower Three Runs were discontinued and no data exists after September 2002.

4.7.2 Water Chemistry and Quality

4.7.2.1 Studies and Monitoring

4.7.2.1.1 <u>Water Quality Monioring</u>

Since 1973, the WSRC Environmental Monitoring Section routinely has monitored the water quality of Lower Three Runs at various locations (below Par Pond and at Patterson Mill). Since 1982, routine monitoring has included only the Patterson Mill station (Figure 4-31; point 02) which currently is sampled monthly for physical and biological parameters and quarterly for metals. Additional samples are collected annually and analyzed for pesticides and PCBs. All routine water quality data reported in the following sections can be found in the annual SRS environmental reports.

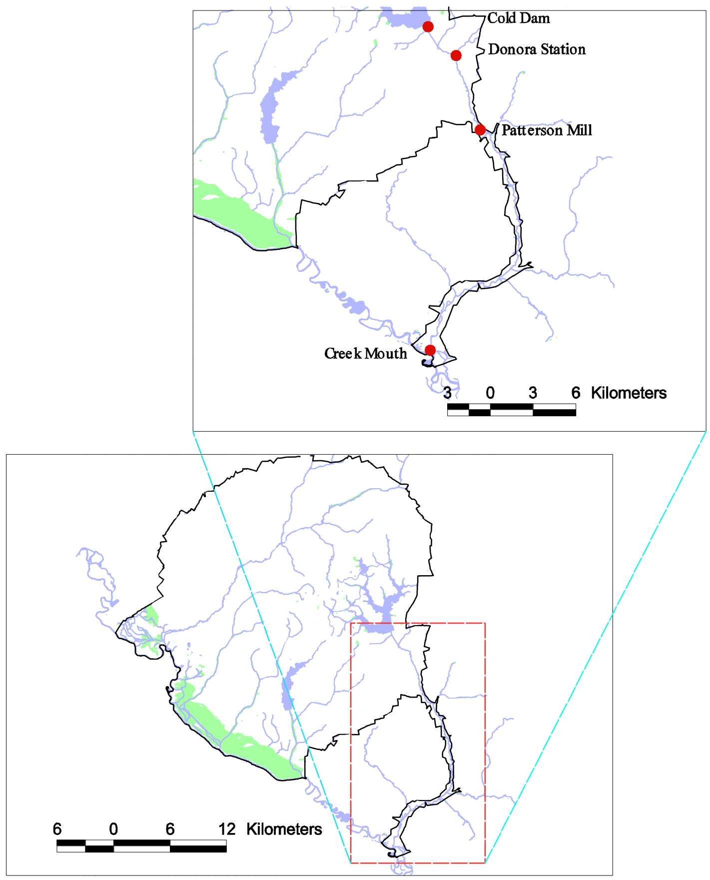

Figure 4-30. Location of Lower Three Runs on SRS

4.7.2.1.2 <u>Comprehensive Cooling Water Study (CCWS)</u>

The CCWS, conducted from 1983 to 1985, included the following sampling locations for Lower Three Runs (Figure 4-31):

- Lower Three Runs at Road B (01): consists of Par Pond effluents only
- Lower Three Runs at Patterson Mill (02): reflects Par Pond effluents and natural runoff waters from Lower Three Runs tributaries
- Lower Three Runs at U.S. Highway 125 (03): combines cumulative effects of natural runoff from entire Lower Three Runs watershed, just above confluence with the Savannah River

Newman et al. (1986) and Lower (1987) discuss the comprehensive results of CCWS data. Gladden et al. (1985) summarized Lower Three Runs water quality data prior to the CCWS. The CCWS data in the following sections reflect impacts associated with reactor operation.

The CCWS and routine monitoring show similar water quality results for Lower Three Runs. Because Lower Three Runs has not received direct thermal discharge since 1958, its water quality and chemistry have remained relatively constant.

01 Road B
02 Patterson Mill
03 Highway 125

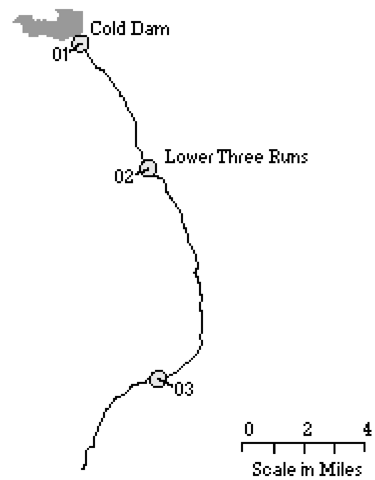

Figure 4-31. Water Chemistry and Quality Sampling Stations for Lower Three Runs

4.7.2.1.3 Priority Pollutant Study

In 1984, a study was conducted to determine the levels of volatile, acid, and base/neutral organic compounds in Lower Three Runs. One location near Road B, was sampled for this study. The results are discussed in the sections that follow and are reported in Lower (1987).

4.7.2.2 Field Data

4.7.2.2.1 Water Temperature

The mean water temperature at sampling locations in Lower Three Runs ranged from 16.0 to 19.3°C (60.8 to 66.7°F) during the CCWS and routine monitoring. Historic monitoring data indicated slightly higher water temperatures from stream-water samples collected just downstream of Par Pond at Road B. Temperatures at this location averaged 2°C (3.6°F) higher than other nonthermal or post-thermal surface waters at SRS (Gladden et al. 1985).

4.7.2.2.2 pH Measurements

During the CCWS, the pH of Lower Three Runs was circumneutral with means ranging from 6.94 just below Par Pond to 7.17 at both Patterson Mill and S.C. Highway 125 near the confluence of Lower Three Runs and the Savannah River. The pH ranged from 5.7 to 7.5 during routine monitoring.

4.7.2.3 Physical Characteristics and General Chemistry

4.7.2.3.1 Dissolved Oxygen

The mean dissolved oxygen concentrations in Lower Three Runs during the CCWS ranged from 7.06 to 7.51 mg/l. From 1987 to 1991, the mean dissolved oxygen concentrations increased to 8.0 mg/l at the Patterson Mill location. The low mean dissolved oxygen value of 7.06 mg/l measured during the CCWS can be attributed to the higher water temperatures found during the CCWS at the sampling location just below Par Pond. The mean dissolved oxygen concentration from 1992 to 1995 was 8.2 mg/l.

4.7.2.3.2 Suspended Solids and Turbidity

Mean turbidity values in Lower Three Runs ranged from 2.8 to 6.3 NTU during the CCWS and routine monitoring. The lowest average (2.8 NTU) was recorded during routine monitoring (1987-1991).

The concentration of suspended solids in Lower Three Runs has not changed substantially since the CCWS. Mean concentrations ranged from 4.11 to 5.40 mg/l during the CCWS. Routine monitoring has recorded a suspended solids mean concentration of 4.9 mg/l between 1987 and 1991 and a mean concentration of 7.5 mg/l from 1992 to 1995.

4.7.2.3.3 Conductivity

Specific conductivity values ranged from 38.9 to 134.8 µS/cm (mean range, 74.1 to 86.3 µS/cm) in Lower Three Runs during the CCWS. From 1987-1995, specific conductance at Patterson Mill has averaged 75 µS/cm with a range of 13-140 µS/cm.

4.7.2.4 Major Anions and Cations

4.7.2.4.1 Alkalinity, Chloride, and Sulfate

The mean total alkalinity in Lower Three Runs during the CCWS ranged from 21.8 mg $CaCO_3$/l at the Cold Dam to 35.1 mg $CaCO_3$/l at Patterson Mill. Routine monitoring from 1987 to 1991 has shown a similar mean value at Patterson Mill (31 mg $CaCO_3$/l). Between 1992 and 1995, mean alkalinity was lower, 26.5 mg $CaCO_3$/l. Generally, alkalinity concentrations increased with distance downstream and reflected the alkaline nature of local groundwaters entering Lower Three Runs (Siple 1967; Newman et al. 1986). Furthermore, calcareous deposits underlying portions of the Lower Three Runs streambed (Langley and Marter 1973) likely contribute to the increased alkalinity of the stream water (Gladden et al. 1985).

Mean chloride values were higher in Lower Three Runs at Road B (6.17 mg/l) than downstream at S.C. Highway 125 (3.71 mg/l). This is consistent with the higher values measured in Par Pond during the CCWS and the L-Lake/Steel Creek Program (mean range: 5.73 to 6.28 mg/l) (Kretchmer and Chimney 1992). Mean sulfate concentrations followed this same trend. During the CCWS, mean sulfate concentrations ranged from 3.51 mg/l at the Cold Dam to 0.78 mg/l at the downstream station. Between the CCWS and the routine monitoring from 1987 to 1991, the mean sulfate concentration at Patterson Mill increased from 1.85 mg/l to 4.5 mg/l. From 1992 to 1995, the mean chloride value was 3.6 mg/l and the mean sulfate value was 2.9 mg/l.

4.7.2.4.2 Calcium, Magnesium, Sodium, and Potassium

The calcium, magnesium, and sodium concentrations (total) measured in Lower Three Runs during the 1987-1995 routine monitoring are similar to the concentrations measured during the CCWS. Potassium concentrations are not measured during routine monitoring, but were often below the detection limit (0.368 mg/l) during the CCWS.

4.7.2.4.3 Aluminum, Iron, and Manganese

During the CCWS, mean total aluminum concentrations ranged from 0.255 to 0.454 mg/l. Mean total iron concentrations ranged from 0.509 to 1.54 mg/l and mean total manganese concentrations ranged from 0.069 to 0.209 mg/l. Both iron and manganese concentrations were highest just downstream of Par Pond. Insufficient data prevented the calculation of mean concentrations for the period of routine monitoring between 1987 and 1991. However, the measurement ranges show that the concentrations of aluminum, iron, and manganese have all decreased since the CCWS. During routine monitoring between 1992 and 1995, mean aluminum concentration was 0.16 mg/l; mean iron concentration was 0.44 mg/l; and mean manganese concentration was 0.078 mg/l.

4.7.2.5 Nutrients

4.7.2.5.1 Phosphorus

All measured forms of phosphorus generally indicate that Lower Three Runs is phosphorus deficient relative to the waters of the Savannah River (Lower 1987). Mean total phosphorus concentrations ranged from 0.037 to 0.053 mg/l during the CCWS. The mean total phosphorus concentration during routine monitoring had decreased to 0.029 mg/l between 1987 and 1991 and increased to 0.04 mg/l between 1992 and 1995. Mean total orthophosphate concentrations ranged from 0.018 to 0.024 mg/l during the CCWS. Orthophosphate is not measured during routine monitoring.

4.7.2.5.2 Nitrogen

During the CCWS, mean concentrations for organic nitrogen and total Kjeldahl nitrogen ranged from 0.200 to 0.255 mg/l and 0.257 to 0.275 mg/l, respectively. Mean ammonia concentrations ranged from 0.029 to 0.086 mg/l. Mean nitrite concentrations ranged from 0.003 to 0.004 mg/l and mean nitrate concentrations ranged from 0.041 to 0.124 mg/l. Concentrations measured during routine monitoring for ammonia fell within these ranges. Mean nitrate concentration between 1992 and 1995 was 0.22 mg/l. Organic nitrogen, total Kjeldahl nitrogen, and nitrite are not measured during routine monitoring.

4.7.2.6 Trace Elements

Low-level concentrations of trace element were measured during the CCWS. The detection limits used during routine monitoring are higher than those used in the CCWS. As is generally the case with SRS thermal, nonthermal, and post-thermal waters, low trace element concentrations, reflecting Savannah River concentrations, were found in Lower Three Runs (Lower 1987).

4.7.2.7 Organic Carbon

In Lower Three Runs, mean total organic carbon concentrations measured during the CCWS increased from 5.4 mg/l downstream of the Par Pond overflow to 8.2 mg/l at the S.C. Highway 125 crossing. This latter mean concentration was the highest found in all waters of onsite streams (Newman et al. 1986).

4.7.2.8 Priority Polluants

Concentrations of all 88 volatile, acid, and base/neutral organic compounds tested in Lower Three Runs at Road B never exceeded the lower limits of detection. Lower (1987) documents the results of this study.

4.7.2.9 Pesticides, Herbicides, and PCBs

The WSRC Environmental Monitoring Section collects a sample annually from Lower Three Runs and analyzes it for pesticides, herbicides, and PCBs. From 1987 to 1995, concentrations of all analytes in Lower Three Runs were below analytical detection limits.

Lower (1987) reports the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985, and results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations also were near or below detection limits at all locations.

4.7.2.10 Chemical, Including Radionuclide, and Toxicity Assessment Studies

No chemical or toxicity assessment studies have been done on Lower Three Runs.

4.7.3 Algae

The algae of Lower Three Runs have not been studied with the exception of two stations that were sampled for periphyton as part of the CCWS conducted during 1984-1985. Periphyton biomass during this study reportedly was similar to that of Upper Three Runs (Specht 1987).

4.7.4 Macrophytes

The only data dealing with aquatic macrophytes in Lower Three Runs comes from the CCWS (Specht 1987) and was collected during the 1984-1985 sampling period. This data may not be representative of the current state of the macrophyte populations in Lower Three Runs.

Summary data from the CCWS appears in Specht (1987). Station 42, located just downstream from Par Pond dam, shows macrophyte development. This is probably attributable to less overstory cover and flow fluctuations from Par Pond. The other two stations show little (Station 43; at S.C. Highway 125) and no (Station 53; Stinson Bridge) macrophyte development. This is probably from extensive shading by the riparian tree canopy.

It is possible that the riparian vegetation structure has been altered by the change in flow regimes brought about first by the shutdown of P Reactor and then by Par Pond drawdown.

4.7.5 Zooplankton

No data are available on the zooplankton of Lower Three Runs.

4.7.6 Macroinvertebrates

4.7.6.1 Sampling Locations and Methods

Lower Three Runs receives no NPDES discharges directly, but receives overflow from Par Pond. Since 1996, the only NPDES discharge that Par Pond received is from PP-1, which consisted of small amounts (< 1 gpm) of rinsewater and backwash from a manganese greensand filter system in the Par Pond Laboratory next to the pumphouse, which is no longer in operation.

Macroinvertebrates were collected at three stations in Lower Three Runs from November 1983 through September 1985 as part of the CCWS (Figure 4-32). Macroinvertebrates were collected from Hester-Dendy multiplate samplers, leaf bags, and drift. Macroinvertebrates also were collected in the mouth of Lower Three Runs from October 1982 through September 1983 using Hester-Dendy multiplate samplers and drift nets. Specht (1987) describes details of sampling methods. Macroinvertebrates were sampled during the summer of 1993 at two locations in Lower Three Runs below the Par Pond dam. Hester-Dendy multiplate macroinvertebrate samplers were deployed for one month (Specht 1994).

Macroinvertebrates also were sampled in September 1994 at Road B, just below the Par Pond dam, in order to develop a biotic index for southeastern streams using Hester-Dendy multiplate samplers. While not specifically designed to characterize SRS streams, these data contribute to a better understanding of them.

1983-1985, 1993, 1994
<u>Station Name</u>
01 Road B
02 Donora Station
03 Patterson Mill
04 Upstream of SR 66, Stinson Bridge
05 Creek Mouth

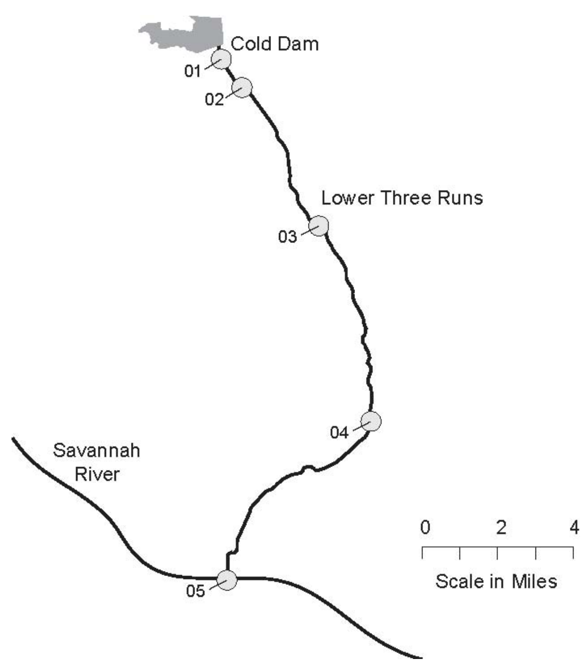

Figure 4-32. Macroinvertebrate Sampling Locations for Lower Three Runs

4.7.6.2 Results

4.7.6.2.1 Community Composition

Table 4-16 consists of a list of macroinvertebrates taken from various stations in Lower Three Run. Par Pond greatly influenced the macroinvertebrate community just downstream from the Par Pond dam (Station 01). Of the 34 stream sampling stations that were sampled for macroinvertebrates using Hester-Dendy multiplate samplers during the CCWS, this station had by far the highest density of macroinvertebrates (5549.8 organisms/m ^{2}). The high density was due in part to large numbers of Tanytarsini chironomids, which composed 39% of the organisms collected from the multiplate samplers. Other abundant taxa at Station 01 included the chironomid groups Orthocladiinae (15.0%), Chironomini (9.6%), and Tanypodinae (3.3%); hydropsychid caddisflies (3.7%); and Simuliidae (blackflies; 1.7%; Firth et al. [1986]). Many of these macroinvertebrates are filter-feeders that fed on the seston inputs from Par Pond.

In 1994, immediately below the dam, density was 2171.0 organism/m ^{2}. Dominant taxa included Hirudinea (leeches; 40%) and the dipteran midges Chironomini (40%), Orthocladiinae (7%), and Tanypodinae (7%). There were few collector-filterers. These data were collected during the Par Pond drawdown and dam repair and reflect the disturbed nature of the stream at that time (Specht and Paller 1995).

Downstream at Station 04 in 1983-1985, densities were comparable to those at many other CCWS stations, averaging 743.5 organisms/m^2. Common taxa at Station 04 included the chironomid groups Chironomini (19.7%), Tanytarsini (17.6%), and Orthocladiinae (17.2%); the stonefly, *Perlesta placida* (5.2%); the mayflies *Ephemerella invaria* (6.5%) and *Stenonema modestum* (2.4%); and the caddisfly *Cheumatopsyche* (2.9%; Firth et al. [1986]).

Macroinvertebrate density in the mouth of Lower Three Runs (Station 05) was higher than at Station 04, averaging 1932.3 organisms/m^2. Chironomids made up 84% of the macroinvertebrates collected from multiplates in the mouth of the creek. Other common taxa included the mayfly *Stenonema modestum* (5.2%) and the caddisfly *Cheumatopsyche* (3%; Chimney and Cody [1986]).

In 1993, the macroinvertebrate community at Donora Station, 1.5 km (0.9 mi) below the Par Pond dam, appeared to be influenced by Par Pond. There were large numbers of collector-filterers (58.8%) and relatively high densities of organisms (2511.7 organisms/ m^2). Filter-feeding caddisflies (52.3%) and orthoclad chironomids (23.5%) numerically dominated the community. Mayflies also were relatively common (8.6% of the organisms collected). Collector-filterers often are found in high numbers below reservoir outfalls, where they feed on the high concentrations of suspended organic matter.

The Patterson Mill station had greater numbers of mayflies (13.0%), Tanytarsini (22.8%) and Chironomini (21.7%) chironomids, and fewer caddisflies (8.0%). Density was 1528.5 organisms/m^2. Lower Three Runs is influenced by Par Pond but maintains a productive and reasonably diverse community (Specht 1994).

Table 4-16. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Lower Three Runs

Class or order	Lowest practical taxa	HD	NS
Oligocheata	*Naididae sp.*		X
	Spirosperma sp.		X
	Tubificidae sp.		X
Hirudinea	*Glossiphoniidae sp.*	X	
Gastropoda	*Campeloma decisum*	X	X
	Elimia sp.		X
	Laevapex sp.		X
	Physella sp.	X	X
Pelycypoda	*Corbicula fluminea*	X	X
Arachnida	*Hydracarina sp.*		X
Crustacea	*Caecidotea sp.*	X	X
	Cambarinae sp.	X	X
	Crangonyx sp.	X	
	Hyallela azteca		X
	Palaemonetes paludosus		X
	Procambarus sp.		X
Ephemeroptera	*Baetis ephippiatus*		X
	Baetis frondalis		X
	Baetis propinquus		X
	Caenis diminuta		X
	Eurylophella doris		X
	Heptagenia sp.		X
	Hexagenia limbata	X	
	Isonychia sp.	X	
	Leptophlebia sp.		X
	Paraleptophlebia sp.		X
	Stenacron interpunctatum	X	
	Stenonema modestum		X
	Stenonema modestum/smithae	X	
	Tricorythodes sp.	X	X
Odonata	*Argia sedula*		X
	Argia sp	X	X
	Boyeria vinosa		X
	Calopteryx dimidiata		X
	Cordulegaster sp.		X
	Enallagma divagans		X
	Gomphus lividus	X	X
	Gomphus notatus		X

Table 4-16. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Lower Three Runs - continued

Class or order	Lowest practical taxa	HD	NS
Heteroptera	*Belostoma lutarium*		X
	Gerris conformis		X
	Neogerris hesione		X
	Notonecta irrorata		X
	Ranatra sp.		X
	Rhagovelia obesa		X
	Sigara virginiensis		X
	Trepobates sp.		X
Megaloptera	*Corydalus cornutus*		X
	Nigronia serricornis	X	X
	Sialis sp.	X	X
Plecoptera	*Acroneuria abnormis*	X	
	Acroneuria mela	X	X
	Leuctra sp.	X	
	Perlesta placida		X
	Pteronarcys sp.		X
Trichoptera	*Brachycentrus nigrosoma*		X
	Cernotina sp.	X	
	Cheumatopsyche sp.	X	X
	Hydropsyche betteni	X	
	Hydropsyche elissoma		X
	Hydroptila sp.	X	X
	Lype diversa	X	
	Molanna uniophila		X
	Oecetis sp.	X	X
	Phylocentropus		X
	Pycnopsyche sp.	X	
Lepidoptera	*Noctuidae sp.*		X
Coleoptera	*Ancyronyx variegatus*	X	X
	Dineutus ciliatus		X
	Dineutus discolor		X
	Dineutus sp.	X	X
	Hydroporus sp.		X
	Hydroporus sp. 2		X
	Macronychus glabratus	X	X
	Optioservus sp.	X	
	Sperchopsis tessellatus		X
	Stenelmis crenata		X
	Stenelmis sp.		X

Table 4-16. Macroinvertebrates Collected from Hester-Dendy (HD) Artificial Substrates and Natural Substrates (NS) in Lower Three Runs - continued

Class or order	Lowest practical taxa	HD	NS
Diptera	*Ablabesmyia mallochi*	X	X
	Apsectrocladius johnsoni		X
	Bezzia sp.		X
	Brillia flavifrons	X	X
	Chelifera sp.	X	
	Chironomus sp.		X
	Clinotanypus pinguis	X	
	Conchapelopia/Meropelopia	X	X
	Cricotopus sp.	X	
	Cricotopus vierriensis		X
	Cryptochironomus fulvus gp.		X
	Dixa sp.		X
	Hemerodromia sp.	X	X
	Labrundinia pilosella		X
	Microtendipes pedellus	X	X
	Nanocladius sp.	X	
	Natarsia sp.		X
	Nilothauma sp.		X
	Palpomyia sp.		X
	Paramerina sp.	X	
	Parametriocnemus lundbecki	X	X
	Paratanytarsus sp.	X	
	Polypedilum fallax	X	
	Polypedilum flavum		X
	Polypedilum illinoense		X
	Potthastia longimana (Diamesinae)		X
	Procladius sp.		X
	Rheocricotopus robacki	X	
	Rheotanytarsus distinctissimus gp.	X	X
	Rheotanytarsus exiguus gp.		X
	Simulium nr. tuberosum		X
	Stempellinella sp.	X	
	Stenochironomus sp.	X	
	Tanytarsus sp.	X	X
	Tanytarsus sp. 3		X
	Thienemanniella xena gp.		X
	Tipula (Nippotipula)		X
	Tipula (Yamatotipula)		X
	Tribelos jucundum	X	X
	Xylotopus par	X	
	Zavrelimyia		X

4.7.6.2.2 <u>Biomass</u>

Macroinvertebrate biomass declined downstream during the CCWS, averaging 0.549 g/ m^2 at Station 01, 0.411 g/m^2 at Station 04, and 0.159 g/m^2 in the creek mouth. This trend held true for the 1993 and 1994 sampling, with the exception of the station just below the Par Pond dam, which was affected by the construction activities associated with dam repair. In more recent studies macroinvertebrate biomass was 0.1012 g/ m^2 just below the dam (1994), 0.3183 g AFDW/m^2 at Donora Station (1993), and 0.1427 g AFDW/m^2 at Patterson Mill (1993). These values are substantially lower than the values reported from the CCWS.

4.7.6.2.3 <u>Taxa Richness</u>

During the CCWS at Station 01, an average of 12.6 taxa was collected per sampler and 56 taxa were collected during the two-year sampling program, while downstream at Station 04, taxa richness was higher, with a mean of 17.6 taxa per sampler and 67 taxa collected. In the creek mouth, an average of 13.8 taxa was found on the multiplate samplers, while 50 taxa were collected. In 1993 and 1994, there was an average of 14.2 taxa per sampler and a total of 23 taxa collected just below the dam, an average of 21.4 taxa per sampler and a total of 32 taxa collected at Donora Station, and an average of 32.2 taxa per sampler and a total of 58 taxa at the most downstream station. Lower Three Runs is influenced by Par Pond but maintains a productive and reasonably diverse community (Specht 1994).

These results suggest that taxa richness may have increased over the past 10 years, as evidenced by increases in the mean number of taxa collected/sampler. However, the total number of taxa collected was lower in 1993 and 1994, because these data represent single sampling periods, rather than monthly sampling over a longer time period. Species that are rare or occur seasonally are usually less likely to be collected unless sampling is conducted over an extended period of time.

4.7.7 Fish

4.7.7.1 Introduction

Fisheries sampling in Lower Three Runs has not been as extensive as in most other SRS streams, although two sampling programs have been conducted. The first, during 1984-1985, was part of the CCWS, which was designed to generate information concerning the effects of thermal discharge from nuclear-reactor operation on SRS streams. This sampling effort included ichthyoplankton sampling at several sites between the mouth and the Par Pond dam (Paller et al. 1986). The second, conducted during the summer of 1990, was part of an effort to assess fish community structure in SRS streams. This program consisted of electrofishing for adult and juvenile fish at several sample sites between the lower reaches of Lower Three Runs and the Par Pond dam plus two sample stations in tributaries of Lower Three Runs. Additional studies of Lower Three Runs fishes are reported in Paller and Dyer (2004). Table 4-17 is based on data from Paller and Dyer (2004).

Table 4-17. Fish Collected from Lower Three Runs

Family	Common name	Scientific name
Lepisosteidae	longnose gar	*Lepisosteus osseus*
Amiidae	bowfin	*Amia calva*
Anguillidae	American eel	*Anguilla rostrata*
Cyprinidae	ironcolor shiner	*Notropis chalybaeus*
	dusky shiner	*Notropis cummingsae*
	coastal shiner	*Notropis petersoni*
	creek chub	*Semotilus atromaculatus*
Catostomidae	creek chubsucker	*Erimyzon oblongus*
	lake chubsucker	*Erimyzon sucetta*
	northern hogsucker	*Hypentilium nigricans*
	spotted sucker	*Minytrema melanops*
Ictaluridae	yellow bullhead	*Ameiurus natalis*
	brown bullhead	*Ameiurus nebulosus*
	flat bullhead	*Ameiurus platycephalus*
	tadpole madtom	*Noturus gyrinus*
	margined madtom	*Noturus insignis*
	speckled madtom	*Noturus leptacanthus*
Esocidae	redfin pickerel	*Esox americanus*
	chain pickerel	*Esox niger*
Aphredoderidae	pirate perch	*Aphredoderus sayanus*
Poeciliidae	eastern mosquitofish	*Gambusia holbrooki*
Atherinopsidae	brook silverside	*Labidesthes sicculus*
Centrarchidae	mud sunfish	*Acantharchus pomotis*
	bluespotted sunfish	*Enneacanthus gloriosus*
	redbreast sunfish	*Lepomis auritus*
	warmouth	*Lepomis gulosus*
	bluegill	*Lepomis macrochirus*
	dollar sunfish	*Lepomis marginatus*
	redear sunfish	*Lepomis microlophus*
	spotted sunfish	*Lepomis punctatus*
	largemouth bass	*Micropterus salmoides*
	black crappie	*Pomoxis nigomaculatus*
Percidae	Savannah darter	*Etheostoma fricksium*
	tesselated darter	*Etheostoma olmstedi*
	blackbanded darter	*Percina nigrofasciata*

4.7.7.2 Comprehensive Cooling Water Study (CCWS)

4.7.7.2.1 Sampling Methods

Sampling efforts during the CCWS emphasized the abundance and distribution of ichthyoplankton (Paller et al. 1986). Samples were collected with 0.5 mm, 0.5 m diameter plankton nets. There were three sampling stations in 1984, one in the Par Pond tailwaters, one near Road A (approximately two-thirds of the distance from Par Pond to the Savannah River), and one in the mouth of Lower Three Runs (Figure 4-33). There were seven sample stations in 1985, three in the Par Pond tailwaters, one in the creek mouth, and three between the creek mouth and the tailwaters (Figure 4-33). Samples were collected during the main spawning period for most SRS fishes, February-July 1984 and March-July 1985.

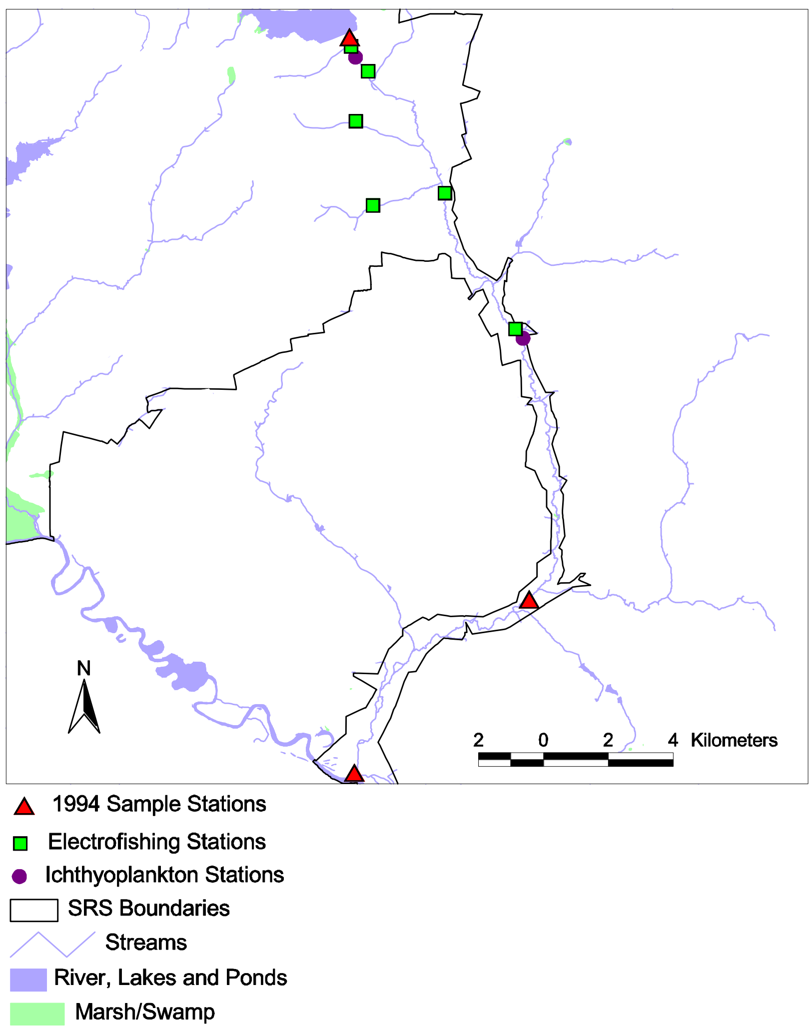

Figure 4-33. Fish Sampling Stations for Lower Three Runs

4.7.7.2.2 1984 Sampling Program

Table 4-18 lists icthyoplankton taxa taken in Lower Three Runs. Most of the 1483 ichthyoplankters collected during 1984 were taken from a tailwater pool just downstream from the Par Pond dam. Densities averaged 625 organisms/1000 m^3 in the tailwaters compared with 14 organisms/1000 m^3 at Road A and 24 organisms /1000 m^3 in the creek mouth. Most of the larvae collected in the Par Pond tailwaters were sunfish and bass, crappie, and yellow perch that probably were spawned in Par Pond and entered Lower Three Runs in Par Pond overflow. Sampling in Par Pond (Paller and Saul 1986) indicated that all three taxa were abundant there (Paller et al. 1986).

Table 4-18. Taxa of Ichthyoplankters Taken in Lower Three Runs

Family	**Taxa**
Clupeidae	*Alosa aestivalis,* blueback herring
	Alosa sapidissima, American shad
	Dorosoma spp., gizzard shad or threadfin shad
Cyprinidae	Unidentified minnows
Catostomidae	Unidenttified suckers
	Minytrema melanops, spotted sucker
Ictaluridae	Unidentified catfish
Aphredoderidae	*Aphredoderus sayanus*, pirate perch
Centrarchidae	*Lepomis* spp., bream
	Unidentified sunfish
	Pomoxis spp., crappie
Percidae	*Perca flavescens*, yellow perch
	Unidentified darters

4.7.7.2.3 1985 Sampling Program

As in 1984, most of the 446 ichthyoplankton collected from Lower Three Runs during 1985 were collected at the sample stations in the Par Pond tailwaters (Figure 4-33). Minnows and darters numerically dominated the tailwater samples early in the spawning season. However, as the season progressed, crappie, sunfish/bass, and brook silversides became increasingly common. Ichthyoplankton densities rapidly declined to comparatively low levels within 400-500 m (1312-1640 ft) of the Par Pond dam, suggesting that ichthyoplankton conveyed from Par Pond to Lower Three Runs were not transported far downstream. Ichthyoplankton collected from the four sample stations downstream of the Par Pond tailwaters consisted primarily of darters, sunfish, and suckers, species typical of most streams on SRS (Paller et al. 1986).

4.7.7.2.4 Comparison of 1984 and 1985 Sampling Programs

Comparisons between 1984 and 1985 indicate that ichthyoplankton densities were fairly similar in the lower half of Lower Three Runs during both years. However, densities in the Par Pond tailwaters were approximately five times higher during 1984 than 1985. The higher densities during 1984 probably were caused by greater discharge from Par Pond into Lower Three Runs during that year, as observed by field personnel (Paller et al. 1986).

4.7.7.3 Stream Fisheries Characterization Study

Electrofishing samples were collected from two first-to-second-order tributaries of Lower Three Runs near the crossings of Road B-6 and B-6.4. Both tributaries were small, sand bottom streams. They were heavily shaded, and the predominant instream structure consisted of snags and woody debris. The fish assemblages in these streams were numerically dominated by small species including pirate perch, shiners, small sunfishes, darters, madtoms, bullheads, and redfin pickerel. These taxa are typical of unimpacted first and second order streams in and around the vicinity of SRS (Paller 1992).

Electrofishing samples also were collected from three locations on Lower Three Runs: near Donora Station, Patterson Mill, and Stinson Bridge. Creek width ranged from 5-10 m (16-33 ft) at Donora Station to 10-15 m (33-49 ft) at Stinson Bridge. Snags and brush provided the dominant instream structure, although aquatic macrophytes were at some stations. The Stinson Bridge sample yielded few fish because it was collected during a high-water period. The other samples were more representative. The Donora Station fish assemblage was dominated by sunfishes (primarily redbreast and spotted sunfish) followed by shiners, pirate perch, and a variety of other taxa. The fish assemblage at the wider, deeper Patterson Mill station was dominated by larger species, including spotted sucker, largemouth bass, and creek chubsucker. This transition from a mixed fauna of medium- and small-sized species, most of which are generalized insectivores, at stream sites of moderate size (i.e., Donora Station) to a fauna dominated by larger benthic insectivorous and piscivorous species at wider, deeper stream sites (i.e., Patterson Mill) is typical in southeastern coastal plain streams (Paller 1992).

4.7.7.4 Radionuclides in Fish

Paller et al. (1999) examined historical trends in ^{137}Cs in fishes of the SRS. The half-life of ^{137}Cs in fish was much shorter than the radioactive half-life indicating that removal is occurring rather than simple radioactive decay. Pond B and Lower Three Runs had longer ecological half-lives for ^{137}Cs in sunfishes (*Lepomis* spp.) and largemouth bass (*Micropterus salmoides*) than other SRS locations and this phenomenon may be related to resuspension of sediment with ^{137}Cs bound to it. Paller et al. (2002) found ^{137}Cs in fishes in Lower Three Runs, Par Pond, and Pond B not falling as fast as in Steel Creek (Figure 4-29).

4.7.8 References

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4.8 L LAKE

4.8.1 Drainage Description and Surface Hydrology

4.8.1.1 General Description

L Lake was formed in 1985 by impounding the headwaters of Steel Creek. L Lake extends about 7 km (4.3 mi) along the Steel Creek valley from the embankment above South Carolina Highway 125 (SRS Road A) to just above SRS Road B (Figure 4-34). The lake width averages about 600 m (0.4 mi), reaching a maximum of about 1200 m (0.8 mi) (DOE 1984). At a normal pool elevation of 58 m (190 ft) above mean sea level, the dam impounds about 31 million m^3 of water and covers about 4.185 km^2 or 418 ha (reported as 1034 acres, nominally 1000 acres) (U.S. Army Corps of Engineers 1987).

The River Water System would continue to supply existing operational cooling and makeup water requirements for the reactor areas and maintain L-Lake at its full pool water level of 190 feet MSL. "…(pending "need for future environmental remediation alternatives for L-Lake under existing CERCLA commitments" "Characterization activities associated with CERCLA are expected to begin in the year 2000 and to be completed in several years."

L Lake both gains and loses water from the surrounding groundwater system. Groundwater flows into L Lake at the upstream end, from the very top, above Road B to approximately one-fourth of the distance to the dam on the west side of the reservoir and to approximately one-half to two-thirds of the distance to the dam on the east side. L Lake loses water to the groundwater system along the remainder of the shoreline (Hiergesell 1997).

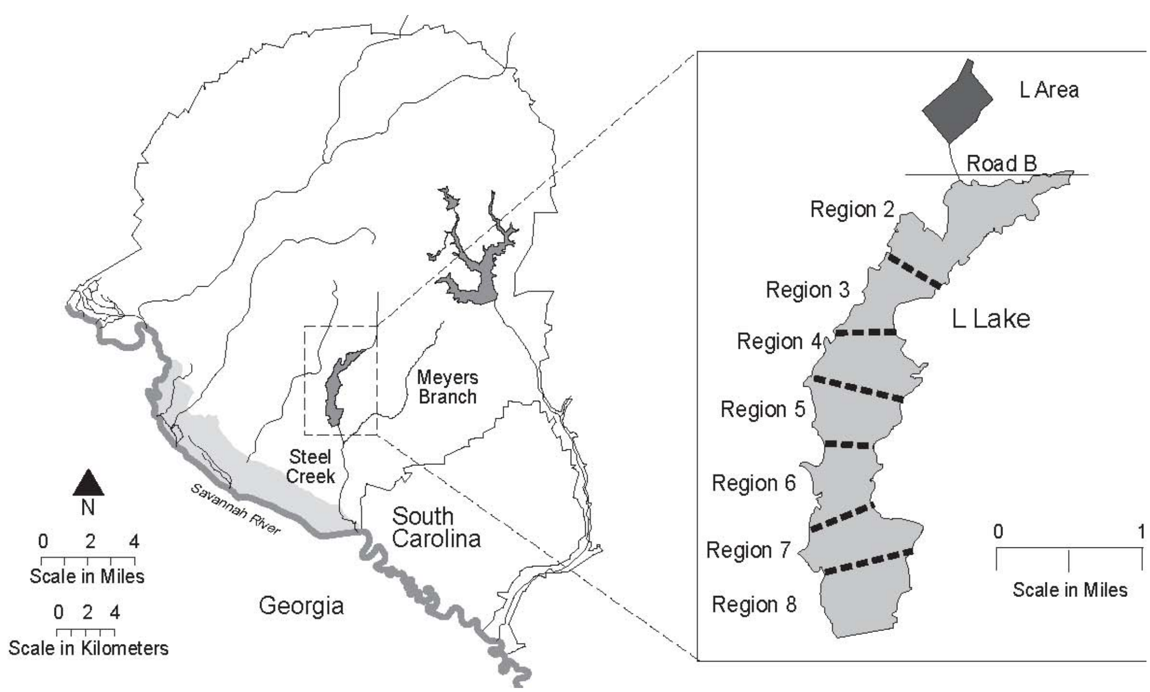

Figure 4-34. Location of L Lake on SRS

4.8.1.1.1 L Lake Dam

4.8.1.1.1.1 Description

The L-Lake dam is approximately 7.2 km (4.5 mi) above the mouth of Steel Creek and about 0.8 km (0.5 mi) north of South Carolina Highway 125. The dam consists of a main embankment of rolled fill construction, with a lower embankment (saddle dike) extending from the right abutment and a service bridge leading to an intake tower extending from the left abutment. The main embankment is about 670 m (0.4 mi) long with a 12-m (39-ft) crest width. The unpaved emergency spillway has a sill elevation of 60 m (197 ft) above mean sea level. A 60-cm (2-ft) thick concrete cutoff wall is on the upstream toe of the main dam to minimize seepage under the dam. The saddle dike is about 520 m (0.3 mi) long with a 12-m (59-ft) crest width. The maximum height of the saddle dike is 3.7 m (12 ft) (U.S. Army Corps of Engineers 1987).

4.8.1.1.1.2 Outlet Structure

The outlet structures for the lake consist of a multigate intake tower, a prefabricated concrete conduit, and a stilling basin in the valley of the left abutment (U.S. Army Corps of Engineers 1987). Water passes through the intake tower and the conduit and is discharged into the stilling basin before being released to Steel Creek. The discharge intake structure was designed to pass the volume of the L-Reactor cooling water flow, the P-Area process water flow, and ambient Steel Creek flow through the dam and to serve as the principal means of flood control.

The system of eight gates in the dual wet well tower regulates the reservoir water level. Two gates near the bottom of the lake (lower gates or emergency gates) and two gates 3 m (10 ft) below the normal pool elevation (upper gates) can be opened to let water into the wet wells. These gates are either fully opened or closed. Under normal operating conditions, both lower gates are closed, and both upper gates are open. The lower gates can be opened to release water if the lake level gets too high

4.8.1.2 Effluent Contribution

Originally, L-Reactor cooling water entered L Lake directly through an effluent canal situated north to south on the north shore of the lake. In 1986, a diversion dike was built to divert the flow into the upper, northeastern portion of the lake to increase the lake's cooling efficiency.

L Lake stratified during the spring and summer due to climatic factors, as is typical of most southeastern lakes and reservoirs. However, stratification occasionally occurred during the winter due to density differences between thermal reactor discharges and underlying lake waters. L Lake received thermal effluent from November 1985 to June 1986, December 1986 to June 1987, and January 1988 to June 1988. Temperatures in excess of 40°C (104°F) occurred near the L-Reactor outfall during periods of reactor operation. However, the maximum recorded water temperature in Regions 4-8 (Figure 4-34) was approximately 34°C (93°F) in June 1986. This temperature was approximately 2°C (3.6°F) higher than the maximum temperatures in southeastern reservoirs with no thermal inputs. The highest recorded 24-hour mean temperature in Regions 4-8 was 32°C (90°F). While the highest absolute temperatures occurred in June, the greatest temperature differences occurred during the winter and early spring when L-Lake waters were elevated as much as 5°C (9°F) above ambient. Littoral zone temperatures exhibited little consistent spatial variation within the study area (Regions 4-8).

4.8.1.3 Flow and Temperature Measurements

The volume of water released from the dam is controlled by the two service gates at the base of the wet wells. Water flows through both upper gates into the two wet wells and through the service gates into the concrete conduit. Flow through service gates can vary from about 2 m^3/sec (71 ft^3/sec) to 29 m^3/sec (1024 ft^3/sec) per gate. Service gates are not operated with an opening of less than about 15 cm (6 in) to avoid cavitation. To release flows less than 2 m^3/sec (71 ft^3/sec), such as the minimum flows required during reactor shutdown, two 46-cm- (18-in) diameter knife gates can be opened. The knife gates can release flows ranging from about 0.3 m^3/sec (10.5 ft^3/sec) to 2 m^3/sec (70 ft^3/ sec) to Steel Creek (du Pont 1985).

A control system electronically monitors the reservoir level and the discharge water temperature and volume. If the computerized operating system should fail, these data can be visually monitored and the gates manually operated at the dam site (du Pont 1985).

4.8.2 Water Chemistry and Quality

4.8.2.1 Studies and Monitoring

L-Lake water quality was monitored regularly between the completion of the reservoir in 1985 and 1991 to meet environmental regulatory requirements associated with the restart of L Reactor. The monitoring was driven primarily by Section 316(a) of the Clean Water Act. L Lake is not monitored as part of the SRS routine water quality monitoring program.

L Lake was divided into eight regions by expected thermal gradients in order to assess the impact of thermal discharge on the L-Lake ecosystem. (Region 1 was above Road B and was not sampled.) Water quality sampling was initiated in November 1985 in regions 4-8 (Figure 4-34). The data collected during periods of reactor shutdown are more representative of current and expected future conditions at a later successional stage of L Lake. See Gladden et al. (1988).

Kretchmer and Chimney (1992) report the results of L-Lake water quality from November 1985 to December 1991. The following subsections summarize that report.

This discussion emphasizes data from 1988-1991, the period after L-Reactor was shut down (no thermal input to the lake), but when river water continued to be pumped into the lake. A one-time sampling was done in September 1995 to analyze for total mercury, gamma emissions, gross alpha emissions, nonvolatile beta emissions and U.S. Environmental Protection Agency (EPA) target analyte list metals (Paller 1996).

4.8.2.2 Field Data

4.8.2.2.1 Temperature

Thermal effluent from L Reactor induced periods of temporary thermal stratification in L Lake during the fall and winter of 1985-1987. However, the effect of this phenomenon on water quality appeared to be minimal, and the water column quickly returned to isothermal conditions with the cessation of reactor activities. Stratification of the lake during the summer was largely attributed to normal climatic heating and was well established by April of each year. Fall turnover usually began in September or October and was completed by November (Kretchmer and Chimney 1992).

4.8.2.2.2 pH Measurements

From 1988 to 1991, pH values in L Lake varied from 4.9 to 10.1; and from 1985 to 1987 the range of values was 5.2 to 9.7. The pH changes in the water column did not appear to be closely related to the establishment or collapse of thermal stratification, but were thought to be more correlated with the intensity of phytoplankton primary productivity.

4.8.2.3 Physical Characteristics and General Chemistry

4.8.2.3.1 Dissolved Oxygen

Changes in dissolved oxygen concentrations throughout the water column from 1985 to 1989 often coincided with the establishment and subsequent collapse of thermal stratification. Oxygen usually decreased in the deeper strata during periods of reactor-induced stratification, but quickly recovered to higher levels when the reactor shut down and the water column remixed. From 1988 to 1991, dissolved oxygen concentrations ranged from <0.1 to 13 mg/l in Region 7. This maximum, measured in 1991, was higher than any value previously reported.

4.8.2.3.2 Suspended Solids

Total suspended solids concentrations ranged from <1 to 20 mg/l from 1988 to 1991. These concentrations were somewhat lower than the concentrations measured in either 1985, 1986, or 1987. The higher concentrations during 1985, 1986, and 1987 may reflect the settling out of high total suspended solids loads in the reactor effluent in the upper regions of L Lake. Turbidity was not measured as part of this study.

4.8.2.3.3 Conductivity

Mean conductivity values in L Lake during 1991 ranged from 45 to 91 µS/cm. These mean values were 10 to 20 µS/cm lower than in 1990, which in turn were 10 to 20 µS/cm lower than in previous years. The highest conductivity values generally were recorded at the lake bottom during the fall of each year. No consistent regional differences in water column conductivity were noted for any year.

4.8.2.4 Major Anions and Cations

4.8.2.4.1 Alkalinity, Chloride, and Sulfate

From 1988 to 1991, alkalinity ranged from 5 to 41 mg $CaCO_3$/l. This range was lower than observed in previous years. Alkalinity values were usually highest in the summer or fall and lowest in the winter. Chloride measurements ranged from 3.2 to 13.8 mg/l and sulfate concentrations ranged from 1 to 10 mg/l from 1988 to 1991. These chloride and sulfate measurements were similar to those first observed in 1985, 1986 and 1987.

4.8.2.4.2 Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, and potassium were similar during all years of the study. Concentrations of total sodium measured from 1988 to 1991 were slightly higher than those measured in 1985, 1986, and 1987. Ranges of concentrations for sodium during the 1988 to 1991 period were 4.02 to 14.4 mg/l, and during 1985, 1986, and 1987 sodium concentration ranges were 5.92 to 13 mg/l.

4.8.2.4.3 Aluminum, Manganese, and Iron

Mean total aluminum concentrations in 1985, 1986, and 1987 were generally slightly greater than the detection limit of 0.1 mg/l. Means and ranges of individual aluminum values in 1988, 1989, 1990, and 1991 were similar, and generally lower than those in 1985, 1986, and 1987.

Total manganese ranged from <0.02 mg/l to 2.0 mg/l from 1988 to 1991. These concentrations were similar to those measured during 1985, 1986, and 1987 with the exception of one measurement at Region 6 (8.46 mg/l). The remaining manganese concentrations ranged from <0.02 to 2.6 mg/l during the 1985-1987 period.

Throughout the years of the study, there was considerable variation in the magnitude of means and ranges of individual concentrations of iron. However, the iron concentrations were similar during all years of the study.

4.8.2.5 Nutrients

4.8.2.5.1 Phosphorus

L Lake acted as an effective nutrient sink and retained most of the total phosphorus and orthophosphorus imported into it. L Reactor effluent had mean total phosphorus concentrations, ranging between 60 and 246 µg/l from 1985 to 1989 (Kretchmer and Chimney 1992). Concentrations of total phosphorus and orthophosphate measured in L Lake ranged from 0.014 to 0.864 mg/l and from <0.005 to 0.816 mg/l, respectively, during all years of the study.

4.8.2.5.2 Nitrogen

L Lake acted as a nutrient sink and retained most of the nitrite, nitrate, and ammonia imported into it. However, L Lake usually exported more total Kjeldahl nitrogen than was present in the reactor effluent waters. Concentrations of nitrogen species measured in L Lake ranged as follows: nitrite, <0.001 to 0.092 mg/l; nitrate, <0.001 to 0.758 mg/l; and ammonia, <0.01 to 2.72 mg/l.

4.8.2.5.3 Regional Lakes Study

In September 1988 and 1989, 10 South Carolina reservoirs were intensively sampled for trophic status, community structure, and biologically balanced community criteria. Based on the results of this study, L Lake had nitrogen and phosphorus concentrations that characterized a eutrophic system (Bowers 1992).

4.8.2.6 Trace Elements

The L Lake/Steel Creek Biological Monitoring Program did not measure for trace elements (arsenic, cadmium, chromium, copper, lead, nickel, and zinc).

4.8.2.6.1 Organic Carbon

Total organic carbon concentrations were similar throughout all years of the study, with ranges of <1 to 15 mg/l.

4.8.2.7 Priority Pollutants, Pesticides, Herbicides and PCBs

L Lake is not sampled for priority pollutants, perticides, herbicides or PCBs.

4.8.2.8 Chemical, Including Radionuclide, and Toxicity Assessment Studies

During the early period of P- and L-Reactor operations, radioactive materials, chiefly cesium-137, were released into Steel Creek where they became sequestered in the sediments on the Steel Creek floodplain and later became inundated when L Lake was filled. While not associated with reactor operations, elevated concentrations of mercury have been recorded in SRS streams and reservoirs.

In 1995, near-surface and near-bottom water samples were collected from the centers of Regions 2, 4, 6, and 8 in L Lake. Radionuclide contaminants were not detected in the four surface water samples. However, cesium-137 (arithmetic mean of 3.01 pCi/l) and alpha-emitting radionuclides (arithmetic mean of 0.49 pCi/l) were in measurable levels in one of the four bottom water samples (Paller 1996), reflecting the contamination of the Steel Creek watershed during reactor operations prior to the construction of L Lake. Cesium-137 remobilizes from sediments under anoxic conditions (Alberts et al. 1987); this is the likely mechanism responsible for the observed elevated cesium-137 concentration.

Several metals, notably iron and manganese, were in much higher concentrations in bottom water samples than in top water samples, reflecting thermal stratification at the time of sampling and dissolution of these metals from the sediments into the anoxic bottom waters of L Lake. None of the metals exceeded EPA acute toxicity screening values for the protection of organisms in surface waters. However, the detection limits for several metals (cadmium, lead, mercury, and silver) were above the chronic toxicity screening values, making it impossible to definitely eliminate them as potential constituents of concern. Iron and beryllium concentrations exceeded their chronic toxicity screening values (Paller 1996).

4.8.3 Sediments

Both P and L Reactors released thermal effluents to Steel Creek in the past. Between 1955 and 1978, approximately 284 curies of cesium were released to Steel Creek. Because cesium has a strong affinity for sediments, the majority of the released material was adsorbed to the sediments and deposited with them in the Steel Creek floodplain. An inventory of the sediments at 1991 decay-corrected concentrations estimated that 8 curies of cesium were upstream of L Reactor, 30 curies were between L Reactor and the Steel Creek delta, 20 curies were in the delta, and 8 curies were in lower Steel Creek, between the delta and the creek mouth (Brisbin 1974; Gladden et al. 1985; Carlton et al. 1992).

In the summers of 1995 and 1996 the Savannah River Technology Center (SRNL) sampled the sediments of L Lake to identify radioactive and metal contaminants in the lake bed. Sampling was done in several phases.

Phase 1 sampled the surface sediments (0-0.3-m [0-1-ft] depth) at 45 L-Lake locations distributed along the old streambed and floodplain and upslope of the submerged floodplain. Two depths (0-0.3 m [0-1 ft] and 0.3-1.3 m [1-4 ft]) were sampled at 13 reference locations. The sediments were analyzed for all EPA Target Analyte List (TAL) metals (except cyanide), gross alpha activity, nonvolatile beta activity, gamma-pulse height, plutonium alpha series isotopes, and uranium alpha series isotopes. Metals results were compared to the EPA screening criteria to determine potential contaminants of concern.

Phase 2 sampled sediment cores in the L-Lake basin for the same constituents sampled in Phase 1. Core intervals were 0-0.3 m (0-1 ft), 0.3-1.2 m (1-4 ft), and 1.2-2.4 m (4-8 ft). Phase 3 measured gamma-emitting radionuclides (mainly cesium-137 and cobalt-60) *in situ* with an underwater High Purity Germanium detector.

The L-Lake cesium-137 activity is primarily located in the submerged Steel Creek floodplain (Figure 4-35). The collective sediment data show most cobalt-60:cesium-137 ratios near 1-2%, but ranging up to 6% in several locations. The higher ratios are found primarily in the vicinity of the L-Reactor discharge canal, but some of the high ratios are evident further downstream in the submerged Steel Creek floodplain (Dunn 1996).

The following metals exceeded their screening criteria in some L-Lake stream/floodplain surface sediments: mercury, copper, lead, zinc, nickel, and chromium. Mercury, copper, and lead also exceeded their screening criteria at reference locations on the SRS and in nonfloodplain L-Lake sediments (Dunn et al. 1996a). Cadmium, chromium, and mercury exceeded screening criteria in the deeper sediments at four locations, only one of which was in the floodplain (Dunn et al. 1996b).

Of the radionuclides analyzed, concentrations of actinium-228, cesium-137, cobalt-60, lead-212, uranium-233/234, uranium-238, gross alpha, and nonvolatile beta in all of the L-Lake surface sediment types were higher than those in reference soils. A comparison of the means of concentrations of cesium-137, cobalt-60, uranium-233/234, uranium-238, gross alpha, and nonvolatile beta in the old Steel Creek stream channel and floodplain with the means in other sediments and the reference soils infers a statistically significant ($P < 0.05$) difference between concentrations in the old channel and floodplain and in the other and reference sediments. Plutonium-239/240 and uranium-235, while detected in measurable concentrations, were not elevated relative to concentrations in the reference soils.

Phase 2 results (deeper cores) showed statistically significant differences between concentrations in the old Steel Creek channel and floodplain and those in other sediments or reference soils for cesium-137, uranium-238, gross alpha, and nonvolatile beta activity. Actinium-228, lead-212, and uranium-233/234 were found in measurable concentrations, but there was no difference between locations. Cobalt-60 was not detected in the majority of samples. Plutonium-239/240 and uranium-235 were at activities detected in measurable concentrations, but results were not elevated relative to background reference concentrations (Dunn et al. 1996b).

Deep sediment cores (0-2.4 m [0-8 ft]) collected from L Lake in 1995 were sampled for metals and radionuclides. Mercury was detected at the 0.3-0.6 m (1-2 ft) depth in one L-Lake segment. The cores had concentrations of cobalt-60, cesium-137, plutonium-238, plutonium-239/240, and strontium-90 (Koch et al. 1996).

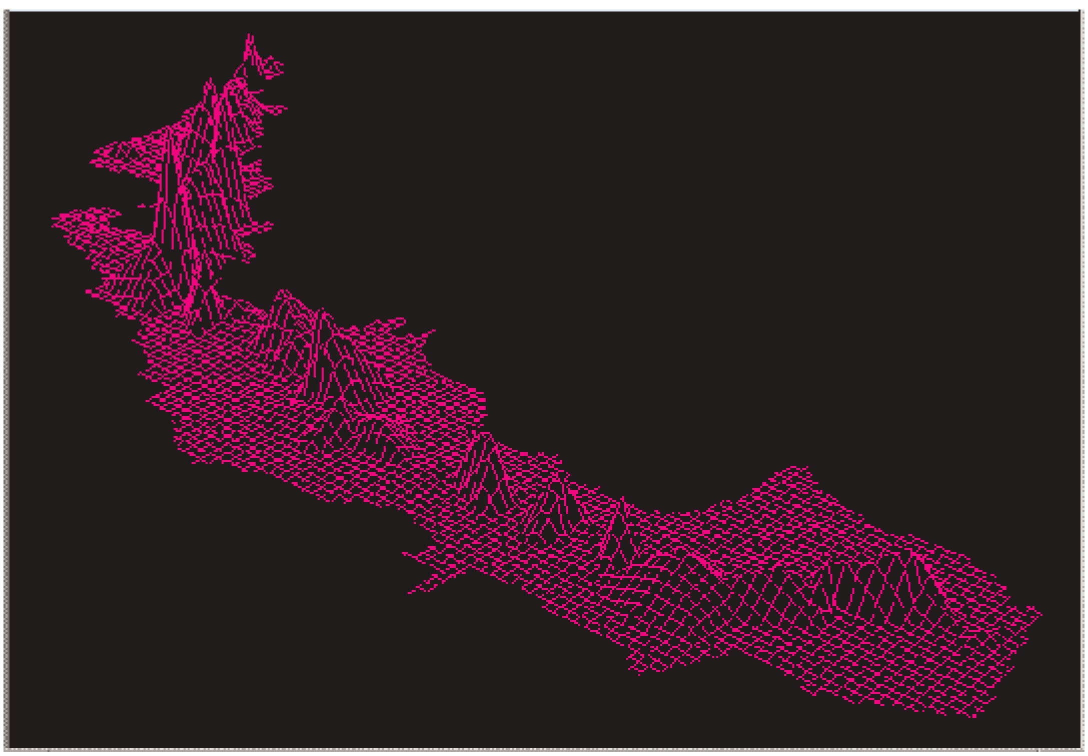

Figure 4-35. Cesium-137 Surface Model Based on 1995 and 1996 Data (Source: Dunn 1996)

4.8.4 Algae

4.8.4.1 Phytoplankton

Phytoplankton samples were collected monthly in L Lake from 1986 through 1991. Regions 4 through 8 were sampled during 1986-1989, while only Regions 5 and 8 were sampled in 1990-1991 (Figure 4-34). This sampling was conducted to determine species composition and abundance expressed as densities of organisms, biovolumes, chlorophyll *a*, dry weight, and ash-free dry weight. Primary productivity of the phytoplankton also was measured. Detailed methods and results can be found in Carson (1992). Data from 1986-1987 have been previously summarized in compliance documents (Gladden et al. 1988; Wike et al. 1989); and the data for 1986-1989 were more recently summarized in a technical report by Bowers (1991).

4.8.4.1.1 Phytoplankton Establishment After the Construction of L Lake

The phytoplankton communities of newly created reservoirs are frequently unstable for the first few years, and this disequilibrium phase may have been confounded in L Lake by the sporadic operation of L Reactor at decreasing power levels during 1986-1988. For example, substantial blooms of the nuisance blue green alga *Microcystis aeruginosa* during the first two years of the lake's existence appeared to be related to the pumping of heated, relatively nutrient-rich secondary cooling water effluent (derived from the Savannah River) into L Lake (Gladden et al. 1988). This nutrient enrichment resulted in phosphorus concentrations that were among the highest recorded in southeastern lakes (Carson 1992). Extremely high chlorophyll *a* and primary productivity levels also were observed concurrently with peak reactor operation during the spring of 1986.

4.8.4.1.2 Current Status of L Lake Phytoplankton

With the cessation of reactor operations in 1988, and the natural succession process, the L-Lake phytoplankton community stabilized and was much more typical of other southeastern reservoirs in 1990 and 1991. Over this time period, algae species richness while productivity and chlorophyll *a* has decreased. The ratio of chlorophyta to cyanobacters has increased through this time period.

4.8.4.1.3 L Reactor Impacts

Impacts of L-Reactor operations on the periphyton community of L Lake were not apparent. There were no consistent regional relationships among periphyton grown on artifical substrates and, although the periphyton in sediment cores varied regionally in terms of species composition, there was no gradient among regions indicative of varying degrees of thermal pollution.

Quantities of total periphyton and primary productivity indicated a trend in the attached algae toward less fluctation and reduced peaks with reservoir aging (and the termination of L Reactor operations). However, chlorophyll *a* and dry weight values on both periphytometers and in sediment cores did not show any discernible pattern over the four-year study period. Densities and biovolumes of bluegreen algae showed a tendency toward reduced temporal and spatial variation and a general reduction in biomass. The relative abundance of bluegreen algae was substantially lower in 1988 and 1989 compared to 1986 and 1987 (Chimney et al. 1990). Both reservoir aging and reductions in thermal and nutrient additions to the reservoir as a result of cessation of reactor operations are likely to have contributed to the diminishing quantities of bluegreen algae observed over the four-year study period.

4.8.5 Macrophytes

L-Lake aquatic macrophytes are not covered in this section, but in Chapter 5—Wetlands and Carolina Bays of SRS.

4.8.6 Zooplankton

Taylor et al. (1993) described zooplankton succession in L Lake for the first three years of the reservoir's existence. During 1986 and 1987, larger macrozooplankton, *Daphnia parvula*, *Daphnia retrocurva*, *Diaphanosoma brachyurum*, *Diaptomus pallidus*, and *Diaptomus dorsalis*, were dominant species. *Bosmina longirostris*, the smallest of the cladocerans, was most abundant during 1988. During the third year of the study, loricate rotifers (*Keratella* spp., *Polyarthra* spp., and *Kellicottia bostoniensis*), *Synchaeta stylata*, and *Conochilus unicornis* dominated the zooplankton assemblage. Size-selective predation by the threadfin shad (*Dorosoma petenense*) was responsible for this shift in community structure.

L Lake total macrozooplankton, mainly zooplankton crustacea (cladocerans, copepods) and total microzooplankton (rotifers and protozoans) reached their greatest abundance during the summers of 1988 and 1989. Numerically, the protozoans dominated zooplankton communities in L Lake. However, copepod and cladoceran densities reveal the striking effect of size-selective predation in L Lake. During 1986 and 1987, when densities of the planktivorous threadfin shad were low, these larger, more easily seen and thus more vulnerable species existed in the lake. However as threadfin shad, voracious consumers of large zooplankton (Drenner and McComas 1980; Drenner et al. 1984; Prophet and Frey 1987) increased, they began to drive their preferred prey to extinction in the lake. By 1990, copepod and cladoceran were nonexistent in the open waters of L Lake.

At the species level, these temporary extinctions were even more apparent. Only *Paracyclops* and *Diaphonosoma* remained at detectable densities and for plausible reasons. *Diaphonosoma* is large and easily seen by planktivorous fish, but this inshore littoral species rarely is found in deeper waters where the threadfin shad feed. Therefore, its behavior significantly reduces predation by a pelagic predator. *Paracyclops* is the smallest of the macrozooplankton and is not as easily detected by the shad. In summary, the size structure and density of zooplankton in L Lake reflected intense planktivorous predation. No large species were collected in open water. Decreases in shad abundance during 1990 and 1991 may be a result of decreases in zooplankton densities.

Another factor that affects macrozooplankton abundance is the presence of the phantom midge, *Chaoborus punctipennis* (Haven 1990). Haven (1990) noted that during periods of high *C. punctipennis* abundance, preferred prey such as soft-bodied rotifers and small cladocerans disappear, while loricate rotifers and larger cladocerans coexist with the predator.

In L Lake, *C. punctipennis* reached its greatest abundance during the summer and fall of 1987, 1989, 1990, and 1991. Protozoans, due to their small size, are not thought to be important *C. punctipennis* prey. Densities of protozoans appeared positively correlated to *C. punctipennis.* Rotifera densities declined in L Lake after 1989, but were not correlated to midge abundance maxima. Cladocerans also declined in L Lake after 1988. This pattern suggests that *C. punctipennis* may be preying extensively on small species. Maximum abundances of *Chaoborus* co-occurred with cladoceran densities during 1987 and 1988 and slightly behind cladocera densities during 1989. Copepod densities, like those of cladocerans, declined after 1988, most likely due to fish predation

4.8.7 Macroinvertebrates

4.8.7.1 Sampling Locations and Methods

4.8.7.1.1 <u>Clean Water Act Section 316(a) Demonstration</u>

From January 1986 through December 1989, macroinvertebrates were collected in Regions 4 through 8 of L Lake (Figure 4-34). Meroplankton (organisms present in the plankon for only a single life state or event) was sampled monthly at night using vertical plankton tows. The benthic littoral community was sampled monthly at two depths (2 and 4 m [6.5 and 13 ft]) using a ponar grab sampler. Emerging adult insects were collected during one week of every month from floating emergence traps placed in each region. In addition, littoral habitats were sampled qualitatively on a quarterly basis in each region using a D-frame dip net.

Beginning in January 1990, the overall level of effort for the macroinvertebrate sampling program was reduced. All macroinvertebrate sampling was limited to Regions 5 and 7. Meroplankton and insect emergence were sampled monthly. Ponar samples were collected quarterly at 1-, 2-, and 4-m (3-, 6.5-, and 13-ft) depths. Qualitative dip net sampling was continued quarterly in Regions 5 and 7. Details of sampling methods for 1986-1989 can be found in Lauritsen (1990), and details of 1990-1991 methods can be found in Trapp (1992).

4.8.7.1.2 1995 Sampling

In September 1995, 72 macroinvertebrate grab samples were collected from 4 transects in Region 5 and 4 transects in Region 7. Along each transect, three replicate samples were collected at water depths of 1-, 2-, and 4-m (3-, 6.5-, and 13-ft) using a petite ponar dredge. To facilitate comparison, samples were collected in the same locations as were sampled in 1988 and 1989 (Specht 1996).

4.8.7.2 Results

4.8.7.2.1 Clean Water Act 316(a) Demonstration

4.8.7.2.1.1 Meroplankton

Table 4-19 lists macroinvertebrates, both meroplankta and benthic, taken in L Lake. As in most lakes, the meroplankton community of L Lake was always overwhelmingly dominated by the phantom midge (*Chaoborus punctipennis)*, which made up 94.3 to 99.9% of the organisms collected annually in the meroplankton samples. Other macroinvertebrate taxa that commonly were collected in the plankton nets included the oligochaetes *Stylaria lacustris, Nais behningi*, and *Nais variabilis*; the amphipod *Hyalella azteca;* and several genera of chironomids (Trapp 1992).

Meroplankton densities during the six-year period ranged from 17,168.6 organisms/1000 m^3 in Region 8 in 1986 to 206,486.4 organisms/1000 m^3 in Region 4 in 1987. Meroplankton densities at all stations were lowest in 1986 and highest in 1987. Meroplankton biomass had a similar temporal pattern, with low biomass in 1986, followed by high biomass in 1987 as the lake community became more established. During the six-year period, mean annual meroplankton biomass ranged from 1.630 g/1000 m^3 at Region 8 in 1986 to 15.371 g/ 1000 m^3 in Region 5 in 1987. Meroplankton density and biomass were generally lowest in Region 8.

4.8.7.2.1.2 Benthic Macroinvertebrates

Dominant Taxa and Taxa Richness - The littoral benthic macroinvertebrate community of L Lake was dominated numerically by oligochaetes including *Lumbriculus variegatus, Limnodrilus hoffmeisteri, Nais communis,* and *Aulodrilus* sp.; turbellarians; the amphipod *Hyalella azteca*; and several genera of chironomids, including *Chironomus, Dicrotendipes,* and *Ablabesmyia*. In most regions, the fewest taxa (9.3 to 11.6 taxa) were collected during the first year of sampling when the littoral community was first becoming established; the most were collected in 1989 (14.4 to 17.3 taxa; Table 5-165). Taxa richness in 1990 and 1991 was somewhat lower than in 1989. In general, taxa richness varied considerably with depth, between sampling stations within the same region, among regions and among seasons (Trapp 1992). However, no consistent pattern was discernible for any of these parameters.

Table 4-19. Invertebrates Taken in L Lake 1986 through 1991

Lowest practical taxa	Emergence Traps	Ponar Grabs	Dip Nets	Meroplankton
Turbellaria			X	
Nematoda		X		X
Hydra sp.		X	X	X
Stylaria lacustris				X
leech		X		
Amnicola		X	X	
Ferrissia rivularis		X		
Helisoma trivolvis		X	X	
Menetus dilatatus		X	X	
Physella heterostropha		X	X	
Pseudosuccinea columella		X	X	
Succinea			X	
Hydracarina		X		X
Gammarus fasciatus		X	X	X
Hyalella azteca		X	X	X
Asellus sp.		X		
Palaemonetes paludosus		X	X	
Collembola			X	
Baetis sp.	X		X	
Callibaetis sp.			X	
Centroptilum sp.	X			
Caenis sp.	X	X	X	X
Ephemerellidae		X		
Hexagenia sp.		X		
Stenonema sp.			X	
Brachymesia gravida		X		
Enallagma sp.		X		
Epicordulia sp.		X		
Erythemis simplicicollis		X		
Gomphus (G.) lividus		X		
Ischnura sp.	X			
Libellula sp.		X		
Pachydiplax longipennis		X		
Belostoma sp.			X	
Corixidae		X	X	
Gerridae		X		
Cheumatopsyche sp.	X		X	X
Chimarra sp.				X
Cyrnellus sp.			X	
Hydropsyche sp.	X			
Hydroptila waubesiana	X			X
Lype diversa		X	X	
Nectopsyche candida			X	
Neureclipsis sp.			X	
Nyctiophylax sp.			X	

Table 4-19. Invertebrates Taken in L Lake 1986 through 1991 - continued

Lowest practical taxa	Emergence Traps	Ponar Grabs	Dip Nets	Meroplankton
Oecetis cinerascens	X		X	
Orthotrichia sp.	X		X	
Oxyethira sp.	X		X	
Triaenodes sp.	X		X	
Pyralidae		X		
Ancyronyx variegatus		X		
Berosus sp.		X	X	
Copelatus sp.			X	
Coptotomus sp.			X	
Curculionidae		X	X	
Cybister fimbriolatus			X	
Dineutus sp.		X	X	X
Dytiscidae		X		
Enochrus			X	
Gyrinus			X	
Haliplus			X	
Hydroporus			X	
Liodessus			X	
Macronychus glabratus		X	X	
Peltodytes sexmaculatus			X	
Stenelmis sp.		X		
Suphisellus sp.			X	
Tropisternus collaris			X	
Ablabesmyia (A.) monilis	X			
Ablabesmyia (A.) ramphe	X			
Ablabesmyia (K.) cinctipes	X			
Asheum beckae	X			
Bradysia?	X			
Ceratopogoniinae	X	X	X	X
Chaoborus punctipennis	X	X	X	X
Chironomus crassicaudatus	X			
Chironomus decorus	X			
Cladopelma edwardsi	X			
Cladotanytarsus sp. *viridiventris*?	X			
Corynoneura sp. 1	X			
Cricotopus (C.) cf. vierriensis	X			
Cricotopus (C.) sp. 1	X			
Cricotopus (C.) sp. 2	X			
Cricotopus (C.) sp. 4	X			
Cryptochironomus cf. *blarina*	X			
Cryptochironomus cf. *sorex*	X			
Culicidae			X	
Diamesiinae		X		
Dicrotendipes modestus	X			

Table 4-19. Invertebrates Taken in L Lake 1986 through 1991 - continued

Lowest practical taxa	Emergence Traps	Ponar Grabs	Dip Nets	Meroplankton
Dicrotendipes neomodestus	X			
Dicrotendipes nervosus	X			
Dixa sp.		X		
Dolichopodidae			X	
Empididae				X
Endochironomus nigricans	X			
Endochironomus subtendens	X			
Ephydridae			X	X
Erioptera sp.			X	
Forcipomyia sp.			X	
Forcipomyiinae		X		
Glyptotendipes (P.) barbipes	X			
Glyptotendipes (P.) lobiferus	X			
Glyptotendipes (P.) paripes	X			
Goeldichironomus carus	X			
Hemerodromia sp.	X	X	X	
Labrundinia becki	X			
Labrundinia pilosella	X			
Larsia planesis	X			
Microchironomus nigrovittatus	X			
Nanocladius (N.) cf. *distinctus*	X			
Nanocladius (N.) cf. *mallochi*	X			
Nanocladius (N.) cf. *minimus*	X			
Nilotanypus fimbriatus	X			
Nilothauma babiyi	X			
Parachironomus carinatus	X			
Parachironomus frequens	X			
Parachironomus monochromus	X			
Parachironomus potamogeti	X			
Parachironomus sp. 1	X			
Parachironomus tenuicaudatus	X			
Parakiefferiella cf. *coronata*	X			
Paralauterborniella nigrohalteralis	X			
Pentaneura inconspicua	X			
Phaenopsectra flavipes	X			
Phaenopsectra punctipes	X			
Polypedilum (P.) illinoense	X			
Polypedilum (T.) digitifer	X			
Polypedilum (T.) griseopunctatum	X			
Polypedilum (T.) halterale	X			
Polypedilum (T.) scalaenum	X			
Polypedilum (T.) simulans	X			
Potthastia sp.	X			
Procladius (H.) sublettei	X			
Procladius (P.) bellus	X			

Table 4-19. Invertebrates Taken in L Lake 1986 through 1991 - continued

Lowest practical taxa	Emergence Traps	Ponar Grabs	Dip Nets	Meroplankton
Psectrocladius vernalis	X			
Pseudochironomus fulviventris	X			
Pseudochironomus rex	X			
Psychoda alternata			X	
Rheotanytarsus cf. *exiguus*	X			
Rheotanytarsus distinctissimus	X			
Scathophagidae			X	
Simulium sp.	X	X	X	X
Stenochironomus (P.) cinctus	X			
Stenochironomus (S.) hilaris	X			
Stenochironomus (S.) macateei	X			
Stratiomyidae		X		
Tanytarsus cf. *curticornis*	X			
Tanytarsus sp. 1	X			
Tanytarsus sp. 2	X			
Tanytarsus sp. 3	X			
Tanytarsus sp. 4	X			
Telmatoscopus sp.			X	
Thienemanniella sp. 1	X			
Tipula sp.			X	
Xestochironomus sublettei	X			
Zavreliella varipennis	X			
Zavrelimyia sinuosa	X			
Trichogrammidae	X			

Densities - Benthic densities were also lowest in 1986, ranging from 3955.5 to 4471.6 organisms/m^2. The density of organisms in most regions peaked in 1988 or 1989, with densities of approximately 10,000 to 12,000 organisms/m^2 occurring in all regions except Region 8, where the maximum mean annual densities in 1988 and 1989 were 8948.1 and 7617.4 organisms/m^2, respectively. Densities in 1991 were substantially lower for both Regions 5 and 7, averaging fewer than 7000 organisms/m^2. The density patterns exhibited in L Lake are typical of those reported for many new reservoirs, with densities peaking in the third or fourth year, and then declining somewhat as the ecosystem approaches equilibrium.

Biomass - Benthic biomass followed a similar trend, with low biomass (<1 g/m^2), reported for all regions during 1986, followed by a gradual increase in 1987 and 1988. Biomass in all regions peaked in 1989 or 1990, with standing crops as high as 17.182 g/ m^2 reported. Biomass in 1991 was somewhat lower than in the previous two years. Biomass in Region 8 was always substantially lower than in the other regions, ranging from 0.749 to 2.094 g/m^2. Benthic habitat in Region 8 was poorer than that of the other regions of the lake, primarily due to the presence of large areas of hard-packed clay, which provided a poor substrate for most species of macroinvertebrates. The biomass pattern exhibited in L Lake is typical of that reported for many new reservoirs, with biomass peaking in the third or fourth year, and then declining somewhat as the ecosystem approaches equilibrium.

Emergence Traps - Emergence traps were used in L Lake to document successful reproduction of aquatic insects in the reservoir and to collect taxa that might be missed by other sampling methods. The majority of the insects collected from the emergence traps were chironomids. The most prevalent taxa included *Glyptotendipes* spp., *Procladius sublettei*, *Cricotopus* sp., *Nanocladius* sp., *Ablabesmyia* sp., *Labrundinia* spp., *Tanytarsus* spp., and *Cladotanytarsus viridiventris* (Lauritsen 1990; Trapp 1992). Other dipterans caught in the traps included *Chaoborus punctipennis*, Ephydridae, and Ceratopogonidae. Mayflies and caddisflies also were collected in low numbers (Lauritsen 1990). As expected, emergence rates were typically highest during the spring and summer (Trapp 1992). Annual mean emergence rates during the six-year period ranged from 0.62 insects/m^2/day in Region 5 in 1991 to 36.47 insects/m^2/day in Region 4 in 1988. Emergence rates were fairly comparable in 1986 through 1989, but were much lower in 1990 and 1991 probably due to a change in the design of the emergence traps (Trapp 1992).

4.8.7.2.2 1995 Sampling

Sixty-seven macroinvertebrate taxa were collected during the 1995 sampling. The most dominant taxa in most samples were oligochaetes (32.8-69.7%) and the amphipod, *Hyallela azteca* (5.6-30.9%). The mean number of taxa collected per replicate ranged from 12.58 to 16.83. Taxa richness in Regions 5 and 7 was similar. In general, fewer taxa were collected at the deeper depths. Densities of organisms was somewhat higher in Region 5 (8622 to 18,826 organisms/m^2) than in Region 7 (7184 to 11,628 organisms/m^2). Densities decreased with increasing depth. Macroinvertebrate biomass was also higher in Region 5 at the 1- and 2-m (3- and 6.5-ft) depths (51.6 and 80.5 g/m^2, respectively) than in Region 7 (12.2 and 27.4 g/m^2, respectively), but the biomass of samples from the 4-m (13-ft) depth in Region 7 was somewhat higher than that at 4 m (13 ft) in Region 5.

The composition of the L-Lake macroinvertebrate community has changed considerably since it was last sampled in the late 1980s. The relative abundance of Chironomini midges has declined substantially, while amphipods, oligochaetes, Tanytarsini midges, Turbellaria, bivalves, and the phantom midge (*Chaoborus punctipennis*) have increased in abundance. Amphipods exhibited the greatest increase in relative abundance. This shift in structure is due, at least in part, to the development of aquatic macrophyte beds in L Lake. The L Lake macroinvertebrate community is similar to those of many other southeastern reservoirs (Specht 1996).

4.8.8 Fish

4.8.8.1 Introduction

The L-Lake fish community was sampled extensively from January 1986 to December 1989; this sampling began approximately two months after the lake was filled in November 1985. Somewhat less-extensive sampling continued from January 1990 through December 1992 and November and December 1995. Both adult and larval fish assemblages were sampled. The extensive sampling program on L Lake provided an unusually complete database documenting the development of the fish community and the relationship between the fish community and other trophic levels. Most of the following discussion is based on research reported in Paller et al. (1992). Table 4-20 lists species of adult and juvenile fish taken in L Lake while Table 4-21 lists taxa of ichthyoplankters taken.

4.8.8.2 Sampling Methods

The lower end of L Lake was divided longitudinally into five sampling regions (Regions 4-8) (Figure 4-34). Distributed throughout these regions were 20 electrofishing sample stations that were sampled from January 1986 to December 1989. The number of stations was reduced to 8 from January 1990 to December 1992. Each sample station consisted of a 100-m (330-ft) transect parallel to the shoreline following the 1-m (3.3-ft) depth contour. Electrofishing samples also were collected from artificial reefs in Regions 4-8. Electrofishing was conducted at night monthly from January 1986 to December 1990 and quarterly thereafter.

Ichthyoplankton were collected during darkness with paired 0.5-m diameter, 0.505 mm mesh plankton nets. From January 1986-December 1989, collections were made weekly during February-July and biweekly during the remaining months. During January 1990-December 1992, collections were made weekly from February-August. Temperature, dissolved oxygen concentration, pH, and conductivity were routinely measured *in situ* at the same times and locations where fish samples were collected. Paller et al. (1992) has more information on fisheries sampling methodologies.

Hydroacoustic methods were used to document the abundance of pelagic fishes. This technology was particularly useful in monitoring threadfin shad abundance. (Paller et al. 1988 has further details).

Table 4-20. Species of Fishes Taken from L Lake by Sampling Method

Family	Scientific Name	Common Name	Trammel Net	Seine	Hoopnet	Fishkill	Shad Scoop
Anguillidae	*Anguilla rostrata*	American eel			X		
Clupeidae	*Dorosoma cepedianum*	gizzard shad	X		X	X	X
	Dorosoma petenense	threadfin shad	X			X	X
Cyprinidae	*Cyprinus carpio*	common carp				X	
	Nocomis leptocephalus	bluehead chub		X	X		
	Notemigonus crysoleucas	golden shiner		X	X	X	
	Notropis petersoni	coastal shiner		X		X	
Catostomidae	*Erimyzon oblongus*	creek chubsucker		X	X		
	Erimyzon sucetta	lake chubsucker	X		X		
Ictaluridae	*Ameiurus brunneus*	snail bullhead	X		X		
	Ameiurus natalis	yellow bullhead	X	X	X	X	
	Ameiurus nebulosus	brown bullhead			X	X	
	Ameiurus platycephalus	flat bullhead	X		X		
	Ictalurus punctatus	channel catfish			X		
Esocidae	*Esox americanus*	redfin pickerel		X			
	Esox niger	chain pickerel			X	X	
Aphredoderidae	*Aphredoderus sayanus*	pirate perch				X	
Poeciliidae	*Gambusia holbrooki*	eastern mosquitofish		X		X	
Atherinopsidae	*Labidesthes sicculus*	brook silverside		X	X	X	
Centrarchidae	*Acantharchus pomotis*	mud sunfish			X		
	Centrarchus macropterus	flier	X		X	X	
	Enneacanthus gloriosus	bluespotted sunfish			X		
	Lepomis auritus	redbreast sunfish	X	X	X	X	
	Lepomis gibbosus	pumpkinseed			X		
	Lepomis gulosus	warmouth		X	X	X	
	Lepomis macrochirus	bluegill	X	X	X	X	X
	Lepomis marginatus	dollar sunfish		X	X		
	Lepomis microlophus	redear sunfish			X		
	Lepomis punctatus	spotted sunfish	X	X	X	X	
	Micropterus salmoides	largemouth bass	X	X	X	X	
	Pomoxis nigromaculatus	black crappie	X		X	X	X
Percidae	*Perca flavescens*	yellow perch			X	X	

Table 4-21. Taxa of Ichthyoplankters Taken in L Lake

Family	Taxa
Clupeidae	*Dorosoma cepedianum*, gizzard shad
	Dorosoma petenense, threadfin shad
Cyprinidae	Unidentified minnows
	Cyprinus carpio, common carp
Poeciliidae	*Gambusia holbrooki*, eastern mosquitofish
Atherinopsidae	*Labidesthes sicculus*, brook silverside
Centrarchidae	*Lepomis auritus*, redbreast sunfish
	Lepomis macrochirus, bluegill
	Micropterus salmoides, largemouth bass
	Unidentified sunfish
	Pomoxis nigromaculatus, black crappie

4.8.8.3 Artificial Stocking Program

L Lake was stocked with approximately 40,000 juvenile (20-30 mm [0.75-1 in]) bluegill in the fall of 1985 and approximately 4000 juvenile largemouth bass in the spring of 1986.

4.8.8.4 Physical and Chemical Conditions in L Lake

L Lake stratified during the spring and summer due to climatic factors, as is typical of most southeastern lakes and reservoirs. However, stratification occasionally occurred during the winter due to density differences between thermal reactor discharges and underlying lake waters. L Lake received thermal effluent during November 1985-June 1986, December 1986-June 1987 and January 1988-June 1988. Temperatures in excess of 40°C (104°F) occurred near the L Reactor outfall during periods of reactor operation. However, the maximum recorded water temperature in Regions 4-8 was approximately 34°C (93°F), in June 1986. This temperature was approximately 2°C (3.6°F) higher than the maximum temperatures in southeastern reservoirs without thermal inputs. The highest recorded 24-hour mean temperature in Regions 4-8 was 32°C (90°F). While the highest temperatures occurred in June, the highest above ambient occurred during the winter and early spring when L Lake waters were elevated as much as 5°C (9°F). Littoral zone temperatures exhibited little consistent spatial variation within the study area (Regions 4-8).

When L Lake stratified, hypolimnetic waters became anoxic; however, the epilimnion remained oxygenated throughout this study. The lowest 24-hour mean dissolved oxygen concentration in the littoral and epilimnetic waters of L Lake was approximately 5 mg/l and the minimum recorded concentration was approximately 3 mg/l. None of the other 36 water-quality variables monitored in the littoral zone of L Lake reached levels detrimental to warm-water fishes.

4.8.8.5 Species that Failed to Colonize L Lake

Most of the 28 species of fish in the reach of Steel Creek that was impounded to create L Lake failed to colonize the reservoir. At least seven of the species that failed to colonize L Lake are known to prefer sites with relatively fast flowing water; they are tesselated darter (*Etheostoma olmstedi*), blackbanded darter (*Percina nigrofasciata*), Savannah darter (*Etheostoma fricksium*), bluehead chub (*Nocomis leptocephalus*), speckled madtom (*Noturus letacanthus*), northern hogsucker (*Hypentilium nigricans*), and yellowfin shiner (*Notropis lutipinnis*) (Meffe and Sheldon 1988). Other species that did not colonize L Lake from Steel Creek may have had other types of habitat requirements that were not met in L Lake. For example, chain pickerel (*Esox niger*), redfin pickerel (*Esox americanus*), and eastern mud-minnow (*Umbra pygmaea*) require aquatic vegetation for successful reproduction, and spotted sucker (*Minytrema melanops*) generally require riffle areas. Neither habitat was present in L Lake when initial colonization was occurring. None of the preceding species was collected from L Lake in more than trace numbers; they may have avoided L Lake because of unsuitable habitat or entered L Lake, but failed to successfully reproduce. Therefore, the first stage of colonization was controlled by the habitat requirements of the species that occupied Steel Creek prior to impoundment.

4.8.8.6 Successful Early Colonists of L Lake

4.8.8.6.1 <u>Early Colonists</u>

Only eight species of fish found in Steel Creek before it was impounded entered L Lake in substantial numbers: eastern mosquitofish (*Gambusia holbrooki*), brook silversides (*Labidesthes sicclus*), coastal shiner (*Notropis petersoni*), golden shiner (*Notemigonus chrysoleucas*), creek chubsucker (*Erimyzon oblongus*) dollar sunfish (*Lepomis marginatus*), redbreast sunfish and spotted sunfish (*Lepomis punctatus*). These eight species can be divided into three groups: those that did not reproduce in L Lake, those that reproduced but did not persist, and those that persisted.

4.8.8.6.2 <u>Species that Did Not Reproduce in L Lake</u>

The creek chubsucker and brook silversides, although collected from L Lake as adults, probably did not reproduce based on an inability to collect larvae or juveniles of either species. These species quickly decreased in abundance after L Lake was filled and were virtually absent from the electrofishing catches by March 1986 and May 1986, respectively.

4.8.8.6.3 <u>Species that Reproduced but Did Not Persist in L Lake</u>

Eastern mosquitofish, golden shiner, coastal shiner, dollar sunfish, and spotted sunfish were able to reproduce but did not persist in L Lake or declined over time to low numbers. Large schools of eastern mosquitofish were observed swimming along the shoreline of L Lake as it was filling in late 1985. Electrofishing catches for this species were relatively high in January 1986 but decreased in February and March (Figure 4-36). Catch rates again increased in April and May 1986 as fish that were spawned in the spring (Figure 4-37) were recruited into the population. In June, however, numbers of eastern mosquitofish declined precipitously, leading to the disappearance of this species from L Lake by late 1986.

Coastal shiner and golden shiner were comparatively abundant in L Lake during January through May 1986 (Figure 4-36) and successfully reproduced during this period as indicated by the collection of larvae (Figure 4-37). Larvae could not have drifted into L Lake from Steel Creek because Regions 4-8 of L Lake were separated from Steel Creek by a thermal barrier (>40°C [104°F]) created by the discharge of reactor effluent at the upper end of L Lake. Despite their ability to reproduce, numbers of coastal shiners and golden shiners decreased sharply after May 1986, and both species disappeared from L Lake by mid-1987.

Dollar sunfish and spotted sunfish were relatively abundant during early 1986 but subsequently decreased in abundance (Figure 4-36). Dollar sunfish persisted until mid-1987, and spotted sunfish persisted in small numbers through the end of the study. Spotted sunfish and dollar sunfish were able to reproduce in L Lake, as indicated by the collection of relatively small individuals (under 80 mm [3 in]) after June 1986. (Juveniles collected prior to this may have been spawned in Steel Creek while L Lake was filling.)

4.8.8.6.4 Species that Persisted in L Lake

Of the eight species that initially dominated the L Lake fish community, only redbreast sunfish increased in number. Unlike the aforementioned species, redbreast sunfish were recruited in large numbers in the summer of 1986, causing the electrofishing catch rate for this species to double or triple from spring levels (Figure 4-38). Recruitment also was observed in 1987 and 1988. By 1988, this species had stable population with substantial numbers of individuals of all sizes from juvenile through adult.

4.8.8.7 Decline of the Early Colonists

Five species of fish established reproducing populations and initially dominated the L Lake fish community, but later declined as related above. It is unlikely that this decline was caused by harsh abiotic conditions because critical water-quality variables, including dissolved oxygen concentration and temperature, did not reach levels in the littoral or epilimnetic portions of Regions 4-8 that were likely to be lethal to the early colonists.

The decline of most of the species that initially colonized L Lake coincided with the establishment and increase in numbers of other species of fish. Catch per unit effort of largemouth bass increased substantially beginning in April 1986 as fish stocked earlier in the spring and those spawned in L Lake early in 1986 grew to catchable size (Figure 4-38). This increase in largemouth bass abundance began just before the abrupt decline of several of the initial colonists, and the monthly average electrofishing catch rate of largemouth bass was inversely correlated with the monthly average catch rates of the early colonists that later declined (i.e., dollar sunfish, spotted sunfish, coastal shiner, eastern mosquitofish, and golden shiner summed) (Pearson $r=-0.78$, $P<0.05$).

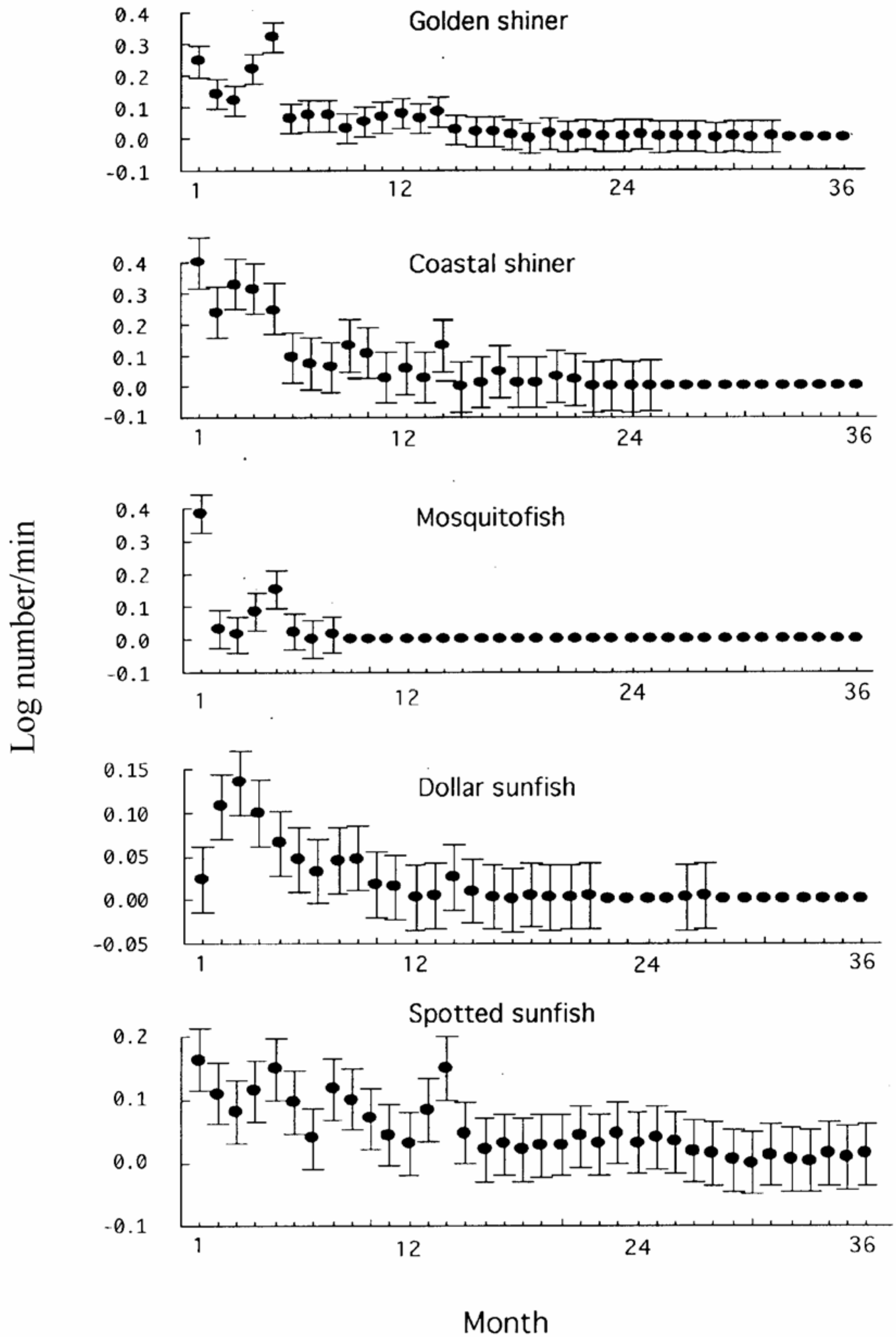

Figure 4-36. Mean Elecrofishing Catch Rates (Logarithmically Transformed) of Five Species of Fish tha Colonized L Lake but then Declined, January 1986 – December 1988 (Source: Paller et al. 1992)

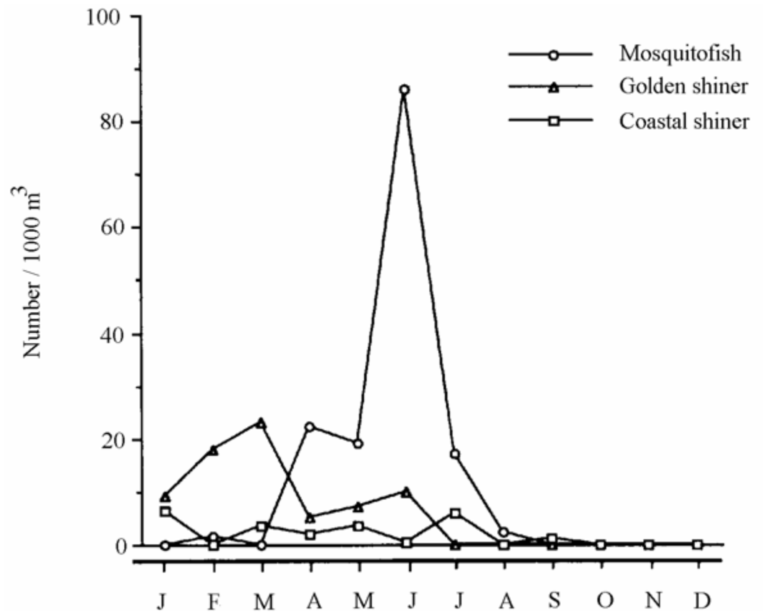

Figure 4-37. Mean Larval Fish Densities (no./1000 m^3) in Regions 4-8 of L Lake during 1986 as Indicated by Plankton Net Tows (Source: Paller et al. 1992)

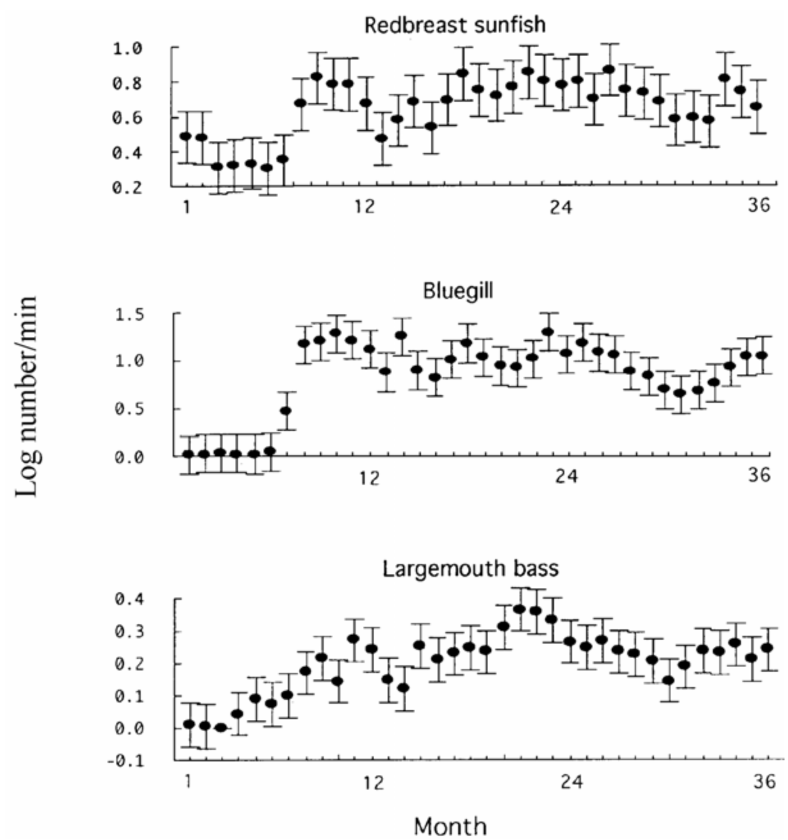

Figure 4-38. Mean Elecrofishing Catch Rates (Logarithmically Transformed) of Three Species of Fish that Persisted After Entering L Lake, January 1986 – December 1988 (Source: Paller et al. 1992)

Bluegill catch per unit effort increased greatly in August 1986 due to the recruitment of large numbers of juvenile fish (Figure 4-38). The juvenile bluegill collected during the summer of 1986 were the progeny of fish stocked in L Lake in November 1985 and of the small numbers of bluegill that may have been present before stocking. Other species that became established in L Lake during 1987 and 1988 were threadfin shad (*Dorosoma petenense*), gizzard shad (*Dorosoma cepedianum*), warmouth (*Lepomis gulosus*), and flat bullhead (*Ameiurus platycephalus*). Larvae of some of these fish may have been transported to L Lake in unheated water pumped to the reservoir from the Savannah River during summer reactor outages.

By 1988, the initial fish fauna of Regions 4-8 of L Lake, with the exception of redbreast sunfish, had been replaced by later arriving species. The only events that closely coincided with the decline of the unsuccessful early colonists were relatively sudden increases in the size of largemouth bass, bluegill, and redbreast sunfish populations. This concurrence of events, coupled with an absence of negative changes in the abiotic environment, indicates that interactions between the early colonists and the rapidly expanding species were responsible for the community changes observed during 1986.

4.8.8.8 Fish Assemblages Upstream from Regions 4-8

High temperatures (>40°C [104°F]) precluded the survival of fish above Regions 4-8 during periods of reactor operation. However, during the extended summer reactor outages, which lasted approximately six months, temperatures decreased to ambient levels, permitting fish from Regions 4-8 to invade the upper portion of L Lake. When L Reactor was restarted in the fall, large numbers of these fish were killed by elevated temperatures (Paller et al. 1988). There was no indication, however, that these fish kills affected community structures in the lower portion (Regions 4-8) of L Lake.

4.8.8.9 Recent Status of the L-Lake Fish Community

Largemouth bass, bluegill, redbreast sunfish, and threadfin shad dominated the L Lake fish community between 1987 and sometime after 1992. The most important trends in the fish community in recent years involve changes in the abundances of these species and interactions between the dominant fish species and lower trophic levels, particularly zooplankton. The latter have been documented by Taylor et al. (1993), who described zooplankton succession in L Lake during the three years following impoundment. During 1986 and 1987, larger macrozooplankton dominated the zooplankton assemblage. However, during 1988, *Bosmina longirostris*, the smallest of the cladocerans, was the most abundant macrozooplankton, and loricate rotifers dominated the zooplankton assemblage. Size-selective predation by threadfin shad was implicated in this shift in community structure.

Several of the dominant fish taxa in L Lake have declined in abundance from previous levels. After reaching peak population densities in 1988, threadfin shad densities have declined to low levels. Threadfin shad were not collected in 1995. Bluegill and redbreast sunfish numbers also have declined from earlier levels. Decreases in bluegill and redbreast sunfish numbers were associated with changes in condition (a measure of weight in relation to length) and size distribution (Sayers and Mealing 1992). There are several possible reasons for these changes, including predatory and competitive interactions and changes in the primary productivity of L Lake.

In 1995, brook silversides (*Labidesthes sicculus*) and coastal shiner (*Notropis petersoni*), which were rare in the reservoir after summer of 1986, were again common. Yellow perch (*Perca flavescens*) and chain pickerel (*Esox niger*), which had never before been common, were numerically important members of the fish assemblage, and threadfin shad (*Dorosoma petenense*), which were very common between 1987 and 1989, were absent (Paller 1996).

It is probable that these changes in the L Lake fish community are largely the result of predation and competition among species with the outcome of these processes strongly influenced by the changing physical and chemical environment in L Lake. The most important of these changes appears to have been the proliferation of aquatic vegetation in L Lake. Also, cessation of reactor operations reduced nutrient loading from Savannah River water input to the reservoir and the maintenance of ambient water temperatures throughout the reservoir throughout the year.

Currently, the L Lake fish community includes at least 19 species with the most abundant being brook silversides, yellow perch, bluegill, redbreast sunfish, coastal shiner, largemouth bass, chain pickerel, and spotted sunfish. These species are generally common in southeastern reservoirs with abundant aquatic vegetation. Most or all of these species appear to have successfully reproducing and self-sustaining populations in L Lake (Paller 1996).

4.8.8.10 Contaminant Levels in L-Lake Fish

The geometric mean total mercury concentration in L-Lake largemouth bass (whole fish) collected in 1995 was 351 µg/kg of body weight. Total mercury concentrations increased significantly with fish size, reflecting bioaccumulation in older fish. The geometric mean total mercury concentration in bluegill and redbreast sunfish from L Lake in 1995 averaged 70 and 76 µg/kg, respectively. Mercury contamination is common in fish taken from SRS water bodies that receive or received input from the Savannah River. The mercury concentrations in largemouth bass from L Lake are similar to those found in largemouth bass collected from the Savannah River (1992-1994 mean of 557 µg/kg).

The geometric mean cesium-137 concentration in L-Lake largemouth bass (whole fish) was 0.62 pCi/g. Body burdens were not significantly related to fish size. Geometric mean concentrations in bluegill and redbreast sunfish were 0.16 pCi/g and 0.18 pCi/g, respectively (Paller 1996).

4.8.9 References

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4.9 PAR POND

4.9.1 Drainage Description and Surface Hydrology

4.9.1.1 General Description

Par Pond is a 1012-ha (2500 acre) reactor cooling reservoir that augmented the cooling requirements for P and R Reactors (Figure 4-39). It was created in 1958 by constructing an earthen dam (Cold Dam) on Lower Three Runs. It runs along the course of Poplar Branch, Joyce Branch, and the upper reach of the Lower Three Runs drainage system (Wilde and Tilly 1985). The U.S. Department of Energy (DOE) has not pumped water from the Savannah River to Par Pond since 1996. Based on hydrogeologic monitoring, the reservoir may fluctuate between 61 m (200 ft) above mean sea level and 59.4 m (195 ft) above mean sea level. Water quality may also change with the cessation of input from the Savannah River. This document does not discuss those potential changes or their implications to the Par Pond biota.

The major meteorological factors that affect the structure and function of the reservoir ecosystem are air temperature, solar insulation, relative humidity (and saturation deficit), wind speed and direction, and precipitation (Wilde and Tilly 1985). Construction activities during the formation of the pond, which resulted in uniform contours leading to the pumphouse and noticeably steep slopes near the Hot Dam, influenced the morphometry of Par Pond. In contrast, the North Arm is more riverine and shallow (Wilde and Tilly 1985).

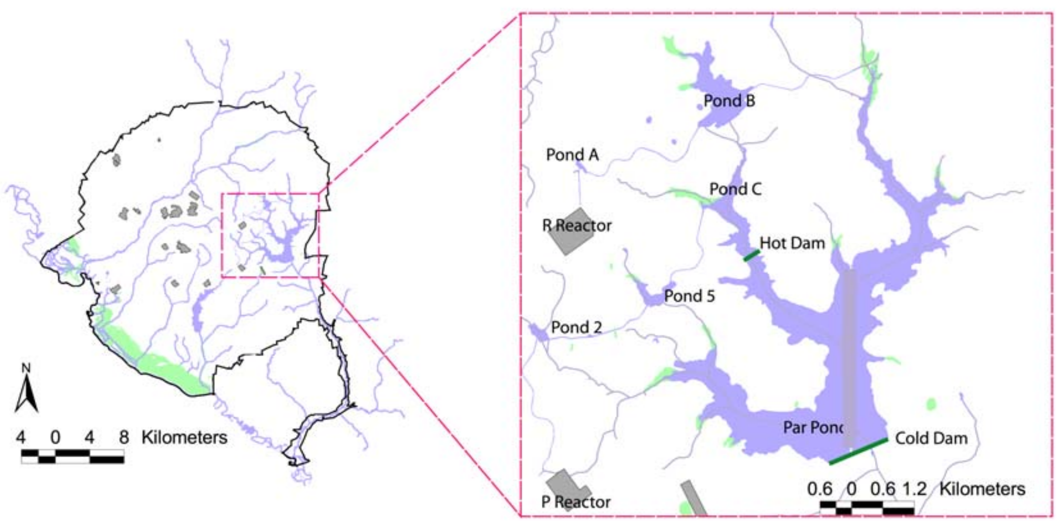

Figure 4-39. Location of Par Pond on SRS

4.9.1.2 Effluent Contribution

From August 1958 to October 1961, Par Pond received thermal effluent from R Reactor only. During this time, R Reactor discharged thermal effluent to the Middle (or "Hot") Arm through precooler Pond C. Both P and R reactors used Par Pond from November 1961 to June 1964. During this period, R Reactor discharged effluent to the North Arm through Pond B, while P Reactor discharged effluent into the middle arm of the reservoir through a series of canals and precooler ponds, including Pond C (Figure 4-39). In July 1964, R-Reactor operations ceased and the reactor was placed on standby. Thereafter, Par Pond received thermal effluent from P Reactor only, and Pond B received no effluent cooling water. A pumphouse on Par Pond South Arm recirculates water from Par Pond to P Area. During Par Pond's operation as a cooling pond, this recirculated water was discharged into the 186-P Basin and mixed with makeup water pumped from the Savannah River (Figure 4-39).

4.9.1.3 Flow and Temperature Measurements

Flow from the Par Pond pumphouse to P Reactor averaged 9.8 m^3/s (346 ft^3/s) when P Reactor was operating (Wilde 1985). During reactor operations, recirculating water flowed through the reactor heat exchangers, where it reached temperatures of approximately 70°C (158°F), and was released through a series of precooler ponds and canals into Pond C (Wilde and Tilly 1985). This precooling system accounted for approximately 86% of the total cooling in the Par Pond system (Wilde 1985). Reactor cooling-water effluent from Pond C passed through a concrete culvert below an earthen dam (Hot Dam) and was funneled under gravity head from the bottom of Pond C into Par Pond. The culvert terminates approximately 2 m (6.5 ft) below the surface of Par Pond. From there, the effluent flowed upward, forming a thermal plume that spread out at the surface of Par Pond (Wilde 1985). Water losses from the Par Pond system due to evaporation and seepage were compensated by pumping makeup water from the Savannah River (Wilde 1985; Wilde and Tilly 1985). Savannah River makeup water was pumped at a rate of 1.0-1.3 m^3/sec (35.3-45.9 ft^3/sec) when the reactor was operating (Wilde 1985). Between 1980 and 1985, the amount of makeup water pumped from the Savannah River averaged 1.1 m^3/s (38.3 ft^3/sec) (Wilde 1985). Other than the addition of Savannah River makeup water and the overflow and seepage to Lower Three Runs through the Cold Dam, Par Pond has operated as a closed loop system.

Weather, drainage basin morphometry, and pumping rates associated with reactor operations influence flow patterns (Wilde 1985). Simple replacement time for the volume of water in Par Pond by rainfall and runoff from 1962 to 1977 averaged 704 days and ranged from 516 to 967 days (Tilly 1981). However, actual replacement time was reduced to 68 days from 1962 to 1977 by reactor operations (Tilly 1981) and to 108.8 days from January 1984 to June 1985 (Chimney et al. 1985).

4.9.2 Water Chemstry and Quality

4.9.2.1 Studies and Monitoring

4.9.2.1.1 Water Quality Monitoring

Routine SRS water quality monitoring does not include sampling in Par Pond other than annual pesticide, herbicide, and PCB monitoring. Wilde (1985) summarizes water chemistry data for Par Pond between 1972 and 1985 from three primary sources (Chimney et al. 1985; Newman et al. 1986; Tilly 1981). Gladden et al. (1985) also summarizes Par Pond water quality data prior to the CCWS. The Savannah River Ecology Laboratory (SREL) was compiling water quality data from the Par Pond drawdown at the time of this document's revision.

4.9.2.1.2 Comprehensive Cooling Water Study (CCWS)

The CCWS water quality monitoring conducted from 1983 to 1985 was designed to assess impacts associated with then current and proposed SRS activities. Two locations on Par Pond were sampled (Figure 4-40):

- Par Pond's South Arm near the pumphouse which reflected the "cold" section of Par Pond (01)
- "Bubble-up" between Pond C and the Middle Arm of Par Pond, where water from Pond C enters Par Pond (02)

A comprehensive biological monitoring program conducted from November 1985 to December 1991 investigated the L-Lake and Steel Creek system. One sampling location was chosen on Par Pond, near the Cold Dam, for data comparison (Figure 4-40; point 03). These data reflect postreactor operation conditions.

01 South Arm
02 Near "bubble up"
03 Cold Dam

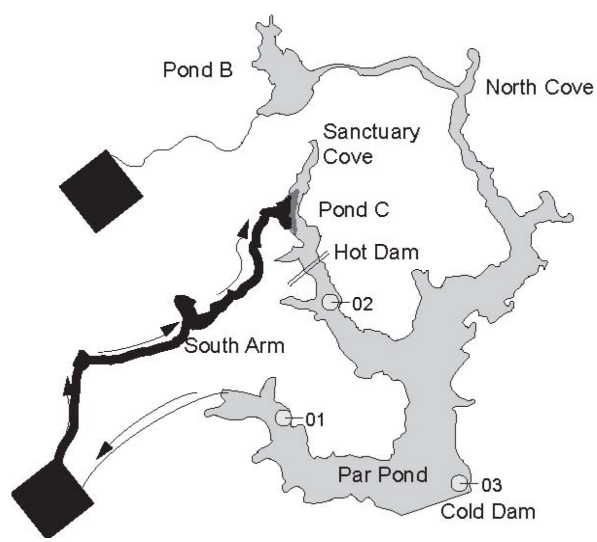

Figure 4-40. Location Map of Par Pond

Comprehensive results and discussion of CCWS data can be found in Newman et al. (1986) and Lower (1987). The CCWS data in the sections that follow reflect impacts associated with reactor operation.

4.9.2.1.3 <u>Chemical Assessment Studies</u>

The 1985-1991 water quality data can be found in "L-Lake Water Quality: L-Lake/Steel Creek Biological Monitoring Program November 1985-December 1991" (Kretchmer and Chimney 1992).

4.9.2.1.4 <u>Regional Lakes Study</u>

In September 1988 and 1989, 10 South Carolina reservoirs were sampled intensively for trophic status, community structure, and biologically balanced community criteria.

This study showed that Par Pond is a meso/eutrophic basin with moderate nutrient enrichment. Pond B is a softwater system. (Bowers 1992).

4.9.2.2 Field Data

4.9.2.2.1 <u>Water Temperature</u>

The mean water temperature at sampling locations in Par Pond ranged from 21.5 to 31.0°C (70.7 to 87.8°F) during the CCWS. The mean water temperature of Par Pond during the L Lake/Steel Creek Program (1985-1991) was 18.1°C (64.6°F). This difference reflects the cessation of thermal discharge into Par Pond associated with the shutdown of P Reactor in 1988.

4.9.2.2.2 <u>pH Measurements</u>

The mean pH of Par Pond water during the CCWS ranged from 7.32 to 7.33. The L Lake/Steel Creek Biological Monitoring program of 1985-1991 indicated a decrease in the mean pH of Par Pond water (6.33) since P-Reactor shutdown.

4.9.2.3 Physical Characteristics and General Chemistry

4.9.2.3.1 <u>Dissolved Oxygen</u>

During the CCWS, mean dissolved oxygen concentrations in Par Pond ranged from 6.44 to 8.20 mg/l. Dissolved oxygen averaged 81-92% saturation in Par Pond (Newman et al. 1986). The mean dissolved oxygen concentration during 1985-1991 was 6.01 mg/l.

4.9.2.3.2 <u>Suspended Solids and Turbidity</u>

Mean concentrations of suspended solids were less in Par Pond than Lower Three Runs during the CCWS, ranging from 2.05 to 3.65 mg/l. The mean suspended solids concentration in Par Pond during the L-Lake/Steel Creek Biological Monitoring Program was 2.02 mg/l. In Par Pond, the mean turbidity ranged from 2.8 to 3.4 NTU during the CCWS.

4.9.2.3.3 <u>Conductivity</u>

Par Pond exhibited a much smaller range of specific conductivity values than Lower Three Runs. During the CCWS, values in Par Pond ranged from 55.2 to 77.0 µS/cm (mean range, 62.9 to 66.4 µS/cm). The range of conductivity values measured during the L Lake and Steel Creek Biological Monitoring Program was 46-126 µS/cm (mean of 70 µS/cm).

4.9.2.4 Major Anions and Cations

4.9.2.4.1 Alkalinity, Chloride, and Sulfate

Monitoring data from Par Pond during the CCWS and the L Lake/ Steel Creek Program have shown similar mean total-alkalinity values (mean range: 14.5-15.6 mg $CaCO_3$/l). Mean chloride concentrations in Par Pond during both the CCWS and the L Lake/Steel Creek Program ranged from 5.73 to 6.28 mg/l. The mean sulfate concentration in Par Pond remained similar throughout the CCWS and the L Lake/Steel Creek Program (mean range: 4.62-5.12 mg/l).

4.9.2.4.2 Calcium, Magnesium, Sodium, and Potassium

Monitoring at the two CCWS sampling locations (near the pumphouse intake and at the "bubble up" between Pond C and the Middle Arm of Par Pond) resulted in almost identical results. The only sampling location in the L-Lake/Steel Creek Biological Monitoring Program (near the Cold Dam) produced concentrations similar to those of the CCWS.

4.9.2.4.3 Aluminum, Iron, and Manganese

Total aluminum concentrations measured in Par Pond have decreased since the CCWS. Mean aluminum concentrations during the CCWS were 0.287 mg/l in the South Arm and 0.28 mg/l in the Middle Arm. Between 1985 and 1991, the mean was 0.032 mg/l.

4.9.2.5 Nutrients

4.9.2.5.1 Phosphorus

All measured forms of phosphorus generally indicated that Par Pond is phosphorus deficient relative to the waters of the Savannah River (Lower 1987). During the CCWS and the L Lake/Steel Creek Program, similar phosphorus concentrations were measured. Mean total phosphorus ranged from 0.022 to 0.042 mg/l, and mean total orthophosphate ranged from 0.005 to 0.007 mg/l.

4.9.2.5.2 Nitrogen

Organic nitrogen was not analyzed during the L-Lake/Steel Creek Program. The mean nitrite concentration found during the L Lake/Steel Creek Program was equal to the nitrite concentrations found during the CCWS. Since the CCWS, the L Lake/ Steel Creek Program has shown a slight increase in concentrations of total Kjeldahl nitrogen, ammonia, and nitrate.

4.9.2.6 Trace Elements

Trace elements were not analyzed during the L Lake/Steel Creek Program. The highest mean concentrations of arsenic (1.9 µg/l), chromium (9.1 µg/l), and nickel (4.3 µg/l were found at the "bubble up" between Pond C and the Middle Arm of Par Pond. The highest mean concentrations of cadmium (0.53 µg/l), copper (2.9 µg/l), and zinc (5.5 µg/l) were found in the South Arm near the pumphouse intake. The mean concentration of lead (1.3 µg/l) was the same at both locations.

4.9.2.7 Organic Carbon

Mean concentrations of total organic carbon in Par Pond waters ranged from 5.7 to 6.2 mg/l. These concentrations are comparable to the mean upriver total organic carbon concentrations of 6.1 mg/l (Lower 1987).

4.9.2.8 Priority Pollutants, Pesticides, Herbicides, and PCBs

The Environmental Monitoring Section of Westinghouse Savannah River Company (WSRC) collects a sample annually from the Par Pond pumphouse and analyzes it for pesticides, herbicides, and PCBs. From 1987 to 1995, concentrations in Par Pond have been below analytical detection limits or practical quantification limits.

Lower (1987) reports the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985; and results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations were also near or below detection limits at all locations.

4.9.2.9 Chemical, Including Radionuclide, and Toxicity Assessment Studies

Chemical studies of the sediments are presented in the following section. The effect of contaminants on fish is reported in the fish section.

4.9.3 Par Pond System Sediments

4.9.3.1 Radionuclides and Mercury in Par Pond

Sediments were collected in September 1995 from the upper 10 cm (4 in) of Par Pond's substrate with a ponar dredge at points along transects running across the north, middle, and south arms of the reservoir, and near the dam. The one-time sampling was performed in conjunction with sampling to assess the impacts of the drawdown on the fish community. The sediments were analyzed for total mercury and gamma emissions.

Mercury was present in detectable concentrations at 20% of the sites. The average concentration (39 µg/kg) was below the U.S. Environmental Protection Agency (EPA) Region IV sediment screening value (139 µg/kg; EPA 1995). The highest mercury concentration, 323 µg/kg, however, exceeded EPA Region IV screening values for mercury in sediments. The highest concentrations occurred in the deeper portions of the reservoir (Paller and Wike 1996a).

Over Site history, Par Pond and Lower Three Runs have received an estimated 8.2 TBq (222 Ci) of radiocesium with 99% of this being ^{137}Cs (Garten et al. 2000). Mean concentrations of ^{137}Cs among these sediment samples was approximately 9.0 pCi/g. The concentrations were variable, with the highest values in the deepest parts of the reservoir. Other gamma-emitting radionuclides present at detectable levels in Par Pond sediments included ^{228}Ac, ^{60}Co, ^{212}Pb, ^{40}K, and ^{234}Th. These constituents had much lower concentrations than ^{137}Cs (Paller and Wike 1996a).

In a separate study to determine the potential effects of contaminants in the Par Pond sediments, sediment samples were collected from the area exposed during the four-year drawdown of the reservoir and analyzed for organics, metal, and radionuclides (Paller and Wike 1996b). Results from Paller and Wike (1996b) indicated that none of the metals or organics measured in the exposed sediments exceeded EPA, National Oceanographic and Atmospheric Administration, or Canadian ecological screening criteria for containments in terrestrial soils. However, the maximum total mercury concentration (485 µg/kg, geometric mean of 62 µg/kg) slightly exceeded the EPA screening criterion for ecological effects in submerged sediments (Paller and Wike 1996b).

A number of radionuclides were detected, but only ^{137}Cs occurred consistently and at levels well in excess of levels at control sites. The ^{137}Cs geometric mean concentration was 7.2 pCi/g; the maximum was 56.7 pCi/g. ^{137}Cs was nonuniformly distributed on both small and large spatial scales, but usually occurred in higher concentrations on the downslopes (58-59 m [190-195 ft] above mean sea level). ^{137}Cs concentrations were higher in sediments with high organic content, and the patchy distribution of these sediments probably contributed to the patchy distribution of ^{137}Cs (Paller and Wike 1996b).

In July 1995, 8-foot sediment cores were collected from 12 locations in Par Pond and 2 locations in Pond C and analyzed for radioactive and nonradioactive constituents. No metals or organics were identified in these cores as potential contaminants of concern. Par Pond cores had significantly greater concentrations of ^{137}Cs , ^{146}Pm, ^{238}Pu, and ^{95}Zr than the reference cores collected from Lake Marion and several SRS creeks (Koch et al. 1996a).

During the drawdown period terrestrial vegetation colonized the exposed sediments initial uptakes by plants of ^{137}Cs were similar to those expected in fresh rather than aged deposits and over the three years decreased as bioavailability decreased (Hinton et al. 1999). Plants classified as terrestrial took up significantly more ^{137}Cs than did those classified as wetland.

^{137}Cs in Pond A was inventoried and estimated to be $4.1 \pm 0.5 \times 10^{10}$ Bq as of 1996 with most of the activity located in the deeper portions (Abraham et al. 2000). While the TLD method is more convenient, coring to help interpret results is required.

There is controversy concerning Pond B. Mohler et al. (1997) report that the ^{137}Cs inventory of the sediment of Pond B decreased from 4.6x1011 Bq in 1984 to 2.3x1011 Bq in 1994 giving an effective half-life of only 10 years. However, Lewis et al. (2000), in Pond B sediments, found no decline in ^{137}Cs beyond what would occur due to radioactive decay. They concluded that because of the very low radionuclide export hundreds or even thousands of sediment cores would be required to detect changes other than due to radioactive decay. Despite long residence in Pond B, ^{137}Cs is primarily in the surface layers of the sediments in Pond B and is associated primarily with fine particles (Pinder et al. 1995). A fraction of cesium sorbs irreversibly to sediment (Stephens et al. 1998) and should thus be very stable over time if sediment is not exported.

4.9.3.2 Results of Other Sediment Studies in the Par Pond System

Two of the Par Pond system precooling ponds and the canal between them were sampled in 1995 and 1996. The intent was to identify the maximum levels of contamination that could be exposed with a drawdown and not to characterize the ponds and canal. Sampling sites were selected based on contour maps of gamma radiation exposure rates measured at 1 m (3.3 ft) above ground level. Three samples from Pond 2 and 11 samples from Pond 5 had low levels of gross alpha activity. The levels in the two ponds were comparable. Nonvolatile beta activity was measurable in most of the Pond 2 and canal samples, but in fewer than half the Pond 5 samples. The highest activities were at two locations in Pond 5 with activities ranging from 71 pCi/g to 240 pCi/g. The only man-made isotopes in any of the samples were ^{60}Co, ^{137}Cs , ^{155}Eu, and ^{241}Am. ^{137}Cs was detected in all but four samples. Six samples had ^{60}Co; one sample indicated the presence of ^{155}Eu; and one indicated the presence of ^{241}Am (Halverson and Noonkester 1996).

^{137}Cs detected in the sediment samples from Pond 2 ranged from 0.987 to 23.9 pCi/g. P-Reactor canal samples ranged from 0.137 to 23.7 pCi/g. In Pond 5, ^{137}Cs ranged from 0.0569 pCi/g to 0.176 pCi/g. One location in Pond 2 had an ^{241}Am concentration of 0.881 pCi/g (Halverson and Noonkester 1996).

Three of the highest nonvolatile beta activities, 71 pCi/g, 110 pCi/g, and 240 pCi/g, were found in samples from one location in Pond 5. However, analytical results for three additional samples at the same location were less than or equal to the screening level. This range could indicate an analytical problem or may reflect the nonhomogenous nature of sediment contamination (Halverson and Noonkester 1996).

Pond B is an 87-ha (215-acre) cooling reservoir constructed in 1961 and used until 1964 for nuclear reactor thermal effluents. During reactor operations it received ^{137}Cs , ^{90}Sr, and plutonium. Studies indicated that, although there has been no input of ^{137}Cs to the reservoir in more than 30 years, it remains in the surface sediments of the littoral zone. Inventories at 2-, 3-, and 4-m, (7-, 10-, and 13-ft) depths were greater than those in shallower areas, but these greater inventories were not associated with areas of sediment accumulation or shallower slopes. The continued occurrence of ^{137}Cs in the surface sediments contradicts the findings of many studies of the ^{137}Cs deposited from weapons testing in the 1960s. ^{137}Cs generated by weapons testing tends to accumulate below the surface and be overlain by relatively uncontaminated sediments. Processes that may account for the continued occurrence of ^{137}Cs in the surface sediments in Pond B include the sorption of ^{137}Cs from the water and the long-term retention of some remnants of the initial deposition on the surface of eroding sediments. Sorption could be accomplished by the remobilization of ^{137}Cs from the sediments during anoxia (approximately April to October of each year) and dispersed to the water column during turnover (November). Alternatively, ^{137}Cs could be released from decaying vegetation (Pinder et al. 1995).

Two studies have analyzed the cycling of plutonium inventories in the Pond B water column (Pinder et al. 1992; Bowling et al. 1994). $^{239/240}Pu$ inventories in the water column of Pond B represent 10^{-3} of the sediment plutonium inventory. A net remobilization of plutonium occurs in the winter, when the water column is holomictic and oxic throughout. This suggests that processes other than anoxic remobilization are responsible. Annual patterns of $^{239/240}Pu$ concentrations are (1) similar concentrations between surface (0-6 m [0-20 ft]) and deep (>6 m [>20 ft]) waters for the dissolved and particulate phases in January and February when the water column is well mixed; (2) the rapid increase of plutonium concentrations in the particulate phase in the deeper waters with stratification; and (3) the increase in $^{239/240}Pu$ concentrations in the dissolved fraction in the hypolimnion with the onset of anoxia. The transfer of plutonium from the surface to deeper waters through the settling of particles apparently is responsible for much of the decline in surface water inventories after stratification (Bowling et al. 1994). Increases observed in the dissolved fraction may not represent dissolved plutonium. The majority of plutonium was not in a dissolved form, but was associated with very small particles (Pinder et al. 1992).

In 1991 and 1992 gamma-emitting radionuclide concentrations in Par Pond and Pond C were measured *in situ* with an underwater HPGe detector. (Winn 1993 and 1995). The predominant radionuclide was ^{137}Cs and the only other radionuclide detected was ^{60}Co.

The Pond C inventory of ^{137}Cs was reported to be only 10% of that of Par Pond, primarily because of the much larger area of Par Pond. However Pond C has a larger average sediment concentration of 8.1 $\mu Ci/m^2$ compared to 4.5 $\mu Ci/m^2$ for Par Pond, which is consistent with Pond C being closer to the origins of the earlier SRS reactor releases. The maximum ^{137}Cs concentration observed for Pond C was 55 $\mu Ci/m^2$, which is about 10% higher than the maximum observed for Par Pond.

4.9.4 Algae

4.9.4.1 Phytoplankton

4.9.4.1.1 <u>Studies in the Par Pond System</u>

Par Pond phytoplankton was most recently studied from February 1995 to September 1996 in association with the refilling of the reservoir after a four-year drawdown for dam repair (Wilde et al. 1997). Previously, the phytoplankton community of Par Pond was quantitatively analyzed monthly from January 1984 through June 1985 (Chimney et al. 1986). In addition, several less comprehensive studies of the phytoplankton in the Par Pond system were conducted before 1984. Wilde and Tilly (1985) summarized these earlier studies.

4.9.4.1.2 Taxonomic Groups Found In Par Pond

The 1995-1996 study (Wilde et al. 1997) identified 173 taxa. The 1984-1985 study (Chimney et al. 1986) observed 337 phytoplankton taxa. Both studies collected taxa representing all of the major taxonomic groups characteristic of North American freshwaters (Smith 1950; Prescott 1962; Whitford and Schumacher 1984). Principal taxonomic groups listed in descending order of overall numerical importance (organisms/ml) were Bacillariophyta (diatoms), Chrysophyta (yellow-brown algae), Cryptophyta (cryptomonads), Chlorophyta (green algae), and Cyanophyta (blue-green algae). Chlorophyta contained the largest number of species observed (152), followed by Bacillariophyta (69) (Chimney et al. 1986).

4.9.4.1.3 Differences in Par Pond Locations

Wilde et al. (1997) found no significant spatial differences in phytoplankton during the 1995-1996 study. Similarly, in the 1984-1985 study, no significant differences were found between a station near the Hot Dam and other Par Pond stations for mean total phytoplankton density, mean density of each of the major taxonomic groups, mean species diversity, species richness, or phytosynthetic efficiency (Chimney et al. 1986). The station near the Hot Dam did have significantly ($P < 0.05$) higher mean quantities of chlorophyll *a* and mean rates of primary productivity than the rest of Par Pond. Chimney et al. (1986) reported that overall mean primary productivity was 1.3 to 1.7 times greater and chlorophyll *a* was 1.4 to 1.5 times greater at the station near the Hot Dam than at other Par Pond stations.

4.9.4.1.4 Effect of Reactor Operation

During reactor operations, there was no indication that Cyanophyta were dominant at the sampling station near the Hot Dam or anywhere else in Par Pond at times other than when they characteristically are dominant in nonthermal lakes and reservoirs in North America (i.e., late summer and early fall; Hutchinson 1967; Smith 1950; and Wetzel 1983). Apparently, the addition of heat from reactor operations increased productivity, but had no significant adverse impact on the phytoplankton community structure in Par Pond (Wilde 1985).

4.9.4.1.5 Changes in Community Structure, 1965-1996

Phytoplankton observed, in the 1995-1996 study were primarily species observed in the earlier studies. An exception was *Anabaenopsis seriata*, which occurred sporadically but abundantly in this study (Wilde et al. 1997). The species identified in the 1984-1985 study by Chimney et al. (1986) included 128 of the 169 phytoplankton species identified by Wilde (1983) in a 1978 study. Data from the study by Chimney et al. (1986) also indicated that the phytoplankton community of Par Pond has maintained species composition, density levels, and species diversity similar to that Wilde (1983) reported for 1978. In addition, primary productivity values for Par Pond reported in the study by Chimney et al. (1986) were similar to the values previously reported for Par Pond in studies conducted between 1965 and 1973 (Tilly 1973, 1974a and b). Thus, the phytoplankton community appeared to have remained relatively stable for many years during reactor operations.

4.9.4.2 Periphyton

Wilde and Tilly (1985) conducted several studies of periphyton attached to glass slides at various locations in Par Pond. These studies also showed that primary production (measured as ^{14}C uptake) and standing crop (measured as dry weight) generally were greater at a station near the Hot Dam than in other areas of Par Pond. This trend was attributed to higher temperature and greater availability of nutrients at the Hot Dam. There was no apparent domination by pollution-tolerant species, and periphyton species composition at the station near the Hot Dam was similar to that of other stations.

4.9.5 Macrophytes

Par Pond aquatic macrophytes are not covered in this section, but in Chapter 5—Wetlands and Carolina Bays of the SRS.

4.9.6 Zooplankton

4.9.6.1 Introduction

The characterization of zooplankton populations in Par Pond is based on three separate studies performed January 1984 to June 1985 (Chimney et al. 1986), September 1988 and 1989 (Bowers 1992), and January 1990 through 1991 (Bowers 1993). The Chimney et al. (1986) and Bowers (1992) monitoring programs were part of larger studies for compliance with Section 316(a) of the Clean Water Act (Gladden et al. 1989). However, in the Bowers (1992) study, the work focused on the L Lake and lower Steel Creek system, with Par Pond serving as a reference reservoir for near comparisons. The sampling performed during 1988-1989 was part of a regional synoptic survey of large South Carolina reservoirs for trophic comparison and eutrophication conditions (Bowers 1992).

4.9.6.2 Study Methods

Methods differed in the studies, but sampling locations and laboratory and enumeration techniques were nearly identical. Zooplankton samples collected during the Chimney et al. (1986) study were collected with an 8.0-l Van Dorn water sampler from four discrete depths. The Bowers (1992 and 1993) studies employed standard vertical net tows for macrozooplankton (Cladocera and Copepoda) and a plankton pump for microzooplankton (Protozoa and Rotifera) pooled over depth. This difference in water column sampling could easily account for differences in the results described in the following sections. Discrete whole-water samples assess a small portion of the water column, while vertical net tows or pooled pump samples integrate the whole water column. The 1984-1985 study sampled several locations in the basin, while the more recent efforts sampled at a deep water location near the Cold Dam. Only results from this deep water station are reported here for uniformity.

4.9.6.3 Analysis Partitions

Analyses are partitioned only into Protozoa, Rotifera, Cladocera, and Copepoda. Species-level evaluations for these taxonomic groups are beyond the scope of this discussion. Additionally, it is important to understand that population cycles in macrozooplankton can only be truly indicated when sampling frequencies are approximately every 14 days. Without this sampling resolution, cycles are missed. Likewise, protozoans and rotifers, having generation times spanning a few weeks, must be sampled at least every seven days to observe population cycles during a season.

4.9.6.4 Group Densities

4.9.6.4.1 Introduction

Seasonal and annual fluctuations of zooplankter densities are difficult to interpret because of the confounding nature of different sampling techniques and genuine changes in community succession. Numerically, protozoans and rotifers always dominate limnetic communities (Wetzel 1983) when compared to cladoceran and copepod densities.

4.9.6.4.2 Protozoan

Protozoan densities were greatest during cooler months (March 1984, May 1984, December 1984, January 1985, February 1985, September 1988, May 1990, November 1990, and November 1991). Dominant species included *Tintinnopsis cylindrata*, *Vorticella* spp., *Strombidium* spp., *Holophryid* spp. (< 50μm), *Uronema* spp., and *Difflugia limnetica*.

4.9.6.4.3 Rotifera

Rotifera were also cool-weather fauna. During 1984-1985, they were most abundant in September 1984, December 1984, and February 1985. However, there was a general increase during 1990-1991, which could reflect different sampling methods. Dominant species included *Conochilus unicornis*, *Collotheca mutabilis*, *Keratella cochlearis*, *Keratella crassa*, *Polyarthra vulgaris*, *Polyarthra remata*, and *Kellicottia bostoniensis*. These species survive during periods of invertebrate predation because of their hard and spiny lorica and, for some, the ability to escape rapidly and avoid being captured by predatory zooplankton (Stemberger 1985).

4.9.6.4.4 Cladoceran

Cladocerans were most abundant during 1984-1985 and 1988-1989. During 1990, abundance estimates were low; however, they increased during 1991. The density ranges shown here are representative of cladoceran populations in southeast reservoirs (Bowers 1992). Dominance during these periods was similar with *Ceriodaphnia* spp., *Bosmina longirostris*, *Daphnia ambigua*, *Diaphanosoma brachyurum*, and *Holopedium amazonicum* collected in appreciable numbers every year.

4.9.6.4.5 Copepoda

Copepoda populations increased significantly after the winter of 1991 compared with all other sampling dates. Because of the magnitude of this increase, sampling differences might be excluded and the increase considered genuine. An increase such as this can result from increased fecundity and reduced mortality. Most likely, the increase resulted from a decrease in planktivorous fish predation that generally regulates macrozooplankton abundances. Dominant species were continuous during the sampling periods: *Tropocyclops prasinus*, *Acanthocyclops vernalis*, *Diaptomus mississippiensis*, and *Epischura nordenskioldi*.

4.9.6.5 Zooplankton in Pond C

The effect of thermal stress on the zooplankton population in Pond C, a reactor cooling reservoir, was studied by Leeper and Taylor (1995). Zooplankton were eliminated from waters with temperatures in excess of 45 ^{o}C (113 ^{o}F). Elevated, but nonlethal, temperatures reduced zooplankton abundance by 1-3 orders of magnitude and typically halved the number of taxa. Reactor operations reduced zooplankton biovolume, often by more than 70%. During intermittent reactor operations, the rotifer *Filinia longiseta* dominated the zooplankton, and two cladocerans of the genus *Moina* were abundant. These species were not abundant during ambient water conditions. Their success was due primarily to their tolerance of high temperatures. Sparse phytoplankton as a food resource probably limited some zooplankton taxa; although some taxa such as *Filinia* may have utilized bacterial resources. When reactor operations restricted fish to thermal refugia, there was probably intense predation on crustacean zooplankton. Repopulation of the reservoir occurred within a few days of reactor shutdown through population explosions from the refuge areas and input of colonists through tributaries (Leeper and Taylor 1995).

4.9.7 Macroinvertebrates

4.9.7.1 Sampling Locations and Methods

From January 1984 through June 1985, benthic macroinvertebrates were sampled quarterly in four areas of Par Pond (Figure 4-41). Quantitative samples were collected using a petite Ponar grab sampler in shallow, intermediate, and deepwater habitats (1, 2, and 4 m [3.3, 6.6, and 13 ft]) and qualitative samples were collected with a D-frame dip net. In addition, near-surface and near-bottom meroplankton samples were collected biweekly during daylight and quarterly for 24-hour periods along eight transects in Par Pond by towing paired 0.5 m (505 µm mesh) plankton nets. Kondratieff et al. (1985) has details of sampling methods.

As part of a regional lakes study, macroinvertebrates were sampled in Par Pond in September 1988 and 1989 using a petite Ponar grab sampler and D-frame dip net. Details of sampling methods are in Hughes and Chimney (1988) and Chimney and Wollis (1989).

Several less comprehensive studies of macroinvertebrates in Par Pond were conducted prior to 1984. These studies are summarized in a literature review paper by Wilde and Tilly (1985).

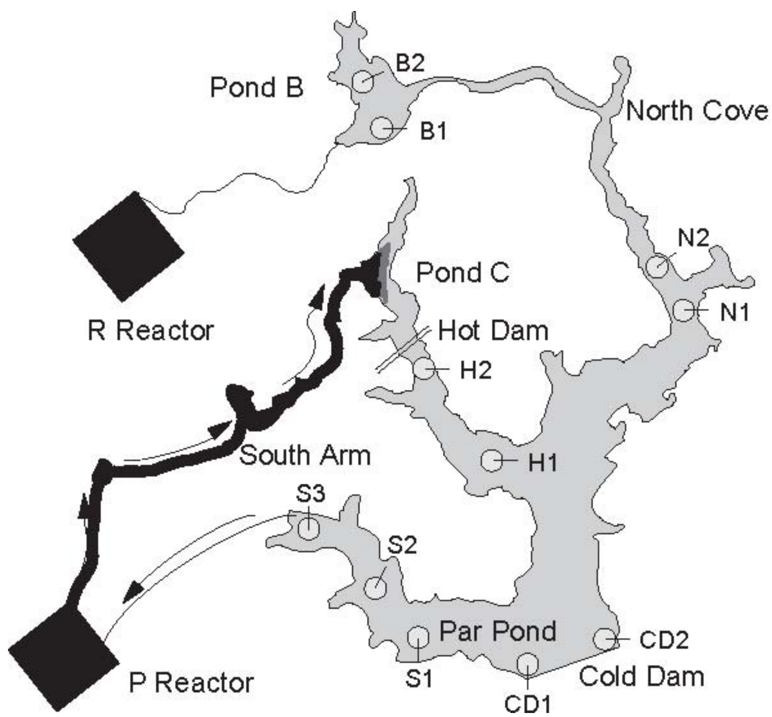

Figure 4-41. Macroinvertebrate Sampling Locations for Par Pond

4.9.7.2 Results

4.9.7.2.1 Number of Taxa Collected

At least 143 macroinvertebrate taxa were collected from Par Pond in 1984-1985 by all sampling methods. During the sampling in 1988 and 1989, 82 taxa were collected. In some instances however, taxonomic resolution differed between the two studies, so the number of taxa collected can not be directly compared. In addition, some taxa are more likely to be collected during certain times of the year, and some rare taxa that were collected very infrequently during the 18-month study in 1984 and 1985 probably were missed in September 1988 and 1989, due to the relatively smaller total number of samples that were collected and the brief interval of sampling (1 month vs. 18 months).

4.9.7.2.2 1984-1985 Meroplankton

Like most lakes, the meroplankton community of Par Pond generally was dominated by dipterans (primarily the phantom midge, *Chaoborus punctipennis*), which composed 28.9-90.6% of the organisms collected in the meroplankton samples during the 18-month sampling program. Chironomid dipterans were also commonly found in the meroplankton. Oligochaetes were the second most abundant group of organisms, accounting for 3.2-41.7% of the marcoinvertebrates collected during the meroplankton tows.

Oligochaetes were almost always collected, which probably indicates that the sampling net contacted the sediment during towing. Other macroinvertebrate taxa commonly collected in the meroplankton nets included Trichoptera (caddisflies; 0.6-45.5%), pelecypods (clams; 0.0-15.8%), and Hydracarina (water mites; 1.2-21.7%; Table 5-182). Caddisflies were collected in substantial numbers only at the pumphouse and consisted primarily of migrating larvae of *Cyrnellus fraternus*. *Cyrnellus* is primarily a lotic species and appears to have been attracted to the flowing water in the pumpwells. Mean species richness ranged from 4.7 at Stations H1 and CD2 to 13.6 at the pumphouse station. The mean density of organisms ranged from 144.6 organisms/1000m^3 at Stations 1 to 711.5 organisms/1000m^3 at the pumphouse and averaged 374.1 organisms/1000m^3 for all stations and dates combined. The high density at the pumphouse relative to other locations primarily was due to an abundance of Trichoptera larvae, which were relatively scarce elsewhere in Par Pond (Kondratieff et al. 1985).

4.9.7.2.3 Benthic Macroinvertebrates 1984-1985 Sampling

A total of 34,715 macroinvertebrates, representing at least 48 taxa, were collected by petite Ponar grab sampling during quarterly quantitative benthic sampling in 1984 and 1985. Average species richness in Par Pond ranged from 11.5 taxa at the Cold Dam to 12.5 taxa in the North Arm of Par Pond. Mean species diversity was similar at all stations, ranging from 1.90 at the Cold Dam to 2.07 in the South Arm. These values were considered moderate, when compared to values from other lentic benthic macroinvertebrate communities (Kondratieff et al. 1985). Diptera dominated the benthic fauna at all stations. Chironomidae were the most abundant Diptera, except at the Cold Dam, where the phantom midge *(Chaoborus punctipennis*) predominated.

Typically, *Chaoborus punctipennis* was the most abundant taxon at the deepest sampling locations, while the amphipod, *Hyallela azteca*, and oligochaetes, nematodes, flatworms (Turbellaria), and chironomids of the subfamily Chironominae, were most abundant in shallower waters. The Hot Arm contained much higher relative abundances and densities of turbellarians (*Dugesia tigrina*), nematodes, oligochaetes, leeches (Hirudinea), and clams (mostly *Corbicula fluminea*) than the rest of Par Pond.

Macroinvertebrate densities ranged from 2416.0 organisms/m^2 in the South Arm to 7224.8 organisms/m^2 in the Hot Arm. Mean ash-free dry weight biomass ranged from 6.76 to 41.76 g/m^2. The Hot Arm had significantly higher biomass than any of the other sampling areas (Kondratieff et al. 1985). The larger biomass in the Hot Arm was largely due to the presence of a large number of *Corbicula fluminea*.

The qualitative dip net sampling in littoral areas of Par Pond yielded a total of 121 macro-invertebrate taxa, including 66 taxa that were not collected in either the macroinvertebrate meroplankton or Ponar dredge samples. Odonata, Gastropoda, and Chironomidae were consistently the most abundant taxa collected by dip nets (Kondratieff et al. 1985). Many of the groups collected, such as the Amphipoda, are associated with the extensive macrophyte beds along the shores of the reservoir (Kondratieff et al. 1985).

4.9.7.2.4 <u>1988–1989 Sampling</u>

Eighty-two macroinvertebrate taxa were collected from dredge samples and dip net samples in Par Pond in September 1988 and 1989. The most abundant groups of organisms in the dredge samples included oligochaetes, snails, clams, chironomids, and the phantom midge *(Chaoborus punctipennis)*.

The overall relative abundance of most groups of macroinvertebrates was fairly similar to that found in 1984-1985. However, in 1988-1989, the relative abundance of oligochaetes was somewhat higher that in 1984-1985, while the relative abundance of dipterans was somewhat lower. The mean density of organisms in the dredge samples was 5762.2 organisms/m^2 in 1988 (Hughes and Chimney 1988), while in 1989, the density was almost twice that of 1988, averaging 10,093 organisms/m^2 (Chimney and Wollis 1989).

4.9.8 Fish

4.9.8.1 Introduction

The fishes of Par Pond have been extensively studied. Most of these studies emphasized the effects of elevated temperatures on fish behavior, physiology, and ecology. There also have been community-level studies emphasizing the abundance and distribution of Par Pond fishes. These studies, too, have dealt extensively with the direct and indirect effects of elevated temperatures. The following discussion has been organized into sections that correspond to the major topics of Par Pond fish studies. This discussion draws heavily on the synopsis of Par Pond data compiled by Wilde and Tilly (1985).

4.9.8.2 Species Composition and Abundance

Table 4-22 lists species of adult and juvenile fishes taken in Par Pond and Ponds B and C. On the basis of general surveys by Clugston (1973), Siler (1975), Hogan (1977), Martin (1980), and Bennett and McFarlane (1983), 30 fish species were identified from Par Pond. Of these species, 17 also were reported from Pond C and 14 from Pond B (Figure 4-39). All of these species have also been reported from Lower Three Runs, which, together with the Savannah River, represent the original source of all fish species in the three reservoirs.

Cove rotenone studies conducted by Clugston (1973), Siler (1975), Hogan (1977), and Martin (1980) showed the following species to be abundant in Par Pond: largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigromaculatus*), lake chubsucker (*Erimyzon sucetta*), brook silversides (*Labidesthes sicculus*), and eastern eastern mosquitofish (*Gambusia holbrooki*). Largemouth bass and bluegill were more abundant in Par Pond than in most other reservoirs.

Table 4-22. Species of Fishes taken from Par Pond

Family	Scientific Name	Common Name
Amiidae	*Amia calva*	Bowfin
Anguillidae	*Anguilla rostrata*	American eel
Clupeidae	*Alosa aestivalis*	Blueback herring
	Dorossoma cepedianum	Gizzard shad
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner
	Notropis petersoni	Coastal shiner
Catostomidae	*Erimyzon sucetta*	Lake chubsucker
	Minytrema melanops	Spotted sucker
Ictaluridae	*Ameiurus natalis*	Yellow bullhead
	Ameiurus platycephalus	Flat bullhead
Esocidae	*Esox americanus*	Redfin pickerel
	Esox niger	Chain pickerel
Aphredoderidae	*Aphredoderus sayanus*	Pirate perch
Poeciliidae	*Gambusia holbrooki*	Eastern mosquitofish
Atherinopsidae	*Labidesthes sicculus*	Brook silverside
Centrarchidae	*Centrarchus macropterus*	Flier
	Lepomis auritus	Redbreast sunfish
	Lepomis gibbosus	Pumpkinseed
	Lepomis gulosus	Warmouth
	Lepomis macrochirus	Bluegill
	Lepomis marginatus	Dollar sunfish
	Lepomis microlophus	Redear sunfish
	Lepomis punctatus	Spotted sunfish
	Micropterus salmoides	Largemouth bass
	Pomoxis annularis	White crappie
	Pomoxis nigromaculatus	Black crappie
Percidae	*Perca flavescens*	Yellow perch

4.9.8.2.1 Largemouth Bass

Gibbons and Bennett (1971), using mark and recapture data obtained by angling, estimated the largemouth bass population of Par Pond to be between 29,000 and 46,000. The larger number was based on collections in the vicinity of the Hot Dam, and the smaller estimate was based on collections from near the Cold Dam. Martin (1980) estimated the adult (>230 mm) largemouth bass population of Par Pond at approximately 100,000 (about 40 individuals per acre). Gilbert and Hightower (1981) reported largemouth bass population estimates of Par Pond to be between 48,000 and 55,000. In contrast, Pond C had a largemouth bass population estimated at approximately 833 fish, or about 5 per acre (Siler and Clugston 1975).

It is clear from these and other studies that the largemouth bass population of Par Pond has remained high and relatively stable, at least from the late 1960s (when studies began) until the time of Par Pond drawdown. It is also clear that largemouth bass are more abundant in the vicinity of the Hot Dam than in other portions of the reservoir (Gibbons et al. 1972; Martin 1980).

4.9.8.2.2 Prey Fish

Prey species (e.g., bluegill) were also significantly more abundant in coves near the Hot Dam than elsewhere in the reservoir (Clugston 1973; Siler et al. 1975; Hogan 1977). The standing crop of prey fish determined from cove rotenone samples in the Hot Arm was almost twice as great as that in the North Arm of Par Pond as reported by Hogan (1977). He suggested that prey fish avoided the discharge area during summer and remained in the vegetation outside the immediate discharge area. Bluegill were the most abundant prey fish collected. In contrast, the coastal shiner (*Notropis petersoni)* and the redbreast sunfish (*Lepomis auritus*) were captured by electrofishing in significantly higher numbers in unheated parts of the reservoir. Blueback herring (*Alosa aestivalis*) were attracted to the Hot Arm in the winter but avoided the heated area during summer, except when the reactor was down and the discharge was unheated (Hogan 1977).

4.9.8.2.3 Adult and Juvenile Fish Surveys

An extensive fisheries survey of Par Pond was conducted during January 1984-June 1985 (Paller and Saul 1985). Sample stations were taken in the Hot Arm, which received heated water; the South Arm, where cooling water was withdrawn; the Cold Dam at the lower end of the lake and the North Arm at the upper end of the lake. Fish samples also were taken in Pond B. The objectives of the study were to characterize the fish communities in Par Pond and Pond B, assess the impact of thermal discharges on the Par Pond fish community, assess the loss of ichthyoplankton from Par Pond due to entrainment, and compare the Par Pond and Pond B fish communities. Electrofishing, hoop-netting, gill netting, and angling samples were taken monthly. Ichthyoplankton samples were taken biweekly.

Paller and Saul (1985) collected 13,166 adult and juvenile fish, representing at least 23 species, from Par Pond. In addition, two other species (eastern mosquitofish and swamp darter) were observed or captured as ichthyoplankton, but not collected as adult fishes. Dominant species in Par Pond were lake chubsucker (18.0% by number), largemouth bass (17.9%), bluegill (14.1%), and black crappie (1.5%). Brook silversides were important numerically (37.8%), but because of their small size, they contributed little biomass. Species composition was fairly similar between the Hot Arm and the other sample areas, except that lake chubsucker represented a slightly smaller percentage of the Hot Arm community. Mean species number was significantly lower in the Hot Arm (7.9) than in the other Par Pond sample areas (9.9-10.6), as was mean Shannon-Weaver diversity (1.11 compared to 1.81-2.24).

Paller and Saul (1985) collected 1,336 adult and juvenile fish, representing at least 13 species, from Pond B. Dominant species in Pond B were gizzard shad (15.9%), largemouth bass (17.7%) brook silversides (34.1%), yellow bullhead (7.4%), bluegill (4.9%), and flat bullhead (3.0%). The lake chubsucker, a dominant species in Par Pond, was absent from Pond B. Mean species number in Pond B (5.7) was significantly lower than in Par Pond (9.6), as was Shannon diversity (1.01 in Pond B compared to 1.78 in Par Pond).

Fish community structure differed among locations in Par Pond. Statistical analyses of catch per unit effort for all species combined indicated that angling, gill netting, and electrofishing catches in the Hot Arm were comparable to or higher than in the other Par Pond sample areas. Catch rates for several individual species, including largemouth bass and black crappie, were significantly higher in the Hot Arm than in the other Par Pond sample areas. Catch rates in Pond B were significantly lower than in Par Pond for electrofishing but not angling. Gill net catch rates were lower in Pond B than in Par Pond during the winter but not the summer. Individual species that exhibited lower catch rates in Pond B were bluegill during the winter and largemouth bass throughout the year.

4.9.8.2.4 Ichthyoplankton Surveys

Table 4-23 lists taxa of ichthyoplankters taken from Par Pond and Pond B. Approximately 165,980 fish larvae and eggs, representing at least 11 taxa, were collected from Par Pond. Black crappie was the most abundant taxon (36.0%), followed by sunfish (*Lepomis* spp.; 32.7%) and darters (*Etheostoma* spp.; 14.9%). Dominance by these three taxa was characteristic of the Cold Dam, South Arm, and North Arm. The Hot Arm had a lower percentage of darters and higher percentage of largemouth bass. There were no significant differences between the average number of ichthyoplankton taxa collected per sample date in each of the Par Pond sample areas (3.8-4.4).

Approximately 48,296 fish larvae and eggs, representing at least 6 taxa, were collected from Pond B. As in Par Pond, the most abundant taxa were sunfish (*Lepomis* spp; 56.7%), black crappie (18.7%), and darters (*Etheostoma* spp.; 10.6%). The average number of taxa collected per sample date was 3.8 in Pond B compared to 4.2 in Par Pond.

Table 4-23. Taxa of Ichthyoplankters Taken in Par Pond and Pond B

Family	Taxa	Par Pond	Pond B
Clupeidae	*Alosa aestivalis*, blueback herring	x	
	Dorosoma cepedianum, gizzard shad	x	x
	Unidentified shad	x	x
Cyprinidae	Unidentified minnows	x	
Catostomidae	Unidentified suckers	x	
Esocidae	*Esox* spp., pickerel	x	
Atherinopsidae	*Labidesthes sicculus,* brook silverside	x	x
Centrarchidae	Unidentified sunfish	x	
	Lepomis macrochirus, bluegill	x	x
	Micropterus salmoides, largemouth bass	x	x
	Pomoxis nigromaculatus, black crappie	x	x
Percidae	*Perca flavescens,* yellow perch	x	x
	Etheostoma spp., darter	x	x

During 1984, there were three major peaks in ichthyoplankton density in Par Pond and three in Pond B. The first two peaks in Par Pond consisted primarily of black crappie and darter larvae, while the last consisted mainly of sunfish larvae. The first peak in Pond B consisted almost entirely of black crappie and darter larvae, while the last two consisted mainly of sunfish larvae. Spawning sequence and larval densities were fairly similar between Par Pond and Pond B during 1984. However, density peaks occurred several weeks earlier in Par Pond than in Pond B.

During 1985, ichthyoplankton densities in Par Pond were much lower (mean of 168/1000 m^3) than during 1984 (mean of 1254/1000 m^3). This decrease was apparent among all three major taxa and occurred in all Par Pond sample areas. Reasons for this reduction are not known, although extreme fluctuations in ichthyoplankton and juvenile fish abundance have been reported in other lakes and reservoirs. In contrast, ichthyoplankton densities in Pond B were similar between 1985 (mean of 1398/1000 m^3) and 1984 (mean of 1380/1000 m^3). Average total ichthyoplankton density from all sample stations in Par Pond (463/1000 m^3) was less than in Pond B.

Average total ichthyoplankton (i.e., all taxa summed together) densities in Par Pond over all sampling dates were 276/1000 m^3 near the Cold Dam, 349.0/1000 m^3 in the Hot Arm, 578/ 1000 m^3 in the South Arm, and 612/1000 m^3 in the North Arm. Statistical analysis indicated that total ichthyoplankton densities in the Hot Arm were not significantly different from the other sample areas in Par Pond. When analyzed by individual taxa, however, darter density in the Hot Arm (mean of 19/1000 m^3) was significantly lower than in the other Par Pond sample areas (means of 55-104/1000 m^3).

Analysis of the diet samples (four samples in 24 hours) taken on six dates in Par Pond and Pond B indicated that ichthyoplankton densities were highest at night for all major taxa in both Par Pond and Pond B.

Based on samples taken during daylight, estimated entrainment into the Par Pond pumphouse was 1975.5 x 10^5 larvae and eggs over the entire January 1984-June 1985 sample period. However, actual entrainment may have been 0.5-5.0 times greater based on the night densities being higher than day densities. While it is difficult to quantify the impact of these losses, several mitigating factors need to be considered. Many areas in Par Pond (such as the North Arm) were not in the main water circulation path and were thus unaffected by entrainment. Ichthyoplankton densities appeared to fluctuate independently of pumping rate, suggesting that entrainment was not controlling ichthyoplankton abundance in Par Pond. A diverse fish community has persisted in Par Pond over the years, despite the effects of entrainment.

4.9.8.2.5 Comparison of Par Pond and Pond B

Paller and Saul (1985) concluded that thermal effects on Par Pond fishes include localized reductions in diversity and number of species in the Hot Arm and early spawning of some species in the Hot Arm and possibly other areas in Par Pond that are slightly warmed (Reproduction in 4.9.8.7). Other possible thermal effects include reduced condition of largemouth bass (Growth and Condition in 4.9.8.3 and Diet in 4.9.8.4) and aggregation of largemouth bass and black crappie in the discharge area.

Despite thermal and entrainment effects, Par Pond compared favorably with Pond B on the basis of most of the fisheries parameters measured by Paller and Saul (1985). Species number and Shannon-Weaver diversity, two parameters often depressed in thermally stressed ecosystems, were higher in Par Pond than in Pond B. Catch per unit effort for most species was higher in Par Pond than in Pond B. Largemouth bass, an important sport fish and the principal predator fish in both Par Pond and Pond B, were larger and in better condition in Par Pond.

4.9.8.2.6 <u>Comparison of Par Pond and Other United States Reservoirs</u>

Comparisons between Par Pond and other reservoirs in the United States indicated that the Par Pond fish community was comparable to other reservoir communities in terms of species number, diversity, and standing crop of all species summed together (Paller and Saul 1985). However, Par Pond differed in having more largemouth bass and lake chubsucker and fewer gizzard shad and carp. Paller and Saul (1985) did not consider apparent replacement of gizzard shad and carp by lake chubsucker in Par Pond deleterious because lake chubsucker are native to natural lakes in the region and since carp and, to a lesser extent, gizzard shad are often considered undesirable. Paller and Saul (1985) concluded that favorable comparisons between Par Pond and other reservoirs, the collection of early life stages of most or all major species, and the historical presence of diverse and abundant fish communities in Par Pond indicated that the impact of reactor operation on Par Pond was not severe.

4.9.8.3 Growth and Condition

4.9.8.3.1 <u>Growth and Condition</u>

Bennett and Gibbons (1978) studied growth and condition factors of juvenile largemouth bass in Par Pond during 1969 and 1970. Juvenile bass collected during their first summer from near the Hot Dam were generally larger and grew significantly faster than young bass collected at stations farther from the Hot Arm. The condition factors of all juvenile bass were generally similar, indicating that the growth and body condition of juvenile largemouth bass were not impaired by elevated temperatures in Par Pond.

Martin (1980) compared the relative weights (Wr) of largemouth bass from Par Pond with those of bass from other lakes throughout the United States. Average values for Par Pond fish were as follows:

Relative Weight	**Length Group**
100.5	250–309 mm
90.3	310–369 mm
84.3	370–429 mm
80.5	430–489 mm
75.5	490–549 mm

A Wr of 100 or greater indicates that fewer than 25% of other bass throughout the United States exhibit a greater weight for that length; whereas, a relative weight of less than 86 indicates that 75% of the bass throughout the country exhibit a greater weight. Thus, young largemouth bass in Par Pond compare favorably with bass from other U.S. lakes, while older bass in Par Pond are thinner than their counterparts in other U.S. lakes. Martin (1980) also noted station and seasonal effects on Wr with the lowest values occurring at the station nearest the thermal effluent in the summer.

Janssen and Giesy (1984) provided an original explanation for the more frequent occurrences of "thin" bass near the point of thermal discharge into Par Pond. Heated reactor cooling water from Pond C sporadically carried zooplankton and dead and moribund fish into Par Pond. These organisms, produced in Pond C during reactor outages and cool winter periods, were killed when temperatures climbed to lethal levels in Pond C. The presence of the zooplankton attracted blueback herring (*Alosa aestivalis*) to the discharge area in Par Pond; largemouth bass followed to feed on the herring. Dying and dead bluegills (heat killed) from Pond C also were eaten by Par Pond bass, which swam into effluent temperatures as high as 46°C (114.8°F) to take these easy prey.

Because the presence of blueback herring and Pond C bluegill in the discharge area was seasonal, there was a strong seasonal component to bass food abundance. Annual oscillations in bass condition (K), with a peak in winter, occurred throughout Par Pond, but were extreme in the discharge area (Gibbons et al. 1978). Winter peaks in food abundance for bass in the vicinity of the Hot Dam correlated with the winter peak in bass condition (Janssen and Giesy 1984), suggesting that the sporadic availability of food rather than temperature was controlling largemouth bass condition.

Gibbons et al. (1978) reviewed Par Pond largemouth bass body condition factor data from 1967 to 1976. (Condition factor, a measure of fish health, is based on the weight of the fish multiplied by a constant and divided by the lengh cubed.) The sample size (n) was >10,000. These data demonstrated significantly lower adult largemouth bass K values in the vicinity of the Hot Dam compared with other areas of Par Pond and significantly lower K values in summer compared to winter in all areas of the reservoir.

Rice et al. (1983) presented a bioenergetics model for largemouth bass that simulated growth as a function of body size, temperature, activity, and consumption level. They applied the model to investigate seasonal changes in condition exhibited by bass in Par Pond. Model simulations were used to evaluate the hypotheses that seasonal changes in condition factor were caused by heated effluent, seasonally variable activity, seasonally variable consumption, or reproductive costs. Results indicate that temperature is not directly responsible for the seasonal changes in condition factor. Bass moderate the influence of the heated effluent by behavioral thermoregulation. Activity is not a major factor, and spawning weight-loss can account for only a small portion of the observed variation. Seasonal changes in body condition were best explained by seasonal variations in consumption.

Largemouth bass exhibited lower condition in the Hot Arm than in the other Par Pond sample areas during the summer. During the winter, largemouth bass condition was approximately the same in the Hot Arm as in the North Arm and at the Cold Dam. The mean condition of largemouth bass from all sample areas in Par Pond (1.15) was lower than the average for other U.S. reservoirs (1.41). However, the mean condition of largemouth bass from Pond B (1.05) was even lower than that in Par Pond.

Paller and Saul (1985) also found that the size distribution of largemouth bass differed between Par Pond and Pond B. A range of sizes was collected in Par Pond, from juveniles to large adults (over 550 mm), suggesting continuous reproduction and growth. In contrast, most of the largemouth bass from Pond B were in the 200–350 mm size range and only one fish under 100 mm was collected, suggesting poor reproduction and growth. Proportional stock density (PSD) calculations indicated that 68% of the bass stock in Par Pond was of “quality” angling size, compared to 35% in Pond B. Most other fish species were comparable in size between Par Pond and Pond B.

4.9.8.3.2 Bluegill and Black Crappie

Condition factors (K factors) were determined for bluegill and black crappie by Bennett (1972), who collected fish near the Hot Dam, Cold Dam, and the pumphouse of Par Pond (South Arm) during 1968-1970. Mean K-factors for adult crappie were significantly higher for specimens collected near the Hot Dam. Mean K-factors for adult bluegill did not differ significantly between sampling locations. However, fingerling bluegills had significantly lower condition factors in the vicinity of the Hot Dam. Paller and Saul (1985) found that the condition of bluegill, black crappie and lake chubsucker was not significantly different between the Hot Arm and the other sample areas in Par Pond.

Belk and Hales (1993) studied the growth and reproduction of the bluegill population in Par Pond. Growth rates of bluegill aged 1-4 years in Par Pond were significantly higher than for the same year classes in other populations, and they approached the maximum reported for the species. Blue gill are vulnerable to predation until they reach a large size. Largemouth bass, the chief predator of bluegill, are 3-4 times as abundant in Par Pond as in other reservoirs and 10-30% larger. Therefore, more bluegill would succumb to more bass, and they would remain vulnerable to predation until they reached a larger size. The few estimates available in the literature suggest that juvenile bluegill densities in Par Pond (0.52 fish/m^2) are relatively low and mortality estimates (67% annual mortality) are relatively high. The most likely way for predation to alter differences in growth is by reducing prey density, thereby increasing per capita resource availability or by altering size-specific mortality rates, thus leading to delayed maturity in Par Pond bluegill. Bluegill in Par Pond mature 1-2 years later and become about 80 mm (3 in) larger total length than bluegill in other reservoirs. Bluegill began reproduction at about 190 mm (7 in) total length, about the same time they outgrow the threat of predation.

Although Par Pond received thermal effluent when Belk and Hales (1993) did their study, their data suggest that thermal effluents are not responsible for their observations. First, growth of age 1 bluegills in the thermally affected area of the reservoir was lower than growth in ambient areas of the reservoir. Second, the thermal effluent only affected one arm of the reservoir, but the observed bluegill population characteristics were not restricted to the thermal or nonthermal areas of the reservoir. Finally, some populations used for comparisons were from reservoirs that receive heated effluents, and the growth in these populations was similar to growth observed in nonthermal reservoirs (Belk and Hales 1993).

4.9.8.3.3 Eastern Mosquitofish

Eastern mosquitofish (*Gambusia holbrooki*) inhabit portions of the littoral zones in Par Pond and Pond C. Falke and Smith (1974) determined that the fat content of this eurythermal species was not significantly affected by temperature. Although differences were found in the fat content among eastern mosquitofish from near the Hot Dam of Par Pond, near the Cold Dam of Par Pond, and Pond C, these differences were attributed to location not temperature. Ferens and Murphy (1974) reported a positive correlation between water temperature and the proportion of female eastern mosquitofish bearing eyed embryos in Par Pond. Theodorakis et al. (1998) report that eastern mosquitofish in Pond A and Pond B have genetic markers, not found in the same species from uncontaminated Risher Pond and Fire Pond, that are "contaminant-indicative" and are similar to markers seen in the western mosquitofish (*G. affinis*) in radioactively contaminated Oak Ridge sites.

4.9.8.4 Diet

Bennett and Gibbons (1972) examined the stomach contents of largemouth bass in Par Pond. Specimens collected from an area near the Cold Dam contained more food than bass taken from an area near the Hot Dam. Unidentifiable species, principally sunfish (*Lepomis* spp.), represented the most frequently observed bass food items in both areas.

Beisser (1978) studied the feeding habits of juvenile bluegills (40-97 mm total length [1.5-4 in.]) from heated and relatively cool littoral areas in Par Pond during 1976. Invertebrate food organisms were collected at the same time to relate food diversity, abundance, and distribution to the diets of these fish. Cladocerans were the predominant food in the diet of the bluegills collected from both heated and cooler areas. The most abundant cladocerans found in bluegill stomachs at the heated stations were *Ceriodaphnia lacustris* and *Alona intermedia*, whereas *Sida crystallina* and *Eurycercus lamellatus* were the most abundant cladocerans found in bluegill stomachs at the cooler stations. Ostracods, aquatic insects, and assorted mollusks were in the stomachs of bluegills at all stations.

Johnson (1975) studied several facets of the feeding ecology of bluegill and largemouth bass in Par Pond and in Pond C. This study revealed that the benthic invertebrate populations in the two reservoirs were markedly different. The Par Pond benthic community was more diverse than the benthic community in Pond C. Oligochaetes and chironomid larvae dominated the benthos in Pond C throughout the year, whereas amphipods and various gastropods shared prominence with these groups in Par Pond. The food habits of subadult largemouth bass from Par Pond and Pond C were similar except in the fall. Par Pond bass depended heavily on fish (primarily brook silversides and small sunfishes) throughout the year. Pond C largemouth bass ate fish (primarily eastern mosquitofish and small sunfish) throughout the year, but relied heavily on invertebrates during the fall. The diets of bluegill were completely different in the two locations. Par Pond bluegill fed heavily on cladocerans during winter, but changed to various aquatic insects at other time. Pond C bluegill fed heavily on immature chironomids throughout the year. There was a significant increase in consumption of filamentous algae by bluegill during the summer in Pond C, probably because of the unavailability of other food in the limited refugia where bluegill could survive.

During the fall, Pond C bluegill again fed primarily on chironomid pupae and the intake of filamentous algae was significantly less. There was little food overlap of bluegill and subadult largemouth bass in either location, except during fall in Pond C when largemouth bass and bluegill fed heavily on invertebrates, primarily chironomid pupae. Overall, the Pond C bluegill population appeared to thrive in the thermally altered environment. The Par Pond bluegill population probably was competing with several other fish species for invertebrate foods and space while competition in Pond C was limited primarily to that among individual bluegills.

Paller and Saul (1985) found that the types of food eaten by largemouth bass and bluegill as well as the percentage of empty stomachs and average stomach fullness were generally similar in the Hot Arm and cooler areas in Par Pond and in Par Pond and Pond B. The diets of both bluegill and largemouth bass from Par Pond were similar to those reported for other lakes and reservoirs except that the percentage of fish eaten by the larger Par Pond bass was relatively low. Paller and Saul (1985) postulated that the latter factor contributed to the low condition of large Par Pond bass.

4.9.8.5 Critical Thermal Maxima

The thermal tolerance of bluegills measured by critical thermal maxima (CTM) was greater for Pond C than for fish collected from Par Pond and from a private pond near Columbia, SC (Holland et al. 1974). The death point of fish collected from the Hot Dam area of Par Pond varied, but was significantly higher than that of fish from the Cold Dam area. Smith and Scott (1975) determined that CTMs for immature largemouth bass collected from Par Pond were 36.71°C (98°F) and 40.08°C (104°F) for fish acclimated to 20°C (68°F) and 28°C (82.4°F), respectively. It appeared that young bass had approximately the same CTMs as young bluegill collected at the same locality (Smith and Scott 1975; Holland et al. 1974). In a study by Murphy et al. (1976), bluegill from Par Pond and Pond C were acclimated at 16, 24, and 32°C (61, 75, and 90°F). Fish from Pond C had a higher CTM and lower rates of respiratory movement at each acclimation temperature than those from Par Pond. Fish in Pond C often frequented water near or even above temperatures reported as lethal. Bluegill were found in water ranging from 35 to 41°C (95 to 106°F). Largemouth bass were common in 32-35°C (90-95°F) water and were found at 36-37°C (96.8-98.6°F) conditions on one occasion (Clugston 1973).

Falke and Smith (1974) reported that eastern mosquitofish on SRS lived at temperatures greater than (up to 44°[111°F]) the CTM reported for northern populations. Eastern mosquitofish have reportedly been dipnetted from portions of Pond C at temperatures greater than 40°C (104°F).

4.9.8.6 Movements and Body Temperatures

Mark-recapture studies proved long-range movement in some instances and restricted home ranges in others. For example, Gibbons and Bennett (1971) examined movement between an area near the Hot Dam and another area near the Cold Dam approximately 6 km (3.7 mi) away. Of more than 2500 bass tagged and released, 95 were recaptured. Five had moved from the Hot Dam to the Cold Dam; five others had moved from the Cold Dam area to the Hot Dam area; each of the other 85 was recaptured within 1500 m (0.9 mi) of the initial capture location. Du Pont (1976) reported long distance movement (up to 12 km [7.4 mi]) by several Par Pond bass carrying sonic tags. Quinn et al. (1978) reported that although movement of bass between the Hot Arm and other locations was infrequent, there was more movement into the Hot Arm than out of it.

Factors other than temperature (e.g., food, water flow, etc.) were deemed responsible for the attraction of bass to the vicinity of the Hot Dam in Par Pond. Martin (1980) observed approximately twice as many bass from cooler areas moving into the Hot Arm of Par Pond (18.6%) than bass from the Hot Arm moving into cooler areas (9.1%). Largemouth bass monitored with ultrasonic transmitters in the Hot Arm of Par Pond did not frequent water above 34.2°C (93.5°F) and usually remained 900 m (984 ft) or more from the discharge point during the summer (Du Pont 1976). Fish in the vicinity of the Hot Dam demonstrated a behavioral adaptation to the thermal effluent by avoiding the immediate discharge area or by selecting deeper cooler water.

Bennett (1971 and 1972) determined that largemouth bass captured in the vicinity of Par Pond Hot Dam had significantly higher monthly body temperatures than those from a station approximately 4.8 km (3 mi) away from the Hot Dam. The highest body temperatures of specimens from the two areas were 36.2°C and 31.4°C (97 and 88.5°F), respectively. Ross (1980) used a multichannel temperature sensing radio telemetry system to obtain dorsal muscle, skin, coelom, heart, and water temperatures from free-swimming bass. In general, body temperatures followed water temperatures closely, but rapidly changing temperatures produced lags of as much as 3.5°C (6.3°F) between body temperatures and water. Skin temperature appeared to be the stimulus for thermoregulatory changes in behavior. Transmitter-equipped fish did not always select optimal temperatures for the species, indicating that habitat selection involves nonthermal as well as thermal stimuli.

4.9.8.7 Reproduction

4.9.8.7.1 Bluegill

Data on the reproduction of fish in the Par Pond system are somewhat limited. Clugston (1973) collected ripe female bluegill from Pond C during every month of the year. He concluded that year-round spawning of bluegills in Par Pond was likely because spawning can occur whenever temperatures exceed 20°C (68°F). Bluegill larvae and Percidae larvae (probably darters) were collected monthly from Par Pond, between December 1983 and April 1984 (Paller and Saul 1985).

4.9.8.7.2 Largemouth Bass

Annual reproductive cycles of largemouth bass collected near the Par Pond Hot Dam were similar to cycles from bass collected at cooler locations during 1969 and 1970 (Bennett and Gibbons 1975). Few monthly differences in gonosomatic indexes were found between heated and unheated areas; however, earlier attainment of maximum gonadal size and the presence of significantly larger juvenile bass at the heated area suggested that reproduction was accelerated by the thermal discharge. However, gonadal condition indicated that the reproductive period started in March and continued through April in both areas. Reproduction may have been advanced in some heated-area bass, although this was not obvious when compared to overall changes in the reproductive cycles of bass from the cooler water locations.

Analysis of temporal changes in gonadal weight during 1983 and 1984 (Paller and Saul 1985) indicated that largemouth bass spawned earlier in the Hot Arm than in the other Par Pond sample areas, probably because of elevated temperatures in the Hot Arm. There were also indications that largemouth bass in the North Arm, South Arm, and Cold Dam spawned earlier than those in Pond B. Lake chubsucker exhibited no indication of early spawning in the Hot Arm, possibly because their spawning cycle is less temperature-dependent than that of largemouth bass.

4.9.8.8 Disease and Parasitism

4.9.8.8.1 <u>Red-Sore Disease</u>

Many largemouth bass in Par Pond suffer from red-sore disease (Esch et al. 1976). Based on data from more than 5000 largemouth bass taken during 1974-1978, Esch and Hazen (1978) proposed that stress, induced by elevated temperatures, was significant in increasing susceptibility of largemouth bass to red-sore. Moreover, they observed a significant ($P<0.05$) positive correlation between reduced body condition and the probability of largemouth bass having red-sore disease. Outbreaks of red-sore disease in several reservoirs in the southeastern United States have been reported. The etiologic agent was thought to be the ciliated protozoan, *Epistylis* spp., with secondary infection by the gram negative bacterium, *Aeromonas hydrophila*. However, in studies on the largemouth bass in Par Pond, *Epistylis* spp. could be isolated from only 35% of 114 lesions from 114 fish, while *A. hydrophila* was found in 96% of the same lesions (Hazen et al. 1978a). Transmission and scanning electron microscopy of lesions associated with red-sore disease indicated that neither the stalk nor the attachment structure of *Epistylis* spp. had organelles capable of producing lytic enzymes. Since other investigators had shown that *A. hydrophila* produces strong lytic toxins, and in absence of evidence to the contrary, Hazen et al. (1978a) concluded that *Epistylis* spp. is a benign ectocommensal, that *A. hydrophila* is the primary etiologic agent of red-sore disease, and that the probable route of infection is the surface epithelium of the fish. Esch et al. (1976) found that all centrachid fish species in Par Pond, with the exception of the black crappie, can be infected with red-sore disease and that largemouth bass have the highest levels of infection. Hazen and Fliermans (1979) determined densities of *A. hydrophila* monthly from December 1975 to December 1977 in Par Pond. Selected water quality parameters and prevalence of red-sore disease among largemouth bass were monitored simultaneously. Largemouth bass from thermally altered parts of the reservoir had a significantly higher incidence of infection. Fliermans et al. (1977), Hazen et al. (1978b), and Hazen and Fliermans (1979) have described distribution and survival of *A. hydrophila*. Greatest densities occurred from March through June in all areas of Par Pond that were sampled. Greater population densities occurred below the thermocline when the lake was stratified (Fliermans et al. 1977). A comparison of *A. hydrophila* densities from 147 natural aquatic habitats in 30 states and Puerto Rico (Hazen et al. 1978c) revealed that Par Pond densities are relatively low and are lower than those in Strom Thurmond Reservoir. Temperature optima studies were conducted by Hazen and Fliermans (1979). When measured along thermal gradients, densities of *A. hydrophila* showed distinct thermal optima (25-35°C [77-95°F]) and thermal maxima (45°C [113°F]). Thermophilic strains could not be isolated at any site.

Extensive monitoring of Par Pond during 1983-1984 suggested a decline in the prevalence of red-sore disease from earlier levels. Obvious red-sore lesions occurred in only 0.09% of the largemouth bass, 0.11% of the bluegill, and 0.34% of the lake chubsuckers (Paller and Saul 1985).

4.9.8.8.2 Helminth Parasites

Eure and Esch (1974) sampled largemouth bass at six locations in Par Pond and inspected them for parasites. Helminth parasites in largemouth bass exhibited a definite seasonal change in intensity of infection but not in incidence of infection. The pattern was most apparent for the acanthocephalan *Neoechinorhynchus cylindratus*. This same pattern held for the tapeworm, nematode, and trematode populations, although the levels of infection were lower than those of the acanthocephalan populations. Fish from all areas had relatively reduced parasite loads from June through October. Maximum worm burdens were reached in December and were maintained through March. The number of parasites per host was significantly higher in fish taken from areas with elevated water temperature when compared to those from cooler areas. Female hosts had higher worm burdens than males.

4.9.8.8.3 Metacercaria of the Trematode *Clinostomum marginatum*

Over a 15-month period beginning in October 1974, approximately 13,500 centrarchids were collected by Hazen and Esch (1978) from Par Pond and examined for evidence of infection with metacercaria of the trematode *Clinostomum marginatum*. Species checked included bluegill, warmouth (*Lepomis gulosus*), redbreast sunfish (*L. auritus*), black crappie, and largemouth bass. Except for the largemouth bass, infection percentages among the five species were less than 1%. Among bass, infection varied seasonally, being highest from January to June. From the spring highs of approximately 25%, the percentages dropped to lows of less than 10% in July and August. There was a jump in September through October to another peak of 30%, and then a steady decline through December, when infection percentages were again less than 10%. Neither body condition nor length of the bass were related to infection percentages or metacercaria density. Infection percentages could not be related to the influence of thermal effluent. Infection percentages varied from location to location within the Par Pond system. A significant rank correlation was established between infection percentage and the amount of littoral zone in the locality from which the bass were taken. It is suggested that the local “bay effects” are the result of limited home and foraging ranges of the bass in relation to the amount of littoral zone present in various locations of the reservoir.

4.9.8.8.4 Strigeid Trematodes

Two parasitic worms, both strigeid trematodes (*Ornithodiplostomum ptychocheilus* and *Diplostomum scheuring*), have been collected from eastern mosquitofish in Par Pond, Pond C, and other SRS waters (Aho et al. 1976; Aho 1979; Aho et al. 1982; Camp 1980; Camp et al. 1982). *O. ptychocheilus* occurs in the brain and eyes. It apparently is favored by warmer-than-ambient water and has been observed in 95% of the eastern mosquitofish collected from Pond C on occasion. It was also more prevalent near the Hot Dam of Par Pond than near the Cold Dam. *D. scheruingo*, which occurs in the body cavity, had just the opposite thermal response. It was absent in Pond C fish and was more abundant in the cooler regions of Par Pond.

4.9.8.9 Contaminant Levels in Par Pond Fish

Fish from Par Pond were sampled in 1995 for mercury and ^{137}Cs concentrations. The geometric mean total mercury concentration in largemouth bass (whole fish) was 581 µg/kg. This mean concentration was greater than that reported in L Lake largemouth bass (351 µg/kg; Paller 1996). Total mercury concentration increased significantly ($P<0.001$) with fish size, reflecting bioaccumulation in older fish. Mercury contamination is common among fish taken from SRS water bodies that receive inputs of Savannah River water. It is likely that much of this mercury originated offsite, as suggested by mercury concentrations in largemouth bass collected from the Savannah River during 1994 (geometric mean of 557 µg/kg; WSRC Environmental Monitoring Section, unpublished data) which were approximately the same as mercury concentrations in Par Pond largemouth bass (Paller and Wike 1996a). Paller et al. (1999) examined historical trends in ^{137}Cs in fishes of the SRS. Peak levels were found between 1960 and 1970 with highest levels concentrations reported for Par Pond being around 6.6 Bq/g. There was a brief increase in ^{137}Cs in Par Pond fishes somewhat after 1990 and this increase is related to the Par Pond drawdown. The half-life of ^{137}Cs in fish was much shorter than the radioactive half-life indicating that removal is occurring rather than simple radioactive decay. Pond B and Lower Three Runs had longer ecological half-lives for ^{137}Cs in sunfishes (*Lepomis* spp.) and largemouth bass (*Micropterus salmoides*) than other SRS locations and this phenomenon may be related to resuspension of sediment with ^{137}Cs bound to it. Paller et al. (2002) found that ^{137}Cs levels in fishes from Par Pond and Pond B continue to decline at a lower rate than for other waer bodies on SRS (Figure 4-29).

The geometric mean mercury concentrations in bluegill and lake chubsucker from Par Pond averaged 154 and 133 µg/kg, respectively, substantially lower than in Par Pond largemouth bass (Paller and Wike 1996a).

The geometric mean cesium concentration in Par Pond largemouth bass (whole fish) was 4.61 pCi/g, nearly an order of magnitude higher than in L Lake largemouth bass (0.62 pCi/g; Paller 1996). Body burden of ^{137}Cs increased significantly ($P<0.001$) with fish size. Geometric mean concentrations of ^{137}Cs in bluegill and lake chubsucker were 1.70 and 3.27 pCi/g, respectively. As with largemouth bass, bluegill from Par Pond were characterized by much higher ^{137}Cs body burdens than bluegill from L Lake (chubsuckers were not analyzed for ^{137}Cs in L Lake). Greater ^{137}Cs body burdens in Par Pond fish probably reflect greater contamination of Par Pond with ^{137}Cs as a result of releases from P and R Reactors (Paller and Wike 1996a).

Largemouth bass condition factors were significantly ($P<0.05$) related to tissue concentrations of total mercury, but not to tissue concentrations of ^{137}Cs .

4.9.8.10 Summary of Results from Fish Studies

At least 30 species of fish reside in Par Pond, which differs from most other Southeastern U.S. reservoirs in that it has unusually high densities of largemouth bass and chubsuckers and unusually low densities of shad. High densities of largemouth bass are due in part to a virtual absence of fishing pressure in Par Pond. The dense largemouth bass population probably resulted in considerable competition for food, particularly in the Hot Arm when P Reactor was operating. Fingerling bluegills are primarily confined to the shallow weedy areas because of the dense predatory fish populations. Water temperatures along the edges of the shallow refuge sites are generally several degrees higher than those of deeper water, thereby causing elevated maintenance requirements for fingerling bluegills and other fishes.

Several species of fish exhibited some degree of aggregation in the Hot Arm during the winter when P Reactor was operational. This phenomenon is most pronounced among the largemouth bass. Fish may have congregated in the Hot Arm during the winter to maintain optimal body temperatures or to forage.

Food is probably the primary limiting factor for largemouth bass in Par Pond, and the population appears to be at or near the carrying capacity. Young largemouth bass in Par Pond compare favorably with largemouth bass from other U.S. lakes and reservoirs in terms of condition (K) factor, while older largemouth bass in Par Pond are thinner than usual. During the time of reactor operations, the condition of largemouth bass in Par Pond was significantly lower in the Hot Arm than elsewhere and significantly lower in the summer than in the winter throughout the reservoir.

Parasitism by *Aeromonas hydrophila*, which causes red-sore disease, appeared to be correlated with increased water temperatures or decreased condition. Largemouth bass from the Hot Arm had a significantly higher incidence of infection. The lowest percentage of infected fish occurred in the winter when body condition factors of largemouth bass were highest.

Fish kills due to rapidly changing water temperature caused by intermittent reactor operation were observed in the precooler to Par Pond (Pond C) but not in Par Pond.

Thermal effects resulting from the operation of P Reactor included localized reductions in diversity and the number of species in the Hot Arm and early spawning of some species in the Hot Arm and possibly other areas in Par Pond that are slightly warmed. Other possible thermal effects included reduced condition of largemouth bass (although forage deficiencies may also contribute to the low condition of Par Pond bass) and aggregation of largemouth bass and black crappie in the discharge area.

Despite thermal and entrainment effects, Par Pond fisheries variables compared favorably with Pond B. Species number and Shannon diversity, two parameters often depressed in thermally stressed ecosystems were higher in Par Pond than in Pond B. Catch per unit effort for most species was higher in Par Pond than in Pond B. Largemouth bass, an important sport fish and the principal predator fish in both Par Pond and Pond B, were larger and in better condition in Par Pond.

Comparisons between Par Pond and other reservoirs in the United States indicated that the Par Pond fish community was comparable to the communities in other reservoirs in terms of species number, diversity, and standing crop. Favorable comparisons between Par Pond and other reservoirs, the collection of early life stages of most or all major species, and the historical presence of diverse and abundant fish communities in Par Pond indicated that the impact of reactor operation on Par Pond was not severe.

4.9.9 Par Pond Drawdown

An inspection of the Par Pond dam in March of 1991 identified a depression on the downstream face. Although further investigations found no indication of impending failure, the reservoir level was drawn down to minimize the potential for failure. Between June and September 1991, the level was drawn down to 55.2 m (181 ft) above mean sea level from the normal elevation of 61.0 m (200 ft) above mean sea level (Arnett et al. 1992).

The drawdown exposed 5 km^2 (1340 acres) of the lakebed, roughly half the normal surface area of the reservoir. In 1995, after dam repairs were complete, the reservoir was refilled. At present, no river water is pumped to Par Pond. Rainfall and inflows from the watershed and groundwater maintain the reservoir level above 59.4 m (195 ft) above mean sea level (DOE 1995 EA-1070).

4.9.9.1 Effect of Drawdown on Fish Community

The following discussion is taken from Paller and Wike (1996a). When Par Pond was drawn down in 1991, the reservoir's surface area was reduced by 50% and the volume was reduced by 65% (DOE 1994). Virtually all the emergent and submerged vegetation was lost from the original littoral zone (Mackey and Riley 1996). Water quality declined, but remained acceptable for warm water fishes (Koch et al. 1996b). Electrofishing data from before, during, and after the drawdown were used to compare the fish community during those times. Chapter 5—Wetlands and Carolina Bays of the SRS discusses the effect of the drawdown on macrophyte communities.

Fish community data were separated into six time periods to identify changes that could be attributed to the drawdown: predrawdown, drawdown 1991, drawdown 1992, refill, spring postrefill, and fall postrefill. Seventeen species of fish were collected from Par Pond during the predrawdown period. The most numerically abundant were brook silversides (50.7%), bluegill (17.9%), and largemouth bass (15.6%). Other species in substantial numbers were lake chubsucker, coastal shiner (*Notropis petersoni*), golden shiner (*Notemigonus crysoluecas*), chain pickerel (*Esox niger*), yellow perch (*Perca flavescens*), redbreast sunfish, black crappie (*Pomoxis nigromaculatus*), and warmouth (*L. gulosus*). Immediately after the drawdown, 12 species were collected; 9 were collected in 1992; and 18 were collected during the fall postrefill sample. Bluegill (46.7%), largemouth bass (16.7%), and blueback herring (14.2%) were most abundant in 1991. Brook silversides (21.7%), bluegill (17.9%), golden shiner (13.2%), and blueback herring (11.0%) were most abundant in the fall post-refill samples.

The average number of species collected from Par Pond declined significantly during the first and second years of the drawdown (Paller 1997). The number of individual fish declined even more, reaching levels approximately an order of magnitude lower than before the drawdown (Paller 1997) Samples collected during the refill (January 1995) indicated a slight increase in number of species and number of individuals, but both variables remained significantly lower than before drawdown. However, samples collected in May and June 1995 (spring post-refill) indicated significant increase to predrawdown levels for both species number and number of individuals. The fall postrefill sample indicated additional increases in both species number and number of individuals, although neither was significantly greater than during the spring postrefill sample.

Species rank abundances during the drawdown were significantly ($P<0.05$) correlated with species rank abundances before the drawdown, reflecting the persistence of species such as bluegill and largemouth bass. Blueback herring (*Alosa aestivalis*) numbers increased during the drawdown, while brook silversides and lake chubsuckers decreased.

The species that declined in number during the drawdown typically prefer littoral zone habitats with extensive aquatic vegetation (Pflieger 1975; Robinson and Buchanan 1988). These observed changes may be explainable by the changes in littoral zone habitat as a result of the drawdown and refill. The drawdown eliminated all the aquatic macrophyte beds, and after the refill the littoral zone vegetation rapidly reestablished.

The drawdown affected the size structure within species. There were few small largemouth bass, lake chubsuckers, or bluegill at the end of the drawdown (as measured during the refill). While postdrawdown community composition (reflected in species richness, species abundance, and rank abundance) rapidly came to resemble predrawdown community composition, the size structure within species remained quite different between pre- and post-drawdown samples; for all species examined, the larger size individuals were relatively less abundant during refill and after refill with young-of-year individuals very abundant during the spring following refill.

Predrawdown largemouth bass and lake chubsucker size structures were dominated by large individuals. In contrast, the postdraw down size structures of both species were dominated by small individuals, reflecting highly successful reproduction following refill. Young-of-the-year were represented prominently in the spring postrefill collections and by the fall post-refill sample. These young-of-the-year fish had grown considerably as indicated by a reduction in the 0-49-mm (0-2-in) size class and a corresponding increase in the 50-99-mm (2-4-in) size class. Bluegill exhibited a similar pattern that was indicative of strong reproductive success following refill.

The Par Pond drawdown severely disturbed the Par Pond fish community, reducing the number of species and abundance, particularly of those species dependent on littoral zone vegetation. The size structure of individual species also was affected. The effects were apparently the result of marked reductions in habitat size and changes in habitat quality, including the temporary loss of the littoral zone and its associated vegetation. However, the fish community structure in Par Pond rapidly recovered following refill, indicating that it is resilient to disturbances from changes in water level.

4.9.9.2 Effect of Drawdown on Macrophytes

For a discussion of the changes in the Par Pond macrophyte community as a result of the drawdown see Chapter 5—Wetlands and Carolina Bays of the SRS.

4.9.9.3 Effect of Drawdown on Alligators

Alligators have inhabited Par Pond since its construction in 1958. The population was studied extensively in the 1970s and 1980s, so much is known about the behavior of the Par Pond alligators. The 1991 drawdown provided an opportunity to study the response of alligators to significant changes in their habitat.

During and immediately after the drawdown, the number of alligators counted in the reservoir by night eyeshining techniques increased, possibly from increased visibility of smaller animals due to the loss of emergent vegetation. High numbers of alligators also were observed during aerial census flights made in spring 1992.

Fourteen adult alligators were fitted with radio transmitters in the fall of 1991. Males showed more extensive fall movement than females who tended to remain near the locations where they were originally captured. There was no evidence that the drawdown affected the survival of the alligators over winter. Six of the telemetered alligators spent the winter in moderately deep water along a stretch of the exposed shoreline that was less than 300 m (1000 ft) long. One female overwintered with her young in a subterranean den that remained dry throughout the winter because of the lowered water level. Six alligators left Par Pond; two of these animals were found dead in nearby smaller impoundments, most likely killed by larger alligators that were established residents of the smaller impoundments.

Three nests initiated before drawdown all successfully hatched young. Despite the greater distance of these nests to water after the young hatched than when the female constructed the nest, all three females continued to tend the nests and moved with their hatchlings as much as 100 m (333 ft) to the water. It is unlikely that many of the young survived, because the inadequate vegetation cover would not hide them from predators (Brisbin et al. 1992).

Refill begun in the summer of 1994 inundated at least one nest, and all of the unhatched nestlings died as a result. This represented a loss of 30.6% of 1994’s potential recruitment on Par Pond (Brisbin et al. 1997).

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4.10 SAVANNAH RIVER

4.10.1 Drainage Description and Surface Hydrology

4.10.1.1 General Description

The Savannah River watershed, which drains about 27,388 km^2 (10,574 mi^2), includes western South Carolina, eastern Georgia, and a small portion of southwestern North Carolina (Figure 4-42). The confluence of the Tugaloo and Seneca Rivers in northeast Georgia forms the river. It flows southeast through the Mountain Province, Piedmont Plateau, and Coastal Plain physiographic regions to the Atlantic Ocean. In its mid and lower reaches (including along the SRS boundary), the river is broad with extensive floodplain swamps and numerous tributaries. The substrate consists of various combinations of silt, sand, and clay (Specht 1987).

4.10.1.1.1 <u>Physiography</u>

4.10.1.1.1.1 Mountain Province

The Mountain Province contains most of the major tributaries of the Savannah River, including the Seneca, Tugaloo, and Chatooga Rivers. The region is characterized by a relatively steep gradient, ranging in elevation from about 1676 m to 305 m (5498 to 1000 ft), and includes 5235 km^2 (2021 mi^2) (19%) of the total drainage basin. The Mountain Province lies in the Blue Ridge mountains and has a bedrock composed of gneisses, granite, schist, and quartzite; the subsoil is composed of brown and red sandy clays. In this region, the Savannah River and its tributaries have the character of mountain streams, with shallow riffles, clear creeks, and a fairly steep gradient. The streambed is mainly sand and rubble (Bauer et al. 1989).

4.10.1.1.1.2 Piedmont Region

The Piedmont Region has an intermediate gradient, with elevations ranging from 305 m to 61 m (1000 to 200 ft). This region includes 13,548 km^2 (5230 mi^2) (50%) of the total drainage basin. Soils in the Piedmont are primarily red, sandy, or silty clays, with weathered bedrock consisting of ancient sediments containing granite intrusions. The Piedmont is bordered by the Fall Line, an area where the sandy soils of the Coastal Plain meet the rocky terrain of the Piedmont foothills. The city of Augusta, Georgia, is near this line. The Savannah River picks up most of its silt load in the Piedmont Region and deposits it in large reservoirs as the river flows through the Piedmont (Bauer et al. 1989).

4.10.1.1.1.3 Coastal Plain

The Coastal Plain has a negligible gradient ranging from an elevation of 61 m (1000 ft) to sea level. The soils of this region are primarily stratified sand, silts, and clays. The Coastal Plain contains 8631 km^2 (3332 mi^2) (31%) of the total Savannah River drainage area (27,388 km^2 [10,574 mi^2]), and includes the city of Savannah, Georgia. In the Coastal Plain, the Savannah River is slow moving. Tidal effects may be observed up to 64 km (40 mi) upriver, and a salt front extends upstream along the bottom of the riverbed for about 32 km (20 mi) (Bauer et al. 1989).

Figure 4-42. Map of Savannah River Watershed

4.10.1.1.2 Dredging Operations

The U.S. Army Corps of Engineers (COE) regulates flow in the Savannah River with three large reservoirs (Hartwell, Russell, and Thurmond) and by locks and dams. In addition to being affected by the reservoirs, the river is influenced by dredging, sewage discharge, and industrial activities (Specht 1987). The COE dredged the Savannah River between the cities of Savannah and Augusta, Georgia. This program, initiated in October 1958, was designed to dredge and maintain a 2.7-m (9-ft) deep navigation channel. The COE placed 61 sets of pile dikes to constrict the river flow, thereby increasing the flow velocities, and laid 11,477 linear meters of wood and stone revetment to reduce erosion on banks opposite from the dikes. In addition, the channel was dredged and 31 cutoffs were made, reducing the total river distance from Augusta to Savannah by about 24.1 km (15 mi). The project was completed in July 1965 and periodic dredging was continued until 1985 in order to maintain the channel (Bauer et al. 1989).

4.10.1.1.3 Natural Levee

Three significant breaches in the natural levee occur along the river boundary of SRS. The breaches are at the mouths of Beaver Dam Creek, Fourmile Branch, and Steel Creek. River water overflows the levee and the creek mouths and fills the swamp at river stages greater than 27 m (88.5 ft). During swamp flooding, the water from the creeks flows through the swamp, behind the levee, parallel to the main channel flow until it mixes with the main river flow at Little Hell Landing, between Steel Creek and the Highway 301 bridge (Bauer et al. 1989).

4.10.1.2 Effluent Contributions

Historically, the Savannah River's water quality has been affected by various pollution sources. Prior to 1975, most domestic and industrial wastes from Augusta, Georgia, were discharged untreated or poorly treated to the Savannah River. Prior to completion of an Aiken County, South Carolina, treatment facility in 1979, domestic and industrial effluents entered the Savannah River. The SRS currently discharges wastewater into tributaries of the Savannah River. These discharges have consisted of thermal effluents, as well as treated domestic and industrial effluents.

The thermal plumes created in the Savannah River by SRS-heated effluents varied in size and temperature as a function of changes in reactor operation, Savannah River water level, and season of the year. When flow in the Savannah River was low, the thermal creeks discharged directly into the river, producing plumes that followed the South Carolina shore. When the river flow was high enough to inundate the SRS floodplain swamp, there were no thermal plumes in the river. During flooding, the creeks discharge into the flooded swamp and the water is channeled downstream along the upland bank of the swamp by the river overflow. In the case of heated effluents, dilution and cooling occurred in the floodplain swamp before the SRS effluent was discharged into the main channel.

4.10.1.3 Flow Measurements

4.10.1.3.1 Droughts

4.10.1.3.1.1 History

Since the mid-1950s, there have been three severe droughts (1954-1956; 1980-1981; and 1985-1989) in the southeastern United States (SAIC 1989). Before the 1980s, the record event for the Savannah River Basin occurred from 1954 to 1956. However, during the 1980s, extremely dry conditions prevailed. The drought period of 1980-1981 was intense but relatively short. The 1985-1989 period is considered the worst on record. Inflows to the Savannah River during the 1985-1989 period are the lowest recorded during this century (U.S. Army Corps of Engineers 1988).

4.10.1.3.1.2 Flows

Average river flows recorded at Augusta during 1981 and 1982 were markedly lower than the historical mean. The mean value for 1981 (197 m^3/sec [6957 ft^3/sec]) was, at that time, the lowest since the very dry year of 1955 (193 m^3/sec [6816 ft^3/sec]; SAIC 1989). The 1985 through 1989 editions of *USGS Water Resources Data for South Carolina* reported mean annual Savannah River discharges at Augusta of 182, 176, 222, 151, and 152 m^3/sec, (6427, 6215, 7840, 5368, 5368 ft^3/sec) respectively. Since 1963, the U.S. Army Corps of Engineers has attempted to maintain a minimum of 178.4 m^3/sec (630 ft^3/sec) below the New Savannah River Bluff Lock and Dam at Butler Creek (River Mile 187.4 [River Kilometer 301] near Augusta, Georgia; U.S. Army Corps of Engineers 1988). During the 18 years from 1964 to 1981 (climatic years ending March 31), the average of the 7-day low flow for each year measured at the New Savannah River Bluff Lock and Dam was 181 m^3/ sec (6392 ft^3/sec) (Watts 1982), or about 2.3 m^3/sec (86 ft^3/sec) less than at SRS (Ellenton Landing, River Mile 156.8 [River Kilometer 252]). Note that River Miles are measured from the mouth, thus the higher the River Mile, the farther upstream the location.

4.10.1.3.2 Flow Requirements

During the 1985-1989 drought, the U.S. Army Corps of Engineers maintained minimum water releases from the Clark Hill/J. Strom Thurmond Dam, based on requirements of downstream users, primarily SRS (SAIC 1989). Low flow tests conducted during 1980 and 1981 established minimum flow requirements of 138 and 117 m^3/sec (4873 and 4130 ft^3/sec) at SRS to ensure three- and two-reactor operation, respectively. Maintaining these flows required a discharge of 102 m^3/sec (13,600 ft^3/sec) from Clark Hill/J. Strom Thurmond Dam. Maintaining water quality and managing fish and wildlife resources downstream required that flows at Augusta be kept close to this value during October and November 1986 and less during the spring, summer, and fall of 1988 (SAIC 1989). During summers for the time period from 1998 through 2002 and again in 2004 the NOAA Climate Prediction Center reported drought conditions for all or part of the Savannah River Basin (http://www.cpc.ncep.noaa.gov/products/monitoring_and_data/drought.html). Figure 4-43 shows that for the years 1998 to 2003 riverflow rates were below average for the river flow measurement station at Augusta.

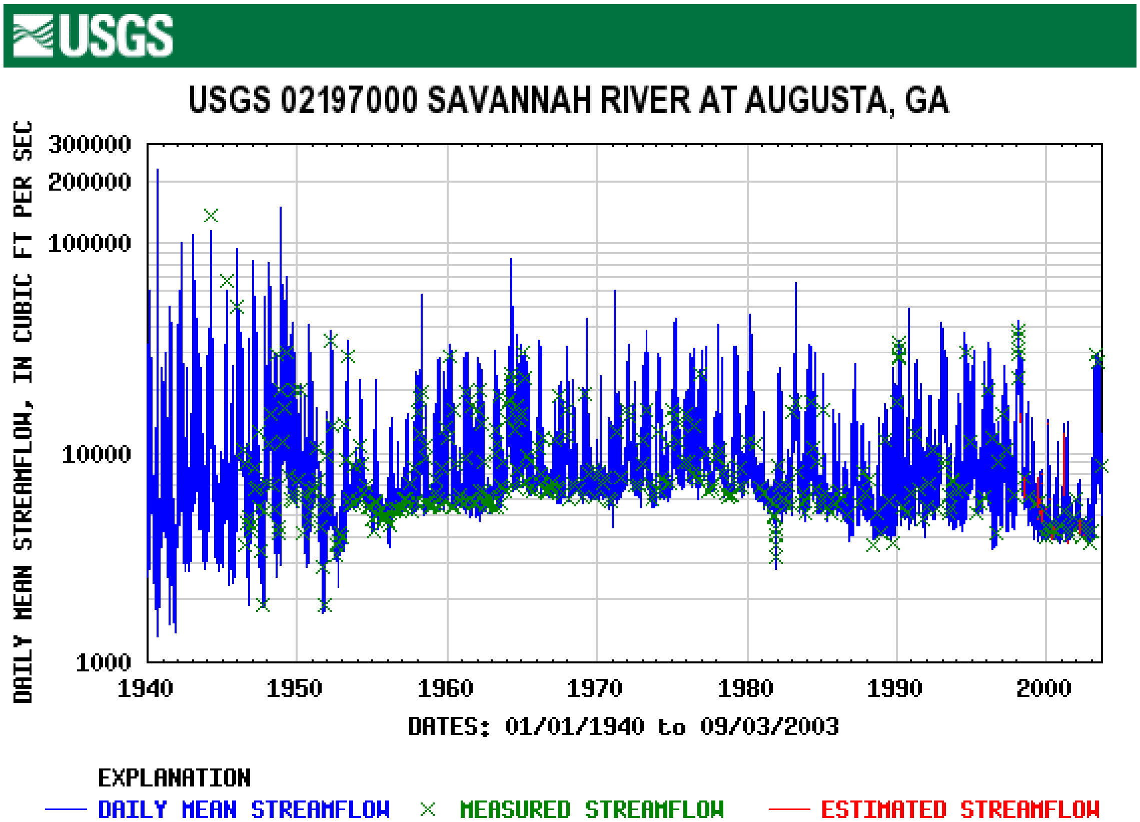

Figure 4-43. Streamflow Rates for the Savannah River

The U.S. Geologic Survey measures flow at several locations on the Savannah River. Table 4-24 summarizes flow statistics for stations at Augusta; near Jackson, South Carolina, (SRS Boat Dock); at Burtons Ferry Bridge near Millhaven, South Carolina (U.S. 301), and near Clyo, Georgia. The station near Jackson measures flow up to (22,000 ft^3/sec [6229 m^3/ sec]).

The water quality of the Savannah River varies considerably throughout its drainage basin, ranging from healthy and productive in most reaches to heavily contaminated with industrial and domestic effluents in local areas (Gladden et al. 1985).

Other activities also have affected the water quality of the Savannah River. From 1958 until 1965, downstream reaches of the Savannah River were dredged to improve channel alignment and maintain a 2.7-m (9-ft) depth for navigability. This dredging temporarily increased suspended solids, turbidity, and dissolved nutrients. Completion of the Clark Hill/J. Strom Thurmond Dam in March 1953 and the filling of the reservoir in July 1954 resulted in decreased silt loading and turbidity in the Savannah River. Industrialization of the river basin in the Central Savannah River Area (CSRA) has increased the total waste loading (DOE 1982).

Table 4-24. Flow Summary for the Savannah River

			Range						7Q10		7-Day Low Flow	
			Mean		Low		High					
Station Name	Sation Number	Period of Record	cms[a]	cfs[b]	cms	cfs	cms	cfs	cms	cfs	cms	cfs
Augusta, GA	02197000	1954-1995	269	9,394	80	2,810	2,393	84,500	122	4,291	106	3,746
Near Jackson, SC (SRS Boat Dock)[c]	02197320	1972-1995	-	-	91	3,220	-	-	118	4,154	107	3,773
Burtons Ferry Bridge near Millhaven, SC (U.S. 301)	02197500	1954-1969 1983-1995	294	10,397	112	3,960	2,030	71,700	123	4,335	113	3,991
Near Clyo, GA	02198500	1954-1995	340	12,019	125	4,400	2,373	83,800	144	5,097	128	4,513

[a]cms = cubic meters per second.
[b]cfs = cubic feet per second.
[c]Gauge not rated for flow above 22,000 cfs.

4.10.2 Water Chemistry and Quality

4.10.2.1 Studies and Monitoring

4.10.2.1.1 <u>Water Quality Monitoring</u>

The Westinghouse Savannah River Company Environmental Monitoring Section has monitored water quality in the Savannah River near SRS monthly since the establishment of sampling stations upstream and downstream of SRS in 1959. Samples are collected monthly for physical and biological parameters, quarterly for metals, and annually for pesticides and PCBs. The upstream sampling point (River-2) is near Jackson, South Carolina, upstream from all SRS stream mouths. The downstream sampling point (identified as River-10) is at the U.S. 301 crossing of the Savannah River, 16.6 km (10.3 mi) downstream of the mouth of Lower Three Runs. A third routine river sampling location adjacent to the 3G SRS pumphouse intake canal was maintained from 1973 through 1981 to determine the physiochemical characteristics of the river water adjacent to the cooling canal intakes. After Plant Vogtle began operating, this sampling station was relocated below the Plant Vogtle effluents to identify any effects these effluents may have on downriver concentrations (Figure 4-44).

4.10.2.1.2 <u>Monitoring Data</u>

Gladden et al. (1985) present water quality data from the three Savannah River monitoring stations from 1973 to 1982. Lower (1987) summarizes water quality data from 1983 through 1985. All routine water quality monitoring data can be found in annual SRS environmental reports. Results of water quality monitoring of the Savannah River from 1987 to 1995 are discussed later in this chapter.

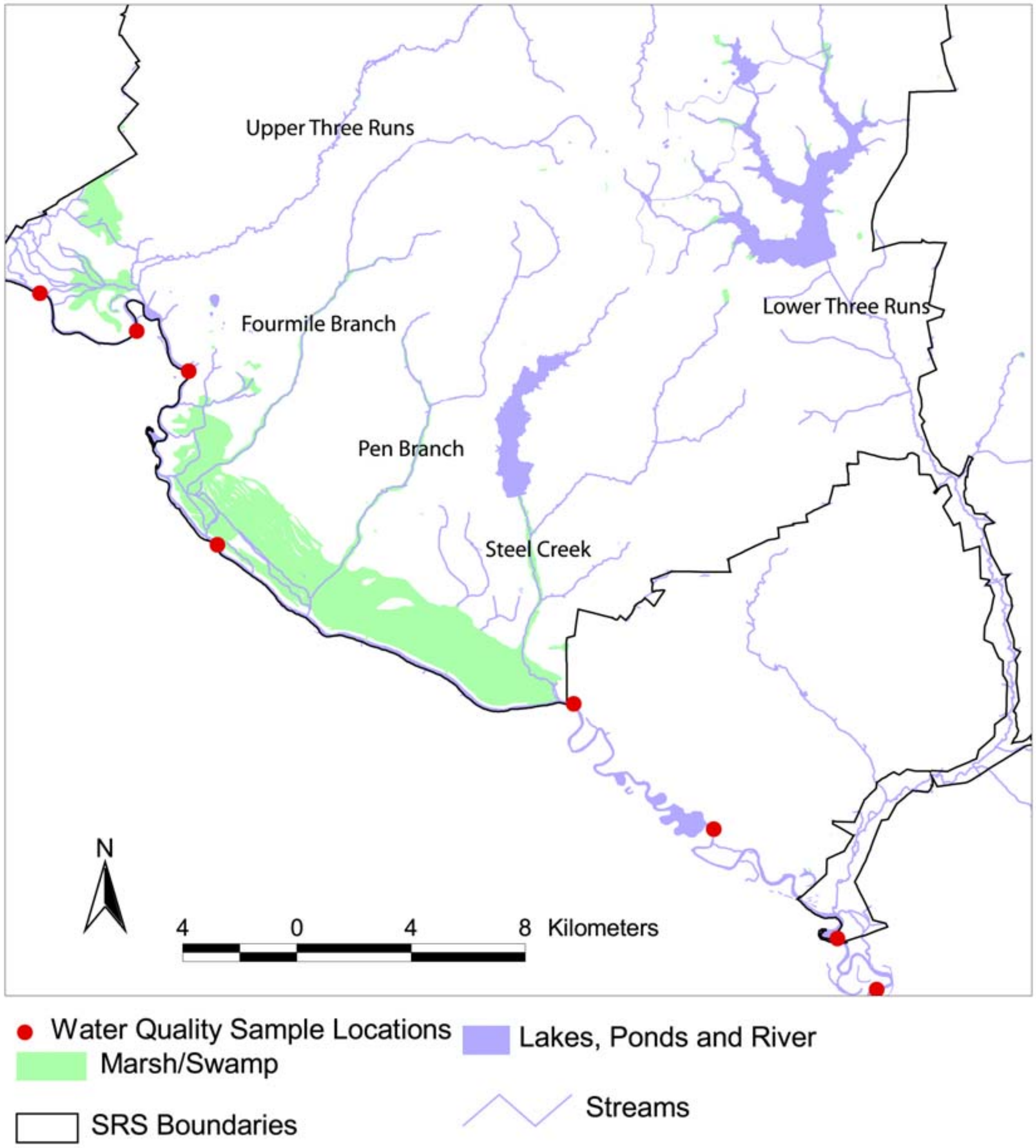

Figure 4-44. Water Quality Sampling Stations for the Savannah River. Sampling locations from upstream to downstream: River-2, RM 160, 3G Pumphouse, River-3, Steel Creek landing, downstream of Steel Creek landing, mouth of Lower Three Runs, River-10

4.10.2.1.3 Comprehensive Cooling Water Study (CCWS)

In July 1983, the CCWS was initiated to study the effects of cooling water intake and discharge to onsite streams and, ultimately, to the Savannah River. Under the CCWS, river water samples were collected from the station upriver of SRS, at the 3G intake canal pumphouse, and downriver of Steel Creek Landing (Figure 4-44) and analyzed for standard water quality parameters, nutrients, major ions, and trace elements. Results of this water quality program are discussed later in this chapter and are documented in Newman et al. (1986) and Lower (1987).

4.10.2.1.4 Priority Pollutant Study

In 1984, another special study was conducted to determine the levels of volatile, acid, base and neutral organic compounds in the Savannah River. Samples were collected from upriver and downriver locations. The results of this study are summarized later in this chapter and in Lower (1987).

4.10.2.1.5 Monitoring Data

Variability of data for all water chemistry parameters has diminished over the last 20 years, primarily due to flow stabilization by upstream dams. Water quality results also indicate the overwhelming similarity in water chemistry between the upstream and downstream SRS monitoring sites. More specifically, a previous report (Lower 1983) documented that no statistically significant changes were evident for the tested parameters between the Savannah River water quality stations upstream and downstream of SRS.

4.10.2.2 Field Data

4.10.2.2.1 Water Temperature

Water temperatures in the Savannah River vary seasonally, ranging from a low of 3.8°C to 28°C (38.8 to 82.4°F). Prior to cessation of reactor operation, the net increase in water temperature of the Savannah River from upstream to downstream of the SRS was approximately 1.2°C (2°F) (Jacobsen et al. 1972) and was attributed to the discharge of thermal effluents to Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek as a consequence of SRS operations. Since cessation of reactor operations, there has been no net difference in the mean temperature of Savannah River water upstream and downstream of SRS.

4.10.2.2.2 pH Measurements

The pH of the Savannah River was similar at all locations sampled during the CCWS and routine monitoring. Generally, the river water was slightly acidic to near neutral, with pH ranging from 4.8 to 8.2. The mean pH of the Savannah River (for all studies) ranged from 6.4 to 6.98.

4.10.2.3 Physical Characteristics and General Chemistry

4.10.2.3.1 Dissolved Oxygen

Dissolved Oxygen Mean dissolved oxygen concentrations in the Savannah River (for all studies) ranged from 7.19 to 8.78 mg/l. The CCWS found that percentage of oxygen saturation varied seasonally and was lowest during the autumn (Newman et al. 1986).

4.10.2.3.2 Suspended Solids and Turbidity

Suspended solids concentrations were comparable at all locations sampled for the CCWS and during routine monitoring. Mean suspended solids concentrations measured during the CCWS ranged from 9.47 to 12.6 mg/l. Mean suspended solids concentrations from 1987 to 1995 ranged from 9.6 to 13.8 mg/l. Turbidity values have been lower since the CCWS. Mean turbidity values ranged from 18.3 mg/l to 21.0 mg/l during the CCWS and from 9.08 mg/l to 10.6 mg/l from 1987 to 1995.

4.10.2.3.3 Conductivity

Mean specific conductivity values range from 68.2 to 84.8 µS/cm. The lowest values generally were measured at the 3G intake canal. The slight difference in water quality values between the 3G intake canal and upriver was attributed to the input of water from Upper Three Runs near the 3G intake canal (Newman et al. 1986).

4.10.2.4 Major Anions and Cations

4.10.2.4.1 Alkalinity, Chloride, and Sulfate

During the CCWS, mean alkalinity ranged from 16.5 mg $CaCO_3$/l at the 3G intake canal to 19.6 mg $CaCO_3$/l upriver of SRS. From 1987 to 1991, mean alkalinity was 21 mg $CaCO_3$/l at all locations. From 1992 to 1995, mean alkalinity ranged from 18.5 mg $CaCO_3$/l to 19.2 mg $CaCO_3$/l.

Mean concentrations of chlorides and sulfates have been slightly higher during routine monitoring than during the CCWS. Mean chloride concentrations during routine monitoring ranged from 7.7 to 8.2 mg/l, while the means during the CCWS ranged from 5.53 to 6.29 mg/l. Mean sulfate concentrations ranged from 6.8 to 8.5 mg/l for routine monitoring, and the means during the CCWS ranged from 5.26 to 6.00 mg/l.

4.10.2.4.2 Calcium, Magnesium, Sodium, and Potassium

Lower concentrations of major cations measured at the 3G intake canal during the CCWS established the presence of Upper Three Runs water at that location. At all locations during the CCWS, mean calcium, magnesium, sodium, and potassium concentrations were within the following ranges: calcium, 3.07-3.42 mg/l; magnesium, 1.21-1.34 mg/l; sodium, 6.62-7.63 mg/l; and potassium, 0.995-1.10 mg/l. These ranges are similar to those that were measured during routine monitoring between 1987 and 1991. Since 1992, calcium and sodium means have increased. Calcium means ranged from 3.6 to 4.17 mg/l; and sodium means ranged from 9.12 to 9.74 mg/l. Magnesium means were similar; potassium no longer is sampled.

4.10.2.4.3 Aluminum, Manganese, and Iron

Newman et al. (1986) noted that approximately 93% of the aluminum and from 42 to 45% of the manganese measured in the Savannah River was associated with the solid phase. Approximately 85% of the iron was associated with particulates. The concentrations of these three cations were similar for both the CCWS and routine monitoring between 1987 and 1991. Since 1992, aluminum and iron concentrations have decreased.

4.10.2.5 Nutrients

4.10.2.5.1 Comparison to SRS Streams

In general, Savannah River waters are nutrient-rich relative to nonthermal and post-thermal stream waters at SRS. Nutrient concentrations in the Savannah River typically were higher than concentrations in waters of onsite surface streams, which do not receive Savannah River source waters for site operations (Newman et al. 1986).

4.10.2.5.2 Phosphorus

Concentrations of phosphorus were similar throughout the CCWS and during routine monitoring. Mean total phosphorus concentrations ranged from 0.094 mg P/l upriver at River-2 to 0.118 mg P/l adjacent to SRS at River-3B. Newman et al. (1986) documented that 48-56% of this phosphorus was dissolved orthophosphate. Since 1992, total phosporus mean concentrations have been 0.06 mg/l or less.

4.10.2.5.3 Nitrogen

Mean nitrate-nitrogen concentrations ranged from 0.262 mg N/l to 0.293 mg N/l during the CCWS. Mean nitrate (nitrate/nitrite) measurements during routine monitoring ranged from 0.265 mg N/l to 0.334 mg N/l. Ammonia concentrations from the CCWS and routine monitoring were similar at all locations, with ranges from 0.082 mg N/l to 0.183 mg N/l. Newman et al. (1986) noted seasonal relationships between ammonia and nitrate and attributed it to the influence of temperature on the nitrification processes within the Savannah River waters

4.10.2.6 Trace Elements

The CCWS measured low levels of trace elements. The detection limits reported for routine monitoring are higher than the concentrations measured during the CCWS; therefore, only CCWS data will be discussed in this section. The highest mean concentrations of arsenic, cadmium, and nickel were observed at the upriver location. Mean arsenic concentrations ranged from 2.5 to 2.6 µg/l; mean cadmium concentrations ranged from 0.21 to 0.51 µg/l; and mean nickel concentrations ranged from 2.4 to 3.7 µg/l. The highest mean concentrations of chromium, copper, lead, and zinc were observed at the downriver location. Mean chromium concentrations ranged from 7.1 to 10.5 µg/l; mean concentrations of copper ranged from 2.3 to 2.5 µg/l; mean concentrations of lead ranged from 1.7 to 2.0 µg/l; and mean concentrations of zinc ranged from 4.6 to 8.0 µg/l.

4.10.2.7 Organic Carbon

During the CCWS, mean total organic carbon concentrations ranged from 6.1 to 6.5 mg C/l and were comparable at all sites. Approximately 80-85% of this total organic carbon was in the dissolved phase. Total organic carbon is not measured during routine monitoring.

4.10.2.8 Priority Pollutants

Lower (1987) reported that concentrations of all 88 tested volatile, acid, base, and neutral compounds were below detection limits in Savannah River during the 1984 priority pollutant survey.

4.10.2.9 Pesticides, Herbicides, and PCBs

Concentrations of all tested materials in the Savannah River were below detection limits from 1987 to 1991. Lower (1987) reported the results of analyses for pesticides, herbicides, and PCBs from 1982 to 1985; results from 1967 to 1981 can be found in Gladden et al. (1985). During these periods, concentrations were also near or below detection limits at all locations.

PCBs and volatile organic compounds no longer are sampled in the Savannah River. Between 1992 and 1995, no herbicides or pesticides were found in concentrations above detection limits (Arnett 1993, 1994, 1995, and 1996).

4.10.2.10 Chemical, Including Radionuclide, and Toxicity Assessment Studies

No toxicity studies of Savannah River water have been done by the Savannah River Site

4.10.2.10.1 Radionuclides and Metals in Savannah River Water, Sediments, and Fish

Over the years, much data has been collected on metals and radionuclides in the Savannah River. By examining these data, one can identify trends and possible sources of contamination. The SRS bounds the Savannah River from approximately River Mile 160 (River Kilometer 257) to River Mile 140 (River Kilometer 225). Constituent concentrations found above River Mile 160 (River Kilometer 257) have a source other than SRS. For those constituents whose concentrations increase between River Miles 160 and 140 (River Kilometer 225), SRS is the likely source, although there are other potential sources along that reach of the river, such as Plant Vogtle, a commercial nuclear power plant.

4.10.2.10.2 Cobalt-60, Cobalt-58

Cobalt-60 enters the Savannah River at approximately River Mile 150 (River Kilometer 241), where Fourmile Branch flows into the river. However, the data are skewed by one sample with a high cobalt-60 concentration (419.2 fCi/l), which was collected in the discharge plume of Plant Vogtle. The elevated concentration appears attributed to sampling in the plume before it mixed with river water. After thorough mixing, downstream samples show only a slight increase in cobalt concentration. Cobalt-60 in Savannah River sediments increases in the vicinity of the SRS. By examining recent data for cobalt-60, it is apparent that concentrations of this radioisotope were highest between 1992 and 1994 (WSRC 1996). The elevated concentrations occurred between June 1993 and July 1994 and coincided with elevated releases from Plant Vogtle.

Radiometric studies of Plant Vogtle have been conducted since late 1986, seven months prior to its startup (Sigg and Winn 1989) by the Nonproliferation Technology Section (NTS), formerly the Environmental Technology Section (ETS). Ultra low-level radiometric measurement techniques routinely detect neutron-activated isotopes in controlled releases from Vogtle. At no time were the controlled release activities found to exceed the applicable federal regulations (Winn 1997).

Vogtle-associated activities were low during early 1997 and 1996, when the largest reported activities occurred during June to August. Only cobalt-60, the dominant radionuclide from Vogtle releases, was observed in early 1997. The maximum cobalt-60 observed was only 11 fCi/l (Winn 1997).

An underwater sodium-iodide detector was successfully used during 1987-1994 at the Highway 301 bridge to monitor cobalt-58 from Vogtle releases (Sundram and Winn 1993; Winn 1995).

4.10.2.10.3 Alpha, Nonvolatile Beta, Tritium

Most of the tritium in the Savannah River is from SRS. Fish caught in the vicinity of SRS have elevated tritium concentrations, and those caught since 1992 do not show a trend of decreasing concentrations. However, since 1960 the concentration of tritium in the Savannah River has decreased (WSRC 1996). This is due first to improved handling of tritium at SRS facilities, and second to the cessation of nuclear production operations. The spike in 1991 is the result of a cooling coil leak in K Reactor.

Water samples are routinely collected both upriver of SRS at Augusta, GA, and downriver at the City of Savannah Industrial and Domestic Water Supply Plant at Port Wentworth, GA, and the Beaufort-Jasper Water Treatment Plant at Beaufort, SC. Results, as concentrations of alpha, nonvolatile beta, and tritium at all of these facilities are reported quarterly to the water treatment plant managers. Alpha and nonvolatile beta concentrations at all locations are typically near or less than minimum detectable concentrations. Measurable quantities of tritium are detected at the downriver water treatment plants (Miller 1997).

Cesium-137 has elevated concentrations in Savannah River sediments in the vicinity of SRS. Fish taken in the vicinity of the SRS exhibit elevated concentrations of the isotope. When samples collected over time are examined, it is apparent that neither the sediments nor the fish exhibit a trend in concentration change (WSRC 1996). The underwater sodium-iodide detector did not routinely detect cesium-137 from SRS effluents between 1987-1994 as concentrations were below the detection limit of the detector.

4.10.2.10.4 Strontium-90

Strontium-90 was examined only in fish. Fish taken in the vicinity of the SRS exhibit elevated concentrations of the isotope. When fish collected over time are examined, no trend in strontium-90 concentrations is apparent (WSRC 1996).

4.10.2.10.5 Mercury

From the available data on fish, the source of mercury is unclear. However, when the data are examined over time, there appears to be a trend of decreasing concentrations (WSRC 1996).

4.10.3 Algae

4.10.3.1 Taxonomic Studies

There have been no quantitative studies of the Savannah River phytoplankton in the vicinity of SRS. However, attached algae (periphyton) in the river above, below and adjacent to the Site have been monitored continually since 1951. These ongoing studies, conducted by the Academy of Natural Sciences of Philadelphia (ANSP), were designed to assess potential effects of SRS contaminants and warm-water discharges on the general health of the river and its tributaries. The studies look for spatial patterns of biologic disturbance and temporal patterns of change that would indicate improving or deteriorating conditions related to SRS effluents.

The studies include semimonthly surveys of diatom communities, semiannual cursory studies of both diatom and nondiatom algae, and detailed surveys of attached algae every four years. The detailed surveys are done at four sampling stations: three exposed to SRS influence (Stations 3, 5, and 6) and an unexposed reference station upstream (Station 1) (Figure 4-45). Only three of these stations are included in the cursory surveys (Stations 1, 5, and 6).

Potential impacts are assessed by determining whether differences between the exposed and reference stations are greater than or of a different character than would be expected from natural differences in sampling sites. Evidence of adverse effects include elevated abundances of species tolerant of pollution and depressed abundances of species sensitive to pollution; decreased numbers of species; decreased numbers of individuals; or numerical dominance by a small proportion of the species present. Pollution tends to reduce individual and population growth rates in a majority of species, while a few tolerate or thrive in such conditions.

In recent years, diatoms were generally the most abundant algal group, and the dominant diatom species were generally *Melosira varians*, which is tolerant of pollution, and *Gomphonema parvulum*, which is common in the presence of organic pollution. Other commonly found diatoms included *Nitzschia kuetzingiana, Cymbella minuta, Eunotia pectinalis* v. *undulata, Navicula neoventricosa, Navicula pelliculosa, Achnanthes biporoma, and Navicula confervacea.*

The most common species other than diatoms include the green algae *Oedogonium* sp., *Stigeoclonium lubricum*, which is associated with pollution, *Closterium moniliferum, Spirogyra* sp. and *Mougeotia* sp.; the blue-green algae *Schizothrix calcicola*, *Microcoleus vaginatus, Schizothrix arenaria, Porphyrosiphon splendidus, Schizothrix friesii,* and *Microcoleus lyngbyaceus*, many of which are associated with pollution; the yellow-green algae *Vaucheria* sp.; and the red algae *Audouinella violacea, Compsopogon coeruleus*, and *Batrachospermum* sp.

The number of recorded species, other than diatoms, ranged from 7 to 19 from 1985 through 1995. The average numbers of species were greater during the fall surveys than the spring surveys for all stations.

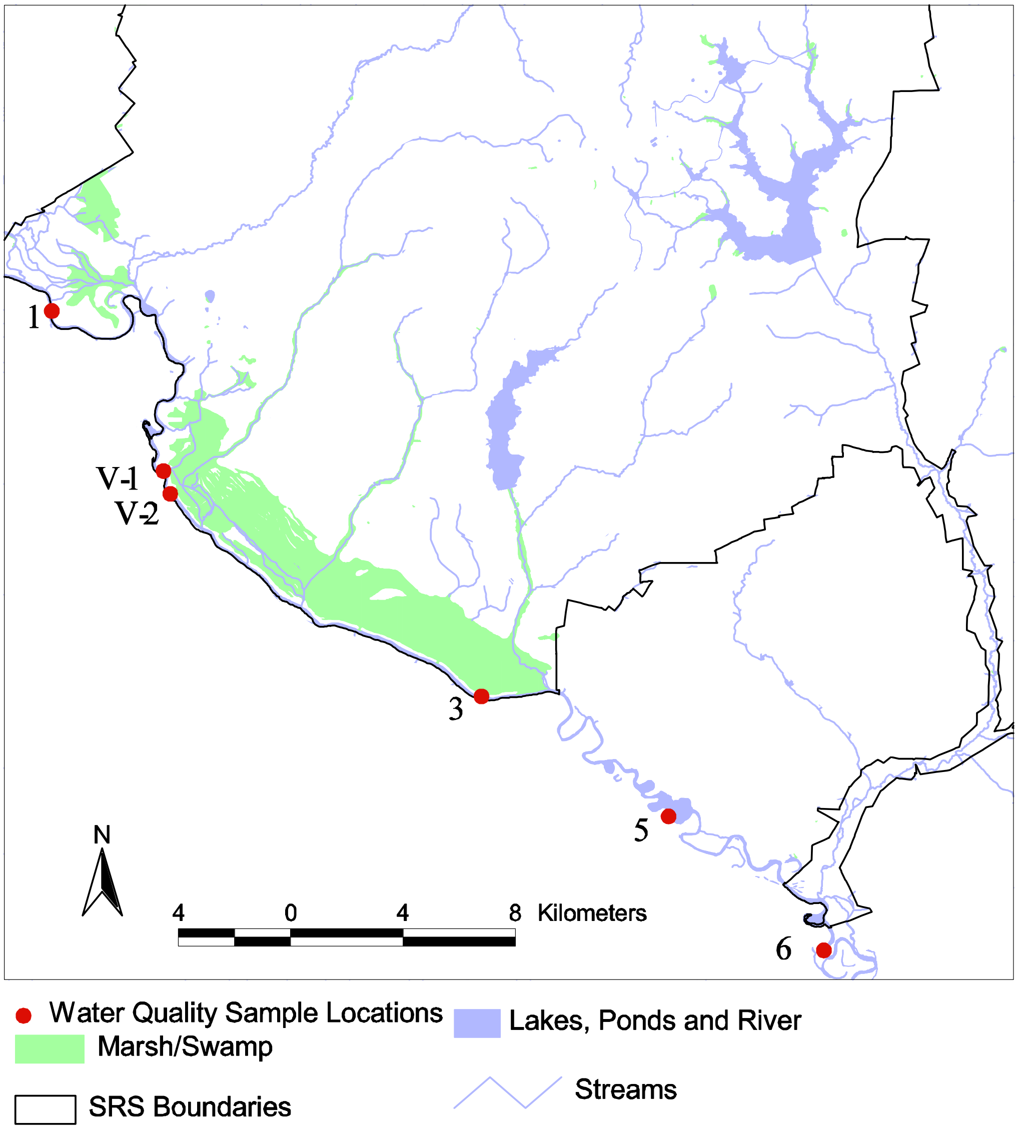

Figure 4-45. ANSP Sampling Stations for the Savannah River

In general, algal growth in recent years has been light to moderate at all stations. Algal-communities were fundamentally similar to those recorded regularly since 1951. The dominant algae consisted of species characteristic of moderate to high nutrient levels and typical of southeastern coastal plain rivers. Algae at exposed and unexposed stations showed evidence of organic pollution, apparently from an upstream source. Results showed no evidence of an adverse impact due to SRS operations.

4.10.3.2 Studies Assessing Dry Weight and Chlorophyll a

In addition to the ANSP studies, which are primarily taxonomic, Savannah River periphyton were studied in 1983-1985 to assess ash-free dry weight and chlorophyll *a* content of material collected from glass slides. Detailed methods and results of these studies can be found in O'Hop et al. (1985), Chimney and Cody (1986), and Specht (1987). These studies of periphyton quantity corroborated the conclusions drawn from the ANSP studies by not finding evidence of appreciable impacts from SRS operations.

4.10.4 Macrophytes

There is no information pertaining to aquatic macrophyte development in the stretch of the Savannah River bordering SRS. Because the river is relatively swift and deep and lacks mainstream backwaters and large structure in this area, one would not expect to find macrophyte beds of significant area or biomass.

4.10.5 Zooplankton

To date, no studies have been performed to assess the zooplankton population in the Savannah River.

4.10.6 Macroinvertbrates

4.10.6.1 Sampling Locations and Methods

Since 1951 the ANSP has sampled the insect community of the Savannah River at three stations (Figure 4-45; Stations 1, 5, and 6). Qualitative sampling methods included dipnetting and collecting insects from submerged substrates, including logs and macrophytes. Quantitative samples were collected using artificial substrates deployed at each location for one month of each sampling event.

As part of the CCWS, macroinvertebrates were collected monthly at nine locations in the Savannah River from October 1983 through September 1985 using Hester-Dendy multi-plate samplers. These locations, an additional station in 1983-1984, and two additional stations in 1984-1985 were sampled for macroinvertebrate drift quarterly (November, February, May, and July) in daylight using 0.5 mm mesh Nitex drift nets. Details of sampling methods can be found in O'Hop et al. (1985) and Chimney and Cody (1986).

4.10.6.2 Results

4.10.6.2.1 <u>ANSP Studies</u>

4.10.6.2.1.1 Qualitative Results

Table 4-25 indicates that for nearly all stations and dates, the levels of species richness have been comparable since 1992. When compared with the earlier surveys, however, there are generally fewer species collected on any given station date in these earlier years, with the exception of the July 1989 survery when additional time was spent collecting invertebrates. Rigorous comparisons should not be made among years and stations for these qualitative data because of potential variations in sampling effort and collecting conditions.

4.10.6.2.1.2 Quantitative Results

A summary of the statistical analyses of six community variables is presented in Table 4-26. This table presents the results of the analysis of variance (ANOVA), and the linear contrasts between the three stations. Linear contrasts were performed within each season of the year when both a significant station effect and a significant date-by-station interaction effect were detected in the ANOVA.

In 1995, for three of the six community variables, significant or marginally signigicant differences were seen among the three stations. The only variable for which a significant station effect was not observed in 1995 was the total abundance of insects. Significant differences among the four sampling seasons were seen for all six community variables. A significant interaction between sampling date and station was observed for three of the community variables. The significant date-by-station interaction, in combination with a signifi cant main effect for these variables, indicates that the pattern of differences among the stations varied with season, or that the pattern of seasonal variation differed among the stations.

Table 4-25. Number of insect species found in qualitative collections on the Savannah River in March, June, September and December 1989-1995

	Survey Period and Station Location											
	March			July			September			December		
Taxa	**1**	**5**	**6**	**1**	**5**	**6**	**1**	**5**	**6**	**1**	**5**	**6**
1995(a)	44	58	47	55	51	50	50	55	44	29	39	29
1994(b)	26	51	48	47	55	52	61	48	50	32	38	44
1993(c)	39	47	39	43	63	63	54	51	55	42	46	53
1992(d)	38	40	36	37	41	41	34	49	48	29	39	39
1991(e)	26	33	31	39	33	30	32	34	34	25	37	31
1990(f)	18	21	36	39	38	35	36	25	28	14	19	35
1989(g)	14	33	30	89	66	76	17	29	25	24	25	31
Overall Mean	29.3	40.4	38.1	49.9	49.6	49.6	40.6	41.6	40.6	27.9	34.7	37.4

	Station 1	Station 5	Station 6
Mean for all quarters and years combined.	39.6	41.6	41.4

[a]ANSP (1996).
[b]ANSP (1995).
[c]ANSP (1994).
[d]ANSP (1993).
[e]ANSP (1992).
[f]ANSP (1991a).
[g]ANSP (1991b); the richness levels for the Spring and Winter surveys for 1989 were calculated without identification of midge larvae (Diptera: Chironomidae), the levels reported here therefore represent the minimum level of taxa richness.

Table 4-26. Summary of Statistical Analyses for 1995 Cursory Sampling Program

For main effects, significant differences are denoted by ‘X’, marginally significant differences by ‘(X)’, and no effect by ‘—’. For linear contrasts, significant differences between stations are specified by the direction of difference, with marginally significant differences in parentheses; no significant contrasts for a variable are denoted by ‘—’. The linear contrasts either specify the stations of difference when no interaction occurred, or the month and station when interactions did occur (e.g., J5 = July at Station 5; S1=September at Station 1).

Variable	Date Effect	Station Effect	Interaction	1 vs. 5	1 vs. 6	5 vs. 6
Abundance of Insects	X	--	--	--	--	--
Number of Taxa	X	X	--	--	6>1	--
Shannon Diversity	X	X	X	J5>J1	(J6>J1)	M6>M5
Community Evenness	X	(X)	X	--		M6>M5
HBI Pollution Tolerance Score	X	X	--	1>5	1>6	--
FBI Pollution Tolerance Score	X	X	X	J1>J5 D1>D5	J1>J6 D1>D6	J6>J6

The results of linear contrasts are particularly noteworthy. Observed values for both HBI pollution tolerance and the number of taxa suggest significantly poorer ecological conditions at Station 1 compared to one or both of the dowstream stations. In addition, for Shannon diversity and the FBI pollution tolerance, the levels at Station 1 during one or more seasons were indicative of poorer ecological conditions that at one or both of the downstream stations.

Also in 1995, the levels of Shannon diversity and community evenness were significantly lower at Station 5 than at Station 6 during March, and the levels of PBI pollution tolerance were significantly higher at Station 5 in July than at Station 6. These three patterns suggest that ecological conditions were more stressful during some periods of the year at Station 5 than at Station 6.

Relative abundances of the dominant insect taxa, the average abundance of insects in each quantitative sample, and the average number of insect taxa (i.e., taxa richness) for each sample were compared among years.

Figure 4-46 presents the relative abundances of the most abundant taxa in the quantitative samples during the past six years of surveys. The patterns in Figure 4-46 indicate that the taxonomic composition, while demonstrating variations among years, has some notable consistencies for the past six years. Specifically, the top 10 taxa for each of these years have composed between 81% and 86% of the total individuals from each sample. In addition, the most abundant taxon on average for these six years has always been the midge subfamily Chironominae, and five taxa have been among the top ten taxa for each of these six years. These five taxa are the midge subfamilies Chironominae and Orthocladiinae, the mayfly *Stenonema*, and the filter-feeding caddisflies *Cheumatopsyche* and *Chimarra*.

4.10.6.2.1.3 Historical Trends

The results of analyses of long-term trends indicate that the taxonomic composition of insects has remained relatively stable in recent years, with five of the most abundant taxa remaining the same during the last six years.

The total abundance of insects in the collections continues to increase. For 1995, the average total abundance at Station 5 was the highest recorded, and the abundance was the second highest recorded for both Station 1 and Station 6. Beginning between 1983 and 1985, this trend of increasing abundance at all three stations has been a consistent pattern in the data set.

Finally, the analyses of taxa richess for the past 35 years indicate that the levels of taxa richness for all three stations during 1995 are within the range of variation seen over the past 10 years.

4.10.6.2.2 Comprehensive Cooling Water Studies (CCWS)

4.10.6.2.2.1 Number of Taxa Collected

During the two-year study, a total of 146 macroinvertebrate taxa were collected from the Savannah River. Of these, 96 taxa were collected from the multiplate samplers and 50 were collected exclusively in the drift. Most dipterans were identified only to family, subfamily, or tribe, rather than to genus or species. Because dipterans were the most abundant group of macroinvertebrates collected, it is likely that level of taxonomic resolution greatly underestimated the actual number of taxa that were in the river.

4.10.6.2.2.2 Dominant Taxa

Dipterans were by far the most common group of macroinvertebrates collected from the multiplate samplers at all stations, accounting for 46.5-73.8% of the organisms collected. The most commonly collected dipterans included chironomids (Chironomini, Orthocladiinae, and Tanytarsini) and blackflies (*Simulium;* O'Hop et al. 1986). Other common insect orders included Trichoptera (caddisflies; 18.5-30.3%), Ephemeroptera (mayflies; 5.2-17.3%), and Plecoptera (stoneflies; 1.2-3.1%). Oligochaetes and amphipods were also locally abundant at one or more stations. *Cheumatopsyche* and *Chimarra* were generally the most common caddisflies on the multiplate samplers; while *Baetis*, *Heptagenia*, and *Stenonema modestum* were the most common mayflies (Chimney and Cody 1986).

The most abundant groups of macroinvertebrates in the drift were oligochaetes and chironomids. Other common taxa included nematodes, Hydracarina, amphipods (*Gammarus, Hyalella*), mayflies (*Baetis*, *Stenonema modestum*, and *Tricorythodes*), caddisflies (*Cheumatopsyche* and *Hydropsyche*), and blackflies (*Simulium*; Chimney and Cody 1986).

4.10.6.2.2.3 Taxa Richness

On the multiplate samplers, the mean number of taxa per sampler ranged from 12.0 to 21.5. Taxa richness at all stations was higher in 1984-1985 than in 1983-1984.

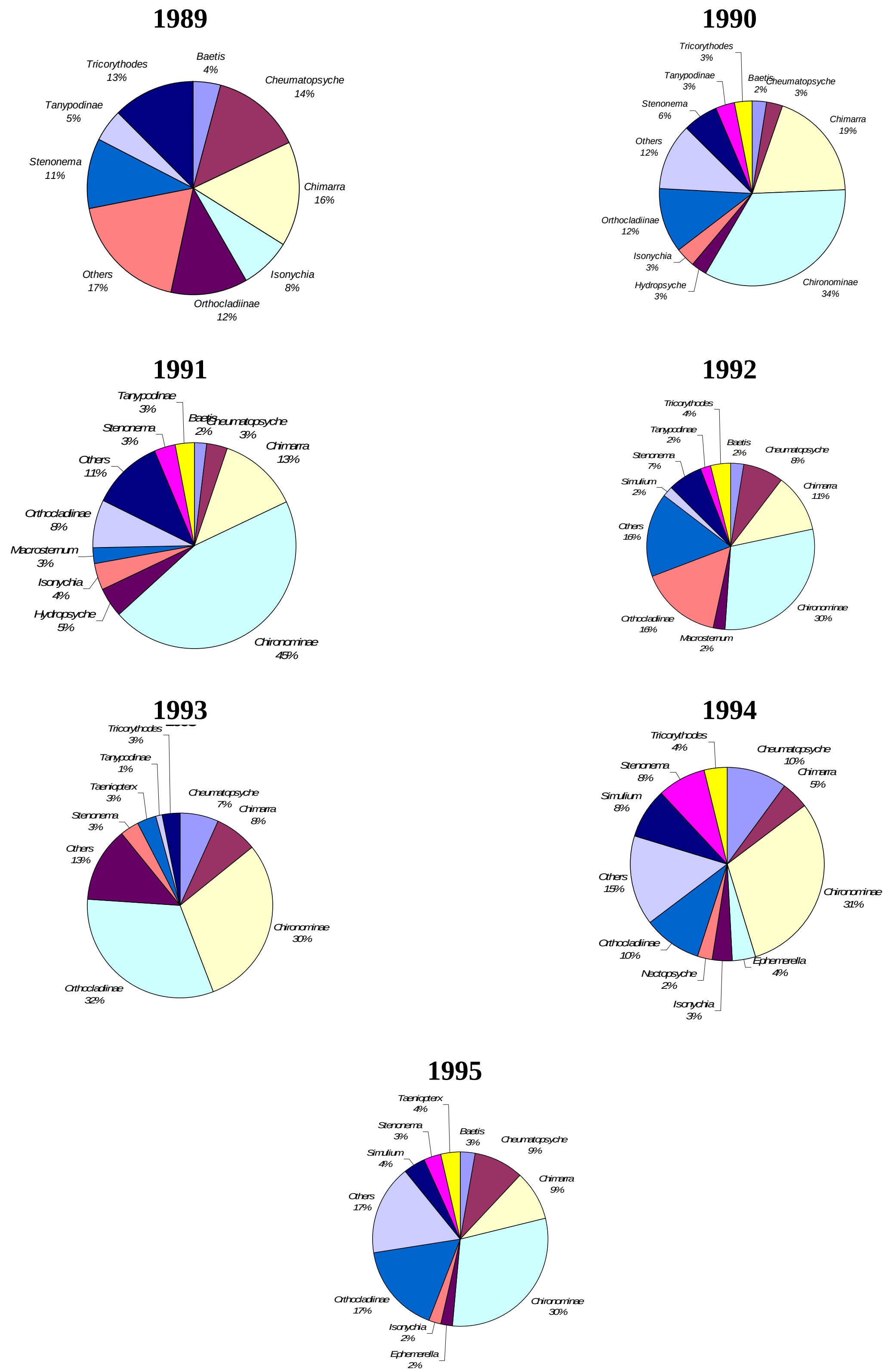

Figure 4-46. Percent Abundance of Insect Taxa Collected in Traps During 1989-1995 Surveys on the Savannah River. The most abundant taxa are labeled.

4.10.6.2.2.4 Densities

The mean density of organisms on the multiplates ranged from 2751.2 organisms/m^2 to 7986.0 organisms/m^2. Macroinvertebrate densities tended to be higher at upstream river stations (River Miles 152.2 to 145.7 [River Kilometer 244.8 to 234.4]) than at downstream stations (River Miles 141.7 to 128.9 [River Kilometers 227.9 to 207.4]). At stations where samplers were placed upstream and downstream from a creek mouth, no differences in invertebrate densities were found that could be related to inflow from the creek.

Macroinvertebrate drift densities ranged from 927.1 to 7298.7 organisms/1000 m^3). Drift densities were higher at all stations in 1984-1985 than in 1983-1984. No spatial trends were observed for drift densities, except that densities were usually slightly higher just downstream from both thermal and nonthermal tributary streams. Drift densities were generally highest in the spring (May) and lowest in the summer (July; Chimney and Cody 1986).

4.10.6.2.2.5 Biomass

Mean biomass on the multiplate samplers ranged from 0.387 to 0.805 g/m^2. No distinct spatial or temporal trends were observed for biomass.

4.10.7 Fish

4.10.7.1 Introduction

The ANSP began sampling Savannah River fish in 1951 to determine the effects, if any, of discharges from the SRS on the fish community. The main goals of the study are to assess the condition of the fish communities in the river upstream, adjacent to, and downstream of SRS; assess spatial differences in the community which may be the result of SRS operations; and assess the temporal trends due to SRS, other anthropogenic inputs, or natural variation (ANSP 1996). Currently the program contains three elements: comprehensive surveys of a variety of habitats at four stations (Stations 1, 3, 5, and 6; Figure 4-45) conducted once every four-five years; annual cursory surveys at Stations 1, 5, and 6; and Vogtle surveys at two stations (V-1 and V-2) associated with Georgia Power's Plant Vogtle. Sampling is concentrated in the slower river backwater areas and not in the main channel. The ANSP surveys provide information on occurrence, abundance, habitat use, size-structure, and growth rates of fish.

Most other fisheries studies in the Savannah River can be grouped into two categories: those emphasizing the reproductive requirements and success of striped bass (*Morone saxatilus*) and those designed to assess the impacts of SRS operations on fish spawning and the survival of fish eggs and larvae. Early efforts concentrated on the identification of striped bass spawning areas and the assessment of tide-gate operations on striped bass spawning success (Rees 1973 and 1974; Gilbert et al. 1986). Interest in this topic has continued with studies on the reproduction, recruitment, and habitat requirements of striped bass (Van Den Avyle et al. 1990; Wallin et al. 1991).

Programs designed to assess the impacts of SRS operations began in 1977 with studies on the entrainment of American shad eggs in the SRS Savannah River intakes. Beginning in 1982, SRS initiated a much larger project in the midreaches of the Savannah River that, at its greatest extent, encompassed 26 sample stations in the river (plus 36 more in oxbows and the mouths of tributary creeks) between River Miles 29.6 and 187.1 (River Kilometers 48 and 301). The objective to assess entrainment rates at SRS water intakes and, more generally, the impact of SRS operations on fish spawning. However, this study also generated considerable information on spatial distribution, temporal distribution, and relative abundance of ichthyoplankton in the Savannah River.

A third and smaller category of studies concerned the spawning requirements and reproductive success of shortnose sturgeon. These studies are summarized in Chapter 3 - Wildlife and Threatened and Endangered Species of the SRS.

4.10.7.2 ANSP Surveys

Between 1980 and 1995, 59 species have been collected in the annual program with a median of 33 species per year. The number of species collected has increased, but this is attributed to changes in sampling protocol, not changes in the fish communities.

In most years, differences in species richness have been constant among stations with upstream Station 1 having the most species and the farthest downstream station (Station 6) having the least (ANSP 1996).

Catch rates in 1995 were lower for some species than in past years. Bluespotted sunfish (*Enneacanthus gloriosus*), pirate perch (*Aphredoderus sayanus*), spotted sunfish (*Lepomis punctatus*), and banded pygmy sunfish (*Elassoma zonatum*) numbers have been decreasing since the late 1980's. The taillight shiner (*Notropis maculatus*), golden shiner (*Notemigonus crysoleucas*), spottail shiner (*N. hudsonius*), and pumpkinseed (*L. gibbosus*) were rare or absent in 1995, despite high catches in the recent past. Other species which had been increasing in abundance, decreased in 1995. These included Eastern silvery minnow (*Hybognathus regius*), black crappie (*Pomoxis nigromaculatus*), spotted sucker (*Minytrema melanops*) and warmouth (*L. gulosus*). For some relatively uncommon species, the 1995 catch rates were further depressed (gizzard shad [*Dorosoma cepedianum*], creek chubsucker [*Erimyzon oblongus*]), or the species were not collected at all (lake chubsucker [*E. sucetta*], golden topminnow [*Fundulus chrysotus*], lined topminow [*F. lineolatus*], flier [*Centrarchus macropterus*], and swamp darter [*Etheostoma fusiforme*]). Some of the noted decreases may be attributed to a change in sampling procedures (from rotenone to electrofishing), but some are a continuation of decreasing trends noted in previous years.

A few species were caught more commonly in 1995 than in the past, including bowfin, whitefin shiner, brook silverside, and the pugnose minnow. The dollar sunfish, redbreast sunfish, and mosquitofish were common, as usual.

There were differences in occurrence and abundance of species among the stations, however, most station differences are not consistent over years.

Because of the change in technique in 1995, it is difficult to determine with certainty the cause of the observed differences. Recent trends in the loss of some species associated with aquatic vegetation can be attributed to the loss of macrophyte cover in the sampling areas. Macrophyte beds have been declining in the sampling areas since the 1970s.

The 1980-1995 surveys show little evidence of long-term increases or decreases in species abundance. Many species show temporary increases in abundance. Such increases may represent strong year classes that persist for one to several subsequent years. However, there is no evidence of detrimental effects on the fishery of the Savannah River in the vicinity of SRS (ANSP 1996).

4.10.7.3 Miscellaneous Fish Studies

Burger et al. (2002) reported levels of arsenic, cadmium, chromium, copper, lead, manganese, strontium and mercury from 11 species of fish from upstream of, along and downstream of SRS. While there were recognizable patterns based on trophic levels of the fish investigated, no geographical patterns would suggest that SRS is the source for any of these contaminants. Burger et al. (2001a) reported levels of mercury and selenium from a number of fish species from upstream of, along, and downstream of SRS. As above, there were recognizable patterns in mercury concentrations related to trophic levels of the fish investigated, but no geographical patterns suggested that SRS is the source for either of these contaminants.

Additional general information (relative abundance, historical distribution, preferred habitat, etc.) concerning fishes of the Savannah River can be found in Marcy et al. (2005).

4.10.7.4 Studies Emphasizing Striped Bass Reproductive Success

Early studies concentrated on locating striped bass spawning areas (Smith 1970; McBay 1968; Rees 1973, 1974). These studies suggested that the primary spawning area for striped bass was in the tidally influenced zone 30-40 km (18.5-25 mi) upstream from the Savannah River mouth. Attention subsequently shifted to the effects of tide-gates in the tidally influenced lower Savannah River on striped bass eggs and larvae. The lower Savannah River is composed of three main channels: the front river, which carries most of the flow and is heavily industrialized; and the middle and back channels, which are relatively shallow and unimpacted by industrial development. The tide-gate is on the back river. It prevents water from moving downstream in the back river and diverts it into the front river. Dudley and Black (1978) found that operation of the tide-gate increased salinity in striped bass spawning areas in the lower river and suggested that this increase could adversely affect striped bass egg survival. They also concluded that the back river is the principle spawning area in the lower river when the tide-gate is not operating. However, much of the back river is not used for spawning when the tide-gate is in operation. These findings were later corroborated by other research (Gilbert et al. 1986).

While early studies emphasized the importance of striped bass spawning areas in the lower river, later work (Paller et al. 1984) demonstrated that striped bass spawn throughout the mid-reaches of the Savannah River, as far north as Augusta. Additional studies were subsequently conducted to assess the importance of spawning sites in the mid-reaches of the Savannah River (Van Den Avyle et al. 1990; Wallin et al. 1991). Assessment of the relative importance of mid-river spawning sites was considered especially important in light of the steady reduction in striped bass spawning success observed in the lower river. These studies are part of a larger effort to assess reproduction, recruitment, and habitat requirements of striped bass in the Savannah River.

4.10.7.5 Studies Emphasizing SRS Impacts and General Ichthyoplankton Distribution

McFarlane et al. (1978) was the first to assess the entrainment of ichthyoplankton and impingement of adult and juvenile fish at the SRS Savannah River intakes. He calculated that approximately 7 million fish eggs and 20 million fish larvae were entrained during April-June 1977. McFarlane (1982) also studied the occurrence of American shad eggs in one of the two large SRS cooling water intake canals. He concluded that the relatively low turbulence within the intake canal was insufficient to keep the semibuoyant American shad eggs in suspension. Upon settling to the bottom, the eggs either suffocated in the soft bottom sediments or were consumed by scavengers, thus justifying the assumption of total egg loss for all eggs drawn into the intake canals.

More extensive studies on SRS impacts were initiated in 1982 and continued through 1985. The basic objective of these studies was to assess spawning activity and ichthyoplankton distribution in the mid- and lower Savannah River and its tributaries by evaluating the possible impact of thermal discharges from SRS and the removal of river water for the secondary cooling of nuclear reactors. Special emphasis was placed on evaluating ichthyoplankton production in Steel Creek because of concern about possible impacts from the restart of L Reactor.

Numerically dominant ichthyoplankton taxa in the Savannah River during 1983-1985 were the anadromous blueback herring and American shad and the nonanadromous threadfin and gizzard shad. Sunfish larvae were also abundant. Spotted sucker larvae were abundant during 1985, and crappie and minnow larvae were abundant during 1983 and 1984. Ichthyoplankton densities in the river were characterized by pronounced temporal changes. The highest densities usually were observed during April and May, although larvae and eggs of various species typically occurred from late February through July. Statistical analysis indicated that most of the variability in ichthyoplankton density was associated with the sampling date, reflecting the influence of seasonal changes in temperature and spawning period on spawning activity. River level also seemed to be an important factor influencing the abundance of species such as blueback herring, minnows, and crappie, which often spawn most successfully in flooded areas. However, river level had less influence on the abundance of species such as American shad and striped bass, which spawn directly in the main river channel.

Potential impacts of SRS on the Savannah River ichthyoplankton assemblage were categorized as plume entrainment and intake entrainment. Plume entrainment occurred when larvae drifting down the Savannah River passed through the thermal plumes at the mouths of Beaver Dam Creek and Fourmile Branch (these streams formerly received thermal discharges from the D-Area Power Plant and C Reactor, respectively). Intake entrainment occurred when fish larvae and eggs were withdrawn from the Savannah River with the water used to cool the SRS reactors.

Investigations of ichthyoplankton distribution and abundance provided no evidence of impacts on the Savannah River ichthyoplankton assemblage from plume entrainment during 1982, 1983, or 1984. During 1985, there were indications that the abundance of spotted sucker larvae may have been reduced due to passage through the Fourmile Branch plume, although the data were inconclusive because of the small number of larvae collected.

Several factors were responsible for the general absence of detectable plume entrainment impacts at SRS. One was river flooding, during which the Savannah River overflows its banks, causing the discharge from Fourmile Branch and Beaver Dam Creek to disperse (and cool) in the floodplain before entering the river. Flooding often coincided with major spring spawning periods, thus reducing the number of larvae exposed to the thermal plumes. Another factor that mitigated plume entrainment was dilution of the thermal plumes with Savannah River water. Thermal imagery studies indicated that temperatures in the Fourmile Branch plume dropped as much as 10°C (18°F) within 400 m (1300 ft) of the creek mouth due to mixing with relatively cool Savannah River water (Bristow and Doak 1982).

The mechanism of intake entrainment losses at the SRS water intakes differed for fish eggs and larvae. Larvae probably were killed by temperature increases and shear forces after being drawn into the reactor cooling system. While some eggs may have been destroyed in this fashion, most were lost because they settled to the canal bottom in the relatively quiescent canal waters (McFarlane 1982).

Intake entrainment at the SRS water intakes was influenced in part by including spawning in the intake canals, water withdrawal rate, ichthyoplankton density, and the spatial distribution of ichthyoplankton in the river in relation to the intake canals. Several taxa, especially gizzard shad in 1982 and 1983, crappie in 1983 and 1984, and spotted sucker in 1985, occurred in unusually high densities in the intake canals, suggesting that they were spawned there. Species that spawned in the intake canals tended to suffer increased entrainment. Similarly, when drifting eggs and larvae were more abundant, more were entrained, although percentage losses did not necessarily increase. The spatial distribution of the fish eggs also influenced entrainment losses. During May 1984, American shad eggs were less abundant near the South Carolina side of the river where the intake canals were located, resulting in less entrainment of this species. Water withdrawal rates were particularly important. Higher rates of water withdrawal increased ichthyoplankton entrainment, especially when river levels were low and SRS water withdrawals represented a greater proportion of the total river discharge.

Paller et al. (1984, 1985) and Paller and Saul (1986) conducted impingement and entrainment studies from 1983-1985. During this period, an average of 7603 fish were impinged on river water pump intake screens each year. Species most affected by impingement were blue-spotted sunfish and threadfin shad. Entrainment losses averaged 10.0 x 10^6 eggs and 18.8 x 10^6 larvae annually. Entrainment losses were primarily American shad and other clupeids.

Dames and Moore (1992) performed additional entrainment-related studies during 1991. The objectives of the studies were to collect information on the spatial (i.e., horizontal and vertical) distribution of ichthyoplankton near the mouths of the SRS intake canals and collect general information on the relative abundance, species composition, seasonal occurrence, and abundance of ichthyoplankton near the SRS water intakes. Dames and Moore (1992) collected 33 taxa during this study. American shad and striped bass accounted for 76% and 5%, respectively, of the fish eggs that were collected. Minnows and spotted sucker composed most of the fish larvae. These patterns were generally similar to those observed during the earlier studies. Four sturgeon larvae were collected, but it was not known if these were larvae of the Atlantic sturgeon or the endangered shortnose sturgeon.

Ichthyoplankton were more abundant at night with densities tending to rise in the evening and fall in the morning. Several statistical procedures were used to adjust densities of American shad eggs for the variation associated with time of day. Controlling this variation led to more accurate assessments of horizontal and vertical differences in egg distribution near the intake canals. Egg densities were significantly higher near the bottom and, depending on the longitudinal position in the river, significantly different between banks.

Relatively low densities of American shad eggs along the South Carolina bank (where the intakes are located) meant that a smaller proportion of these eggs were subject to entrainment than if the eggs were uniformly distributed. Density in the South Carolina sector of the river just above the 1G intake canal has an average approximately 30% lower than the average density in the river as a whole. Based on a comparable analysis, the risk of entrainment from the river just above the 3G intake canal was only 65-70% as great as expected by the rate of water removal (Paller et al. 1995).

Paller (1994) evaluated entrainment losses in light of low Savannah River levels and recent changes in the SRS mission. He found entrainment was greatest when periods of high river water usage coincided with low river discharge during the spawning season. The two species of greatest concern, American shad and striped bass, spawn primarily during April and May in the mid-reaches of the Savannah River. An analysis of Savannah River discharges during April and May 1973-1989 indicated the potential for entrainment of 4-18% of the American shad and striped bass eggs that drifted past the SRS (assuming that percentage entrainment was equal to percentage water withdrawal). Average April and May entrainment rates would have consistently exceeded 12% during the low water years of 1985-1989. This analysis assumed the concurrent operation of L, K, and P Reactors.

Additional scenarios investigated were 1) shutting down L and P Reactors, maintaining minimum flows to Steel Creek (required to protect aquatic habitat), and operating K Reactor with a recycle cooling tower; and 2) shutting down L and P Reactors, eliminating minimum flows to Steel Creek, and operating K Reactor with a recycle cooling tower. The former scenario reduced potential entrainment to 0.7-3.3%, and the latter scenario reduced potential entrainment to 0.2-0.8%. Cessation of reactor operatins and the concomitant lack of need for cooling water withdrawals have reduced entrainment substantially.

Burger et al (2001a) report levels of mercury and selenium in 11 species of fishes from above, along, and below the SRS. For mercury, top predators such as bowfin (*Amia calva*) and largemouth bass (*Micropterus salmoides*) had highest average concentrations (0.94 ppm and 0.46 ppm respectively) while omnivores such as bluegills (*Lepomis macrochirus*) and redbreast sunfish (*Lepomis auritus*) had lowest (0.14 ppm and 0.13 ppm respectively). It was reported that larger, and therefore older, specimens of all species tended to have higher mercury concentrations than smaller.

Two species, largemouth bass and yellow perch (*Perca flavescens*) had significantly higher concentrations of mercury downstream from SRS than upstream while bowfin had significantly higher concentrations above SRS than downstream or along SRS. Redbreast sunfish had significantly higher concentrations of mercury along SRS than upstream but no samples were available from downstream. Selenium concentrations were more complicated to explain than mercury. For selenium, channel catfish (*Ictalurus punctatus*) had the lowest concentration (0.21 ppm) while redbreast sunfish had the highest concentration (0.64 ppm).

Three species, bowfin, largemouth bass, and spotted sucker (*Minytrema melanops*) had significantly higher concentrations of selenium in fish from upstream of SRS than along or downstream (spotted sucker samples were not available downstream). Six species, channel catfish, chain pickerel (*Esox niger*), yellow perch, black crappie (*Pomoxis nigromaculatus*), bluegills, and redbreast sunfish, had significantly higher concentrations of selenium along SRS than above or below (no samples of redbreast sunfish were available from downstream).

Burger et al. (2002) report concentrations of arsenic, cadmium, chromium, copper, lead, manganese, mercury and strontium in fish species from above, below and along the SRS. All species showed a positive correlation between size and metal concentration except for strontium. For strontium there was a significant negative correlation for bowfin, largemouth bass, yellow perch and redear sunfish and there was no significant correlation for the other species examined. Higher trophic level fishes tended to have higher levels of contaminants. A few species had locational differences in contaminant loads.

For arsenic, bowfins had highest levels upstream while chain pickerel and American eel (Anguilla rostrata) had higher levels below SRS and spotted sucker had higher levels along the SRS (no samples of spotted sucker were available from below SRS). For cadmium, channel catfish and American eels had higher concentrations above SRS while spotted sucker had higher levels along the SRS. For chromium, black crappie had higher concentrations along the SRS while yellow perch had highest concentrations downstream. Bowfin had highest copper concentrations downstream as did redear sunfish while American eel had highest concentrations up stream and spotted sucker had higher concentrations along SRS.

For lead, the three species that had significant differences, bowfin, chain pickerel, and bluegill, had highest concentrations upstream. Manganese concentrations in largemouth bass and bluegill are highest upstream while concentrations in black crappie are highest downstream; redear sunfish have similar concentrations at and below SRS, but concentrations above SRS are much lower. Mercury concentrations in bowfin and redbreast sunfish are highest upstream of SRS while largemouth bass have highest concentrations below SRS. Bowfin had highest concentrations of strontium along the SRS while strontium in largemouth bass was highest above the SRS.

4.10.7.6 Radionuclides in Fish

Burger et al. (2001b) examined radiocesium (^{137}Cs)in the fishes of Steel Creek and the Savannah River. Fish collected from Steel Creek had significantly more ^{137}Cs (about an order of magnitude) than those captured in the Savannah River. Fish sampled from above SRS and from below SRS had no significant differences in ^{137}Cs except for bowfin and redear sunfish (*Lepomis microlophus*). Bowfin from above SRS had median concentrations of 0.0055 Bq/g compared to median values of 0.002 below SRS. For redear sunfish the similar values were 0.002 Bq/g and 0 Bq/g (below detection limit), so that even thought the differences are significant, they run counter to what would be expected if SRS is a significant source of ^{137}Cs in Savannah River fish.

4.10.8 References

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5.0 WETLANDS AND CAROLINA BAYS OF SRS

The SRS Savannah River swamp borders 16 km (10 mi) of SRS on the southwest. Bottomland hardwood forests border the six streams that drain SRS. Other SRS wetlands include Carolina bays, former cooling-water canals and reservoirs, former farm ponds, and freshwater marshes. The main streams on SRS are Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs. SRS cooling water discharges have influenced all of these streams except Upper Three Runs. The discharges, as much as 10 to 20 times the natural flows, overflowed the streams' original banks along much of their length, scouring upstream sediments and depositing them in deltaic fans where the streams enter the river swamp. This reduced or modified the original bottomland hardwood forests along much of Fourmile Branch, Pen Branch, and Steel Creek.

SRS wetlands support a variety of vegetation species and forms. Species that are characteristically dominant in a given wetland type may differ depending on whether the wetland is undisturbed, has received thermal effluents, or is undergoing successional revegetation following cessation of cooling-water releases. Also, in wetlands undergoing successional revegetation, species may differ depending on the stage of succession.

5.1 SITEWIDE WETLAND RESOURCES

5.1.1 Recent Sitewide Wetland Inventory

Several inventories of SRS wetlands have been developed using aerial photography (Mackey et al. 1985; Shields et al. 1982; Schalles et al. 1989). Shields et al. (1982) reported that approximately 199 Carolina bays exist on SRS, and Mackey et al. (1985) indicated that wetlands cover more than 21% of the site. More recently, Kirkman et al. (1996) increased that count to 299 Carolina bays and bay-like depressional wetlands. The primary wetland cover types summarized in Mackey et al. (1985) are bottomland hardwood forest, cypress-tupelo swamp forest, scrub-shrub areas, emergent marsh, and open water. Most of the cypress-tupelo swamp forest is in a part of the Savannah River swamp. Scrub-shrub and emergent marsh areas are found in post-thermal areas of the SRS Savannah River swamp and in the post-thermal streams (Fourmile Branch, Pen Branch, and Steel Creek) along the shoreline of the former cooling reservoirs, and in Carolina bays.

Table 5-1 summarizes the estimated areas of wetland types on SRS as derived from a land-cover and landuse geographic information system (GIS) database developed from multidate aerial photography taken in the late 1980s (Guber 1993). Most of the pond/reservoir class in Table 5-1 is from the Par Pond system and L Lake. Figure 5-1 is a map of the wetlands as derived from the landcover and landuse GIS database. As with all photographic surveys, these aerial estimates and maps provide guidance to locations and types of wetlands on SRS; however, field verification would be needed for detailed mapping and wetland delineation. Figure 5-2 identifies the USGS quadrangle sheets available for SRS. The GIS information has been plotted on these 7.5 min. maps and is used by scientists studying SRS wetlands.

Table 5-1. Estimate of Current SRS Wetlands Derived from Landcover and Landuse Geographic Information System (GIS) Database and of Historic SRS Wetlands Derived from 1943 and 1951 Black and White Aerial Photography[a]

Wetland Class[b]	Historic Area (ha)[c]	Recent Area (ha)
bottomland hardwood	15,077.1	13,823.7
swamp forest	2,340.7	2,331.7
scrub-shrub	1,548.1	843.1
emergent wetlands	407.7	519.4
aquatic beds		85.9
intermittent flooded		51.2
non-vegetated wetland		24.8
Carolina bay		15.0
open water	438.2	
pond/reservoirs		1,528.9
Savannah River		381.9
streams		138.4
canals		45.5
other waterways		29.7
drained wetlands	319.5	
Total	**20,131.3**	**19,819.2**

[a]Landcover and landuse Geographic Information System recently derived wetland classes are those as described in Ezra and Tinney 1985, Guber 1993. Historic area based on estimates by Christel-Rose 1994.
[b]Direct comparisons are not possible because of the quality and resolution of the two data sets.
[c]To convert hectares to acres, multiply by 2.471.

A constructed treatment wetland was recently built to provide metal removal from a permitted wastewater outfall in A-Area. While this is not a natural wetland feature of the SRS, the ability of wetlands to improve water quality is being utilized in a cost-effective manner for site cleanup. The facility and its performance are documented in Nelson et al. (2002; 2003). Similar facilities for additional outfalls to meet new National Pollutant Discharge Elimination System (NPDES) permit requirements are anticipated in the future.

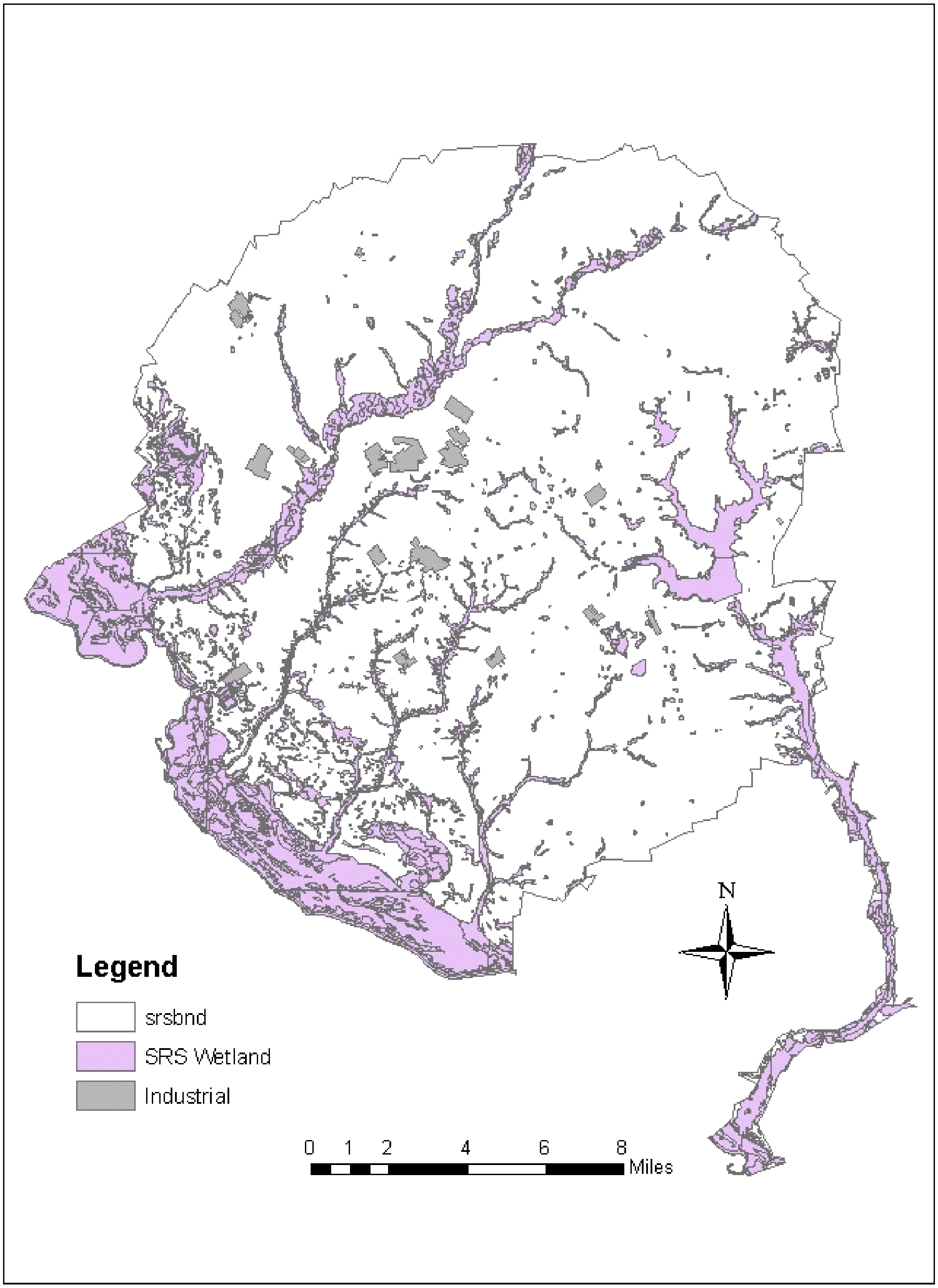


Figure 5-1. Sitewide Wetlands Map

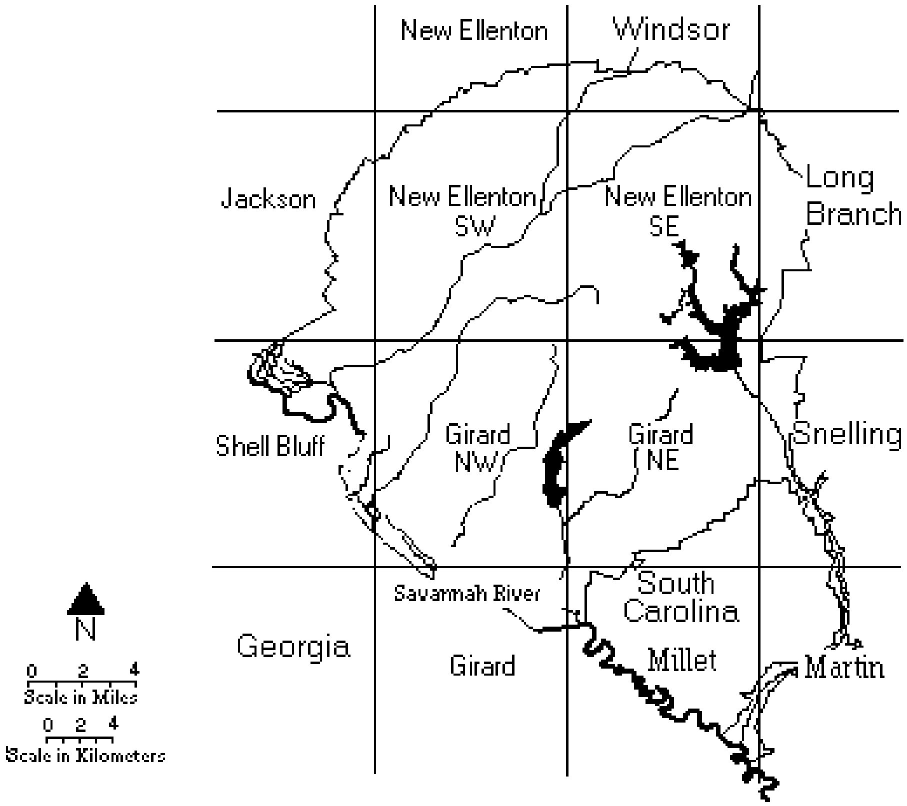


Figure 5-2. SRS Map Showing Names of USGS Quadrangles

5.1.2 Pre-SRS Wetland Distribution

To evaluate long-term changes or trends in SRS wetlands Christel-Rose (1994) evaluated vertical aerial photography of SRS, taken principally in January and May 1951 with supplemental photography in March, April, and May 1943. Six wetland classes were identified: bottomland hardwood forest, swamp forest, open water area, bottomland scrub-shrub, emergent wetland, and drained wetland (wetland that appeared to have been ditched for conversion to agricultural uses). These data are summarized in Table 5-1. When pre-SRS data are compared with the 1989 landcover and landuse GIS-derived wetland classes, the principle trends identified are a decline in bottomland hardwood forest and an increase in large bodies of open water. This change is from the discharge of cooling water effluent to SRS steams (principally Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek) and the result of the construction of two large cooling water systems on SRS: the Par Pond system on Lower Three Runs in 1958 and L Lake on Steel Creek in 1985. Differences between the pre-SRS wetlands estimates and the 1989 estimates (Table 5-1) may vary based on the quality and types of photographic material available for the two time periods; because of this, averages are indicators of only general trends and potential changes. Figure 5-3 illustrates historic SRS wetlands derived from aerial photographs taken before the land was purchased for the SRS.

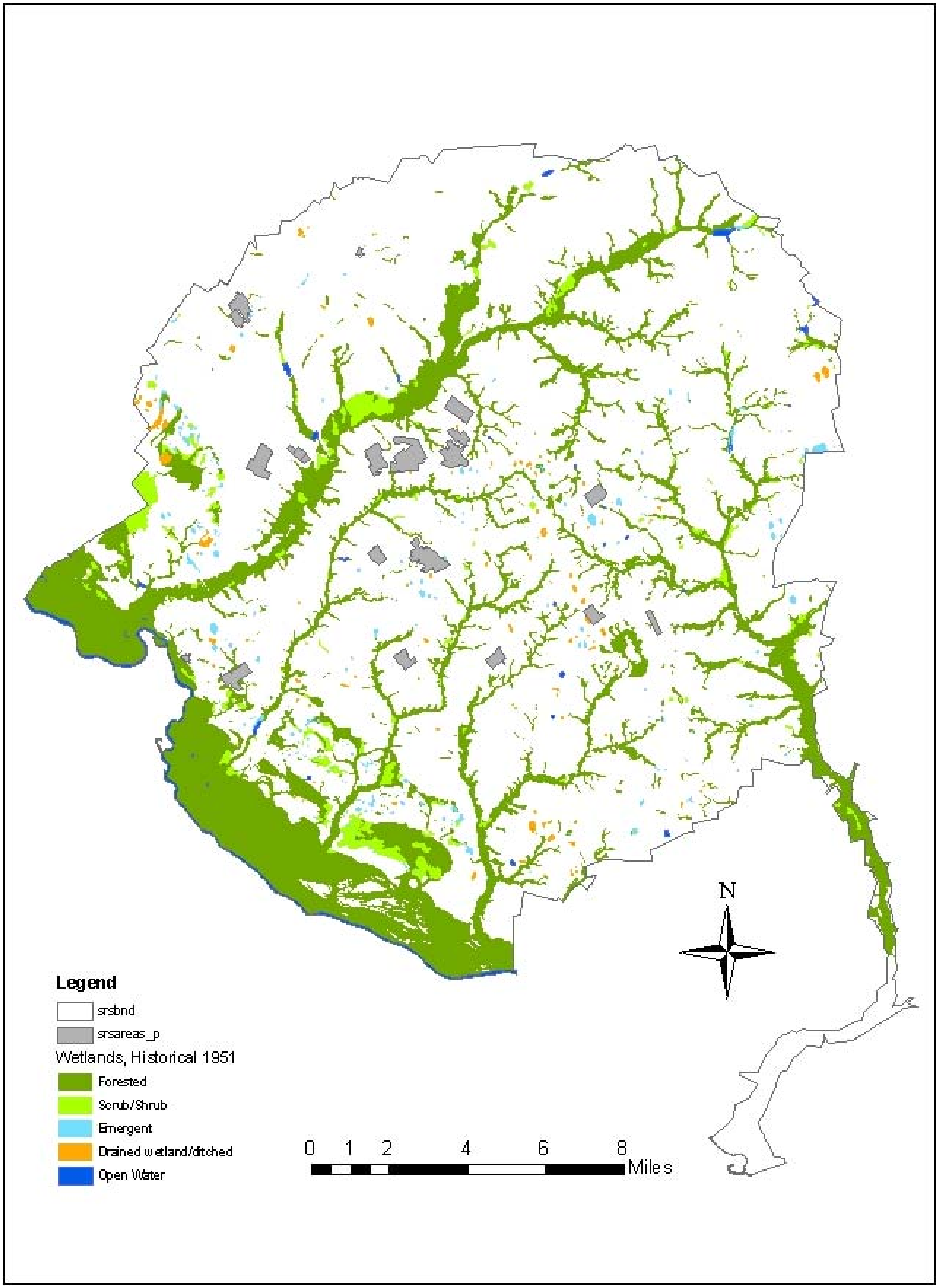


Figure 5-3. Area Wetlands Before Establishment of SRS

5.2 SAVANNAH RIVER SWAMP

5.2.1 Introduction

About 3800 ha (9390 acres) of the Savannah River swamp lie within SRS between Upper Three Runs Creek and Steel Creek; this area is referred to as the SRS Savannah River swamp. The SRS Savannah River swamp borders the Savannah River for approximately 16 km (10 mi) and has an average width of about 2.2 km (1.4 mi) (Figure 5-4). A levee and embankment run along the east side of the Savannah River. Breaches in the levee allow water from Beaver Dam Creek, Fourmile Branch, and Steel Creek to flow to the river. The combined discharges of Steel Creek and Pen Branch enter the river near the southeast edge of the SRS Savannah River swamp.

On the landward side of the levee, the Savannah River swamp contains stands of bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) trees, bottomland hardwoods, scrub-shrub, and open marsh areas. During periods of high water, river water overflows the levee and floods the swamp. The river begins to overflow into the swamp when river elevations reach between 27 and 28 m (88.5 and 92 ft) above mean sea level (MSL) or at flows of about 15,300 cfs. During flooding, the water from SRS streams flows through the swamp parallel to the river and enters the river downstream of Steel Creek.

A variety of environmental perturbations influence the wetlands community structure of the SRS Savannah River swamp. Like most riverine swamps of the southeastern United States, this forest was logged selectively. Virtually all of the swamp was dominated by second-growth timber in the early 1950s. When SRS initiated operations, the swamp was characterized primarily by a closed-canopy forest of bald cypress and water tupelo in the deep water sites and poorly drained sloughs, and by bottomland hardwoods on the island ridges (Sharitz et al. 1974a; Mackey 1987; Tinney et al. 1986).

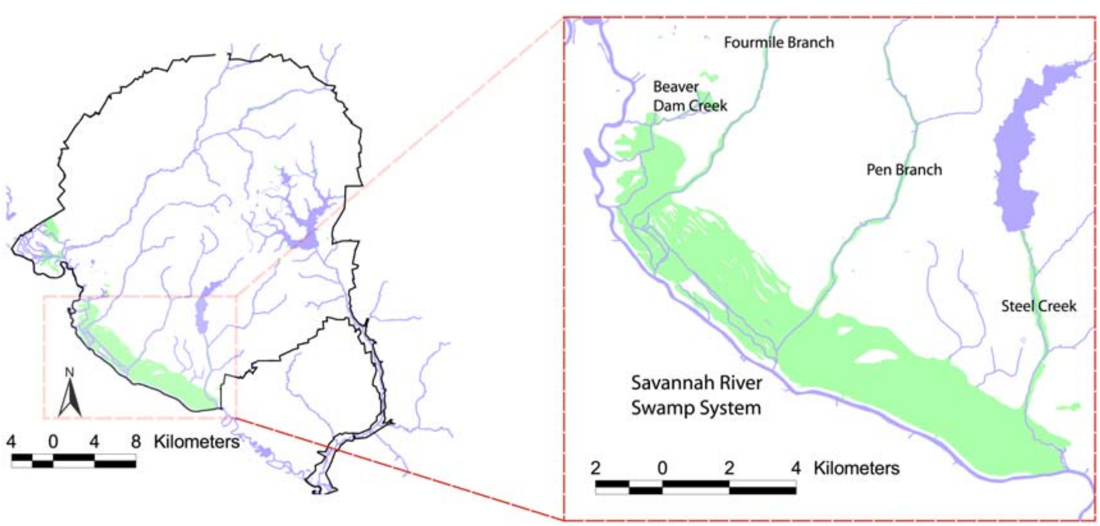


Figure 5-4. Location of the SRS Savannah River Swamp

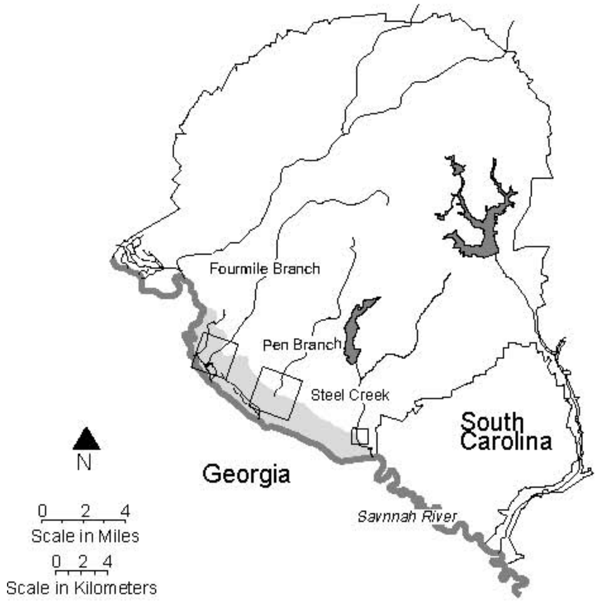
The SRS Savannah River swamp currently receives thermal effluent from the D-Area power plant and formerly received thermal effluent from C Reactor (until late June 1985), K Reactor (until summer 1988), and L Reactor via L Lake (until summer 1988). The discharge of cooling water effluents from the SRS reactors and the coal-fired power plant modified the SRS Savannah River swamp in several ways. Deposition of sediment from erosion associated with increased flow to creeks formed sedimentation deltas in the swamp (Figure 5-5) (Ruby et al. 1981). Water temperatures in those portions of the swamp near where thermal effluents entered the swamp exceeded the thermal tolerances of most vascular plant species and caused extensive forest mortality (Sharitz et al. 1974b; Tinney et al. 1986; Mackey 1987). Finally, the input of increased volumes of cooling water from the creeks into the SRS Savannah River swamp modified the hydrologic regime of the system. Flood-control activities on the Savannah River further influenced this change in hydrologic regime (Figure 5-6). Examination of long-term discharge fluctuations in the Savannah River revealed that following construction of Lake Strom Thurmond in the early 1950s, water levels in the river have been neither as high nor as low as they were prior to dam construction. SRS effluent discharges maintained relatively higher water levels in the SRS Savannah River swamp near the deltas throughout the year. Dry periods necessary for extensive regeneration of the dominant woody swamp-forest species seldom occurred under this modified hydrologic regime (Sharitz et al. 1986).

5.2.2 General Wetland Patterns of the SRS Savannah River Swamp

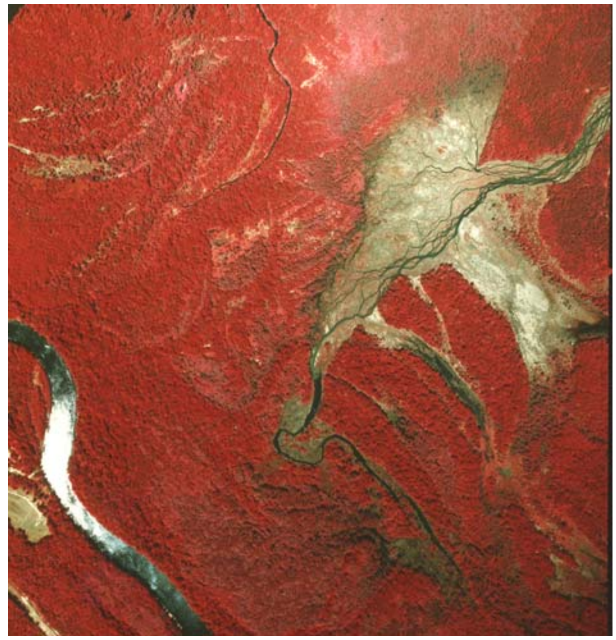
5.2.2.1 Pre-SRS Logging of the Swamp

To understand the status of the SRS Savannah River swamp prior to SRS operations, an historical review of pre-SRS photography of the swamp was conducted. To identify the extent of logging activities in the swamp, black-and-white, vertical, aerial photography taken in 1938, 1943, and 1951 was interpreted to locate the logging railroads, roads, haul lines, timber staging areas, and clear cuts in the SRS portion of the Savannah River swamp.

Lumbering was an important industry in early America and exploitation of the abundant swamp and bottomland-forest resources for export rendered barrel staves and heads from the oaks; shingles from the durable cypress wood; building lumber, turpentine, pitch, and tar from loblolly pine; and naval stores (ship building supplies) from a combination of the timbers (Herndon 1979). Timber companies were early supporters of the railroads, as the lines were extended toward regions of vast virgin timber (Scott 1979). Where swampy terrain inhibited conventional methods of moving timber, the lumber companies built mills along railroads and constructed their own railways into the swamps to facilitate movement of timber (Fetters 1990). Usually, they used cypress trees to construct elevated trestles into otherwise inaccessible areas. This apparently was the case in the area of SRS (Fetters 1990).

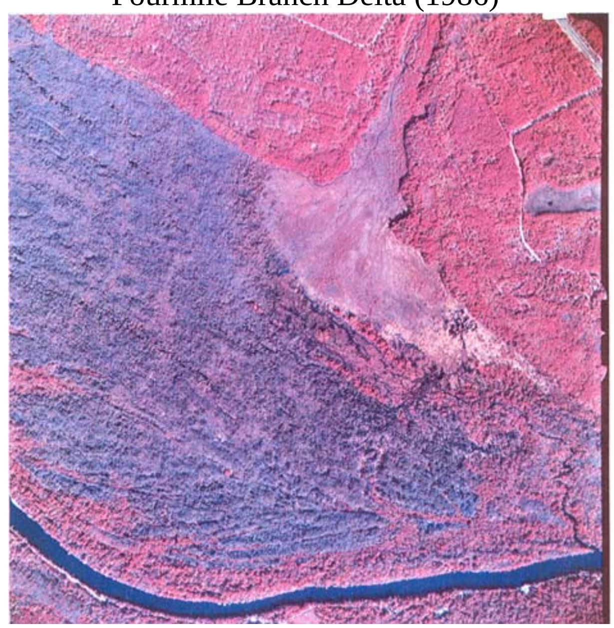


Approximate Locations of Photographs



Fourmile Branch Delta (1986)

Pen Branch Delta (1981)



Steel Creek Delta (1974)

Figure 5-5. Sediment Fans at the Fourmile Branch Delta Area (1986), the Pen Branch Delta Area (1981), and the Steel Creek Delta Area (1974)

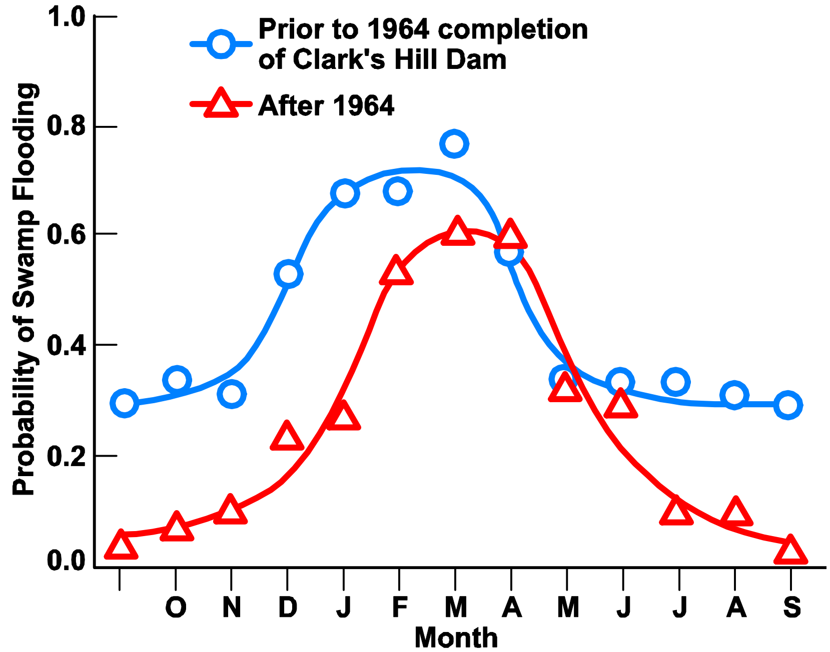


Figure 5-6. Monthly Probabilities of the Savannah River Flooding

The swamp forests at SRS remained intact until the early part of this century due to the difficulty in accessing the swamp. To access the best timber of the SRS Savannah River swamp, 14 miles of track, (two-thirds on trestles), were constructed (Fetters 1990). Dikes were built at breaks in the levee along the Savannah River to lower the water level in the swamp, and roads were constructed along and outward from the railroad. Staging areas were established at points along the railroad to which the logs were snaked. Railroad, staging areas, and haul lines allowed greater access to the bottomland hardwoods and created distinctive patterns in the swamp that are distinguishable on the historical aerial photography.

The timbering features in the swamp in 1938, 1943, and 1951 were classified as railroad, logging roads, drag points (the staging areas to which logs were hauled), haul lines, and an areal boundary of harvested land. Estimates of land disturbed by lumbering in the swamp were calculated for each year to provide an estimate of lumbering impact prior to SRS. These totals are presented in Table 5-2. The data derived from the aerial photography indicate that the 3800-ha (9400-acre) SRS Savannah River swamp had been disturbed by lumbering activities prior to the government purchase. The 1973 aerial photography shows that additional areas were lumbered after SRS was established. In total, approximately 2296 ha (5670 acres) was directly or indirectly impacted by lumbering operations (Burkhalter 1994). This lumbering information can be combined with photographic and image-change detection data, delta sedimentation data, and data on effects of previous thermal effluents to provide a more complete picture of the current SRS swamp environment.

Table 5-2. Areal Estimates of Pre-SRS Lumbering in the SRS Savannah River Swamp

Year	Buffered Lumbered Zones (Hectares)[a]	Harvested Areas (Hectares)[a]	Total (Hectares)[a]
1938	1,100	1,116	1,488
1943	856	17	871
1951	229	32	241
Total			**2,600**

[a]To convert to acres, multiply by 2.471.

5.2.2.2 Wetland Communities of the SRS Savannah River Swamp

The composition of the SRS Savannah River swamp forest has been examined extensively. Repaske (1981), Whipple et al. (1981), and Smith et al. (1981, 1982) have provided summaries of the wetland community structure of the swamp. Gladden et al. (1985) also studied the swamp in 1983 and 1984. These data provided information on density, size class (relative basal area), and importance values of woody species distributed throughout disturbed and relatively undisturbed portions of the SRS Savannah River swamp (Table 5-3). In addition, since 1981, numerous remote sensing surveys have been conducted of the swamp, which provide evaluations of changes in specific areas of the swamp largely influenced by cooling water effluents from SRS operations (Brewster and Tinney 1984; Christensen et al. 1986, 1988; Ezra et al. 1985; Jensen et al. 1983, 1984, 1986a and b, 1987; Tinney et al. 1986; Mackey 1990, 1993; Blohm 1993).

In the late 1970s and early 1980s, data from the woody species surveys of the swamp were analyzed using standard plant community analysis procedures (Mueller-Dombois and Ellenberg 1974). Importance values were calculated using relative density and relative dominance (basal area). Detrended correspondence analysis ordination was used to array the data along axes calculated using the importance values of the plant species (Hill 1979a; Smith et al. 1981, 1982). This technique grouped the wetland communities along gradients that can be interpreted to reflect plant community responses to environmental perturbations (Hill and Gauch 1980). A two-way indicator species analysis was then used to separate the data into major plant community types, based upon importance of dominant woody species (Hill 1979b). Comparisons of species arrays or groupings and community types with environmental characteristics provided an indication of the major environmental variables responsible for woody species distribution in the SRS swamp (Gladden et al. 1985).

Table 5-3. Importance Values[a] of Dominant Woody Species in the SRS Savannah River Swamp[b]

Species	Deciduous Natural (N=34)[c]	Swamp Forest/ Thermal (N=20)	Swamp Forest/ Post-Thermal (N=21)	Scrub-Shrub Revegetated (N=49)	Deciduous Bottomland Forest (N=24)
Nyssa aquatica	103	126	75	<1	7
Taxodium distichum	68	54	64	11	11
Fraxinus spp.	10	12	44	12	7
Itea virginica	3	3	-	5	<1
Planera aquatica	2	2	5	9	4
Cephalanthus occidentalis	<1	1	9	76	1
Liquidambar styraciflua	<1	-	-	-	25
Quercus laurifolia	<1	-	1	-	16
Salix spp.	-	<1	-	82	<1
Carpinus caroliniana	-	-	-	-	28
Quercus nigra	-	-	-	-	17

Source: Gladden et al. 1985.
[a]Importance value (Curtis and McIntosh 1950) = relative density + relative dominance (as percentage).
[b]All values are prior to reactor shutdowns beginning in 1985.
[c]N = number of plots sampled.

Each site was assigned a relative value of 1 to 3 based on a hydrologic scale (1 = deeply and continuously flooded, 2 = shallowly and continuously flooded, 3 = occasionally flooded) and on a perturbation scale (1 = tree mortality characteristic of natural swamp, 2 = low perturbation with slight tree mortality, 3 = high perturbation and high tree mortality). Based on these scalars, the swamp forest communities are distributed along two major environmental axes: a water depth or hydrologic gradient and a disturbance gradient. Thus, quadrats symbolized by squares or triangles show no or low levels of disturbance. Quadrats symbolized by circles are highly disturbed and contain no or almost no species representative of the original swamp forest. Open symbols represent sites occurring in areas of only occasional flooding. Partially darkened or completely darkened symbols represent quadrats at shallow or deeply flooded sites (Gladden et al. 1985).

The two-way indicator species analysis (Hill 1979b) separated the swamp forest into major wetlands community types. Deciduous bottomland hardwood forests occur in areas that are slightly elevated and better drained and that are flooded only occasionally during the year. These communities are dominated by a mixture of oak species (*Quercus nigra, Q. laurifolia, Q. michauxii, Q. lyrata),* as well as red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), ash (*Fraxinus caroliniana and F. americana*), and other hardwood species. The wetness of the substrate appears to control the species composition of the understory. Sweet bay (*Magnolia virginiana*), tulip poplar (*Liriodendron tulipifera*), and hollies (*Ilex spp*.) are found in drier localities, while red bay (*Persea borbonia*) and ironwood (*Carpinus caroliniana*) occur in stands with longer periods of soil saturation. Greenbrier (*Smilax spp*.) and woody vines are common (Gladden et al. 1985).

The deciduous swamp forest, which occurs in deeper water and on continuously flooded sites, is characterized by two canopy dominants: bald cypress and water tupelo. The understory is typically sparse and is composed of ash, bald cypress, occasional black gum (*Nyssa sylvatica*), water tupelo, red maple, and water elm (*Planera aquatica*). Most saplings are restricted to stumps, logs, or accumulated sediments and debris at the bases of the trees. St. John's wort (*Hypericum* spp.), Virginia willow (*Itea virginica*), false nettle (*Boehmeria cylindrica*), and woody vines such as poison ivy (*Toxicodendron radicans*) and pepper-vine (*Ampelopsis arborea*) occur in the understory on stumps and fallen logs. The ground cover is limited in the swamp forest by continuous flooding and low light penetration through the canopy. In areas of slow current, duckweed (*Lemna* spp. and *Spirodela* spp.), waterweed (*Egeria densa*), and coontail (*Ceratophyllum demersum*) are found (Gladden et al. 1985).

Woody plant community types occurring in the most highly disturbed areas are dominated by successional scrub-shrub species, such as willow (*Salix* spp.) and buttonbush (*Cephalanthus occidentalis*). These scrub-shrub communities occur where the original swamp forest has been eliminated, but where water temperatures were not too high to preclude the growth of woody species. Willow-dominated scrub-shrub communities tend to occur on sand bars or on occasionally flooded sites; buttonbush-dominated scrub-shrub communities occur on sites with deeper water and represent the early successional invasion of deeper water sites (Gladden et al. 1985).

The understory of the buttonbush community contains nonpersistent emergent wetland species such as hydrolea (*Hydrolea quadrivalvis*), aneilema (*Aneilema keisak*), waterpepper (*Polygonum hydropiperoides*), water purslane (*Ludwigia palustris*), and wapato (*Sagittaria latifolia*). Climbing hemp (*Mikania scandens*) and pepper-vine also occur (Gladden et al. 1985). Herbaceous vegetation in the willow community is often sparse due to the dense canopy. Small patches of herbs include redtop panicgrass (*Panicum agrostoides*), water-pepper, false nettle, St. John's wort, sensitive fern (*Onoclea sensibilis*), climbing hemp, and pepper-vine (Gladden et al. 1985). In addition to wetlands surveys of individual sites in the SRS Savannah River swamp, remote sensing overflights were conducted in 1981 to provide a wetlands map of the SRS Savannah River swamp (Jensen et al. 1984). Individual maps of each delta area were also prepared to quantify wetland areas and to establish a data base to evaluate future changes in the swamp (Christensen et al. 1986). High altitude imagery was used to map the entire SRS Savannah River swamp, and low altitude imagery was used to map individual delta areas (Jensen et al. 1984).

5.2.2.3 Wetlands Classification Scheme

The Savannah River swamp contains areas of diverse cover types, such as woody vegetation, mud flats, and open water. A classification scheme comparable with ground survey data collected from the swamp was developed for use with the remotely sensed data. The classification scheme selected was adopted with minor modifications from the wetlands classification system developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) and used for the National Wetland Maps (Stewart et al. 1980). Nine of the wetland classes commonly identified in the SRS Savannah River swamp are (Jensen et al. 1984; Christensen 1987; Sharitz et al. 1990; Burkhalter 1994):

- Water (W) appears as open water in the photographs.
- Mudflat (MF) appear as bare, unvegetated mudflats.
- Persistent emergent (PE) wetland dominated chiefly by perennial herbaceous species, including cattail (*Typha latifolia*), bulrush (*Scirpus cyperinus*), cutgrass (*Leersia* spp.) and false nettle (*Boehmeria cylindrica*). *Aneilema keisak*, an annual, also is abundant locally.
- Nonpersistent emergent (NPE) wetland contains several species of knotweed (*Polygonum* spp.), and hydrolea in the deeper water areas. The NPE vegetation type is characterized by water primrose (*Ludwigia* spp.) on shallow sandbars and mud flats.
- Scrub-shrub (SS) wetland dominated by willow (*Salix nigra* and *S. caroliniana*) on the sandbars, and buttonbush in deeper water. Typically, SS represents a transition from emergent marsh to swamp forest.
- Deciduous swamp forest (DSF) dominated by bald cypress (*Taxodium distichum)* and water tupelo (*Nyssa aquatica*).
- Deciduous bottomland forest (DBF) characterized by oaks, red maple, sweetgum, and hickory (*Carya* spp.). DBF vegetation is less water-tolerant than DSF vegetation.
- Pine characterized by loblolly pine (*Pinus taeda*).

Estimates of the wetland vegetation areas for the Steel Creek, Pen Branch, and Fourmile Branch deltas in 1981 and 1992 are listed in Table 5-4 through Table 5-6. Discussions of classification methods, accuracy assessment, and phenology problems are presented in Jensen et al. (1984, 1986a), Christensen et al. (1986) and Burkhalter (1994).

Table 5-4. Wetland Classification of the Steel Creek Delta based on 1981 and 1992 MSS Data

	1981		1992		
Wetland Cover Class	**Ha[a]**	**Percent of Delta Area**	**Ha[a]**	**Percent of Delta Area**	**Difference**
Water (W)	4.0	3	9.3	6	+3
Mudflat (MF)	0.0	0	0.0	0	-
Nonpersistent emergent (NPE)	36.9	25	2.6	2	-23
Persistent emergent (PE)	36.3	25	14.6	10	-15
Scrub-shrub (SS)	19.6	13	62.3	43	+30
Pine	0.0	0	0.0	0	-
Deciduous bottomland forest (DBF)	10.0	7	13.7	9	+2
Deciduous swamp forest (DSF)	39.5	27	43.9	30	+3
Total Area	**146.4**	**100**	**146.4**	**100**	

Source: Burkhalter 1994.
[a]To convert to acres, multiply by 2.471.

Table 5-5. Wetland Classification of the Pen Branch Delta based on 1981 and 1992 MSS Data

	1981		1992		
Wetland Cover Class	**Ha[a]**	**Percent of Delta Area**	**Ha[a]**	**Percent of Delta Area**	**Differences**
Water (W)	36.5	18	18.5	9	-9
Mudflat (MF)	9.4	5	0.0	0	-5
Nonpersistent emergent (NPE)	32.2	16	24.8	12	-4
Persistent emergent (PE)	0	0	67.9	34	+34
Scrub-shrub (SS)	0	0	25.1	12	+12
Pine	2.5	1	0.0	0	-1
Deciduous bottomland forest (DBF)	52.6	17	29.2	15	-11
Deciduous swamp forest (DSF)	68.7	34	36.4	18	-16
Total Area	201.9	100	201.9		

Source: Burkhalter 1994.
[a]To convert to acres, multiply by 2.471.

Table 5-6. Wetland Classification of the Fourmile Branch Delta based on 1981 and 1992 MSS Data

	1981		1992		
Wetland Cover Class	**Ha[a]**	**Percent of Delta Area**	**Ha[a]**	**Percent of Delta Area**	**Differences**
Water (W)	44.7	11	19.0	5	-6
Mudflat (MF)	32.3	8	4.9	1	-7
Nonpersistent emergent (NPE)	14.2	4	6.5	2	-2
Persistent emergent (PE)	0.0	0	17.0	4	+4
Scrub-shrub (SS)	42.4	11	51.7	13	+2
Pine	14.3	4	25.3	6	+2
Decidious bottomland forest (DBF)	104.1	26	177.7	45	+19
Deciduous swamp forest (DSF)	144.1	36	94.1	24	-12
Total Area	396.2	100	396.2	100	

Source: Burkhalter 1994.
[a]To convert to acres, multiply by 2.471.

5.2.3 Long-Term Trends and Effects of Cooling-Water Releases on SRS Streams and the SRS Savannah River Swamp

5.2.3.1 Introduction

From 1953 until the late 1980s, cooling water discharges from SRS reactors and the D-Area powerhouse altered wetland vegetation in the SRS stream floodplains and the Savannah River swamp. High effluent flows eroded stream banks and deposited sediments, forming a delta at the junction of each of the four streams and the swamp. To assess the status and predict future changes of the SRS swamp deltas, aerial photographs from 1951-1985 were analyzed (Tinney et al. 1986) using photo interpretation and computer techniques to provide the following information:

- past and current expansion rates
- location and changes of impacted areas
- estimates of total areas affected

Multispectral remote sensing data from 1981 to 1993 are also available for the SRS swamp areas. These multispectral scanner (MSS) data allow estimation of changes by wetland community types for the delta areas for given time periods. For example, Christensen et al. (1986) evaluated changes in the swamp delta areas for 1981-1985 with MSS data and updated the Steel Creek delta through 1987, and Blohm (1993) conducted a detailed evaluation of the Pen Branch delta for 1987-1991. Burkhalter (1994) compared historic photos with 1992 MSS data.

The wetlands changes in Steel Creek are particularly interesting. Both L and P Reactors discharged effluents into the stream from 1954 to 1963. L Reactor continued to discharge thermal effluent to Steel Creek from 1963 to 1968. When P Reactor stopped releasing thermal effluents to Steel Creek in 1963, the upper Steel Creek corridor began to revegetate. In 1968, thermal discharges into Steel Creek ceased and the lower Steel Creek floodplain and delta region began undergoing post-thermal succession or revegetation (Smith et al. 1981, 1982; Christensen et al. 1986). In 1985, L Lake was built on the midreach of Steel Creek. It received thermal output from the reactivated L Reactor intermittently until 1988. Flow and temperature increased downstream of the L-Lake dam when the reactor discharged.

Pen Branch and Fourmile Branch began receiving reactor effluents in 1954 and 1955, respectively. In contrast to Steel Creek, neither stream received effluents from more than one reactor. Additionally, both reactors operated with only minor changes in operating conditions after the initial startup. C Reactor was shut down in late June 1985, and the Fourmile Branch corridor and delta began undergoing successional revegetation. K Reactor was shut down in the spring of 1988, and Pen Branch delta began undergoing successional revegetation (Mackey 1990, 1993; Blohm 1993). Neither creek has received thermal discharge since the reactors were shutdown; however, Pen Branch received elevated flows during testing of the K-Reactor cooling tower.

A fourth source of thermal effluent to the SRS Savannah River swamp is from D Area, which contained a heavy water production facility (placed on standby in 1982 and since dismantled) and a coal-fired power plant (currently operating). Effluents from D Area were consistently lower in both volume and temperature than effluents from the reactor areas.

5.2.3.2 Multispectral Scanner Surveys of the SRS Swamp Delta Areas

One of the most powerful uses of digital remote sensing data is to evaluate land-use and land-cover changes through time. Remote sensing change detection combines multiple-date data and image analyses to identify temporal and spatial changes. Multispectral scanner (MSS) data analysis can quantitatively discriminate among a variety of vegetation types (Jensen et al. 1986a). Baseline vegetation maps of the Savannah River swamp and the four delta swamp areas (Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek) were prepared using aircraft MSS data (Jensen et al. 1984; Gladden et al. 1985) (Figure 5-7). Satellite MSS data (Landsat, Thematic Mapper, and SPOT) are commonly used to detect and monitor change. For the most part, satellite data are useful for large-scale change detection because the ground resolution currently available with Thematic Mapper is 30 x 30 m (98 x 98 ft) with SPOT HRV is 20 x 20m (66 x 66 ft), and with SPOT panchromatic is 10 x 10 m (33 x 33 ft).

Aircraft-based sensors fly lower and have ground resolutions of a few meters. At this scale, much more detailed discrimination of vegetation types and area estimates can be made. However, change detection using high-resolution, aircraft MSS data seldom is conducted. Classification consistency and registration difficulties are probably the two major reasons that aircraft MSS data are used infrequently for change detection studies. Research on the Savannah River swamp deltas addressed both of these considerations (Christensen et al. 1986; Jensen et al. 1987; Blohm 1993).

Portions of the Pen Branch, Fourmile Branch, Steel Creek, and Beaver Dam Creek deltas in the Savannah River swamp were evaluated for wetlands vegetation change using aircraft MSS data acquired at 1220 m (4003 ft) and 2440 m (8006 ft) altitude from 1981 to 1985. The MSS data for each delta were registered and classified, and wetlands vegetation change detection categories were determined (Christensen et al. 1986; Jensen et al. 1983, 1984, 1986a and b, 1987).

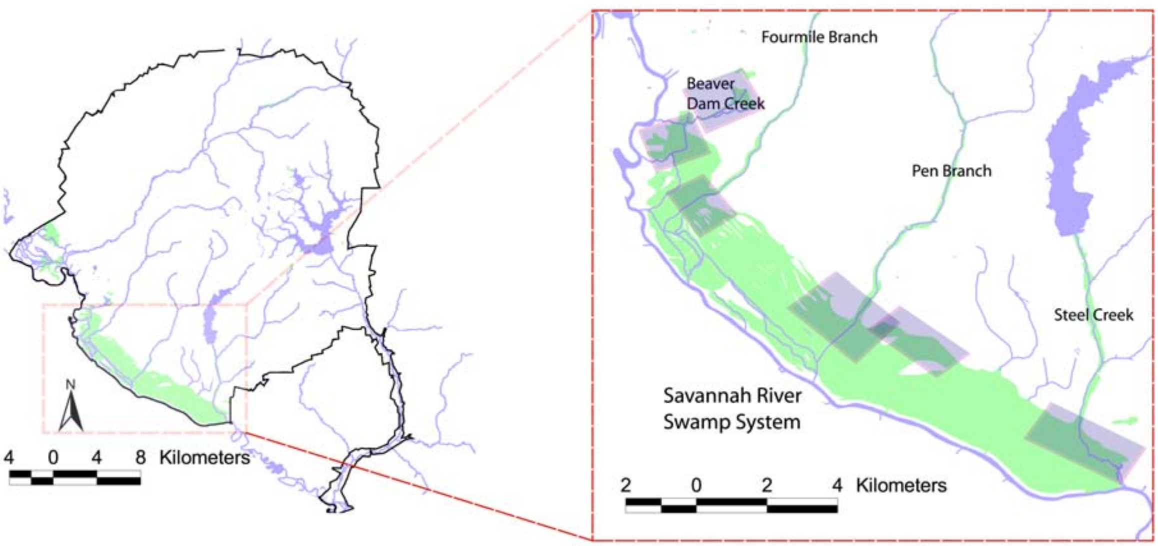


Figure 5-7. Areas of the SRS Savannah River Swamp Analyzed Using MSS Data, 1981 - 1985

5.2.3.3 Comparison of the Photographic and MSS Surveys, 1981-1992

In general, even though the data were analyzed with different approaches and criteria for wetland change detection, the wetland community trends in the delta areas of the SRS Savannah River swamp observed with the MSS surveys from 1981 to 1985 agreed with the changes in the photographic surveys. For example, in the thermally influenced deltas of Fourmile Branch (until 1985) and Pen Branch, expansion of these deltas into the deciduous swamp forest (DSF) was still occurring. Using photographic techniques, about 30 ha (74 acres) of cypress-tupelo forest were estimated to have been converted to open water marsh or scrub-shrub wetlands in the Fourmile Branch delta area from 1981 to 1984. Using MSS data to analyze about one-half of the same Fourmile Branch delta area, approximately 14 ha (35 acres) of swamp forest were estimated to have been converted to either marsh or scrub-shrub wetland communities. When evaluated with photographic methods, the thermally influenced Pen Branch delta showed a decline in cypress-tupelo forest of about 37 ha (91 acres) from 1981 to 1985 with most of the decline occurring in the Pen Branch "tail" area. MSS data analyses of the tail region showed a decline of swamp forest of 28.7 ha (71 acres) from 1981 to 1985.

Burkhalter (1994) continued monitoring changes in the swamp by comparing 1992 MSS data with the 1981 surveys. The remainder of this chapter describes the changes to the swamp due first to sediments deposition and increased water temperature and more recently to reduced flows and ambient water temperatures.

5.2.3.4 Beaver Dam Creek

5.2.3.4.1 <u>Beaver Dam Creek Watershed Characteristics</u>

Beaver Dam Creek is a small stream that carries thermal effluents from the D-Area coal-fired power plant. Until 1982, it also carried effluent from the heavy water production facility. Prior to SRS operations, Beaver Dam Creek was probably an intermittent stream. The creek is 1-3 km (0.6-1.8 mi) west of Fourmile Branch (Figure 5-8). A narrow band of bottomland hardwoods and scrub-shrub forest borders the stream from the D-Area process-water outfall to the river swamp. Beaver Dam Creek received from 2.1 to 3.5 m^3/sec (74 to 123.5 ft^3/sec) of heated process water discharges from the heavy water production plant and the steam plant when both were operating. As heavy water operations were reduced, discharges decreased.

5.2.3.4.2 <u>Beaver Dam Creek Delta Characteristics</u>

Two different effluent sources from D Area affected the Beaver Dam Creek delta area (Evans and Giesy 1978; Gladden et al. 1985). Cooling water discharges from the D-Area powerhouse and heavy-water facilities primarily were responsible for vegetation damage in the middle and lower parts of the delta. The upper portion also was affected by ash-basin overflow (Evans and Giesy 1978). Since the early 1970s, cooling-water temperature and flows and sediment basin discharges have decreased. Portions of the delta have begun to revegetate, especially in the upper part, which no longer receives discharges.

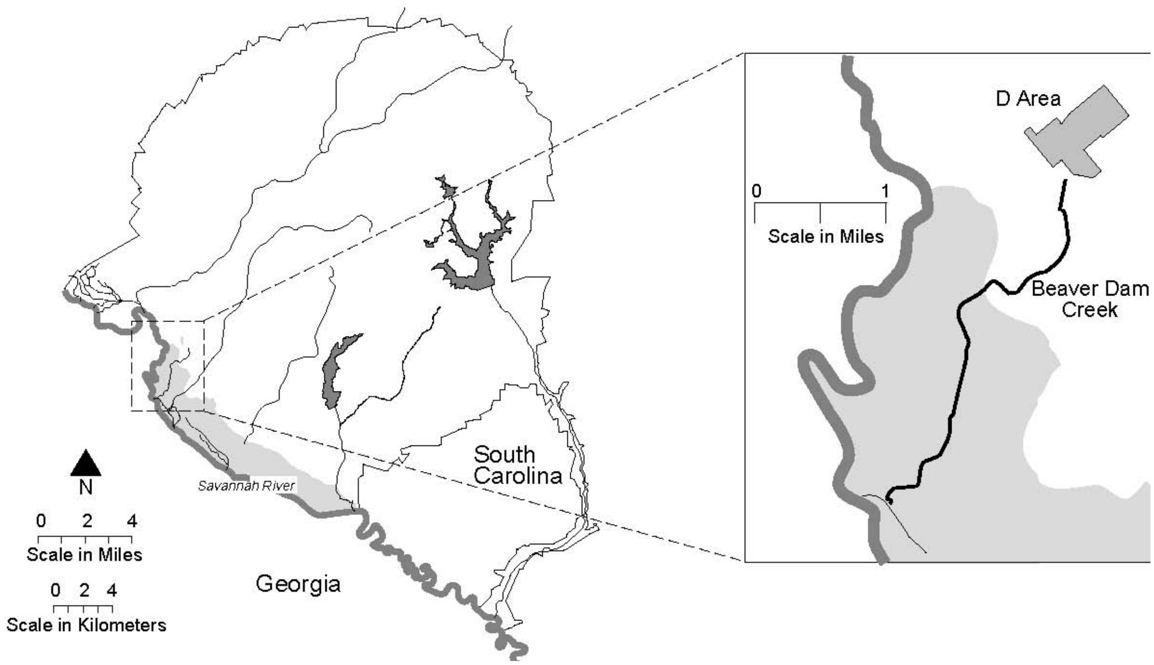


Figure 5-8. Location of Beaver Dam Creek on SRS

Of the four deltas, the most change from 1991 to 1995 was on the Beaver Dam Creek delta, even though the change period had been the shortest. Almost the entire upper portion of the delta experienced extensive revegetation. At the present due to a reduction in discharges, the upper delta remains dry most of the year (except during flooding of the Savannah River). As a result, less water-tolerant scrub-shrub (willow and buttonbush) and deciduous bottomland forest species (sycamore [*Platanus occidentalis*], ash, tulip poplar, and oak) have colonized the former marsh (persistent emergent and nonpersistent emergent).

5.2.3.4.3 Beaver Dam Creek Delta Trends

In 1952, D Area began discharging heated effluents through a canal to Beaver Dam Creek (Figure 5-8). Both the D-Area heavy water facility and the coal-fired powerhouse used Savannah River water for cooling. Additionally, river water was pumped for the extraction of heavy water (Gladden et al. 1985). Table 5-7 summarizes the history of discharges to and changes in the Beaver Dam Creek delta. Canopy decline was observed in 1956 aerial photography. The affected area totaled 19 ha (47 acres) and received an average flow of about 120 cfs (33 cm^3/sec). During the next 11 years, the Beaver Dam Creek delta expanded at a variable rate with a maximum rate of about 10 ha (25 acres)/yr between 1961 and 1966. Effluent temperatures began to decrease in 1973 and continued to decline until 1978; a concurrent net decline of delta expansion occurred. By 1985, a total of about 14 ha (34 acres) had revegetated in the Beaver Dam Creek area. The annual average effluent temperature declined from 38°C (100^o F) to 27-28°C ($81\text{-}82^o$ F). The affected Savannah River swamp area associated with Beaver Dam Creek in 1985 totaled about 160 ha (395 acres) and was revegetating at a rate of about 4.2 ha (10.3 acres)/yr. Relatively little change has been noted in the Beaver Dam Creek delta from 1986-1992 (Figure 5-9). In addition to thermal discharges, the Beaver Dam Creek delta area also received coal fly ash basin effluent discharge (Evans and Giesy 1978). Coal fly ash deposition affected at least 8-10 ha (20- 25 acres) of swamp (Gladden et al. 1985).

Table 5-7. Discharge Conditions and Estimated Impacts to Beaver Dam Creek from D-Area Discharges, 1952-1995

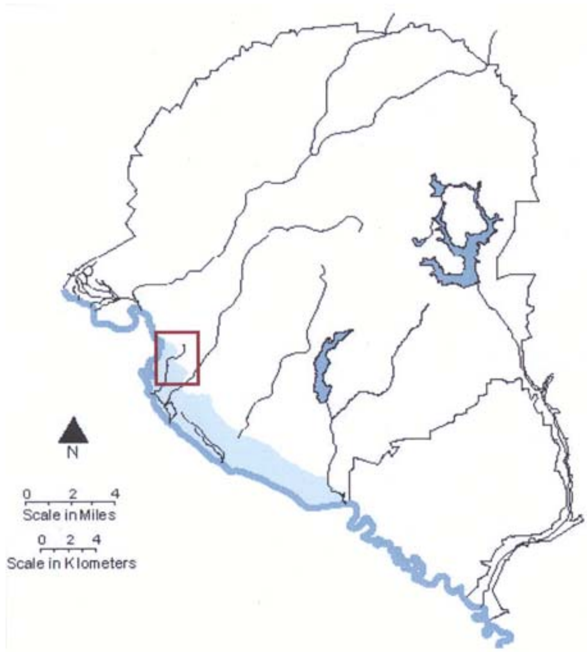
Year	Total Impacted Area (ha)[a]	Average Expansion Rate (ha/yr)	Average Annual Discharge (cfs) or Flow at USGS Station[b]	Average Annual Temperature (°C)[c]
1952	-	-	-	-
1953	-	-	-	-
1954	-	-	-	-
1955	-	-	-	
1956	19.0	-	121	-
1957	-	-	123	-
1958	-	-	108	-
1959	-	-	104	-
1960	-	-	91	-
1961	54.0	7.0	88	-
1962	-	-	89	-
1963	-	-	-	-
1964	-	-	88	-
1965	-	-	-	-
1966	103.7	9.9	-	-
1967	-	-	-	-
1968	-	-	-	-
1969	-	-	-	-
1970	-	-	-	-
1971	-	-	-	-
1972	-	-	-	38
1973	-	-	-	38
1974	167.0	7.9	-	36
1975	-	-	92	34
1976	-	-	78	32
1977	-	-	78	28
1978	164.8	0.6[d]	74	27
1979	-	-	79	28
1980	-	-	82	27
1981	-	-	113	27
1982	157.0	2.0[d]	90	27
1983	-	-	89	-
1984	164.1	3.6[d]	84	-
1985	159.9	4.2[d]	89	-
1986	-	-	89	-
1987	-	-	88	-
1988	-	-	71	-
1989	-	-	67	-
1990	-	-	73	-
1991	-	-	95	-
1992	-	-	70	-
1993	-	-	78	-
1994	-	-	71	-
1995	-	-	71	-

[a]To convert to acres, multiply by 2.471.
[b]For the years 1956-1964, the data are for the 681-5G pumphouse, which supplies river water to D Area. For the years 1975-1982, the data are flow measurements at the Health Protection Monitoring Station on Beaver Dam Creek before the flow discharges into the Savannah River swamp on SRS. For the year 1983-1991, the data are from the USGS recording station (35.32 cfs =1 m^3 /sec).
[c]For the years 1972-1983, the temperature data are annual average data at the Health Protection Monitoring Station on Beaver Dam Creek before the flow enters the Savannah River swamp on SRS. To convert to °F, multiply by 9/5 and add 32.
[d]Revegetation rate.

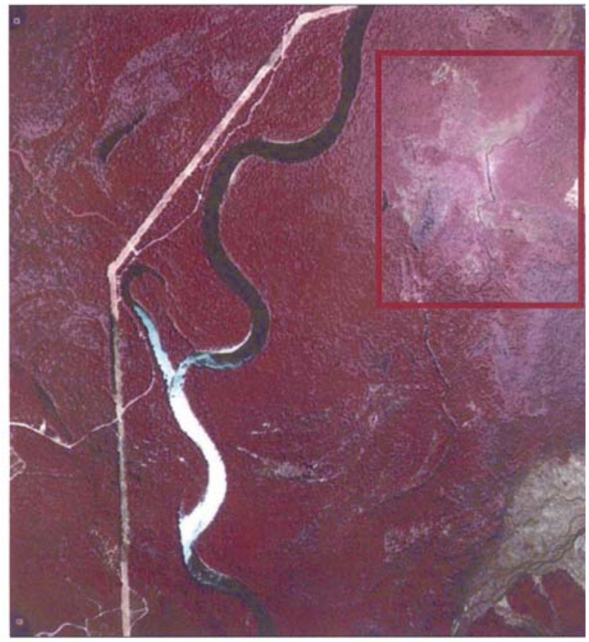
5.2.3.4.4 MSS Surveys of the Beaver Dam Creek Delta, 1981-1985

Multispectral scanner (MSS) data of the Beaver Dam Creek delta were acquired at 2440 m (8006 ft) above ground level (AGL) on March 31, 1981, and at 1220 m (4003 ft) on April 26, 1985. Table 5-8 and Table 5-9 list the changes in landcover from March 31, 1981, to April 26, 1985. For the upper Beaver Dam Creek delta, the most noticeable decreases in landcover type were of nonpersistent emergent marsh (60.0%), persistent emergent marsh (52.2%), and deciduous swamp forest (12.6%). Conversely, the area experienced increases in deciduous bottomland forest (35.7%), scrub-shrub (10.0%), and water (13.5%). The upper Beaver Dam Creek area returned to a more wooded condition.

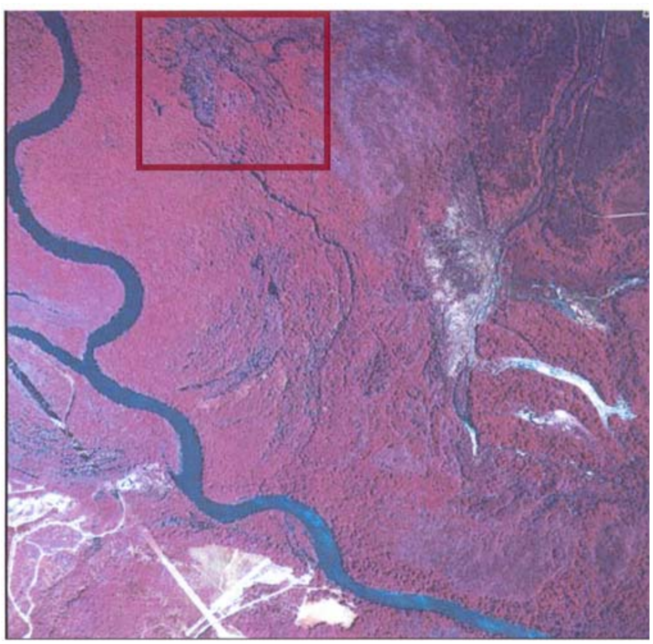
In the lower Beaver Dam Creek delta, the nonpersistent emergent marsh decreased tremendously (99.9%). This wetlands type probably changed into persistent emergent marsh, which showed a substantial increase (24.4%). Deciduous swamp forest, scrub-shrub, and water all decreased (7.4%, 3.5%, and 1.1%, respectively). The deciduous bottomland forest increased (5.52%). These statistics suggest that while change took place in the lower Beaver Dam Creek delta, it was not as marked as the changes in the upper Beaver Dam Creek delta



Approximate Location of Photographs



April 1986



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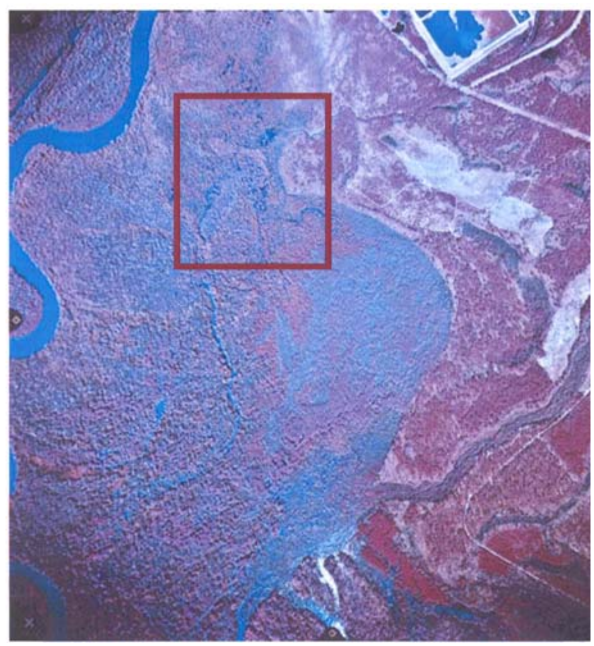


March 1998

Figure 5-9. Vertical Aerial Photography of the Beaver Dam Creek Delta Area, Spring 1986, 1992, and 1998

Table 5-8. Wetlands Change in the Upper Beaver Dam Creek Area from 1981-1985 Based on Aircraft MSS Data

	Number of Hectares[a]			
Wetlands Type	**1981**	**1985**	**Difference**	**Percentage Change**
water	14.8	16.8	+2.0	+13.5
nonpersistent emergent marsh	8.5	3.4	-5.1	-60.0
persistent emergent marsh	32.9	15.7	-17.2	-52.2
scrub-shrub	35.7	39.3	+3.6	+10.0
deciduous swamp forest	65.8	57.5	-8.3	-12.6
deciduous bottomland forest	70.3	95.4	+25.1	+35.7

[a]To convert to acres, multiply by 2.471

Table 5-9. Wetlands Change in the Lower Beaver Dam Creek Area from 1981-1985 Based on Aircraft MSS Data

	Number of Hectares[a]			
Wetlands Type	**1981**	**1985**	**Difference**	**Percentage Change**
water	35.2	34.8	-0.4	-1.1
nonpersistent emergent marsh	7.1	0.0	-7.1	-99.9
persistent emergent marsh	9.4	11.7	+2.3	+24.4
scrub-shrub	8.5	8.8	-0.3	-3.5
deciduous swamp forest	76.0	70.4	-5.6	-7.4
deciduous bottomland forest	194.2	204.8	+10.6	+5.5

[a]To convert to acres, multiply by 2.471

5.2.3.5 Fourmile Branch

5.2.3.5.1 Fourmile Branch Watershed Characteristics

Fourmile Branch flows southwest for 24 km (15 mi) before emptying into the Savannah River, and together with Beaver Dam Creek drains more than 59 km^2 (23 mi^2). In the swamp, part of the flow from Fourmile Branch combines with Beaver Dam Creek. Most of the Fourmile Branch flow discharges into the Savannah River through an opening in the levee between the swamp and river, while another portion of the flow moves downstream through the swamp and joins water from Steel Creek and Pen Branch, which leaves the swamp by Steel Creek. During river flooding the flow from Fourmile Branch travels through the swamp beyond Steel Creek and enters the river near or downstream from Steel Creek. Fourmile Branch receives effluents from F and H Areas. Until 1985, it received thermal discharges from C Reactor (about 11.3 m^3/sec [399 ft^3/sec]).

5.2.3.5.2 Fourmile Branch Corridor and Delta

Photographic data of the Fourmile Branch corridor and delta were evaluated (Table 5-10 and Figure 5-10). As of 1985, 93.0 ha (1000 acres) of Fourmile Branch had been affected (Table 5-10). The impacted area of the Savannah River swamp canopy totaled 357.3 ha (883 acres) and the area in the Fourmile Branch corridor totaled 93 ha (230 acres). Since late June 1985, C Reactor has been shutdown and natural successional revegetation is occurring in the corridor and delta. Flows to Fourmile Branch have remained low since June 1985 (Table 5-10). Figure 5-11 shows the progression of revegetation in the Fourmile Branch delta area from 1986-1992 with invasion of a scrub-shrub community into the lower corridor and the delta sediment fan.

The shape and expansion history of the Fourmile Branch impact delta are different from other areas of the swamp receiving reactor effluents. Even though Fourmile Branch had a flow and temperature history similar to that of Pen Branch, the Fourmile Branch impact area (357 ha [883 acres]) is more than twice as large as the Pen Branch delta impact area (152 ha [375 acres]).

One explanation for the size difference is that the geomorphology of the swamp at the mouth of Fourmile Branch is not like that at the other two deltas (Stevenson 1982). Hardwood islands and former river channels are common in the region of the Savannah River swamp contiguous to the Fourmile Branch. In contrast, Steel Creek and Pen Branch drain into an area of the swamp with fewer hardwood islands and former river channels in the immediate vicinity. As a result of the local geomorphology, Fourmile Branch discharges to the swamp spread not only in the traditional deltaic form (similar to Pen Branch and Steel Creek deltas), but also between elevated hardwood ridges in the Savannah River swamp (Figure 5-10).

Table 5-10. Discharge Conditions and Estimated Impacts to Fourmile Branch from Reactor Discharges, 1955-1995

	Savannah River Swamp		Fourmile Branch Corridor		Annual Average Reactor Discharge or Fourmile Branch Flows	
Year	Total Affected Area (ha)	Expansion Rate (ha/yr)	Total Affected Area[a] (ha)	Expansion Rate of Forest Canopy Mortality (ha/yr)	Flow (cfs)[b]	Temperature (°C)[c]
1955	-	-	-	-	100[d]	47
1956	0.0	-	-	-	156	60
1957	0.0	-	-	-	220	66
1958	-	-	-	-	200	71
1959	-	-	-	-	273	71
1960	-	-	-	-	327	71
1961	15.8	-	105.8	17.5	389	66
1962	-	-	-	-	389	67
1963	-	-	-	-	385	68
1964	-	-	-	-	390	66
1965	-	-	-	-	385	30
1966	97.9	16.4	106.7	0.2	390	67
1967	-	-	-	-	391	71
1968	-	-	-	-	395	71
1969	-	-	-	-	390	70
1970	-	-	-	-	387	64
1971	-	-	-	-	388	65
1972	-	-	-	-	387	67
1973	-	-	-	-	387	58
1974	246.8	18.6	-	-	316	62
1975	-	-	-	-	352	59
1976	-	-	-	-	376	62
1977	-	-	-	-	376	62
1978	-	-	-	-	376	62
1979	-	-	-	-	376	61
1980	-	-	-	-	377	63
1981	-	-	-	-	376	63
1982	-	-	-	-	376	64
1983	-	-	-	-	375	68
1984	350.8	10.4	-	-	375	-
1985	357.3	6.5	93.0	0.7[e]	220	-
1986	-	-	-	-	47	-
1987	-	-	-	-	32	-
1988	-	-	-	-	20	-
1989	-	-	-	-	24	-
1990	-	-	-	-	33	-
1991	-	-	-	-	64	-
1992	-	-	-	-	44	-
1993	-	-	-	-	54	-
1994	-	-	-	-	30	-
1995	-	-	-	-	35	-

[a]Greater than 5% canopy loss; to convert to acres, multiply by 2.471.
[b]35.32 cfs = 1 m^3/sec. For years 1955-1984, the data are from Tinney et al. 1986. For years 1985-1991, the data are from the USGS.
[c]To convert to °F, multiply by 9/5 and add 32.
[d]Approximate.
[e]Revegetation rate.

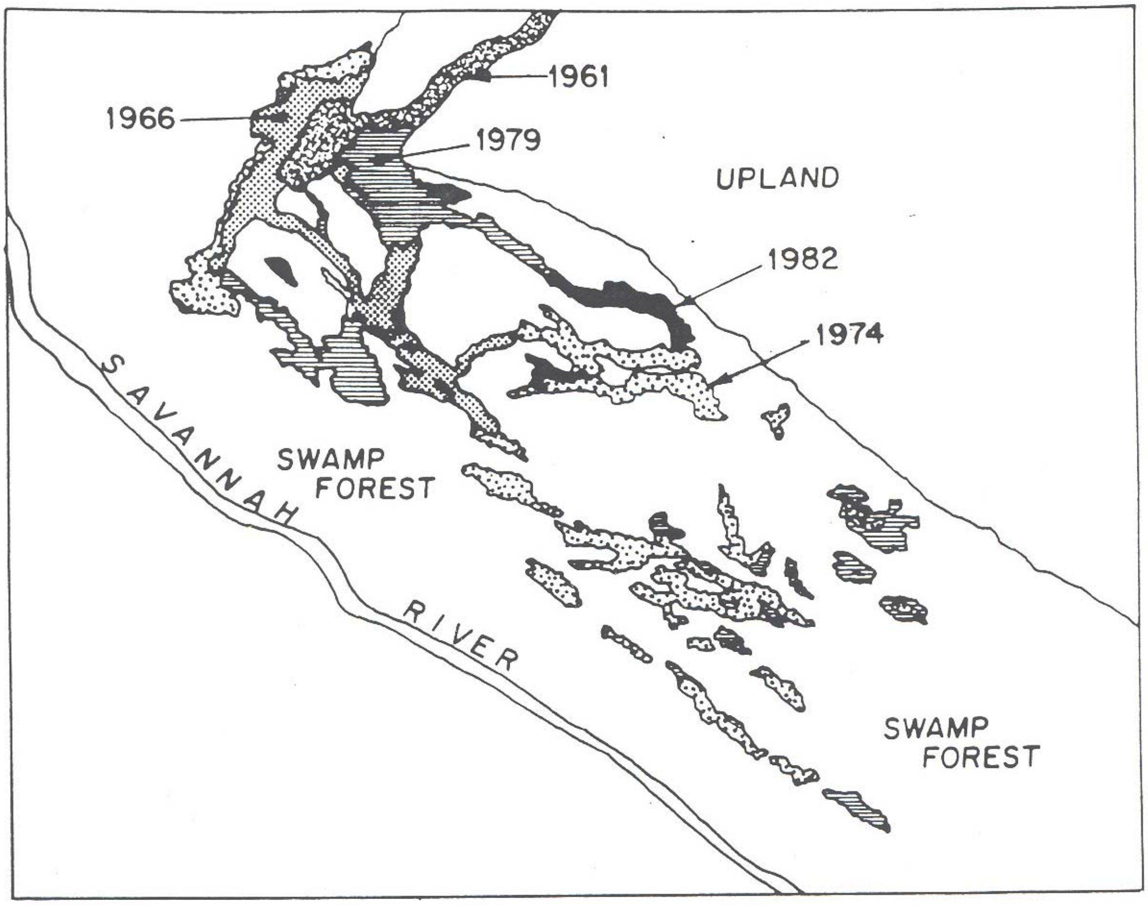
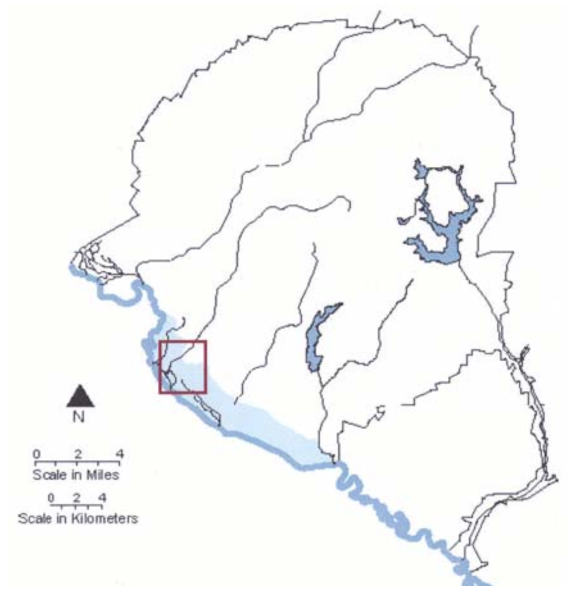
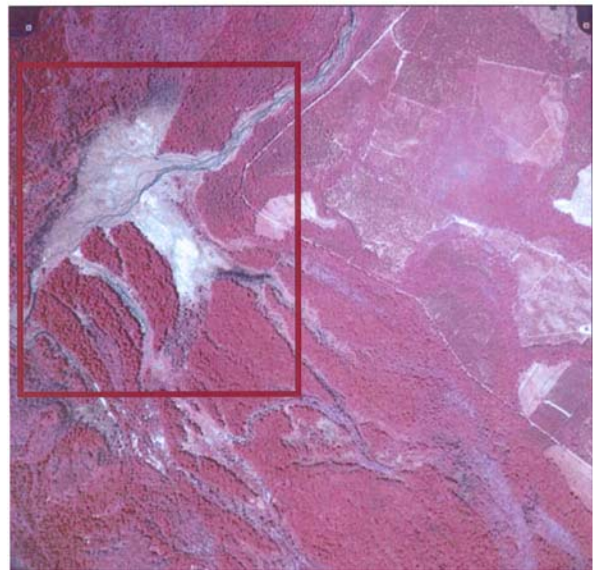


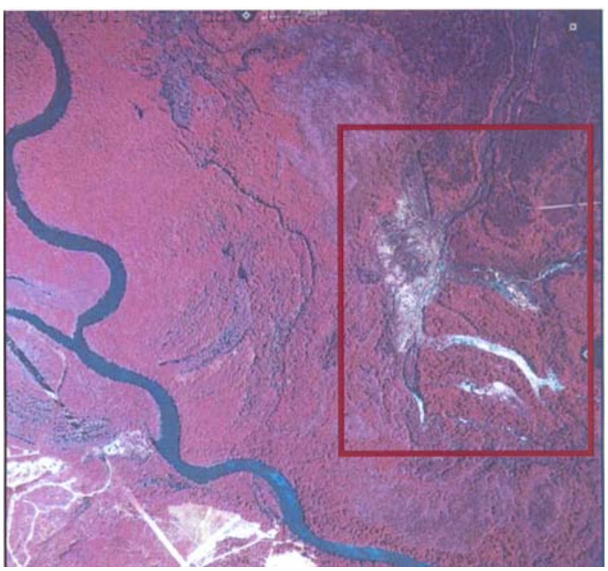
Figure 5-10. Fourmile Branch Delta Expansion Composite Image, 1961-1982 (Source: Gladden et al. 1985)



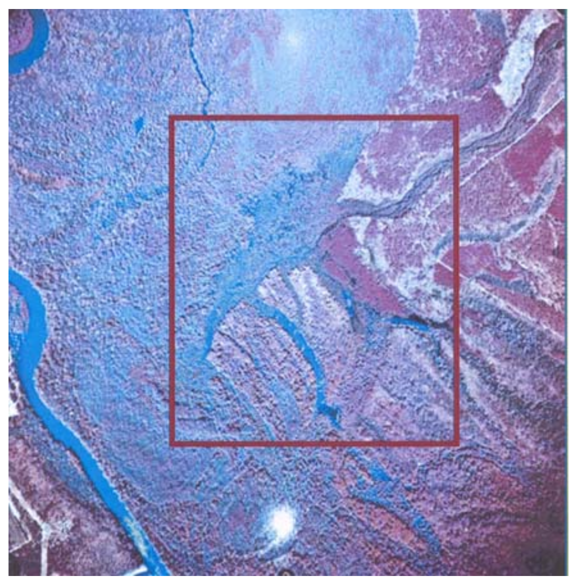
Approximate Location of Photographs



April 1986



May 1992



March 1998

Figure 5-11. Vertical Aerial Photography of the Fourmile Branch Delta Area After C-Reactor Shutdown

5.2.3.5.3 Fourmile Branch Delta – MSS Surveys 1981-1992

A 190-ha (469-acre) area of the Fourmile Branch delta was evaluated for wetlands changes using 1981 and 1984 airborne MSS data, (Figure 5-7). The April 1984 image was registered to the March 1981 image. The major change was a loss of swamp forest (cypress tupelo) to nonpersistent emergent (NPE) wetland (9.3 ha [23 acres]). Most of the change occurred along the northern and western delta fringes, where a thinned cypress community had existed in 1981. Two areas of persistent emergent (PE) wetland (1.6 ha [4 acres]) replaced swamp forest near the southern edge of the delta. Swamp forest loss totals were similar to those in the Pen Branch delta, and loss rates from 1981 to 1984 were similar to previous rates determined from aerial photographic techniques (Gladden et al. 1985; Tinney et al. l986).

Since the cessation of effluent in 1985, the amount of water flowing across the delta decreased significantly. A few distinct channels remain; the rest of the delta is being revegetated by scrub-shrub species. A pine stand is developing along the northern border of the delta. Table 5-11 shows degradation in vegetation communities and Table 5-12 shows revegetation in the Savannah River swamp deltas between 1981 and 1992 (Burkhalter 1994).

5.2.3.5.4 Fourmile Branch Ground Surveys 1982, 1987, 1989, 1990

Fourmile Branch received cooling water discharge from C Reactor between 1955 when the reactor began operation, and June 1985, when the reactor was shut down. The delta was criss-crossed by numerous small channels interspersed with islands. With the shutdown of C Reactor in 1985, all but two of the main channels disappeared and the delta became much drier (Figure 5-11). In mid-August 1987, a fire caused by lightning burned a large portion of the delta. Another lightning fire started on the delta in June 1988.

Field surveys in 1982 and photography and MSS analyses of 1981 data identified six communities that seemed to be defined by water temperature and depth of deposited sediments. These were (1) thermal delta; (2) post-thermal delta; (3) scrub-shrub wetland; (4) reduced-canopy cypress-tupelo forest; (5) bottomland hardwood ridges; and (6) closed-canopy cypress-tupelo forest. Communities 1-4 are in decreasing order of disturbance, and 5 and 6 are undisturbed communities.

Table 5-11. Degradation of Savannah River Swamp Vegetation Communities in the Vicinity of the Deltas Formed by Formerly Thermal Creeks[a]

Delta Area = Hectares[c]			
Vegetation Change Class[b]	**Fourmile Branch**	**Pen Branch**	**Steel Creek**
DSF to SS	1.76	8.9	6.27
DSF to PE	3.91	17.34	0.15
DSF to NPE	2.64	6.25	0.05
DSF to MF	0.22	-	-
DBF to SS	2.68	3.94	0.54
DBF to PE	1.09	4.04	-
DBF to NPE	0.42	3.08	-
DBF to MF	0.13	-	-
PINE to SS	0.62	0.22	-
PINE to PE	0.2	0.26	-
PINE to NPE	0.14	0.18	-
PINE to MF	0.02	-	-
SSF to SS	-	2.04	-
SSF to PE	-	10.04	-
SSF to NPE	-	2.8	-
SS to PE	1.24	-	1.9
SS to NPE	0.21	-	0.33
SS to MF	0.33	-	-
PE to NPE	-	-	1.74
PE to MF	-	-	-
NPE to MF	0.58	-	-
Total Degradation	**16.19**	**59.09**	**10.98**

Source: Burkhalter 1994.
[a] Calculation of vegetation change based on analysis of Daedalus MSS data obtained on March 31, 1981 and April 23, 1992 using the change matrix (degradation).
[b]DSF = deciduous swamp forest. SS = scrub-shrub. PE = persistent emergent. NPE = nonpersistent emergent. SSF = stressed swamp forest; defined as swamp forest with a notably thinned canopy. DBF = deciduous bottomland forest. MF = mud flat.
[c]To convert to acres, multiply by 2.471.

Table 5-12. Revegetation of the Savannah River Swamp in the Vicinity of the Deltas Formed by Formerly Thermal Creeks[a]

Delta Area = Hectares[c]			
Vegetation Change Class[b]	**Fourmile Branch**	**Pen Branch**	**Steel Creek**
SSF to DSF	-	1.71	-
SSF to DBF	-	1.17	-
SSF to PINE	-	-	-
SS to DSF	10.27	-	3.33
SS to DBF	23.66	-	1.8
SS to PINE	2.7	-	-
PE to DSF	-	-	2.31
PE to DBF	-	-	1.04
PE to PINE	-	-	-
PE to SS	-	-	21.15
NPE to DSF	2.53	0.88	5.25
NPE to DBF	2.61	0.51	1.22
NPE to PINE	0.85	-	-
NPE to SS	5.32	3.49	19.96
NPE to PE	1.44	18.7	4.02
MF to DSF	4.62	0.18	-
MF to DBF	3.87	0.12	-
MF to PINE	3.46	-	-
MF to SS	11.21	1.05	-
MF to PE	4.55	5.69	-
MF to NPE	0.42	2.06	-
Total Revegetation	77.51	35.56	60.08

Source: Burkhalter 1994.
[a] Calculation of vegetation change based on analysis of Daedalus MSS data obtained on March 31, 1981 and April 23, 1992 using the change matrix (degradation).
[b]DSF = deciduous swamp forest.
SS = scrub-shrub.
PE = persistent emergent.
NPE = nonpersistent emergent.
SSF = stressed swamp forest; defined as swamp forest with a notably thinned canopy.
DBF = deciduous bottomland forest.
MF = mud flat.
[c]To convert to acres, multiply by 2.471.

The Fourmile Branch delta vegetation was resampled during the summers of 1987 and 1989 by the Savannah River Ecology Laboratory (SREL) (Wike et al. 1994). Sampling was conducted in the mid and lower corridors, the delta, and in nearby cypress-tupelo and hardwood island stands. Community analyses were grouped to correspond to the six communities identified in the 1982 surveys. An additional category, the dry delta, was added. The closed-canopy cypress-tupelo swamp was not sampled. The reduced canopy cypress-tupelo community remained largely unchanged with false nettle still a dominant herb. Marsh St. Johns wort (*Hypericum walteri*) replaced bugleweed (*Lycopus* spp.) as another dominant. Pepper-vine, buttonbush, and Virginia willow were common shrubs in this community.

The bottomland hardwood island showed little change in woody flora between 1982, 1987, and 1989 with a continued high diversity of trees. Due to C-Reactor shutdown, the island no longer received woody detritus from the disturbed delta and the ground layer shifted from greenbrier, poison ivy, and grape (*Vitis rotundifolia*) to two grasses (*Panicum* spp. and *Arundinaria gigantea*) and palmetto (*Sabal minor*).

The scrub-shrub transition zone was no longer continuously flooded, but buttonbush, pepper-vine, and false nettle remained dominant. The major component of the woody vegetation of the post-thermal area (the southeast side of the delta) was pine although some sweetgum saplings were present. The herbaceous layer of this side of the delta was similar to that of the southwest side. Bulrush and fireweed (*Erechtites hieracifolia*) were common. Neither the dry delta, nor the areas along the stream, had many species that had been present in the thermal delta. Water primroses (*Ludwigia leptocarpa, L. alternifolia*, and *L. decurrens*) were still present, but not common. Swamp loosestrife (*Ammania coccinea)* and *Rotala ramosior* were no longer present. Almost 50% of the herbaceous cover of the delta had burned immediately prior to sampling in 1987.

As would be expected in an early successional stage, the most dominant species were herbaceous. Fireweed and false nettle were found in more than 50% of the plots surveyed in 1987. Species having a mean cover greater than 25% included fireweed, bulrush, *Sacciolepsis striata,* and plume grass (*Erianthus giganteus*). Shrubs were less frequent, with young willows, the most abundant, occurring in 20.7% of the plots. Trees were even less abundant (approximately 1900/ha), especially those greater than 10 cm diameter-breast height (dbh) (approximately 300/ha). Willows and ash (*Fraxinus* spp.) had the greatest densities (more than 500/ha) but were primarily less than 10 cm dbh.

In 1989, the two species most frequently found in 1987 were joined by three additional species (knotweed [*Polygonum hydropiperoides*], bulrush, and grass [*Paspalum urvillei*]) with combined frequencies greater than 50%. No species had a mean percent cover greater than 25%. Seventeen herbaceous species were found in 1989, in contrast to the 12 found in 1987. New species included broom sedge (*Andropogon virginicus*), poison ivy, and briars (*Rubus* spp.) Rush (*Juncus effusus*) doubled its frequency from 1987 to 1989, while *Carex alata* was absent by 1989.

The most frequently occurring shrub in 1989 was briar, which replaced the young willow found in 1987. The abundance of trees did not change greatly between 1987 and 1989. Willow density declined by a third, while ash density increased slightly. Two additional species, sweetgum and southern red oak *(Quercus falcata*), were found. Sweetgum is an aggressive species, capable of dominating sites. Southern red oak is more characteristic of a mixed-species bottomland forest.

In the summer of 1990, an additional survey was conducted of the lower corridor and upper delta area of Fourmile Branch (Wike et al. 1994); 68 species were found within the sampling area. Summaries of the major strata are in the following subsections.

5.2.3.5.4.1 Overstory Stratum

No overstory vegetation was found in the area of braided stream in the Fourmile Branch floodplain. Overstory vegetation was killed by the thermal effluent and sedimentation from C Reactor operations. Snags, mainly bald cypress, remained standing in the delta region of Fourmile Branch.

5.2.3.5.4.2 Understory Stratum

The understory stratum had a total of seven species. Tag alder and black willow were the dominant species. Both tag alder and black willow had a relative frequency of 23.08%. Tag alder had the greatest relative dominance (41.14%) and the greatest relative density (45.3%).

5.2.3.5.4.3 Shrub Stratum

Ten species were measured within the shrub stratum of Fourmile Branch. The dominant species were black willow, tag alder, and bay berry (*Myrica heterophylla*). Black willow had the highest relative frequency (25.8%) and the highest relative dominance (52.7%).

5.2.3.5.4.4 Ground Cover Stratum

Seventy-two species were recorded. Cutgrass (*Leersia oryzoides*) had the greatest dominance followed by climbing hemp, false nettle, and tear-thumb (*Polygonum sagittatum*). The species with the greatest frequency were climbing hemp (7.99%), false nettle (7.35%), knotweed (*Polygonum punctatum*) (6.39%), and tear-thumb (5.43%)

5.2.3.6 Pen Branch

5.2.3.6.1 Pen Branch Watershed Characteristics

Until Pen Branch enters the Savannah River swamp, it follows a path parallel to Steel Creek and Fourmile Branch. Pen Branch enters the swamp and flows southeast toward the Steel Creek delta 5 km (3 mi). The only significant tributary is Indian Grave Branch, which flows into Pen Branch about 8 km (5 mi) upstream from the Savannah River swamp. Pen Branch and Indian Grave Branch drain about 55 km^2 (21 mi^2) of SRS. Indian Grave Branch received effluent cooling water from K Reactor. Above the K-Area discharge, Indian Grave Branch flow averages about 0.03 m^3/sec. Above the confluence of Indian Grave Branch, Pen Branch is also a small stream, with a flow averaging 0.14 to 0.28 m^3/sec (Newman et al. 1986).

The headwaters of Pen Branch consist of a largely unperturbed blackwater stream. Downstream from K Area, thermal effluent from K Reactor entered Pen Branch via Indian Grave Branch. When K Reactor operated, cooling water from K Area accounted for more than 98% of the stream volume. Where Pen Branch discharges into the swamp, it formed a delta. The flow from Pen Branch usually spread over the delta and continued through the swamp as shallow sheet flow until it entered the lower reaches of Steel Creek and discharged into the Savannah River. However, when the Savannah River inundated the floodplain swamp, the flow from Pen Branch was forced against the northern upland edge of the swamp, across the Steel Creek delta, to discharge into the Savannah River downstream from the mouth of Steel Creek (Shines and Tinney 1983).

Some hardwoods exist on the outer perimeter of the thermally affected areas, but most occur in nonthermal tributaries or upstream of the K-Area discharge (Ezra et al. 1986). Emergent marsh and open water are common on the delta (Mackey 1990, 1993).

5.2.3.6.2 <u>Pen Branch Corridor and Delta Trends</u>

In 1951, the Savannah River swamp and Pen Branch corridor had a closed canopy forest. In 1954, K Reactor began discharging thermal effluent to Pen Branch. The discharge volume (approximately 2.8 m^3/sec [100 cfs]) and temperature were low (Table 5-13). However, canopy change in the corridor was visible in the aerial photographs taken as early as 1955 and 1956. About 11 ha (27 acres) of bottomland hardwood forest along the corridor were partially defoliated by May 1955. Because discharge temperatures were relatively low, flooding from reactor effluents was probably the major cause of damage.

Reactor discharge temperatures began to rise steadily during 1955 and 1956, and by the end of March 1956, 54 ha (133 acres) along the corridor had been affected. By 1961, canopy defoliation was apparent throughout the corridor (113 ha [279 acres]) and had reached the Savannah River swamp (4.5 ha [11 acres]) (Table 5-13). Most of the trees were affected, probably due to the increasing temperatures (x = 65°C [149°F]) and flows (x = 10 m^3/sec [338 cfs]). During the next five years, the Pen Branch corridor impact area stabilized (at 116 ha [287 acres]), and a delta formed in the swamp at a rate of 9 ha (22 acres)/yr, reaching 51 ha (126 acres) by 1966 (Table 5-13). Average flow (11 m^3/sec [395 cfs]) and temperature (64°C [147°F]) remained relatively high (Tinney et al. 1986).

With lower K-Reactor power levels, discharge temperatures were reduced to 53°C (127°F) by 1966 (Table 5-13). The delta expansion rate decreased to 1.6 ha (4 acres)/yr. Reduced power operations and discharge temperatures continued through 1974 when SRS began an energy conservation program in all reactor areas. Because less cooling water was used, K-Reactor discharges dropped an average of 0.56 m^3/sec (20 cfs) (Table 6-13). However, delta growth accelerated to 6.6 ha (16 acres)/yr after 1973 despite the reduced flows and temperatures. After 1979, reactor power levels began to return to higher levels. Effluent temperatures increased (x = 65°C [149°F]) and the Pen Branch growth continued to expand. In 1985, the impact zone was about 152 ha (375 acres) and was expanding at a rate of about 4 ha (10 acres)/yr (Table 5-13) (Tinney et al. 1986).

Table 5-13. Discharge Conditions and Estimated Impacts to Pen Branch from Reactor Discharges, 1954 - 1995

	Pen Branch Savannah River Swamp		Pen Branch Corridor		Annual Average Reactor Discharge or Pen Branch Flows	
Year	Total Affected Area (ha)	Expansion Rate (ha/yr)	Total Affected Area[a] (ha)	Expansion Rate of Forest Canopy Mortality (ha/yr)	Flow (cfs)[b]	Temperature (°C)[c]
1954	-	-	-	-	100[d]	26
1955	0	-	11.0	-	100[d]	42
1956	0	-	53.8	42.8	131	63
1957	-	-	-	-	183	64
1958	-	-	-	-	214	66
1959	-	-	-	-	277	70
1960	-	-	-	-	334	66
1961	4.5	9.4	112.9	11.8	398	63
1962	-	-	-	-	399	63
1963	-	-	-	-	394	66
1964	-	-	-	-	394	67
1965	-	-	-	-	392	62
1966	51.4	-	115.7	0.6	389	53
1967	-	-	-	-	389	58
1968	-	-	-	-	389	63
1969	-	-	-	-	389	57
1970	-	-	-	-	386	46
1971	-	-	-	-	388	57
1972	-	-	-	-	390	55
1973	63.1	1.7	-	-	388	59
1974	-	-	-	-	324	61
1975	-	-	-	-	373	58
1976	-	-	-	-	376	57
1977	-	-	-	-	375	57
1978	-	-	-	-	378	57
1979	102.4	6.6	-	-	379	61
1980	-	-	-	-	380	64
1981	-	-	-	-	380	64
1982	121.0	6.2	-	-	381	67
1983	-	-	-	-	380	-
1984	147.4	13.2	-	-	370	59
1985	151.8	4.4	92.6	-1.2	367	-
1986	-	-	-	-	270	-
1987	-	-	-	-	329	-
1988	-	-	-	-	140	-
1989	-	-	-	-	78	-
1990	-	-	-	-	57	-
1991	-	-	-	-	200	-
1992	-	-	-	-	160	-
1993	-	-	-	-	54	-
1994	-	-	-	-	56	-
1995	-	-	-	-	49	-

[a]Greater than 5% canopy loss; to convert to acres, multiply by 2.471.
[b]35.82 cfs = 1 m^3/sec. For years 1954-1984, the data are from Tinney et al. 1986. For years 1985-1991, the data are from the USGS recording station at Road A-13.2. For 1992 the data are from Mackey 1993.
[c]To convert to °F, multiply by 9/5 and add 32.
[d]Approximate.

As of 1985, approximately 245 ha (605 acres) of forested wetlands had been affected by thermal discharges from K Reactor. Defoliated canopy was visible in both the stream floodplain (93 ha [230 acres]) and SRS swamp (152 ha [375 acres]). Although the Pen Branch delta was expanding at a rate of 4-5 ha (10-12 acres)/yr in 1985, no additional wetlands changes were expected in the stream corridor (Tinney et al. 1986).

Much of the swamp canopy loss in the early to mid-1980s near Pen Branch delta occurred southeast of the main Pen Branch delta, adjacent to the upland terrace along the Savannah River swamp (Figure 5-12) (Sharitz et al. 1986; Christensen et al. 1986; Jensen et al. 1987).

Thermal infrared surveys showed that during river flooding, thermal effluents from both Fourmile Branch and Pen Branch were channeled along the northeast bank of the swamp away from the river (Shines and Tinney 1983). Times of river flooding seemed to correlate with the southeastern progression of the Pen Branch delta. From 1966 to March 1973, the southeastern tail changed little (Figure 5-12). Spring flooding frequency and duration were low during this period. After 1973, there was an increase in springtime flooding frequency and the tail began to increase in size. The channeling of thermal effluents during the spring and summer growing season, when the cypress-tupelo forest is most sensitive, may have increased mortality (Sharitz et al. 1986). The post-1973 increase in river flooding intensity may have caused the increase in the delta expansion rate from 1.7 to 6.6 ha (4 to 16 acres)/yr, when reactor discharge temperatures and flows remained relatively constant (Wike et al. 1994).

5.2.3.6.3 <u>Wetland Characteristics of the Pen Branch Delta Area, Early 1980s</u>

Pen Branch received thermal effluent from K Reactor. Temperatures of the reactor effluents at the point of release into Pen Branch commonly exceeded 65°C (149°F). Water temperatures throughout the length of the then-thermal portion of Pen Branch typically exceeded 40°C (104°F) in the summer. The original flora of the stream and associated floodplains were destroyed and the area underwent successional revegetation. Sharitz et al. (1974a) found only 34 species of vascular plants in the Pen Branch corridor at a site immediately above the delta where the stream enters the Savannah River swamp. All of the plants were growing above the water on sandbars or small islands formed by fallen logs and tree stumps. Only 56% of the floodplain area sampled supported vascular plant life. The Pen Branch floodplain flora was characterized by herbaceous plants. The dominant species was water primrose (*Ludwigia leptocarpa*), which was shown to have a relatively high tolerance to the elevated thermal conditions of the SRS swamp (Christy and Sharitz 1980). The other species were mostly perennial herbaceous plants characteristic of disturbed areas. Perennial herbs constituted 60% of the Pen Branch flora and annual herbs another 20%. In another early survey, Irwin (1975) sampled the vegetation of stump communities at three sites in the thermal portion of Pen Branch. Fifteen stumps were evaluated from each of three areas corresponding to mean annual water temperatures of approximately 50°C, 45°C, and 40°C (122°F, 113°F, and 104°F). The vegetation of the stump communities in Pen Branch included old-field species, roadside weeds, and aquatic herbs. Twenty-six of the species were herbaceous, and of the nine woody species, three were tree seedlings.

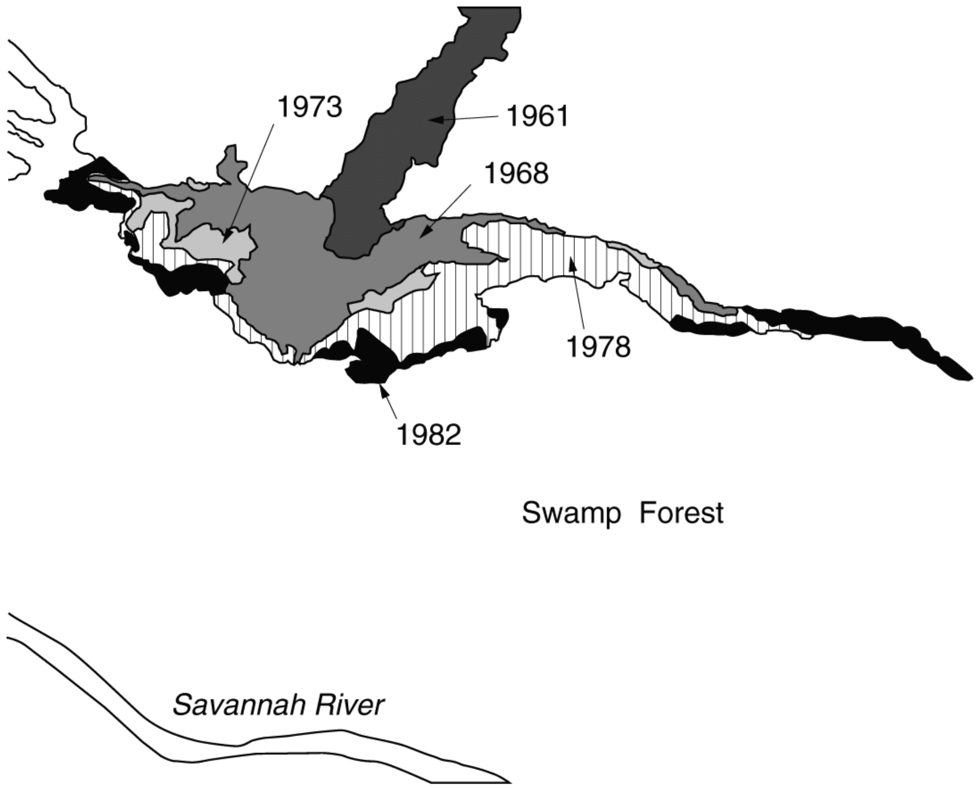


Figure 5-12. Pen Branch Delta Expansion Composite Image, 1961-1982 (Source: Wike et al. 1994)

There was no clearly distinguishable relationship between stream water temperature and stump community composition, although the upstream sites (water temperature approximately 50°C [122°F]) were dominated by several old-field species, including dogfennel (*Eupatorium* spp.) and broom sedge. Downstream sites (water temperatures approximately 40-45°C [104-113°F]) had a greater dominance of aquatic species, such as water primrose and swamp loosestrife. Woody plants were relatively intolerant of the elevated temperatures and substrate conditions. The Comprehensive Cooling Water Study and other studies at SRS from 1983 to 1985 (Firth et al. 1986) summarize additional information on the in-stream habitat formers of the thermal and nonthermal SRS streams.

5.2.3.6.4 <u>MSS Surveys – Pen Branch Delta</u>

5.2.3.6.4.1 Central Portion MSS Surveys, 1981–1994

The April 1984 MSS data were registered to March 1981 data for a 190-ha (469 acre) area centered on the Pen Branch delta. The most obvious difference between 1981 and 1984 was the expansion of the emergent marsh into thinned cypress-tupelo areas. Nonpersistent emergent and persistent emergent wetlands replaced about 12 ha (30 acres) of cypress-tupelo. The majority of the cypress-tupelo area lost was adjacent to the existing thermal delta or to the southeast, along the Savannah River swamp terrace edge.

Burkhalter (1994) compared 1992 MSS data with 1981 data and determined that deciduous swamp forest beyond the delta in 1981 had been degraded to persistent emergent and scrub-shrub wetlands by 1992. The most striking feature was the tremendous invasion of the persistent emergent marsh (mostly cattails, particularly in the tail region). The delta had been exposed mudflat or vegetated with nonpersistent emergent vegetation in 1981. By 1992, much of the delta supported persisted emergent and scrub-shrub species, an indication that the delta was undergoing succession.

Mackey (1990, 1993) summarized the changes in the lower Pen Branch corridor and delta as evaluated from SPOT HRV data for 1987-1992. In addition to bottomland hardwood and cypress-tupelo, four wetland cover types dominated the Pen Branch delta: deep- and open-water areas, nonpersistent emergent marsh, persistent marsh, and scrub-shrub communities, which consist primarily of willow and buttonbush. Since *Ludwigia* frequently overgrows shallow water, mud flats, and sand bars by late summer or early fall, these cover types were included with the NPE cover class; areas of shallow-water covered by duckweed also were included in the NPE class. Late April to mid-May proved to be the best time of year to distinguish the wetland types from each other with discrimination in the summer and early fall more difficult (Jensen et al. 1986a; Mackey 1990).

In mid-April 1988, K Reactor shut down. Flows in Pen Branch decreased from levels near $11m^3$/sec (400 cfs) to 1.4-1.7 m^3/sec (50-60 cfs) in 1989 and 1990. This decrease in flow was reflected in a decline in the deep-and open-water areas as evaluated with the SPOT HRV data (Table 5-14). As the Pen Branch delta became drier in 1988 through 1990, it also became more difficult to distinguish areas of *Ludwigia* dominance from areas dominated by cattail beds. Part of this difficulty is the result of large beds of dead, brown biomass from the *Ludwigia* areas and cattail beds still present in the spring from growth during the previous summer.

Furthermore, some areas in the lower Pen Branch stream corridor north of the upper delta began to resemble old-field sites. Similar invasion of old-field species has been observed in the drier portions of the Fourmile Branch corridor and delta since C-Reactor shutdown. Since 1990, the main portion of the Pen Branch delta has become increasingly dominated by persistent cattails beds and by invading scrub-shrub species, primarily willow and buttonbush (Table 5-14). The overall shift from wetland communities dominated by more thermally and flood tolerant herbaceous species to wetland communities dominated by persistent and scrub-shrub species is likely to continue without disturbance.

5.2.3.6.4.2 Summary of Changes

Table 5-15 and Table 5-16 summarize trends in wetlands for the Pen Branch corridor and delta. After the reduction in K-Reactor operations in 1987, the shift was from nonpersistent vegetation and water to more persistent vegetation and drier conditions. The area of willows and hardwoods increased tremendously, as the willows and scrub-shrub expanded down the corridor into the delta, gradually being replaced by other hardwoods or becoming large enough to be classified as hardwoods. The area of deep water was large in the early years, but decreased substantially in 1990-1992, reflecting the drying of the corridor and delta. As the delta dried, water primrose declined markedly from 1990 to 1991. This allowed other vegetation, such as cattails, to increase dramatically by 1991 (Mackey 1993; Blohm 1993).

Table 5-14. Major Wetland Cover Types Based on Classification of SPOT HRV Data for the Pen Branch Delta, Spring 1987-1992

	Year and Date of SPOT HRV Data					
Wetland Cover Type	**1987 Apr 24**	**1988 May 02**	**1989 May 17**	**1990 May 11**	**1991 May 02**	**1992 May 5**
Deep/open water	13.1[a]	4.0	0.0	1.1	23.2[b]	26.2[b]
Non-Persistent emergent marsh						
Shallow water/mud flats	65.5	29.0	0.4	11.4	-	-
Ludwigia spp.	34.0	56.8	97.4[c]	92.2	66.2[b]	31.8[b]
Duckweed	3.2	10.1	3.6	0.1	0.3	-
Persistent emergent marsh, primarily cattails (*Typha* spp.)	31.2	38.5	c	6.0	44.8	55.5
Scrub-shrub	-	-	-	11.7	3.4	23.6
Total	**147.0**	**138.4**	**101.4**	**122.5**	**137.9**	**137.1**

Source: Mackey 1993.
[a] Hectares; to convert to acres, multiply by 2.471.
[b]In May 1991 and 1992, the Pen Branch delta was wetter from spring Savannah River flooding and moderate flows to Pen Branch, thus it was difficult to sort between shallow-water/mudflats and *Ludwigia* beds. This difficulty probably accounts for an apparent increase in deep water areas.
[c]In May 1989, it was not possible to distinguish between the nonpersistent beds of *Ludwigia* and stands of cattails in the SPOT HRV data.

Table 5-15. Wetland Classification Scheme for the Pen Branch Tail Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data

	Representative Species	
Wetlands Class	**Common Name**	**Scientific Name**
Open water		
Emergent marsh	Bulrush	*Scirpus cyperinus*
	Cutgrass	*Leersia* spp.
	False Nettle	*Boehmeria cylindrica*
	Water Primrose	*Ludwigia* spp.
	Hydrolea	*Hydrolea quadrivalvis*
Deciduous swamp forest	Cypress	*Taxodium distichum*
	Tupelo	*Nyssa aquatica*
Deciduous bottomland forest	Oak	*Quercus* spp.
	Sweetgum	*Liquidambar styraciflua*
	Red Maple	*Acer rubrum*
	Hickory	*Carya* spp.

Table 5-16. Pen Branch Tail Wetlands Change Detection Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data

From	To	Hectares
Deciduous swamp forest (DSF)	Emergent marsh	3.64
DSF	Transition-DSF	12.14
DSF	Open water	9.30
Transition-DSF	Emergent marsh	2.42
Transition-DSF	Open water	1.21
Transition-DSF	No Change	5.66

MSS data were used to assess the continuing successional changes in the Pen Branch corridor and delta in 1993 and 1994. Cypress acreage was increasing. The hardwood and scrub-shrub classes were gaining acreage until the area was treated by herbicides in the winter of 1993 in preparation for selective planting. Some of the hardwood class were actually willow that were mislabeled in the earlier assessment. Old-field acreage in the corridor has increased, due to site preparation prior to seedling planting. In general, the nonpersistent vegetation that maintained dominance under conditions of thermal discharges and fluctuating water levels (such as *Ludwigia* spp.) is being replaced by more persistent species (such as cattails). Drier conditions in the delta support increased acreages of the most tolerant hardwoods, scrub-shrub, and willow stands, cypress, and persistent wetlands vegetation (Christel 1996). Hardwoods expanded down the corridor, and cattails expanded over the delta (Blohm 1993).

5.2.3.6.4.3 Tail MSS Surveys, 1981-1994

Expansion of the Pen Branch delta occurred southeast of the main portion of the delta along the SRS Savannah River swamp terrace edge. The Pen Branch tail extended southeast for approximately 3 km (2 mi) along an upland terrace adjacent to the Savannah River swamp. This area was influenced by thermal effluents, especially during flood events. A separate evaluation of this area was conducted using aircraft MSS data from March 31, 1981, and April 29, 1985. Two 375-ha (927-acre) subsets from the 1981 and 1985 MSS data were evaluated (Figure 5-7).

The MSS data were classified into the following wetland vegetation classes once the 1981 and l985 imagery were registered to one another:

- Open water
- Emergent marsh (persistent and nonpersistent)
- Deciduous swamp forest
- Deciduous bottomland forest

One additional class of deciduous swamp forest, referred to as a transition deciduous swamp forest, was found in both the 1981 and 1985 imagery. A transition deciduous swamp forest consists of cypress-tupelo swamp forest with a sparse, stressed canopy, which allows radiant flux from the emergent marsh below to be integrated within a typical pixel. The stressed cypress-tupelo community was documented *in situ* in the Pen Branch tail by Scott et al. (1986) and radiometrically by Jensen et al. (1986b). Table 5-16 summarizes the statistics associated with the changes in the Pen Branch delta from 1981 to 1985. Table 5-10 and Table 5-12 show changes between 1981 and 1992. Since 1992, there has been some return of young cypress to the tail area (Christel 1996). Section 5.5 of this chapter discusses the reforestation project in the Pen Branch corridor and delta.

5.2.3.6.5 Pen Branch Ground Surveys, 1990

In the summer of 1990, a series of vegetation surveys was conducted along the Pen Branch drainage from the K-Reactor discharge canal to the Pen Branch tail area (Wike et al. 1994). These surveys are summarized in the following paragraphs by survey area along the creek and for each vegetation stratum.

5.2.3.6.5.1 Indian Grave Branch Section

Introduction - Indian Grave Branch, a 4-km (2.5-mi)-long tributary to Pen Branch, has steep, incised banks with a flow approximately 4.5-6 m (15-20 ft) wide. Sampling plots were established along Indian Grave Branch beginning approximately 300 m (1000 ft) north of Road B and extending south to the confluence of Pen Branch. Ninety-nine species were found.

Overstory Stratum -Thirteen species were found in the overstory. The average height of the overstory canopy was 19 m (62 ft). The most dominant species occurring within the sample plots were yellow poplar and black gum. Red maple had the highest density within the sampling plots. Following red maple in relative density were black gum, yellow poplar, sweet gum, and sycamore.

Understory Stratum - Fourteen species were found in the understory. American holly (Ilex *opaca*) had the highest importance value. Following American holly were sweet gum, red-bay, and tag alder. American holly also had the greatest relative density.

Shrub Stratum -Twenty-seven species were found in the shrub stratum. American holly had the greatest relative dominance, followed by tag alder. Red bay had the greatest relative density, followed by American holly and sweet bay.

Ground Cover Stratum -One hundred and five species were found in the ground stratum. Soft rush had the highest importance value. Following soft rush were netted chainfern (*Woodwardia areolata*), dogfennel (*Eupatorium capillifolium*), and cutgrass.

5.2.3.6.5.2 Mid-Corridor Section

Introduction -This section began approximately 60 m (100 ft) north of South Carolina Highway 125 and extended south for approximately 5 km (3 mi). For approximately 0.6 km (1 mi), the sampling area has steep banks leading down to the floodplain of the creek. Downstream of this point, the topography around Pen Branch flattens. Due to the flat terrain, the surface runoff contributing to Pen Branch flows as wide sheets of water rather than being confined to small intermittent tributaries. Eighty-eight plant species were found along this section of Pen Branch.

Overstory Stratum -The average canopy height of the overstory vegetation was 21 m (70 ft). Red maple, black gum, yellow poplar, and ash were the most common species in this stratum.

Understory Stratum -Fifteen species were recorded within the understory of this section. Wax myrtle (*Myrica cerifera*) was the dominant species. Wax myrtle had the highest importance value for the area, followed by black willow, tag alder, and sweet gum.

Shrub Stratum - Nine species were found in the shrub layer. Black willow had the highest importance value followed by wax myrtle, tag alder, red maple, and sweet gum.

Ground Cover Stratum -One hundred one species were recorded from the ground cover. False nettle had the highest importance value, followed by woolgrass (*Scirpus cyperinus*), jewel weed (*Impatiens capensis*), climbing hemp, and marsh dewflower (Murdannia keisak), all with about equal importance values.

5.2.3.6.5.3 Lower Pen Branch Corridor

Introduction -The lower Pen Branch corridor begins south of Road A-13.2 (Risher Pond Road) and extends south for approximately 0.2 km (0.75 mi). This stretch of Pen Branch drops only 3 m (10 ft) in elevation. This area had a series of parallel braided streams and was dominated by scrub-shrub growth. Within the braided streams were many islands on which thick masses of persistent emergent ground cover were thriving. Nonpersistent emergent vegetation also was well represented. Seventy-six species were found.

Overstory Stratum -The overstory vegetation in this area was represented by seven species. The average canopy height was 19.5 m (64 ft). Sweetgum and black gum were the dominant species, followed by red maple.

Understory Stratum - Nine species were found in the understory. The dominant species was black willow. Following black willow were black gum, tag alder, buttonbush, and American holly.

Shrub Stratum - Thirteen species of shrubs were recorded. Black willow had the highest importance value. Black willow was the most common, followed by tag alder, buttonbush, and sweet bay.

Ground Cover Stratum - Seventy-eight species were found in the ground cover. False nettle was the dominant species, followed by fireweed and woolgrass.

5.2.3.6.5.4 Upper Delta Area

Introduction - The upper delta (Figure 5-13) was similar to the lower corridor in that it had braided streams and islands within the broad, flat floodplain. Elevation ranged from 29.5 m (97 ft) above msl to 24 m (80 ft) above msl. Standing dead trees were common, and woody debris was scattered throughout. The lack of an overstory resulted in thick scrub-shrub and persistent emergent vegetation. Sixty-one species were found in the upper delta.

Overstory Stratum - No overstory vegetation was recorded. All sampling plots were located in the wide floodplain of the lower section of Pen Branch. The area once was well forested; however, in 1990 it contained only many snags of black gum and bald cypress.

Understory Stratum - Only five species were found in the understory stratum. Black willow was the dominant species, followed by buttonbush.

Shrub Stratum - The shrub stratum had 12 species. Black willow dominated followed by buttonbush.

Ground Cover Stratum - The ground cover was dominated by false nettle, followed by fireweed and dogfennel. The presence of dogfennel, an upland species, demonstrates the drier nature of the Pen Branch delta sediments since K-Reactor shutdown in 1988 (Mackey 1993).

5.2.3.6.5.5 Mid-Delta Area

Introduction - The mid-delta area (Figure 5-13) is within the confluence of Pen Branch and the Savannah River floodplain swamp. The area has a soft substrate that is inundated with water. It was dominated by persistent and nonpersistent vegetation. The elevation of the sampling area is approximately 24 m (80 feet) above msl. This area is west of the Pen Branch boardwalk. Little shrub and understory vegetation was observed, and no overstory stratum was sampled. Thirty-one plant species were found within the mid-delta region.

Overstory Stratum - There was no overstory vegetation.

Understory Stratum - Only one wax myrtle met the criterion for understory vegetation.

Shrub Stratum - The shrub layer contained three species: black willow, buttonbush, and wax myrtle.

Ground Cover Stratum - Thirty-four species were measured in the ground cover stratum. Broad-leaf arrowhead (*Sagittaria latifolia*) had the greatest importance value, followed by water primrose (*Ludwigia leptocarpa*), cattail (*Typha latifolia*), and beggar tick (*Bidens frondosa*).

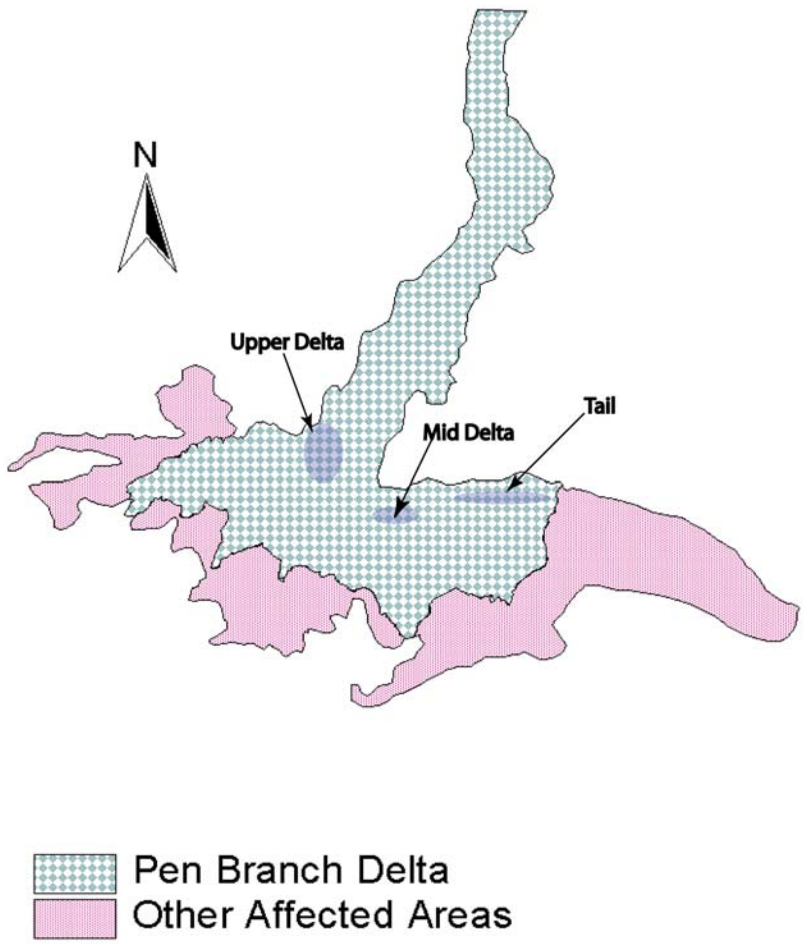


Figure 5-13.   Locations of Upper Delta, Mid-Delta, and Tail Region of Pen Branch Delta

5.2.3.6.5.6   Pen Branch Tail Area

Introduction - The Pen Branch tail area begins east of the Pen Branch boardwalk and extends east for approximately 2 km (1.25 mi). Persistent and nonpersistent emergent vegetation dominated the area. Eastward, there was an increase in mature bald cypress, and the density of seedlings and saplings greatly increased. Seventy-seven species were found in the area.

Overstory Stratum - The overstory consisted of bald cypress, water tupelo, and black gum. The average height of the sparse canopy was 24 m (78 ft). The overstory vegetation became progressively more dense as distance from the mouth of Pen Branch increased.

Understory Stratum - Four species were measured in the understory stratum; wax myrtle was the most common, followed by black willow.

Shrub Stratum - The shrub stratum, like the overstory and understory strata, was represented by only a few species, in this case five. Wax myrtle was the dominant species, followed by buttonbush.

Wax myrtle appeared to be better established in this area than the other species. The Pen Branch tail lies within the Savannah River floodplain. The plot was just below the wetland/upland boundary of the Savannah River floodplain and remains inundated with water for a great portion of the growing season. The area sampled was undergoing succession from persistent and nonpersistent vegetation to a palustrine forest.

Ground Cover Stratum - Sixty-eight species were found in the ground cover stratum of the Pen Branch tail. Marsh dewflower, a highly successful introduced plant, was the most common. Broad-leaf arrowhead, cattail, and false nettle were also common.

5.2.3.6.5.7 Summary of 1990 Pen Branch Ground Survey

Because past disturbances from reactor effluent removed the overstory in some areas of Pen Branch, growing conditions in those areas were excellent for typical pioneer plant species. Except in areas of deep water, after the reactor outage, the vegetation over much of the corridor and delta produced dense herbaceous and woody growth. Cover at these sites generally approached 100%. The exact species composition depended on substrate and hydrology and chance colonization events (Mackey 1990, 1993; Blohm 1993).

5.2.3.7 Steel Creek

5.2.3.7.1 Steel Creek Watershed Characteristics

Steel Creek is near the eastern boundary of SRS. Steel Creek and its major tributary, Meyers Branch, drain approximately 91 km^2 (35 mi^2) of upland before entering the swamp and flowing to the Savannah River. The drainage basin for Meyers Branch constitutes more than half of the watershed (50.85 km^2 [20 mi^2]). The stream slope changes from 4.6 m/km (25 ft/mi) at the head to 0.8 m/km(5 ft/mi) as it enters the Savannah River (Newman et al. 1986).

5.2.3.7.1.1 Steel Creek Corridor and Delta Through 1982

In 1951, a closed canopy forest extended throughout much of the Savannah River swamp and Steel Creek corridor. Although portions of the forest had been previously logged (Jensen et al. 1993), a second-growth forest of bald cypress, water tupelo, and bottomland hardwoods was present. In 1954, both L and P Reactors began releasing thermal effluents to Steel Creek. The discharge volume (approximately 5.6 m^3/sec [200 cfs] total) and temperature (30-48°C [86-104°F]) were relatively low (Table 5-17). Approximately one year after startup, 48 ha (119 acres) of bottomland forest were partially defoliated in the Steel Creek corridor below both L and P Reactors (Table 5-17. Canopy loss continued into 1956 with 132 ha (326 acres) of corridor floodplain forest damaged (Table 5-17. At the same time, the first signs of canopy loss also appeared in the swamp. In one year, 73 ha (180 acres) of cypress-tupelo canopy were partially defoliated in the swamp.

Canopy loss in the swamp continued at an overall rate of 10 ha (24 acres)/yr while in the Steel Creek floodplain defoliation slowed to 2.2 ha (5.4 acres)/yr from 1956 to 1961 (Table 5-17). During this period, reactor discharge temperatures averaged approximately 70°C (158°F) (Table 5-17).

Maximum flow in Steel Creek occurred between 1960 and 1963 (Table 5-17). However, from 1961 to 1966, the floodplain and the swamp impact zones grew at a rate of about 0.5 ha (1 acre)/yr. The slower growth rate probably occurred because P-Reactor thermal effluents were diverted to Par Pond in 1963. From 1961 to early 1963, reactor discharges to Steel Creek averaged 21 m^3/sec (760 cfs), but dropped to about 10 m^3/sec (370 cfs) from 1963 to 1968 (Table 5-17). Water temperatures remained relatively constant. In 1966, the total impact area was near its maximum size at 124 ha (306 acres) in the swamp and 146 ha (360 acres) in the Steel Creek corridor (Table 5-17).

In 1963, P-Reactor thermal effluents were diverted to Par Pond, allowing the natural successional revegetation of bottomland forest to begin in the upper portion of the Steel Creek corridor. When L Reactor discontinued operations in 1968, the swamp and remainder of the corridor floodplain forest also began to revegetate. Between 1968 and 1982, new forest canopy cover established in the swamp at a rate of less than 1 ha (2.5 acres)/yr. After 1982, the canopy recovery rate accelerated to about 8 ha (20 acres)/yr as young hardwoods matured. However, most new regrowth of woody species was of willow (*Salix* spp.) and not the original cypress-tupelo swamp forest (Repaske 1981; Smith et al. 1981). Some cypress-tupelo regeneration occurred in fringe areas of the swamp impact zone where thermal exposure had been less extreme (Tinney et al. 1986).

Some cypress-tupelo regeneration occurred offsite in the Creek Plantation swamp (southeast of SRS). Thermal effluent from Steel Creek entered the area beginning in 1956, particularly when the swamp was flooded in late winter and early spring. By 1961, about 5 ha (12 acres) of offsite swamp canopy had been altered. After 1963, the canopy began to recover. By 1966, the impact area visible on aerial photographs had been reduced to 4 ha (10 acres). Currently, a closed canopy exists in the previously impacted offsite area (Tinney et al. 1986).

5.2.3.7.2 Wetland Characteristics of the Steel Creek Drainage Area, Early 1980s

The wetlands of the Steel Creek drainage have been studied extensively since 1981. Smith et al. (1981, 1982) summarized the results of many of the early studies. These initial studies were expanded during the Comprehensive Cooling Water Study that continued into 1985, immediately prior to the restart of L Reactor in 1985 (Mackey 1987). Generally, these studies documented that the Steel Creek ecosystem was in a state of successional revegetation from the 1968 L-Reactor shutdown to 1985, when clearing began for L Lake.

With long-term reactor shutdown, plant succession on the Steel Creek delta proceeded rapidly. The initial flora of the emergent sandbars was dominated by fimbristylis (*Fimbristylis autumnalis)*, water primrose (*Ludwigia leptocarpa* and *L. decurrens*), sedges (*Cyperus* spp.), and echinochloa (*Echinochloa walteri*) (McCaffrey 1982). Knotweed, broad leaved arrowhead, and cut grass became dominant species four to eight years after reactor shutdown. Seven years after shutdown *Aneilema keisak* became an additional dominant; cut grass increased and smartweed decreased in dominance.

Table 5-17. Discharge Conditions and Estimated Impacts to Steel Creek from Reactor Discharges, 1954-1995

Steel Creek Delta Savannah River Swamp			Steel Creek Corridor		Annual Average Reactor Discharge or Creek Flow	
Year	**Total Affected Area[a] (ha)**	**Expansion and Revegetation Rate (ha/yr)**	**Total Affected Area[a] (ha)**	**Expansion Rate of Forest Canopy Mortality (ha/yr)**	**Flow (cfs)[b]**	**Temperature (°C)[c]**
1954	0	-	-	-	200	32
1955	0	-	48.1	48.1	200	44
1956	72.8	72.8	132.2	84.1	257	64
1957	-	-	-	-	270	71
1958	-	-	-	-	386	69
1959	-	-	-	-	557	72
1960	-	-	-	-	649	72
1961	122.6	10.1	143.4	2.2	758	67
1962	-	-	-	-	763	68
1963	-	-	-	-	372	66
1964	-	-	-	-	376	67
1965	-	-	-	-	371	69
1966	124.2	0.4	146.0	0.5	370	70
1967	-	-	-	-	368	69
1968[d]	-	-	-	-	370	67
1974	120.6	0.4	147.0	0.1	-	-
1981	-	-	-	-	32	-
1982	113.3	0.9[d]	-	-	56	-
1983	-	-	-	-	72	-
1984	90.1	7.8[d]	-	-	79	-
1985	81.9	8.1[d]	76.1	5.9[e]	83	-
1986	-	-	-	-	249	-
1987	-	-	-	-	260	-
1988	-	-	-	-	242	-
1989	-	-	-	-	127	-
1990	-	-	-	-	128	-
1991	-	-	-	-	160	-
1992	-	-	-	-	112	-
1993	-	-	-	-	116	-
1994	-	-	-	-	87	-
1995	-	-	-	-	78	-

[a]Greater than 5% canopy loss; to convert to acres, multiply by 2.471.
[b]35.31 cfs = 1 m^3 /sec. For years 1954-1968, the data are from Tinney et al. 1986. For years 1981-1991, the data are from the USGS recording station on Steel Creek at Road A.
[c]To convert to °F, multiply by 9/5 and add 32.
[d]L Reactor discharged for two months before shutdown.
[e]Revegetation rate.

Begger ticks, marsh St. John's-wort, false nettle, and bulrush had an intermediate ranking in importance four to eight years after reactor shutdown. Redtop panicgrass also had an intermediate ranking at the later date. Buttonbush and willow appeared during this time; while seedlings of other woody species were ephemeral. According to Martin et al. (1977), the Steel Creek delta was covered with water and resembled a freshwater marsh in 1975. The vegetation was characterized by a low, dense herbaceous cover with numerous clumps of large graminoids and widely spaced shrubs. In 1981, there were three major stages of succession in the persistent emergent wetland: areas of abundant knotgrass that generally fit the description by Martin et al. (1977), areas in which numerous small buttonbush and willow plants were nearly as tall as the knotgrass (approximately 1.5 m [5 ft]), and other areas dominated by a mixture of willow and buttonbush taller than the knot grass.

In 1981-1982, following 14 years of revegetation, cut grass remained dominant in habitats similar to those described by Martin et al. (1977). Knot grass had increased importance and redtop panicgrass was common. *Aneilema keisak* and waterpepper were still abundant, especially in the more deeply flooded areas.

After 15 years of successional revegetation, the dominant species was willow. Seedlings of bald cypress, water ash, water elm, and red maple also occurred, especially toward the delta periphery. The survival and growth of these plants are largely dependent upon the duration and timing of flooding (Broadfoot and Williston 1973; Whitlow and Harris 1979; Sharitz et al. 1986; McLeod et al. 1986; Scott et al. 1985).

Because of a raised substrate on which hardwood species can become established, it is likely that the deltaic fan eventually will become more like deciduous bottomland hardwood forest (overcup oak-water hickory [*Carya aquatica*] - water tupelo) than the original deciduous swamp forest.

Succession in areas of deeper water is dependent upon water depth and flow. Here, submerged aquatic plants (coontail and *Myriophyllum brasiliense* [parrotfeather]) colonized submerged logs. These species are joined by numerous emergent aquatic species, including knotweed and aneilema in deeper water with low flow. Hydrolea dominated the periphery of the deltaic fan and occurred over a wide range of water depths, along with parrot-feather and *Ludwigia* spp. The shallower areas had broad-leaved arrowhead abundant rhynchospora (*Rhynchospora corniculata*). Waterpepper occurs in similar habitats. Both wapato and waterpepper are transitional species occurring in both nonpersistent emergent wetlands and in persistent emergent wetlands.

5.2.3.7.3 <u>Steel Creek Corridor and Delta, 1985-1992</u>

The L-Lake/Steel Creek Biological Monitoring Program (1985-1992) monitored the effects of the restart of L Reactor on the riparian wetland habitat of Steel Creek from L Lake dam to the Savannah River. During 1986 through 1989, quarterly surveys were conducted at 12 stations on Steel Creek and 1 station on Meyers Branch (Peter and Westbury 1990) (Figure 5-14). In 1990-1992, the program was reduced to four stations sampled semiannually when L Reactor was shut down (Westbury 1992). At each station, two parallel belt transects were established perpendicular to the main channel and bisecting instream habitat mapping reaches.

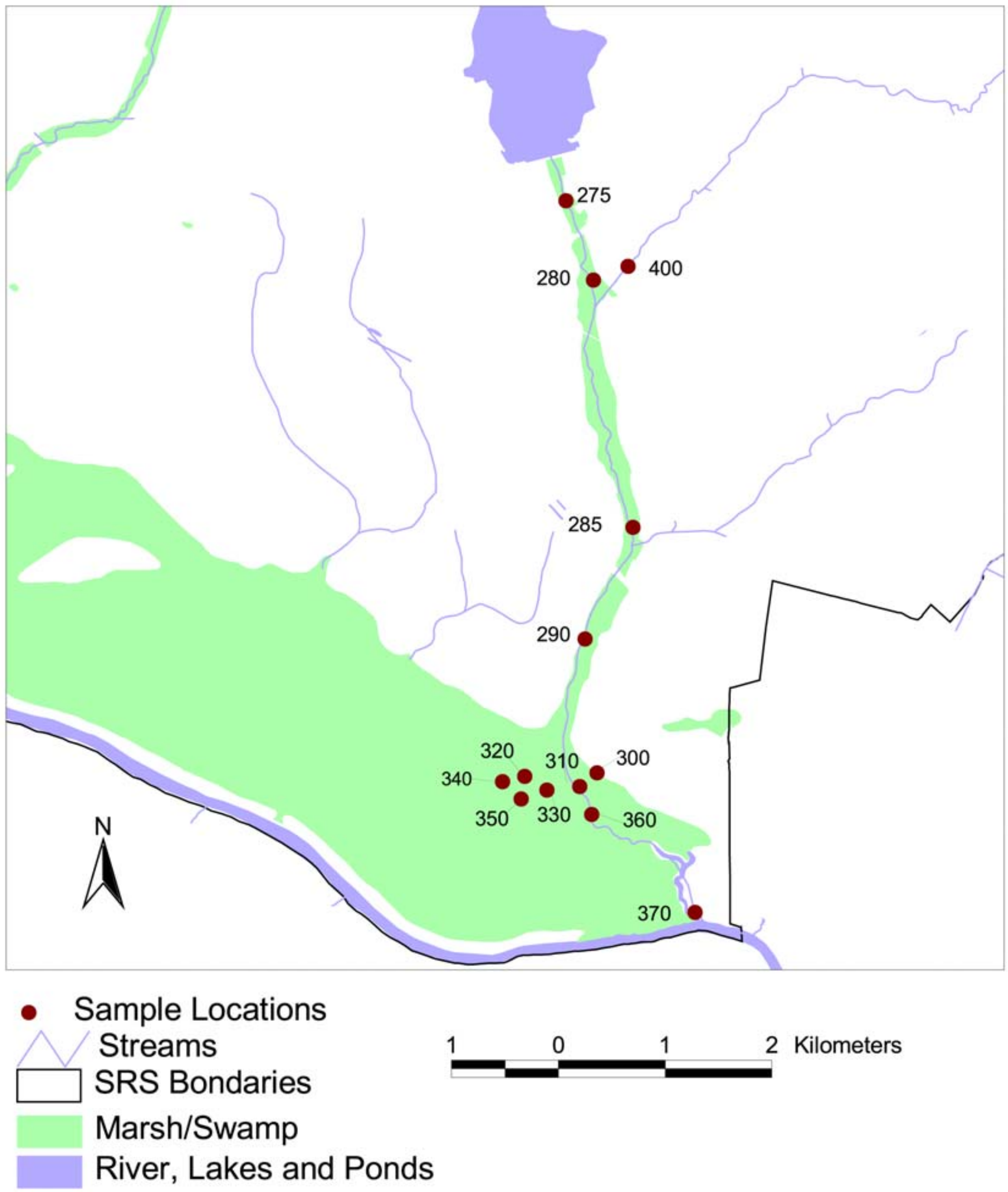


Figure 5-14. Steel Creek Sampling Stations

These belt transects extended to the upland boundary of the floodplain or for a total length of no more than 150 m (522 ft). Variables reported in these data include the frequency, width and cross-sectional area of all channels; percent inundation; the density of logs, knees, and stumps; the density, diameter, basal area, and importance values of trees; shrub density; canopy cover; taxa richness; growth form analysis; and herbaceous cover (Table 5-18 through Table 5-24). Taxonomic identification and analysis were largely at the species level, with annual taxa lists exceeding 200 species in 1989 (Table 5-25 and Table 5-26) (Peter and Westbury 1990).

The Steel Creek corridor station (290) was chosen to represent the upper portion of the study area. The floodplain was relatively narrow, and the influence of L-Lake discharge rates was the greatest. The decrease in percent inundation between 1988 and 1989 (Table 5-20) is a result of L Reactor shutdown. The reduction in canopy cover observed during the same time (Table 5-21) was due to wind damage from several violent storms. Mean stand basal area was not affected because no trees in the belt transects were thrown. The decrease in canopy cover due to the storm damage increased herbaceous cover (Table 5-24).

Station 330 represented the open-canopy marsh habitat of the Steel Creek delta, which had the lowest canopy cover, shrub density, and tree basal area. L Lake discharge and water levels in the Savannah River influenced inundation at this station. High river water levels were responsible for the increase in inundation observed in 1990. Herbaceous cover was high at this station, but generally decreased in response to fluctuating water levels during the period of L-Reactor operation. A drop in herbaceous cover in 1991 was attributed to an infestation of smut fungus on the fruit of the dominant plant, *Polygonum densiflorum*.

Station 350 characterized the semipermanently flooded, closed-canopy Savannah River swamp system. Inundation at this station was influenced by flow rates from Steel Creek, Pen Branch, and by water levels in the Savannah River. Despite the high inundation, canopy cover at this station was reduced during 1988-1989, apparently due to the small leaf size in response to low rainfall. Trees at station 350 were water tupelo; shrubs were confined to stumps and logs. The most common herbaceous plants at this station were duckweed and waterweed.

The Steel Creek channel station (370) was in a mature mixed deciduous forest. A wide, deep channel contained the flow from the delta and upstream Savannah River swamp. Water levels in the Savannah River influenced this station. High release volumes from Lake Strom Thurmond in 1990 greatly reduced the shrub density and herbaceous cover. Although the mean basal area at station 370 was lower than at station 350 due to the wider spacing of the trees, canopy cover was greater due to the larger crowns and greater diversity of species.

During 1986-1992, few changes were observed that could be directly attributed to L-Reactor operations (Figure 5-15). L Lake discharge was the dominant hydrologic influence only at the corridor station. The greatest changes in the riparian wetlands of Steel Creek during this period were caused by the wind storm in the corridor, the smut fungus infection of *Polygonum densiflorum* in the marsh in 1991, and flooding of the Savannah River in 1990.

Table 5-18. Steel Creek Delta Wetland Areas Based on Aircraft MSS Data, March 31, 1981, and April 26, 1985

	March 31, 1981		April 26, 1985	
Wetland Classes	**Hectares[a]**	**Percentage**	**Hectares**	**Percentage**
Water	0.00	0.00	4.26	1.79
Non-persistent emergent	29.75	12.53	16.33	6.84
Persistent emergent	27.07	11.40	11.32	4.74
Scrub-shrub	28.17	11.87	56.82	23.81
Deciduous swamp forest	82.04	34.56	80.57	33.75
Deciduous bottomland hardwood	14.40	6.07	13.47	5.64

[a]To convert to acres, multiply by 2.471.

Table 5-19. Steel Creek Delta Wetland Areas Based on Aircraft MSS Data with Improved Discrimination of Scrub-Shrub and Deciduous Swamp Forest, April 26, 1985

Wetland Classes	Hectares[a]	Percentage
Water	4.26	1.79
Nonpersistent emergent marsh	16.33	6.84
Persistent emergent marsh	11.32	4.74
Scrub-shrub (buttonbush)	38.63	16.18
Scrub-shrub (willow)	18.20	7.62
Deciduous swamp forest (tupelo)	36.26	15.19
Deciduous swamp forest (cypress)	44.31	18.56
Deciduous bottomland hardwood	13.47	1.79

[a]To convert to acres, multiply by 2.471.

Table 5-20. Annual Mean Percent Floodplain Inundation

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	71.3	60.4	65.0	54.2	49.7	58.4	44.4
Marsh	330	100	100	55.4	55.4	81.6	76.6	58
Swamp	350	100	99.5	87.8	96.8	86.7	87.1	93.4
Channel	370	17.1	27.1	16.1	20.7	31.8	26.6	35.7

[a]See Section 4.5 for location of Steel Creek sampling stations.

Table 5-21. Mean Percent Summer Canopy Cover

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	89.0	92.8	80.7	62.4	61.1	58.3	66.9
Marsh	330	33.1	26.8	21.9	17.9	20.0	20.2	21.2
Swamp	350	88.8	78.8	67.1	61.6	78.2	71.2	73.1
Channel	370	90.6	83.1	63.6	67.8	84.1	85.1	81.0

[a]See Section 4.5 for location of Steel Creek sampling stations.

Table 5-22. Mean Stand Tree Basal Area (m^2/ha)

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	10.6	11.8	12.8	13.3	13.8	13.6	12.7
Marsh	330	5.9	6.9	6.8	6.6	6.5	7.0	7.9
Swamp	350	59.1	59.2	57.5	58.3	58.5	59.8	60.5
Channel	370	28.6	31.1	31.8	31.9	31.7	31.7	32.2

[a]See Section 4.5 for location of Steel Creek sampling stations.

Table 5-23. Mean Shrub Density ($no./m^2$)

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	0.95	1.37	1.04	1.18	0.65	1.30	1.30
Marsh	330	0.06	0.07	0.02	0.05	0.04	0.05	0.04
Swamp	350	0.13	0.21	0.07	0.14	0.14	0.09	0.09
Channel	370	0.13	0.29	0.49	0.55	0.32	0.19	0.28

[a]See Section 4.5 for location of Steel Creek sampling stations.

Table 5-24. Mean Percent Herbaceous Plant Cover

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	9.3	15.8	10.1	17.6	54.3	38.1	51.0
Marsh	330	104.7	76.1	50.5	46.2	95.7	73.6	110.9
Swamp	350	86.2	92.9	51.2	32.8	67.9	42.9	68.3
Channel	370	7.9	6.4	10.3	7.5	7.1	2.4	1.4

[a]See Section 4.5 for location of Steel Creek sampling stations.

Table 5-25. Total Number of Plant Taxa Identified

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	91	86	89	91	100	111	105
Marsh	330	49	44	51	66	47	38	50
Swamp	350	47	47	58	66	65	58	52
Channel	370	91	100	121	117	99	72	65

[a]See Section 4.5 for location of Steel Creek sampling stations.

Table 5-26. Aquatic, Semiaquatic, and Riparian Taxa Identified at Select Steel Creek Sampling Stations, January-December 1992

Family	Taxon	290	330	350	370
Acanthaceae	*Justicia ovata*				X
Aceraceae	*Acer rubrum*	X			X
Alismataceae	*Echinodorus cordifolius*		X		
Alismataceae	*Sagittaria latifolia*	X	X		
Alismataceae	*Sagittaria subulata*			X	
Amaranthaceae	*Alternanthera philoxeroides*	X	X	X	
Anacardiaceae	*Toxicodendron radicans*	X		X	X
Apocynaceae	*Trachelospermum difforme*				X
Aquifoliaceae	*Ilex decidua*				X
Aquifoliaceae	*Ilex opaca*	X			
Araceae	*Peltandra virginica*	X			
Asclepiadaceae	*Asclepias perennis*				X
Aspidiaceae	*Onoclea sensibilis*		X	X	X
Azollaceae	*Azolla caroliniana*		X	X	
Balsaminaceae	*Impatiens capensis*	X	X	X	
Betulaceae	*Alnus serrulata*	X			
Betulaceae	*Carpinus caroliniana*				X
Betulaceae	*Ostrya virginiana*				X
Bignoniaceae	*Bignonia capreolata*	X			X
Bignoniaceae	*Campsis radicans*	X			X
Blechnaceae	*Woodwardia areolata*	X			X
Bromeliaceae	*Tillandsia usneoides*	X	X	X	X
Bryophyta	*Riccia* sp.		X	X	
Callitrichaceae	*Callitriche heterophylla*	X	X	X	
Campanulaceae	*Lobelia cardinalis*	X			
Caprifoliaceae	*Lonicera japonica*	X			
Cariophyllaceae	*Styrax americana*		X	X	X
Ceratophyllaceae	*Ceratophyllum demersum*	X	X	X	
Charophyta	*Nitella* sp.		X		
Chlorophytae	Unidentified macro algae		X		
Commelinaceae	*Commelina virginica*	X			X
Commelinaceae	*Murdannia keisak*	X	X	X	
Compositae	*Aster pilosus*				X
Compositae	*Aster* sp.	X			
Compositae	*Bidens tripartita*	X	X	X	
Compositae	*Compositae* sp.				X
Compositae	*Erechtites hieracifolia*	X			X
Compositae	*Eupatorium compositifolium*	X			
Compositae	*Gnaphalium purpureum*	X			
Compositae	*Krigia virginica*	X			
Compositae	*Mikania scandens*	X		X	
Compositae	*Senecio vulgaris*	X			
Compositae	*Solidago* sp.	X	X		
Compositae	*Spirodela polyrhiza*	X		X	
Convolvulaceae	*Cuscuta* sp.	X			

Table 5-26. Aquatic, Semiaquatic, and Riparian Taxa Identified at Select Steel Creek Sampling Stations, January-December 1992 - continued

Family	Taxon	290	330	350	370
Cornaceae	*Cornus foemina*	X			
Cucurbitaceae	*Melothria pendula*				X
Cyperaceae	*Carex comosa*				X
Cyperaceae	*Carex glaucescens*				X
Cyperaceae	*Carex lurida*	X			
Cyperaceae	*Carex* sp.	X			
Cyperaceae	*Cyperaceae*	X	X		X
Cyperaceae	*Cyperus haspan*	X			
Cyperaceae	*Cyperus* sp.	X		X	X
Cyperaceae	*Cyperus virens*			X	
Cyperaceae	*Rhynchospora caduca*	X			
Cyperaceae	*Rhynchospora corniculata*		X		
Cyperaceae	*Scirpus cyperinus*	X	X		
Ebenaceae	*Diospyros virginiana*	X			
Euphorbiaceae	*Acalypha gracilens*				X
Fagaceae	*Quercus laurifolia*	X	X		X
Fagaceae	*Quercus lyrata*				X
Fagaceae	*Quercus nigra*				X
Fagaceae	*Quercus* sp.	X			
Gramineae	*Andropogon virginicus*	X			
Gramineae	*Arundinaria gigantea*	X			X
Gramineae	*Chasmanthium latifolium*				X
Gramineae	*Erianthus giganteus*	X			
Gramineae	*Leersia lenticularis*		X		X
Gramineae	*Leersia oryzoides*	X	X	X	
Gramineae	*Leersia virginica*				X
Gramineae	*Panicum dichotomum*				X
Gramineae	*Panicum gymnocarpon*	X	X	X	
Gramineae	*Panicum rigidulum*	X	X		
Gramineae	*Panicum scoparium*	X			
Gramineae	*Panicum* sp.	X	X	X	
Gramineae	*Paspalum distichum*				X
Gramineae	*Paspalum notatum*	X			
Gramineae	*Paspalum repens*	X	X		
Gramineae	*Sacciolepis striata*	X	X		
Guttiferae	*Hypericum hypericoides*	X			
Guttiferae	*Hypericum mutilum*	X			
Guttiferae	*Triadenum walteri*	X		X	
Haloragaceae	*Myriophyllum aquaticum*	X	X	X	
Hamamelidaceae	*Liquidambar styraciflua*	X			X
Hydrocharitaceae	*Egeria densa*	X	X	X	
Juncaceae	*Juncus effusus*	X			
Juncaceae	*Juncus* sp.	X			
Juncaceae	*Juncus validus*	X			
Labiatae	*Lycopus rubellus*	X		X	

Table 5-26. Aquatic, Semiaquatic, and Riparian Taxa Identified at Select Steel Creek Sampling Stations, January-December 1992 - continued

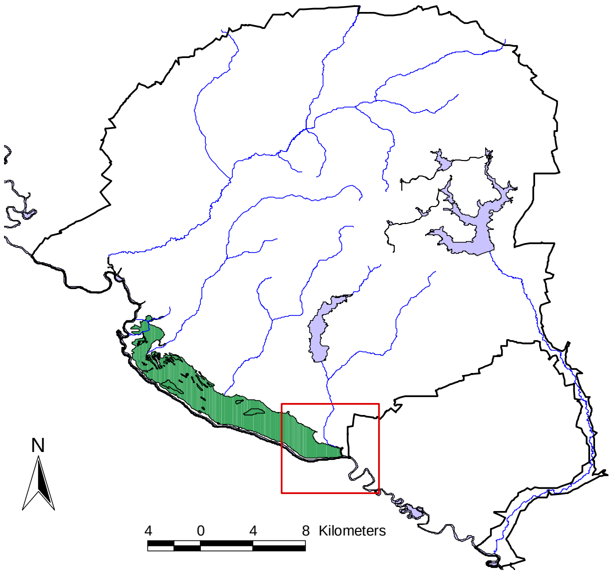
Family	Taxon	290	330	350	370
Labiatae	*Lycopus virginicus*	X		X	
Labiatae	*Scutellaria lateriflora*	X			
Leguminosae	*Apios americana*	X			
Leguminosae	*Gleditsia aquatica*			X	X
Leguminosae	*Wisteria frutescens*	X		X	
Lemnaceae	*Lemna* spp.	X	X	X	
Liliaceae	*Smilax bona-nox*				X
Liliaceae	*Smilax rotundifolia*	X		X	X
Liliaceae	*Smilax* sp.				X
Liliaceae	*Smilax walteri*			X	
Malvaceae	*Hibiscus militaris*		X		X
Malvaceae	*Hibiscus moscheutos*	X			
Moraceae	*Morus rubra*				X
Myricaceae	*Myrica cerifera*	X			
Nymphaceae	*Nuphar luteum*			X	
Nyssaceae	*Nyssa aquatica*		X	X	X
Oleaceae	*Forestiera acuminata*		X		
Oleaceae	*Fraxinus caroliniana*	X	X	X	X
Onagraceae	*Ludwigia alternifolia*	X			
Onagraceae	*Ludwigia glandulosa*	X			
Onagraceae	*Ludwigia leptocarpa*	X		X	
Onagraceae	*Ludwigia palustris*	X		X	X
Ophioglossaceae	*Botrychium biternatum*				X
Osmundaceae	*Osmunda regalis*			X	
Palmae	*Sabal minor*		X		
Passifloraceae	*Passiflora lutea*				X
Pinaceae	*Pinus* sp.	X			
Platanaceae	*Platanus occidentalis*				X
Polygonaceae	*Polygonum cespitosum*			X	
Polygonaceae	*Polygonum densiflorum*	X	X	X	
Polygonaceae	*Polygonum hydropiperoides*	X			
Polygonaceae	*Polygonum punctatum*	X	X	X	X
Polygonaceae	*Polygonum sagittatum*	X			
Polygonaceae	*Polygonum setaceum*			X	
Polypodiaceae	*Polypodium polypodioides*				X
Potamogetonaceae	*Potamogeton diversifolius*		X		
Rhamnaceae	*Berchemia scandens*			X	X
Rosaceae	*Crataegus viridis*				X
Rosaceae	*Rubus betulifolius*	X			X
Rubiaceae	*Cephalanthus occidentalis*	X	X		
Rubiaceae	*Galium obtusum*	X			
Rubiaceae	*Galium* sp.	X	X	X	
Rubiaceae	*Galium tinctorium*	X	X	X	
Salicaceae	*Populus deltoides*				X
Salicaceae	*Salix nigra*	X	X		

Table 5-26. Aquatic, Semiaquatic, and Riparian Taxa Identified at Select Steel Creek Sampling Stations, January-December 1992 - continued

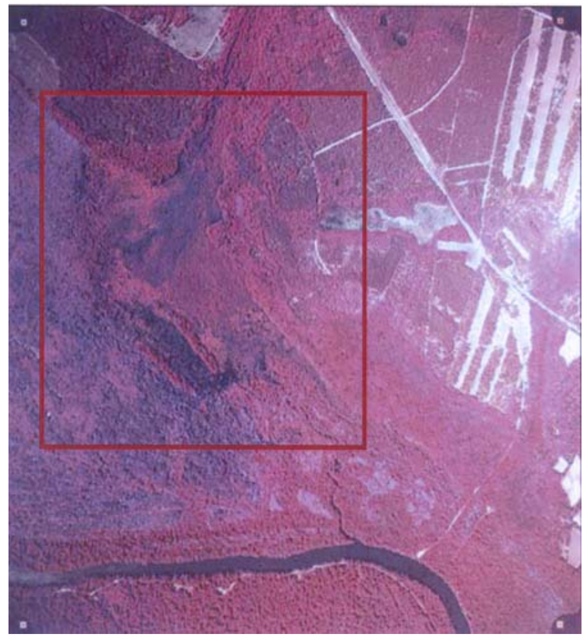
Family	Taxon	290	330	350	370
Saururaceae	*Saururus cernuus*	X	X	X	X
Saxifragaceae	*Itea virginica*	X	X	X	X
Scrophulariaceae	*Bacopa caroliniana*	X			
Scrophulariaceae	*Micranthemum umbrosum*	X		X	
Scrophulariaceae	*Mimulus ringens*	X			
Sparganiaceae	*Sparganium americanum*	X	X	X	
Taxodiaceae	*Taxodium distichum*	X	X	X	X
Ulmaceae	*Celtis laevigata*			X	
Ulmaceae	*Celtis occidentalis*	X			
Ulmaceae	*Planera aquatica*		X		X
Ulmaceae	*Ulmus americana*		X		X
Umbelliferae	*Cicuta maculata*	X			
Umbelliferae	*Hydrocotyle ranunculoides*		X	X	
Umbelliferae	*Hydrocotyle verticillata*	X		X	
Urticaceae	*Boehmeria cylindrica*	X	X	X	X
Urticaceae	*Pilea pumila*	X			
Violaceae	*Viola papilionacea*				X
Violaceae	*Viola rafinesquii*	X			
Vitaceae	*Ampelopsis arborea*	X	X		X
Vitaceae	*Parthenocissus quinquefolia*				X
Vitaceae	*Vitis aestivalis*				X
Vitaceae	*Vitis cineria*	X			X
Vitaceae	*Vitis rotundifolia*	X			X

5.2.3.7.4 Steel Creek Delta MSS Surveys, 1981-1992

The Steel Creek delta was formed between 1954 and 1968 by cooling water discharges from L and P Reactors. The visibly impacted zone covered about 140 ha (346 acres) and was shaped in the traditional deltaic form, with an extended tail stretching parallel to the adjacent upland terrace and Savannah River (Tinney et al. 1986). Steel Creek delta revegetation has been well documented (Sharitz et al. 1974b; Smith et al. 1981; Mackey 1982; Jensen et al. 1984; Christensen et al. 1986; Gladden et al. 1985; Mackey et al. 1985). Early Steel Creek delta wetland maps based on ground surveys and vertical aerial photographic interpretation showed fairly distinct communities, distributed according to sedimentation patterns and water levels (Smith et al. 1981). After 1981, successional vegetation changes continued on the Steel Creek delta. The most obvious change observed with the MSS data was the extensive replacement of persistent emergent communities with scrub-shrub communities in the center portion of the delta. Sediment accumulations from past reactor discharges raised this part of the delta, keeping water depths lower and favoring scrub-shrub invasion and establishment. Scrub-shrub vegetation has expanded in the marsh, replacing nonpersistent emergent vegetation; persistent emergent vegetation has colonized areas that formerly had nonpersistent emergent vegetation. Most of the thinned cypress-tupelo canopy was consolidated along the margins of the Steel Creek delta area (Christensen et al. 1986).

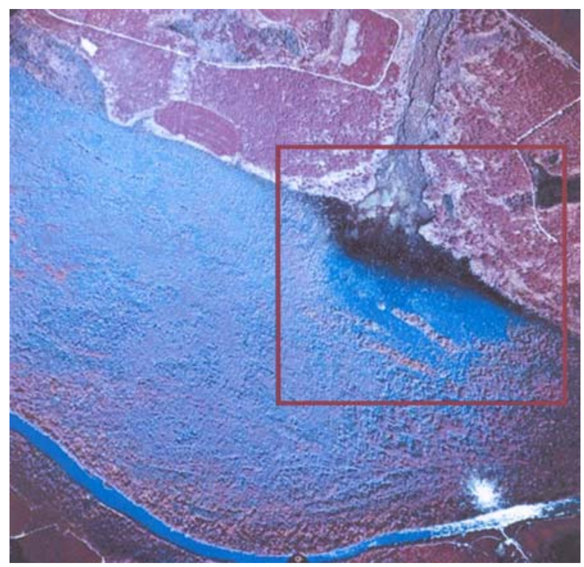


Approximate location of photographs



April 1986

May 1992



March 1998

Figure 5-15. Vertical Aerial Photography of the Steel Creek Delta Area During (1986), and After (1992, 1998) L-Reactor Shutdown

Multispectral Scanner data for Steel Creek delta were collected on April 26, 1985, and compared to the March 31, 1981, data. Multispectral Scanner data for 1981 and 1985 for an area of 240 ha (590 acres) centered on the Steel Creek delta was registered (Figure 5-7). The 1981 and 1985 data were classified into the following wetland vegetation classes:

- Water
- Emergent marsh (persistent and nonpersistent)
- Deciduous swamp forest
- Deciduous bottomland forest

Christensen et al. (1986) describes wetlands classification techniques used with these data. The wetland acreage statistics for the 1981 and 1985 classification maps are shown in Table 5-27 and Table 5-28, respectively.

The classification maps were compared to document the change from 1981 to 1985. Table 5-27 summarizes the results. With the restart of L Reactor, additional water was in Steel Creek delta in 1985. The delta wetlands vegetation changed rapidly from 1981 to 1985. Approximately 1.9 ha (4.7 acres) of persistent emergent marsh changed to nonpersistent emergent marsh. About 14 ha (35 acres) of persistent emergent marsh changed to scrub-shrub. Approximately 1.1 ha (2.7 acres) of nonpersistent emergent marsh changed to persistent emergent marsh. Also, 8.6 ha (21 acres) of non-persistent emergent marsh changed to scrub-shrub. Some nonpersistent emergent marsh was replaced by water (3.3 ha [8 acres]). Some scrub-shrub (3.3 ha [8 acres]) changed to persistent emergent marsh, and some (1.4 ha [3.5 acres]) changed to nonpersistent emergent marsh in certain regions of the delta.

The Steel Creek corridor and delta were surveyed in spring 1985, 1986, and 1987 using aiborne MSS. Data obtained during the remote sensing overflights were processed to obtain estimates of the aerial coverage of major wetland vegetation classes for each year so that estimates of wetland change following the restart of L Reactor in 1985 could be made.

Bottomland hardwood and scrub-shrub vegetation dominated the Steel Creek corridor area between L-Lake Dam and the Savannah River swamp (Table 5-28). The only trend evident across the three years was a shift from bottomland hardwood to emergent wetland vegetation types. Portions of the hardwood forest canopy along the Steel Creek corridor became more open, and herbaceous vegetation invaded areas where light penetrated the canopy. Although changes in coverage occurred in both the scrub-shrub and open-water classes, consistent trends did not appear during the survey years.

Vegetation cover changes in the delta were small after the restart of L Reactor in 1985 (Table 5-29). Neither deciduous bottomland forest nor deciduous swamp forest vegetation classes exhibited changes that indicated substantial community alteration from 1985 to 1987. Scrub-shrub, nonpersistent emergent marsh, persistent emergent marsh, submerged, and open-water cover classes appeared to have undergone changes related to increased flooding from L Reactor operations.

Specifically, cover of scrub-shrub and persistent emergent marsh vegetation appeared to decline while nonpersistent emergent marsh, submerged, and open-water cover classes increased in aerial extent from 1985 to 1987. Between 1987 and 1993, flows to Steel Creek remained low to moderate (Table 5-17) and little change was noted in the vegetation patterns of Steel Creek delta.

Burkhalter (1994) noted that while the process of revegetation was interrupted from 1985-1987 with L-Reactor restart, imagery from 1992 indicated continued revegetation. In 1992, much of the thermally altered areas were revegetated with scrub-shrub vegetation, and deciduous swamp forest was returning around the periphery of the affected area.

Table 5-27. Steel Creek Delta Wetlands Changes Based on Aircraft MSS Data, March 1981 and April 1985

From	To	Hectares[a]
Nonpersistent emergent marsh	Water	1.10
Nonpersistent emergent marsh	Persistent emergent marsh	3.26
Nonpersistent emergent marsh	Scrub-shrub	8.62
Persistent emergent marsh	Nonpersistent emergent marsh	1.87
Persistent emergent marsh	Scrub-shrub	13.79
Scrub-shrub	Persistent emergent marsh	3.26
Scrub-shrub	Nonpersistent emergent marsh	1.40

[a] To convert to acres, multiply by 2.471.

Table 5-28. Changes in Area of Wetland Vegetation Classes in Steel Creek Corridor from L Lake Dam to Steel Creek Delta. Estimates of Areas Covered (in hectares) by Wetland Vegetation Types in Steel Creek Corridor in 1985, 1986, and 1987

	Hectares[a]		
Vegetation	1985	1986	1987
Bottomland hardwood	162	160	151
Scrub-shrub	106	95	105
Emergent wetland	3	11	14
Open water	1	7	2
Total	272	273	272

[a] To convert to acres, multiply by 2.471.

Table 5-29. Changes in Area of Wetland Vegetation Classes in Steel Creek Delta, 1985, 1986, and 1987

	Hectares[a]		
Vegetation	**1985**	**1986**	**1987**
Deciduous bottomland forest	77	72	80
Deciduous swamp forest	108	100	105
Scrub-shrub	68	69	58
Nonpersistent emergent marsh	9	19	19
Persistent emergent marsh	14	<1	0
Submerged	0	13	8
Open water	11	13	15
Total	287	287	285

[a] To convert to acres, multiply by 2.471.

5.3 WETLANDS

5.3.1 Wetlands of L Lake

L Lake is a 400-ha (1000 acre), once-through cooling reservoir constructed on SRS in 1985 to receive thermal effluent from L Reactor (Figure 5-16). (The water quality, limnology, and biology of L Lake are described in Chapter 4-Streams, Reservoirs, and the Savannah River.) Aquatic macrophytes began natural invasion of the L Lake shoreline upon completion of the lake's filling (Firth and Irwin 1987; Firth 1988; Westbury 1989, 1990, 1991, 1992). Additionally, extensive and reasonably successful macrophyte planting was done along the L Lake shoreline (Wein and McCort 1988; Kroeger 1990; Wein et al. 1987). Survival and growth of the natural and introduced macrophytes along the L Lake shoreline continued following the L Reactor shutdown in 1988 and the cessation of thermal discharges to the lake (Jensen et al. 1992).

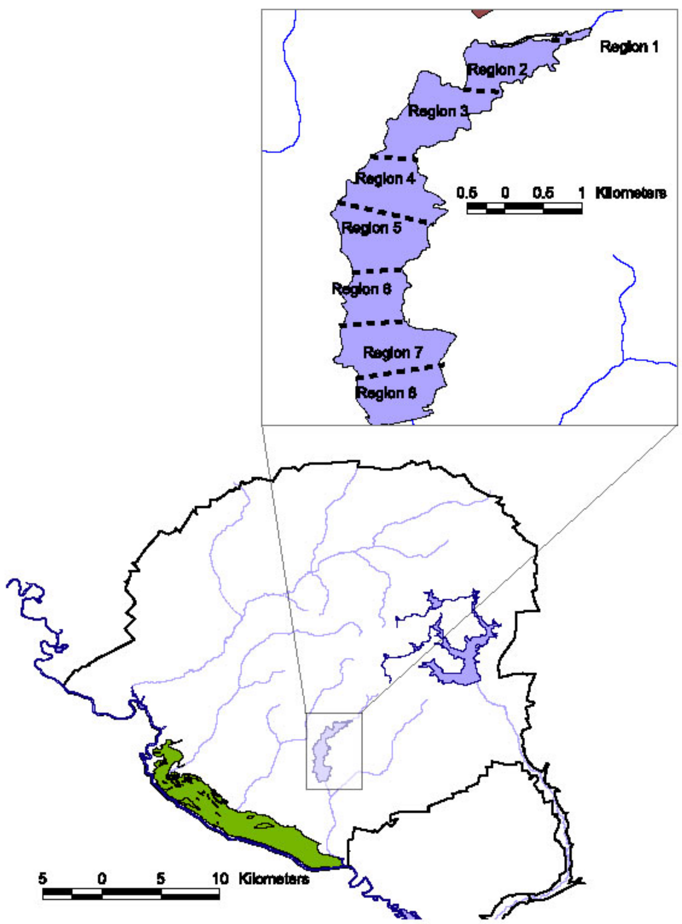


Figure 5-16. Location of L Lake on SRS

5.3.2 Habitat Formers

5.3.2.1 Introduction

During construction of L Lake, most of the upland vegetation in the lake bed was removed or burned onsite. The shoreline was cleared to 1-1.5 meters (3-5 ft) above maximum pool elevation and seeded to control erosion. The shoreline vegetation above the cleared area was primarily planted pine.

The L Lake habitat formers (macrophytes) portion of the L Lake and Steel Creek biological monitoring program addressed the development and composition of the shoreline and littoral-zone plant communities (Westbury 1992). Monitoring was conducted at four study plots in L Lake Regions 5 and 7, and on 100-m (328-ft) transects in Regions 4 through 8 of the lake (Figure 5-16). A variety of plants, some of which have been reported from thermal areas of SRS (Irwin 1975; Sharitz et al. 1974a and b), were in L Lake in 1987. Because the littoral community in L Lake was in an early successional stage, its diversity was low in 1987 compared with Par Pond and other older lakes of similar morphometry and environmental characteristics in the southeast (Grace 1985a and b; Dames and Moore 1985; Barry 1980).

5.3.2.2 Plant Community Composition

When the L Lake basin was constructed, most of the shoreline was cleared and graded. In 1986 and 1987, most of the plants were terrestrial weeds typical of disturbed areas (Firth and Irwin 1987; Firth 1988). By 1988, plants adapted to wetland conditions had become established in the littoral zone of the lake (Westbury 1989).

The total number of plants identified in each of the study plots was less in 1991 than in 1990 at all stations except on the east side of Region 7, where total taxa numbers for 1990 and 1991 were equal. In general, total taxa numbers increased from 1986 to 1989 and decreased in 1990 and 1991. The majority of plant taxa at all stations comprised herbaceous species and accounted for most of the changes in taxa numbers (Westbury 1992).

Between 1986 and 1988, plant taxa identified at each station increased every year (Table 5-30). In 1989, taxa decreased at Region 5 East but increased at all other stations. In 1991, taxa decreased at all stations except Region 7 East (Westbury 1992).

In 1990, the number of hebaceous species at each station was lower than it had been in 1989. In 1991, the number of herbaceous taxa at each station continued to decrease except at Station 7 East. Changes in numbers of herbaceous species accounted for most of the year-to-year changes in number of taxa (Westbury 1992).

Tree taxa increased in 1986 and 1987 and decreased or remained constant in 1989, 1990, and 1991 (except at Station 7 East, where they increased in 1991). Shrub taxa increased or remained constant at all stations through 1990. In 1991, shrub taxa decreased at all stations except Station 7 East, where they increased. Other taxa decreased or remained the same at all stations in 1991 (Westbury 1992).

Table 5-30. Total Number of Plant Taxa Identified on the Shoreline of the Two Regions, January 1986-December 1991

Region	1986	1987	1988	1989	1990	1991
5 East	54	79	91	80	73	64
5 West	66	88	101	116	112	88
7 East	57	94	104	118	104	105
7 West	51	73	87	97	93	74

Source: Westbury 1992.

Between 1986 and 1988 the number of plant taxa identified at each station increased every year (Table 5-30). In 1989 the number of taxa decreased at Region 5 East, but increased at all other stations. In 1991 taxa numbers decreased at all stations except Region 7 East (Westbury 1992).

In general, between 1986 and 1991, approximately 75% of total plant taxa were herbaceous species, approximately 10% were tree, 10% were shrub species, and approximately 5% were woody vines or succulents (Westbury 1992).

5.3.2.3 Areal Cover and Expansion

Between 1986 and 1990, the areal cover of aquatic macrophytes in the littoral zone of the survey plots of L Lake was low. The annual mean areal cover increased markedly, from 527.51 m^2/ha in 1990 to 1359.9 m^2/ha in 1991. Water celery *(Vallisneria americana*), water lotus *(Nelumbo lutea)*, and pondweed (*Potamogeton diversifolius*) accounted for most of the increase in cover in the study plots. The mean extent of vegetation into the lake as measured along 100-line transects also increased from 13.59 m (44.58 ft) in 1990 to 21.15 m (69.38 ft) in 1991. The mean percent cover of the first 24 m (79 ft) increased from 28.39% in 1990 to 49.40% in 1991 (Westbury 1989, 1990, 1991, 1992).

5.3.2.4 Line Transects vs. Plots

Aquatic macrophyte coverage measured along the first 24 m (79 ft) of the 100-line transects was higher than the coverage within the monitoring program study plots, none of which occurred in planted areas. The line transects included areas planted by the University of Georgia's Savannah River Ecology Laboratory (SREL) and covered more of the shoreline than did the plots. The transects were sampled in the summer, near the time of maximum plant cover. When only summer data were considered for the study plots, the increase in percent cover from 1990 to 1991 was similar for both line transects and study plots. The summer-only percent cover of the study plots in 1991 was similar to the percent cover of the line transects in 1990 (Westbury 1992).

5.3.2.5 Littoral-Zone Change

In the six years that the littoral vegetation was monitored after the creation of L Lake, plant cover in littoral-zone communities increased. Taxa present in the plots changed from terrestrial species that are common invaders of disturbed sites to the more aquatic species likely in littoral habitats. While percent cover in areas that were planted was greater than the percent cover in study plots (which were not planted), the plant cover in the study plots increased markedly in 1991 (Westbury 1992).

5.3.2.6 Macrophyte Planting Program

5.3.2.6.1 Introduction

The SREL in 1987 conducted a wetlands planting program in L Lake. Plant material, either transplanted from Par Pond or obtained from commercial nurseries, was planted between January and August, 1987. Approximately 100,000 plants of more than 40 species were planted along more than 4000 m (13,123 ft) of the southern shoreline of L Lake (Table 5-31). A submersed/ floating-leaved zone, an emergent zone, and an upper emergent/shrub zone were created. During the summers of 1987, 1988, and 1989, SREL sampled the vegetation in plots along permanent transects established in planted and unplanted areas. Details on species planted, source of plant material, and planting density are in Wein et al. (1987) and Kroeger (1990).

5.3.2.6.2 Submersed and Floating-leaved Zone (30 to 100-cm Water Depth)

Nine plant species were transplanted into the submersed and floating-leaved zone. Water lotus, a floating-leaved species, and water celery, a submersed plant, were the only species that survived through 1989. Wave action and low initial planting density apparently made establishment difficult or impossible for some species (Kroeger 1990).

Water lotus and water celery rapidly colonized empty plots within the submersed and floating-leaved zone, and cattails (*Typha latifolia)* moved into the submersed and floating-leaved zone from the emergent zone. In 1987, 95% of the plots sampled contained no vegetation. In 1989, 62% of the plots were empty. In 1987, mean cover per plot was 1%. However, by 1989, mean cover had increased to 22% (Kroeger 1990).

No submersed or floating-leaved plants were found in the unplanted areas in 1989 and most plots remained unvegetated. Two emergent species, cattails and water pennywort *(Hydrocotyle umbellata)* were found in a few of the unplanted plots (Kroeger 1990).

5.3.2.6.3 Emergent Zone (Waterline to 30-cm Water Depth)

Approximately 30 species were planted in the emergent zone. Through 1989, individuals of most still were surviving. In 1987, 32% of the plots sampled in planted areas contained no vegetation. By 1989, only 16% of the plots had no vegetation. Mean cover per plot increased from 22% in 1987 to 40% in 1988 and 1989 (Kroeger 1990).

Table 5-31. Species Planted at L Lake between January and August 1987

Scientific Name	Common Name
Submersed/Floating-Leaved Zone	
Brasenia schreberi	Water Shield
Eleocharis acicularis	Spike Rush
Najas gracillima	Bushy Pondweed
Nelumbo lutea	Water Lotus
Nymphaea odorata	White Waterlily
Nymphoides aquatica	Floating Heart
Potamogeton pulcher	Pondweed
Potamogeton vaseyi	Pondweed
Vallisneria americana	Water Celery
Emergent Zone	
Axonopus sp.	Carpet Grass
Bacopa caroliniana	Blue Hyssop
Carex comosa	Sedge
Carex glaucescens	Sedge
Dulichium arundinaceum	Three-Way Sedge
Echinochloa crusgalli	Wild Millet
Echinodorus cordifolius	Burhead
Eleocharis equisetoides	Spike Rush
Eleocharis quadrangulata	Spike Rush
Erianthus giganteus	Beard Grass
Glyceria striata	Manna Grass
Hydrochloa caroliniensis	Grass
Hydrocotyle umbellata	Water Pennywort
Juncus acuminatus	Rush
Juncus brachycarpus	Rush
Juncus effusus	Soft Rush
Juncus diffusisimus	Rush
Leerisa oryzoides	Rice Cutgrass
Lycopus rubellus	Water Horehound
Panicum hemitomon	Panic Grass
Paspalum virgatum	Switchgrass
Paspalum distichum	Knotgrass
Polygonum sp.	Knotweed
Pontederia cordata	Pickerelweed
Sagittaria latifolia	Arrowhead
Scirpus cyperinus	Bulrush
Sparganium americanum	Bur Reed
Typha domingenis	Cattail
Typha latifolia	Cattail
Upper Emergent/Shrub Zone	
Acer rubrum	Red Maple
Cephalanthus occidentalis	Buttonbush
Mikania scandens	Climbing Hempweed
Nyssa sylvatica	Blackgum
Salix nigra	Black Willow
Taxodium distichum	Cypress

Source: Kroeger 1990.

Within the planted areas, changes in emergent species from 1987 to 1989 were a slight increase in relative frequency of spikerush and cattails, a large increase in relative frequency of water pennywort and water celery, a slight increase in relative frequency and relative cover of the *Panicum/Sacciolepis* group of grasses, and a large decrease in both relative frequency and cover of the shoreline grasses. Water lotus and water celery, which grew into the emergent zone from the submersed and floating-leaved zone, had become important components of the emergent zone by 1989 (Kroeger 1990).

In contrast to that in planted areas, emergent vegetation in unplanted shoreline areas established slowly. The annual frequency of empty plots remained approximately 85% from 1987 to 1989. Those plots containing vegetation had low species diversity. Alligator weed (*Alternanthera philoxeroides)*, water pennywort, and cattails were the only emergent species in unplanted areas with absolute frequencies greater than 5% in 1989 (Kroeger 1990).

5.3.2.6.4 Upper Emergent/Shrub Zone (Waterline to 30-cm Above Waterline)

All species planted in the upper emergent/shrub zone in 1987 were present in 1989. Abundance of terrestrial species kept the proportion of empty plots low (15.6%) from 1987 to 1989. Mean cover per plot in planted areas increased from 59% in 1987 to 69% in 1988. In 1989, it decreased to 55%, partly from rooting by feral pigs (Kroeger 1990).

Changes from 1987 to 1989 included major growth of black willow (*Salix nigra*) shoots; a striking decrease in relative frequency and cover of shoreline grasses; a gradual increase in frequency and cover of *Panicum/Sacciolepis*; and a decrease in frequency and cover of cattails. Black willow and the *Panicum/Sacciolepsis* grasses were the most important species in this vegetation zone. The emergents, soft rush *(Juncus effusus*), knotweed, arrowhead (*Sagittaria latifolia)*, and cattails, were also important species in this zone (Kroeger 1990).

In unplanted areas, facultative emergent and terrestrial species were the most important components. No soft rush, smartweed, or *Panicum*/*Sacciolepis* was found. Black willow had a higher frequency in the unplanted areas than in the planted areas (Kroeger 1990).

5.3.2.7 Seed Bank Enhancement

Five years after the macrophtye plantings, the seed bank of L Lake did not reflect planted and unplanted regions, indicating that planting wetland vegetation in a created reservoir does not enhance seed bank development or create a seed bank that differs from natural revegetation. In addition, shoreline convolutions, which might be constructed, apparently have little influence on the number of seeds, although species accumulated in coves. This would suggest that the inclusion of variable shoreline in created wetlands design would not enhance the development of the seed bank in systems with a stable water level. In contrast, the common management practice of a periodic drawdown may enhance seed bank and vegetation development in a reservoir such as L Lake by redistributing seeds with the waterline and by allowing input of seeds of facultative wetland species. (Collins and Wein 1995).

5.4 WETLANDS OF THE PAR POND SYSTEM

Par Pond, a 1012-ha (2,500-acre) reactor cooling-water reservoir, was created in 1958 by constructing an earthen dam (Cold Dam) on Lower Three Runs. Par Pond formed along the course of Poplar Branch, Joyce Branch, and the upper reach of the Lower Three Runs drainage system (Wilde and Tilly 1985).

Par Pond served as a recirculating cooling-water reservoir for R Reactor until 1963 and for P Reactor from 1961 until 1988. P Reactor operated approximately 70% of the time prior to 1988. During the summer, the temperatures near the bubble-up in Par Pond (Figure 5-17) ranged from 22 to 42°C (72 to 108°F) (Jones et al. 1979). Maximum shoreline water temperatures in the vicinity of the bubble-up ranged from 32 to 35°C (90 to 95°F) (Liu et al. 1978). The thermal effluent cooled rapidly as it dispersed, primarily through the southern half of the reservoir (Ezra and Tinney 1985). The north and south arms of Par Pond had temperatures at or only slightly above typical for the region (Liu et al. 1978). Since 1988, Par Pond has received no thermal effluents.

The water level of Par Pond remained relatively stable, fluctuating typically less than 0.15 m (0.5 ft) in most years. Natural invasion of macrophytes occurred over the 33-year history of the lake prior to mid-1991, when Par Pond was lowered from 61 m (200-ft) above mean sea level (msl) to 55 m (181 ft) above msl. Prior to lowering in 1991, extensive beds of persistent and nonpersistent aquatic macrophytes bordered Par Pond. These beds often exceeded 20-40 m (65-130 ft) in width and in several areas exceeded 100 m (328 ft).

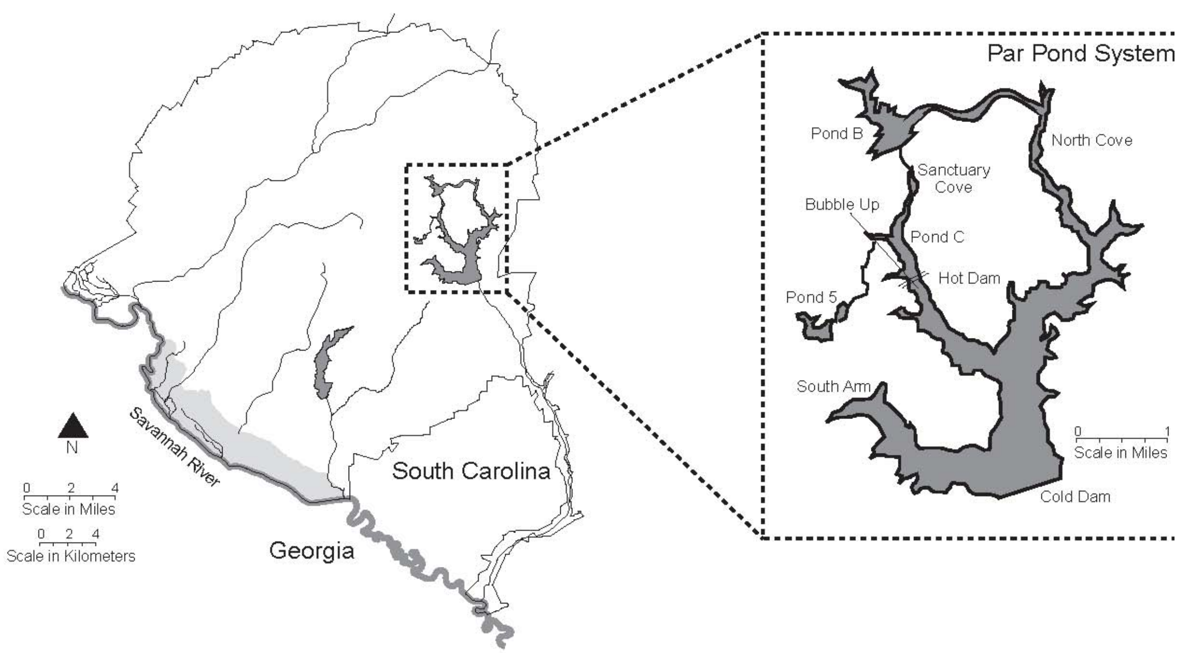


Figure 5-17. Map of the Par Pond System

5.4.1.1 Macrophyte Distributions

5.4.1.1.1 <u>Introduction</u>

Several studies of the macrophytes of Par Pond were conducted during the 1970s. Wilde and Tilly (1985) presented the following conclusions from these studies:

- A well-developed macrophyte community occurs in Par Pond.
- Relatively stable water levels enhance macrophyte development.
- The dominant macrophyte species in Par Pond are typical of this geographical region.

Grace (1985a) provided a series of maps on wetland vegetation observed in July 1984 at several sites throughout the reservoir (Table 5-32). Most of the species had been reported in earlier studies (Wilde and Tilly 1985). Grace (1985a) concluded that Par Pond wetlands are principally middle-to-late successional and relatively homogeneous.

5.4.1.1.2 <u>Scrub-Shrub Communities</u>

The shoreline scrub-shrub communities along the lake include willow, buttonbush, red maple, and alder.

5.4.1.1.3 <u>Cattails</u>

Cattail (*Typha* spp.) beds exist year-round in Par Pond. They begin to sprout in early to mid-April and often form a full, green canopy by late May. Cattails begin to senesce in late September or early October, remaining brown throughout the winter. A similar pattern of cattail development has been documented in the Pen Branch delta (Mackey 1990, 1993). Cattails generally occupy the shallow water (1 m [3 ft] in depth or less) adjacent to the lake shoreline. Cattail beds were considerably reduced during the drawdown (1991-1994) and had not recovered by the 1997 growing season.

5.4.1.1.4 <u>Nonpersistent Macrophytes</u>

Water lilies, lotus, and several other species along the Par Pond shoreline do not persist through the winter. They generally begin to appear at the water edge of the cattail beds by late April or early May and reach full growth 6-8 weeks later. The water lily beds generally continue to expand into the open-water areas of the lake through September and typically extend to depths of 2-5 m (6-15 ft). The beds persist until about mid-October to mid-November with lotus beds senescing before the water lily beds. The best time of year to estimate the areal extent of these beds is from June until mid-October. These phenological or seasonal patterns are important when interpreting historical aerial photography or satellite remote sensing data of Par Pond (Jensen et al. 1991, 1993). After refill in 1995 and through the 1997 growing season, water lilies and lotus occupied much of the area that had been occupied by cattails prior to the drawdown.

Table 5-32. Plant Species Observed in Par Pond Wetlands, July 1984

Species	Common Name
Acer rubrum	Red Maple
Alnus serrulata	Tag Alder
Alternanthera philoxeroides	Alligator-Weed
Bacopa caroliniana	Blue Hyssop
Betula nigra	River Birch
Boehmeria cylindrica	False-Nettle
Brasenia schreberi	Water Shield
Cephalanthus occidentalis	Buttonbush
Echinodorus cordifolius	Creeping Water Plantain
Eleocharis quadrangulata	Square-Stem Spike-Rush
Erianthus giganteus	Giant Plume Grass
Hydrocotyle sp.	Pennywort
Juncus effusus	Rush
Myrica gale	Sweet Gale
Nelumbo lutea	Water Lotus
Nymphaea odorata	Water Lily
Panicum hemitomon	Maidencane
Peltandra virginica	Arrow-Arum
Polygonum sp.	Knotweed
Pontederia cordata	Pickerelweed
Salix nigra	Black Willow
Scirpus americanus	Three-Angled Bulrush
Scirpus cyperinus	Bulrush
Sphagnum sp.	Sphagnum Moss
Typha domingensis	Southern Cattail
Typha latifolia	Common Cattail
Woodwardia virginica	Virginia Chain-Fern

Source: Grace 1985a.

5.4.1.2 Comparison of Par Pond Macrophyte Communities to Regional Reservoirs

Relatively little data are available to compare macrophyte communities in Par Pond to other Coastal Plain reservoirs. It appears, however, that the floating-leaved macrophyte communities of Par Pond are similar to those in other large Coastal Plain ponds and reservoirs with moderate or low turbidity (Wilde and Tilly 1985). Emergent macrophyte communities are generally similar except stands of cattails and bulrush may be better developed in Par Pond.

5.4.1.2.1 Changes in Phenological Cycle

One possible effect exposure to thermal effluents had on macrophytes was a modification of their phenological cycle. Observations by Jensen et al. (1991, 1993) indicated that there might have been an earlier emergence of macrophytes such as water lilies and lotus in the warmer regions of Par Pond. Grace and Tilly (1976) reported similar findings for the submerged macrophytes in Par Pond. In a recent study, Mackey (1990) observed early emergence of cattails in moderately thermal portions of the SRS Savannah River swamp. Early development was observed in two species of semiaquatic plants, swamp primrose (*Ludwigia leptocarpa*; Christy and Sharitz 1980) and swamp loosestrife (*Ammannia coccinea*; Gibbons and Sharitz 1981). These species were found to flower earlier and produce more fruits and seeds in warmer areas of the Savannah River swamp than in natural temperature habitats. Modification of senescense patterns has not been reported for Par Pond wetland species.

5.4.1.2.2 Floating-Leaved and Emergent Macrophytes

There appeared to be a slight enhancement of the relative abundance of both floating-leaved and emergent macrophytes within the warmer portion of Par Pond (Wilde and Tilly 1985). Grace and Tilly (1976) presented similar findings in a study of Par Pond submerged macrophytes. Their data suggested that conditions for parrotfeather, a dominant submerged macrophyte species, were nearly optimal in the warmer region of Par Pond.

5.4.1.2.3 Plants Tolerant of Thermal Conditions

Studies from Par Pond also have indicated that some plants are more tolerant than others of exposure to thermal effluents. These more tolerant species may become abundant when temperatures are too high for the less tolerant species (Gibbons and Sharitz 1974). The nature of these tolerance mechanisms has been examined for cattails in Par Pond. For example, Liu et al. (1978) examined the thermal sensitivities of two species of cattail (*T. latifolia* and *T. domingensis*) that occur along the Par Pond shoreline. Their study concluded that *T. latifolia* was more thermally tolerant than *T. domingensis*, and they presented a possible biochemical explanation for the differences in thermal tolerance. Both species had six major malate dehydrogenase (MDH) isozymes. Three of the isozymes in *T. latifolia* were stable at 50°C (122°F); whereas, all six of the isozymes in *T. domingensis* were denatured at this temperature. It was hypothesized that the apparent increased temperature tolerance of *T. latifolia* is related to the thermal stability of the MDH isozymes (Jones et al. 1979).

5.4.1.3 Changes in Par Pond Macrophyte Growth

5.4.1.3.1 Introduction

Surface macrophyte maps of Par Pond have been prepared on occasion using *in situ* measurements, aerial photography, multispectral scanner data, and SPOT satellite data (Ezra and Tinney 1985; Jensen et al. 1991, 1993). Field studies examined the distribution and abundance of submerged macrophytes in Par Pond (Grace and Tilly 1976). More recent mapping of surface macrophytes was accomplished using photographic interpretation and satellite analysis techniques, and represents conditions in Par Pond from 1988 to mid-1991 (Jensen et al. 1993). Recent surveys examined only the surface extent of aquatic macrophytes. No attempt was made to evaluate species composition, diversity, or total biomass. Additionally, examination of photographs from 1958 to 1990 allowed for an estimation of developmental and growth trends for these communities over the 33-year history of Par Pond, prior to the recent 6-m (19-ft) lowering of Par Pond. The size and type of macrophyte bed are dependent on depth, slope, soil type, and exposure to wave and wind action (Jensen et al. 1993).

5.4.1.3.2 Photographic Studies, 1958-1990

5.4.1.3.2.1 Introduction

Thirty years of large scale, aerial photography was analyzed to (1) identify rates of aquatic macrophyte development between years and over the history of the lake,
(2) compare *in situ* aquatic macrophyte data versus aquatic macrophyte data interpreted from aerial photography for specific recent years, and (3) document seasonal changes in aquatic macrophyte development.

Phenology data indicate that for many of the macrophyte species found in Par Pond, the later stages of the growing season prior to leaf-drop and dormancy is September to October. During this period, the macrophytes are at or near their maximum areal coverage or extent. Cowardin and Myers (1974) also found that spring and fall photography proved most useful in identifying wetland species.

5.4.1.3.2.2 Macrophyte Classification

Introduction - A detailed species inventory of Par Pond aquatic macrophytes was beyond the scope of the historical photographic survey. Thus, the classification scheme used for the macrophyte mapping included only two general life-form categories: floating-leaved and emergent macrophytes. Table 5-33 names the principal species in each of the two categories mapped for Par Pond.

Floating-Leaved Macrophytes - The floating-leaved macrophyte category consists of plants that grow primarily on the water surface for most of the growing season. This category corresponds with the rooted-vascular and floating-vascular subclasses of the aquatic bed class established in the U.S. Fish and Wildlife Service Wetlands and Deepwater Habitats classification scheme (Cowardin et al. 1979). These macrophytes are attached either to the substrate or float freely on the water surface. Water lotus and water lily, which are both in the rooted-vascular subclass primarily dominated the floating-leaved macrophytes.

***Emergent Macrophytes* -** Emergent macrophyte species generally occurred between the upland scrub-shrub/tree boundary and the floating-leaved zone. The emergent macrophyte category consists of erect, rooted, herbaceous plants that are present for most of the growing season. Emergent macrophytes, which are included in the emergent wetland class described by Cowardin et al. (1979), are generally species that are considered either persistent emergent or nonpersistent emergent. Persistent emergent wetlands are dominated by species that normally remain standing at least until the beginning of the next growing season. Nonpersistent emergent wetlands are dominated by plants that fall to the surface of the substrate or below the surface of the water at the end of the growing season so that, in certain seasons of the year, there is no obvious sign of emergent vegetation. The emergent macrophytes in Par Pond consisted of persistent emergent beds of primarily cattails, spikerush (*Eleocharis quadrangulata*), and, to a lesser extent, maidencane (*Panicum hemitomon*), pickerel weed (*Pontederia cordata*) and bulrush (*Scirpus americanus*). Cattails extend to an average depth of slightly more than 1 m (3 ft) and floating-leaved macrophytes to a depth of slightly more than 4 m (13 ft) at their outer margins.

5.4.1.3.3 *In Situ* Data and Aerial Photographic Comparison for Par Pond

In situ aquatic macrophyte information was collected in the spring and fall from 1988 through 1991 to (1) determine the effectiveness of aerial photography and satellite imagery for mapping aquatic macrophytes versus *in situ* measurements and (2) document the seasonal trends (general phenology) of aquatic macrophyte beds in Par Pond (Jensen et al. 1991, 1993). The *in situ* aquatic macrophyte bed widths measured on May 17, 1989, were highly correlated with measurements made using May 8, 1989, color infrared aerial photography. Therefore, it is possible to use the 30 years of aerial photography to document aquatic macrophyte development in Par Pond.

5.4.1.3.3.1 Macrophyte Succession and Stabilization

Rapid growth of the persistent beds of macrophytes along the Par Pond shoreline apparently did not begin until the early to mid-1970s and essentially stabilized by the early 1980s. Extensive growth of the nonpersistent macrophytes began a few years after the persistent beds and stabilized by the early to mid-1980s. These results are valuable because they provide an estimate of how long succession takes to establish aquatic macrophytes and reach equilibrium in a relatively stable reservoir such as Par Pond.

5.4.1.3.3.2 Changes in Par Pond Wetland Macrophytes, 1975–1983

Grace (1985b) examined aerial photographs from 1975, 1980, and 1983 to evaluate changes to the wetland vegetation of Par Pond. He also compared the aerial photographs with ground-level vegetation maps developed from field surveys conducted during July 1984 (Grace 1985a). A comparison of photographs from August and December 1983 evaluated seasonal changes; the main seasonal change in the coverage of wetland vegetation was the wintertime loss of nonpersistent species such as lotus and water lily.

Table 5-33. Par Pond Macrophyte Species

Class	Species	Common Name
Floating-leaved macrophytes		
	Brasenia schreberi	Water Shield
	Nelumbo lutea	Water Lotus
	Nymphaea odorata	Water Lily
Emergent macrophytes		
	Alternanthera philoxeroides	Alligator-Weed
	Bacopa caroliniana	Blue Hyssop
	Boehmeria cylindrica	False-Nettle
	Echinodorus cordifolius	Creeping Water Plantain
	Eleocharis quadrangulata	Square-Stem Spike-Rush
	Erianthus giganteus	Giant Plume Grass
	Hydrocotyle spp.	Pennywort
	Juncus effusus	Rush
	Panicum hemitomon	Maidencane
	Peltandra virginica	Arum
	Polygonum spp.	Smartweed
	Pontederia cordata	Pickerelweed
	Scirpus americanus	Three-Angled Bulrush
	Typha domingensis	Southern Cattail
	Typha latifolia	Common Cattail

Comparisons between September 1980 and August 1983 showed that the lakeward extent of nonpersistent macrophytes increased by an average of 8.2 m (27 feet), although not all sites changed equally. Grace (1985b) also found that for persistent macrophytes (principally cattails), the average increase in lakeward extent between December 1975 and August 1983 was 3.5 m (11 ft). Most of the cattail beds appear to have been well established by the mid-to-late 1970s with little expansion after the early 1980s (Jensen et al. 1993). This represents a 20% increase in width in three years. The extensive development of water lily beds in Par Pond and the substantial spread of vegetation between 1975 and 1983 indicated the high suitability of the habitat in Par Pond for the growth of these aquatic plants (Grace 1985b).

5.4.1.3.4 Seasonal and Annual Changes in Par Pond Macrophyte Beds, 1988-1990

5.4.1.3.4.1 Seasonal Changes

The phenological cycle of cattails and water lilies provides a means to measure the areal extent of these two macrophyte communities in Par Pond. Cattail beds persist year-round in Par Pond and generally are found in shallow water (<1 m [3 ft] deep) adjacent to the shore. They begin growing in early April and often have a full, green canopy by late May (Workman and McLeod 1990). Cattails senesce in late September to early October, yet they persist through the winter (Mackey 1990; Gao and Coleman 1990). Conversely, water lilies and other nonpersistent species do not live through the winter. They appear at the outermost edge of the cattails in May and reach full emergence 6-8 weeks later. The waterlily beds sometimes persist above water into early November but eventually disappear. Figure 5-18 shows an example of the 1988 distribution.

5.4.1.3.4.2 The Multiple Year Changes in Aquatic Macrophyte Distribution

Because the 1988, 1989, and 1990 SPOT data were registered to a common map projection, it was possible to perform multiyear aquatic macrophyte change detection. Analysis using image differencing revealed that there were 192 ha (475 acres) of cattails during the 1988 growing season, 179 ha (442 acres) in 1989, and 175 ha (432 acres) in 1990. There were 150 ha (370 acres) of water lilies in 1988, 126 ha (310 acres) in 1989, and 149 ha (368 acres) in 1990.

5.4.1.3.4.3 Effects of Reduction in Cooling-Water Discharges

In situ and aerial photography data from Par Pond since early 1988 indicate that aquatic vegetation, especially floating-leaved macrophytes, was less abundant (as measured by bedwidth) following the cessation of cooling water-discharged to Par Pond (Figure 5-18). Springtime emergence appears to be delayed approximately one month, from early to mid-April to mid- to late May, as measured by both percentage of cover and width of the macrophyte beds (Jensen et al. 1991, 1993).

5.4.1.4 Par Pond Drawdown

Beginning in June 1991, Par Pond was lowered from 61 m (200 ft) above msl to 55 m (181 ft) above msl (Figure 5-19 and Figure 5-20). Water was siphoned to Lower Three Runs and pumped to Steel Creek, Pen Branch, and Fourmile Branch during this drawdown. This lowering was sufficient to expose both the emergent and nonemergent macrophyte beds of the Par Pond shoreline to drying conditions. Therefore, extensive macrophyte losses occurred. Initial surveys in August 1992 by SREL indicated some reinvasion on the newly exposed shoreline. Plant succession was occurring on about 65% of the exposed lake bed with approximately 35% still barren. Grasses, sedges, and rushes were the dominant forms but were mixed with old-field species including dog-fennel and daisy fleabane (*Erigeron* spp.). Table 5-34 summarizes the August 1992 survey data.

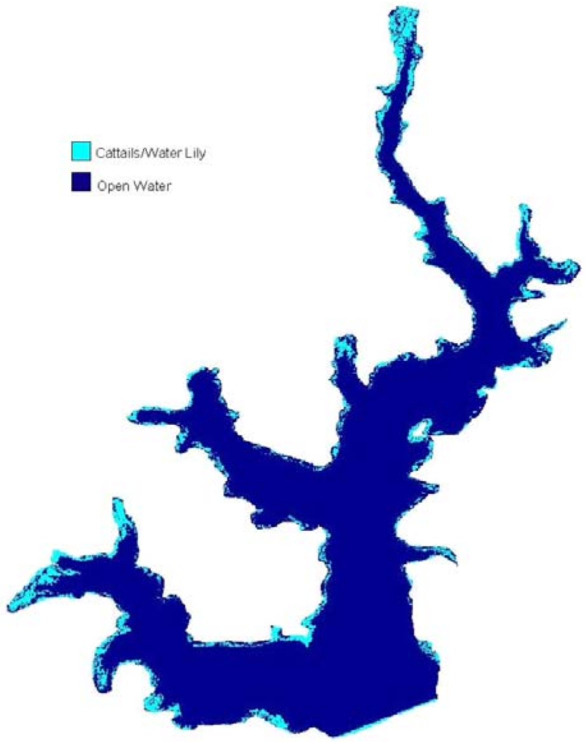


Figure 5-18. Water Lily and Cattail Distribution in Par Pond as Detected by SPOT Panchromatic Analysis, April 17, 1988, and October 25, 1988 (Source: Jensen et al. 1993).

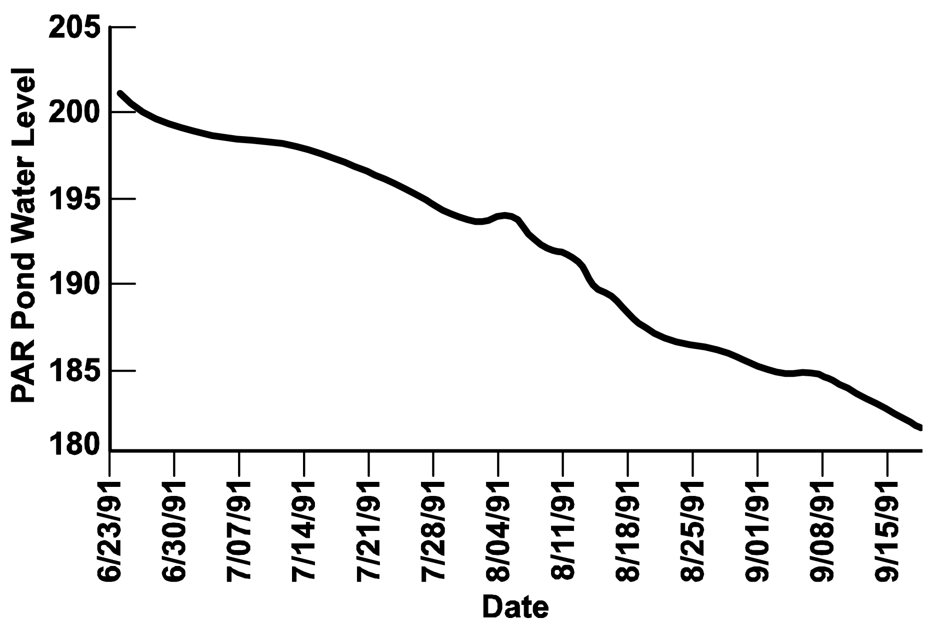


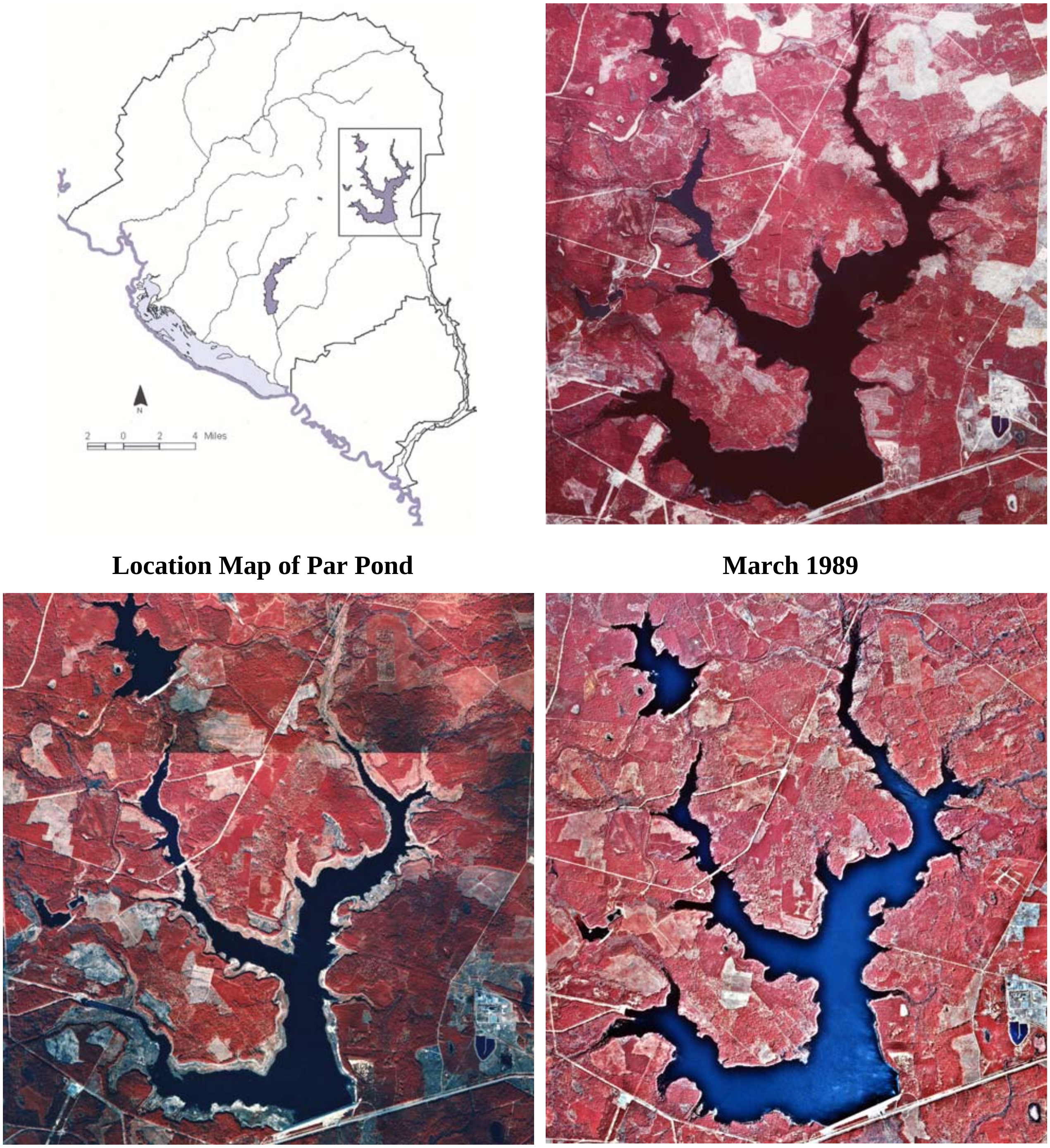
Figure 5-19. Par Pond Water-Level Change during Drawdown

Several studies documented changes in the wetland and aquatic macrophyte communities that occurred from the four-year drawdown. Between June and September of 1991, the water level in Par Pond was lowered from 61 m (200 ft) above mean sea level to 55 m (181 ft) above mean sea level, exposing littoral zone sediments. It remained at that level until the spring of 1995. The vast majority of emergent and floating-leaved vegetation did not survive the drawdown (Narumalani et al. 1997). During that time, early successional plant species invaded the exposed shoreline.

In spring 1992, dead vegetation occupied approximately 35% of the exposed sediments, 7% was bare soil, and 9% had been invaded by spikerush (*Eleocharis* sp.). By May 1992, spikerush occupied 20% of the area. This species colonized the low-lying areas and coves where groundwater seeps or stream inflow maintained high soil moisture. As the soils dried over the extended drawdown, spikerush coverage declined. By the fall of 1994, it covered only 11% of the area (Jensen et al. 1997).

Old field species (dogfennel, broom sedge, poke berry [*Phytolacca americana*], briars, and others) quickly succeeded spikerush and bare soil. Between May and October 1993, old field land cover increased to 26%. Pine (lobolly) and hardwood (willow and red maple) seedling coverage also increased from little cover in 1992 to 10% by the fall of 1994 (Jensen et al. 1997).

Three months after Par Pond was refilled in March 1995, the shoreline aquatic plant communities were surveyed to document their reestablishment. Surveys were repeated at intervals throughout the summers of 1995 and 1996. A series of transects was resurveyed around Par Pond, based on transects that had been established in 1988. Two zones were established at each transect: an inner zone, from the original 1988 persistent and nonpersistent bed boundary shoreward, and an outer zone from the original 1988 persistent and nonpersistent boundary outward to deeper water.



Location Map of Par Pond | **March 1989**

Jan 1994 | **March 1999**

Figure 5-20. Vertical Aerial Photography Showing the Results of the Par Pond Drawdown

In the first summer after refill, the shoreline vegetation rapidly reestablished. From June until the fall, maidencane was the most common emergent macrophyte. Other dominant species included lotus, water lily, watershield (*Brasenia schreberi*), and spike rush. The increased occurrence of these species of macrophytes may represent widespread seed dispersion and availability from previous years. Cattails, which were common prior to drawdown, were present during the summer of 1995 in small, widely scattered beds. Water level fluctuated about 0.2 m (0.6 ft) the first summer following refill, allowing a small band of primrose to develop along the exposed shoreline (Mackey and Riley 1996).

The percent cover of the transects' outer zones in 1989 and 1991 was between 65 and 70%. In late 1995, the average cover for the outer zones of the same transects was approximately 45%. SPOT data from April 1995 estimated 994 ha (2455 acres) of open water in Par Pond, and data from October 1995 estimated 120 ha (297 acres) of emergent macrophytes at the end of the growing season (Mackey and Riley 1996).

Studies by Ezra and Tinney (1985) of airborne mutispectral scanner data estimated that there were approximately 266 ha (657 acres) of emergency macrophytes along the Par Pond shoreline in the fall of 1985. Estimates of cattails or persistent emergent macrophytes along the shoreline of Par Pond using SPOT satellite data, were 192 ha (474 acres) during the 1988 growing season, 179 ha (442 acres) during the 1989 growing season, and 175 ha (432 acres) during 1990. Estimates of water lilies or other nonpersistent macrophytes were 150 ha (371 acres) in 1988, 126 ha (311 acres) in 1989, and 149 ha (368 acres) in 1990 (Jensen et al. 1993; Narumalani 1993).

Surveys begun in 1995 continued in 1996. Maidencane remained the dominant species, although it declined from its 1995 peak in abundance in the outer zones. Other species that were dominant prior to the drawdown continued to increase in importance from 1995 to 1996, particularly lotus, water lily, and watershield in the outer zones and lotus and spikerush in the inner zones. A new dominant in the inner zones, beginning in October 1995, is pickerel weed (*Pontederia cordata*). Cattails are throughout much of the lake, but no major beds developed in the first two summers after drawdown. Most shallow areas occupied by cattails prior to the drawdown now support maidencane, pickerel weed, and lotus as the dominant species. The occurrence of lotus increased in 1996 in many of the deeper areas formerly dominated by cattails (Mackey and Riley 1996).

Table 5-34. Par Pond Lake Bed Vegetation Cover, August 1992[a]

Vegetation type	Mean	±Std Error	Frequency, % of transects
Bare ground	35	4	95
Juncus spp. (rushes)	15	2	86
Panicum hemitomon (maidencane)	13	2	95
Scirpus cyperinus (bulrush)	7.6	1.9	62
Eupatorium/Erigeron (dog-fennel/daisy-fleabane)	7.2	1.4	76
Cyperus erythrorhizos (sedge)	6.8	1.5	81
Typha (dead cattail beds)	5.3	2.1	29
Eleocharis acicularis (spike-rush)	2.0	0.9	24
Pinus spp. - (seedling pine)	1.5	0.8	19
Phytolacca americana (pokeweed)	1.3	0.6	24
Polygonum spp. (smart weed)	1.2	0.5	24
Unidentified grasses	1.2	0.5	24
Bacopa caroliniana (blue hyssop)	1.2	0.7	19
Unidentified forbs	0.8	0.4	19
Typha spp. (cattail)	0.5	0.3	10
Ludwigia spp.	0.4	0.2	14
Unidentified shrubs	0.4	0.4	5
Pontederia cordata (pickerelweed)	0.2	0.2	5
Hydrocotyle umbellata (pennywort)	0.2	0.2	5
Eleocharis equisetoides (spike-rush)	0.2	0.2	5

Source: data provided by the Savannah River Ecology Laboratory.
[a]All areas represented except South Arm. Based on 21 point-intercept transects, 501 total points, running perpendicular to shoreline and from new to previous shoreline. Mean transect length = 99 m (324 feet). Total length, all transects = 2.8 km (1.29 mi).

5.4.1.5 Pond B

5.4.1.5.1 Site Description

Pond B, an 87-ha (215-acre) impoundment (Figure 5-21) constructed in 1960 as part of the Par Pond cooling reservoir system, received cooling-water discharge until 1964. Since then, Pond B has equilibrated to a water chemistry determined by precipitation-dominated hydrologic inputs and has developed extensive stands of aquatic macrophytes (Kelly 1989). Kelly (1989) and Whicker et al. (1990) provide a brief limnological description of Pond B and references to more detailed studies.

5.4.1.5.2 Macrophytes

5.4.1.5.2.1 Introduction

Several Pond B studies conducted in the 1970s and 1980s examined different aspects of macrophyte vegetation. Parker et al. (1973), in a comparative study of thermally affected aquatic environments, surveyed the shoreline macrophytes of Pond B. Kelly (1989), as part of a larger study to assess the role of macrophytes in cesium-137 cycling in Pond B, described species composition, structure, and seasonal changes in the standing crop of macrophytes. Whicker et al. (1990) sampled macrophyte standing crop as part of a survey of radioactive contaminants in the Pond B ecosystem.

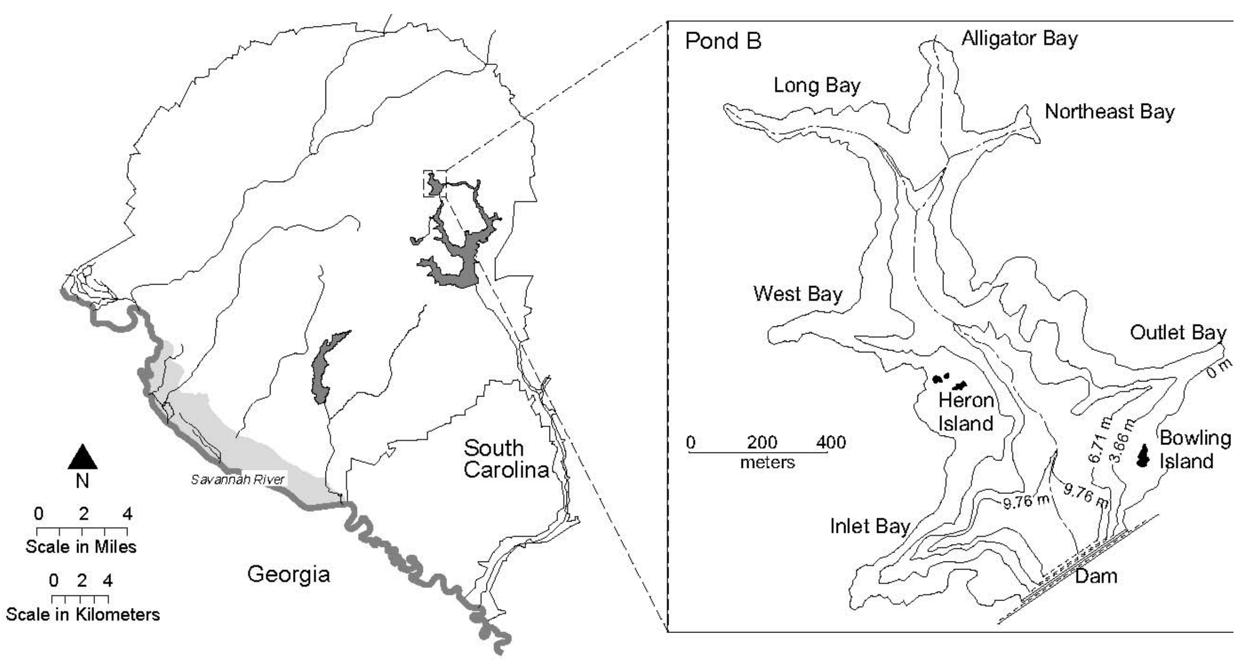


Figure 5-21. Map of Pond B

5.4.1.5.2.2 Macrophyte Distribution and Standing Crop

Kelly (1989) presents information on the species composition and structure of the vegetation in Pond B, documents seasonal changes in standing crop of dominant macrophytes, and compares the vegetation in Pond B with vegetation in other aquatic systems in the region, including Par Pond.

5.4.1.5.2.3 Species composition and structure

Fourteen species of vascular plants, in four growth forms, occurred in quadrats sampled in 1986. No ferns, macroalgae, or mosses were found. Three floating-leaved species, water lily, water shield, and *Nymphoides cordata*, which occurred primarily in the two shallowest sampling depths, made up more than half (51.8%) of the total standing crop harvested. Two species of bladderworts, *(Utricularia floridana* and *Utricularia inflata),* both free-floating, nonrooted submerged forms, made up 32.0% of the total standing crop. The free-floating growth form (as *U. floridana)* was important at all sampling depths and was most abundant at depths from 2.5 to 3.0 m (8 to 10 ft). Rooted submerged species, principally fanwort *(Cabomba caroliniana*), and blue hyssop (*Bacopa caroliniana*) accounted for 15.4% of the total standing crop. Other rooted submerged species included spike rush, bushy pondweed (*Najas guadalupensis*), bag moss (*Mayaca aubleti*), and parrotfeather. Two emergent species, pennywort and arrowhead (*Sagitaria isoetiformis),* were infrequently encountered only at the 0.5-m (1.5-ft.) sampling depth, and together made up less than 1% of the standing crop (Kelly 1989).

5.4.1.5.2.4 Comparison With Other Aquatic Systems

The macrophyte vegetation in shallow areas (<2.5 m [8 ft] deep) of Pond B was dominated in 1986 by an association of floating-leaved species and bladderwort (Kelly 1989). Bladderwort and fanwort dominated macrophyte vegetation in deeper areas. Similar associations of floating-leaved species and bladderwort have been described from numerous other permanently flooded freshwater habitats on the southeastern coastal plain, all of which have been described as having dilute water chemistry from precipitation-dominated hydrologic inputs. These habitats include freshwater ponds and lagoons in southeastern Louisiana, the Okefenokee Swamp, and permanently or semipermanently flooded herbaceous Carolina bays (Kelly 1989).

5.4.1.5.2.5 Comparison with Par Pond

Historically, the macrophyte vegetation of Pond B was similar to that in Par Pond, with cattails the dominant offshore macrophyte (Kelly 1989). In a 1971 survey, Parker et al. (1973) listed 19 vascular plant species. Cattails *(Typha latifolia)* occurred in large stands and were widely distributed over 39% of the shoreline. Low numbers of water lilies occurred in two of the north coves. Pondweed, hornwort (*Ceratophyllum* sp.), and parrotfeather were listed as present. However, macrophyte vegetation of Pond B as described by Kelly (1989) differed in several respects from that described for Par Pond by Grace (1985a), Wilde and Tilley (1985), and Liu et al. (1978).

5.5 PEN BRANCH RESTORATION

5.5.1 Introduction

The Pen Branch delta, like the other delta areas of the SRS Savannah River swamp, is a dynamic area that undergoes seasonal and annual changes (Christensen 1987; Christensen et al. 1988; Jensen et al. 1987; Tinney et al. 1986). The extent of the Pen Branch delta's revegetation and the vegetation community types depends on a variety of factors, including previous K-Reactor flow, thermal conditions in the delta, and Savannah River flooding patterns (Tinney et al. 1986; Jensen et al. 1987; Repaske 1981; Christy and Sharitz 1980; Irwin 1975; Sharitz et al. 1974a and b; Scott et al. 1985; Sharitz and Lee 1985). Additionally, when reactor operations ceased in 1988, rapid colonization or revegetation of exposed mud flats and sand bar islands occurred in the delta areas of the SRS Savannah River swamp (Jensen et al. 1986a; Sharitz et al. 1974a and b). The revegetation patterns included persistent and nonpersistent wetland communities and scrub-shrub communities (Sharitz et al. 1974a and b; Tinney et al. 1986; Smith et al. 1981, 1982).

Heterogeneous mixtures of wetlands plant communities could be found in the SRS Savannah River swamp, especially on the delta areas, within a few years of reactor shutdown (Christensen 1987; Christensen et al. 1988; Jensen et al. 1983, 1986a). Analysis of SPOT HRV data from 1987 through 1992 (Mackey 1990, 1993) and of airborne multispectral scanner (MSS) data from 1987 through 1991 (Blohm 1993) indicated continued rapid change in vegetation patterns on the Pen Branch delta after reactor operations were reduced in 1987 and halted the next year.

Wetland patterns of the Pen Branch corridor and delta area were evaluated using aerial photographic surveys (Sharitz et al. 1974b; Repaske 1981; Tinney et al. 1986), MSS aircraft surveys (Christensen 1987; Christensen et al. 1986, 1988; Jensen et al. 1986a, 1987), and ground-based surveys (Dunn and Scott 1987; Huenneke and Sharitz 1986; Scott et al. 1985, 1986; Sharitz and Lee 1985; Gladden et al. 1985; Christy and Sharitz 1980). These surveys generally indicated that the Pen Branch delta continued, at least through 1985, to expand at a rate of about 5-10 ha (12-25 acres) per year (Tinney et al. 1986), primarily along a terrace bordering the northern edge of the SRS Savannah River swamp (Jensen et al. 1987; Scott et al. 1986). Expansion into this Pen Branch delta "tail" area may have been related primarily to thermal effluent from Pen Branch being directed southeasterly along the terrace edge by flood waters during late spring and summer months (Scott et al. 1985, 1986; Jensen et al. 1987; Tinney et al 1986).

The Record of Decision for the Final Environmental Impact Statement, Continued Operation of K, L, and P Reactors, Savannah River Site, Aiken, S.C. (DOE 1991) required degraded Pen Branch wetlands to be restored to functional forested wetlands to the extent possible. In the years since 1991, pumping was reduced, allowing the natural succession of mostly herbs, grasses, and shrubs. Areas with sufficient natural vegetation of desired species will be allowed to continue natural revegetation. Areas that are not naturally reforesting have been planted with seedling of desired species.

A mitigation action plan (MAP) was formulated to guide the restoration. The Environmental Analysis Section (EAS) of the Savannah River National Laboratory oversaw and coordinated a multidisciplinary and multi-organizational approach to restore the Pen Branch wetland forest. Many organizations were implementing the MAP, including the U.S. Army Corps of Engineers, the U.S. Forest Service, the Center for Forested Wetlands Research, the Savannah River Ecology Laboratory, Clemson University, the University of South Carolina, the University of South Carolina-Aiken, and the University of Georgia. The U.S. Forest Service Savannah River Forest Station coordinated seedling plantings in sections of the corridor. EAS coordinated and developed remote sensing and monitoring methods to follow the progress of the mitigation. Through these cooperative efforts, a better understanding of the forested wetland ecosystem emerged and provides a basis for making decisions on the mitigation of similarly impacted areas.

The successful completion of the MAP will require three approaches. The first and second are occurring simultaneously: (1) the rehabilitation of the Pen Branch corridor and delta by natural succession and (2) the reforestation of the corridor and delta by planting. The third approach will be the compensatory mitigation of other impacted areas on the SRS and will be initiated following evaluation of the success of the first two approaches. The process is expected to take a decade. Success criteria for evaluating the establishment and functionality of the forested wetlands will be established based on the monitoring of the project. Presentation to the regulatory agencies was expected to occur in 2000 (Nelson 1996).

5.5.2 History of Thermal Discharge

Pen Branch is a third order stream whose watershed lies entirely within the SRS. Pen Branch flows into the Savannah River swamp, a mosaic of bottomland hardwood and cypress-tupelo (*Taxodium distichum-Nyssa aquatica*) forests. Between 1950 and 1954, the Atomic Energy Commission constructed K Reactor adjacent to Indian Grave Branch, a first-order tributary of Pen Branch. Heat was dissipated from the reactor's closed-loop cooling system by pumping water from the Savannah River across a heat exchanger and discharging the heated water into Indian Grave Branch.

K Reactor began discharging thermal effluent into Indian Grave in 1954. The reactor's contribution to stream flow varied temporally, but was consistently 1 to 2 orders of magnitude greater than the stream's base flow. The average annual temperature of the effluent was as high as 70°C (158°F). Thermal discharges ended in 1989.

5.5.2.1 Environmental Impacts

5.5.2.1.1 <u>Deforestation</u>

In 1951, the Savannah River swamp and Pen Branch corridor had closed-canopy forests (Wike et al. 1994). During the early years of reactor operation, as discharge rates and temperatures increased, flooding and elevated temperatures progressively killed the vegetation in the stream corridor. By 1961, canopy defoliation was apparent through 113 ha (279 acres) of the corridor and 4.5 ha (11 acres) of the delta (Wike et al. 1994). From 1961 to 1989, the thermal effluent gradually denuded a fan-shaped delta in the Savannah River swamp forest and a narrow tail to the southeast toward Steel Creek, near the swamp's upland boundary. The area of severe canopy loss in the delta reached a maximum of about 152 has (275.5 acres) in the mid 1980s (Wike et al. 1994).

5.5.2.1.2 <u>Colonization by Pioneer Species</u>

Early successional plants recolonized the corridor and delta since the cessation of reactor operations. In the corridor, these consisted of willow (*Salix* spp.), alder (*Alnus* spp.), wax myrtle (*Myrica cerifera*), buttonbush (*Cephalanthus occidentalis*), and sumac (*Toxicodendron* sp.), with a few red maple (*Acer rubrum*). Almost no species were typical of the canopy of a mature bottomland hardwood forest. The prolonged thermal discharges had eliminated seed sources and living root stocks from the floodplain. Most of the delta remained flooded, even after reactor operations stopped. The delta was colonized by cattails (*Typha* spp.) and bulrush (*Scirpus* spp.). Rates of forest recovery after the cessation of the thermal impacts were examined for the deep swamp areas. Density of regeneration was related to severity of impact and years since last disturbance (De Stevens and Sharitz 1997).

5.5.2.2 Reforestation

The primary mitigation objective is to establish a bottomland hardwood ecosystem on 69 ha (170 acres) in the Pen Branch corridor and a cypress-tupelo system on 202 ha (500 acres) in the delta. The corridor includes a stream reach 2.5 km (1.5 mi) long with a floodplain from 100 to 300 m (328 to 1000 ft) wide immediately upstream of the delta. About 53 ha (130 acres) around the edge of the delta are naturally revegetating with cypress and tupelo (Nelson, Dulohery, et al. 2000).

Twenty-five percent of the total artificial regeneration area was reserved for nontreated, nonplanted control strips (Figure 5-22). The sites were prepared for planting beginning in 1992. The lower corridor was planted in February and March 1993, the upper corridor in January 1994, and the delta in January and February 1995. Also in 1995, the upper and lower corridor was interplanted to compensate for mortality (Dulohery et al. 1995).

Approximately 8700 seedlings were planted (747 trees/ha [303/acre]) in the lower corridor (15 ha [37 acres]) without site preparation, which was deemed unnecessary. Species composition of the seedlings was cherrybark oak (*Quercus pagodaefolia*; 7%), swamp chestnut oak (*Q. michauxii*; 30%), green ash (*Fraxinus pennsylvanica*; 33%), water tupelo (11%), and bald cypress (19%) (Dulohery et al. 1995).

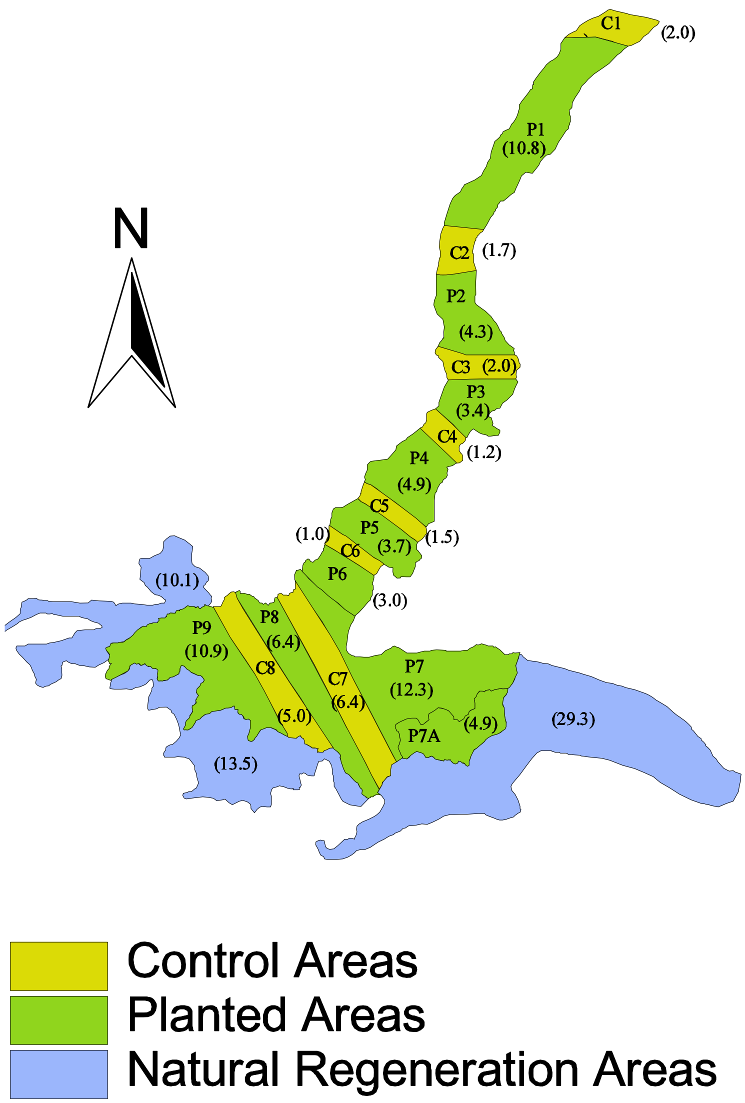


Figure 5-22. Pen Branch Treatment Areas (Source: Dulohery et al. 1995)

The upper corridor (24 ha [59 acres]) was planted in the winter of 1994, after the application of a wetland-approved herbicide to control the willow population and a prescribed burn to clear brush and vines. Target planting density was 747 trees/ha (303/acre) with a mix of swamp chestnut oak (17%), cherrybark oak (16%), water oak (*Q. nigra*; 20%), water hickory (*Carya aquatica*; 18%), green ash (14%), persimmon (*Diospyros virginiana*; 7%), swamp tupelo (*N. sylvatica*, var. *biflora*; 2%), and bald cypress (4%). Studies indicated that the presence or absence of a willow canopy had little influence on the survival and growth of the planted species (Dulohery et al. 2000; Fletcher et al. 2000; McLeod 2000; McLeod et al. 2001). The removal by herbicide application may therefore have been unnecessary to ensure the reforestation effort in the corridor.

Clearing and burning the understory appeared to induce severe herbivory by wild pigs such that two-thirds of the planted seedlings, including nearly all of the oaks and hickories, were lost to the pigs before the beginning of the first growing season. The pig herbivory occurred only in the burned areas. Recovery of the herbaceous understory during the second growing season provided sufficient cover for the seedlings to protect them from the pigs (Mayer et al. 2000).

The delta was planted (and portions of the corridor replanted) in 1995 after the application of only herbicide on about 12 ha (30 acres) to eliminate dense willow thickets. The target density was 1078 trees/ha (436/acre). Estimated percentages of the planted species were 60% water tupelo, 30% bald cypress, and 10% green ash.

The upper corridor was replanted with 1078 trees/ha (436/acre), composing cherrybark oak (26%), water oak (17%), green ash (5%), sycamore (*Platanus occidentalis*; 9%), pignut hickory (*C. glabra*; 2%), shumard oak (*Q. shumardii*; 13%), water hickory (11%), and swamp tupelo (17%). The lower corridor was replanted with 549 additional trees/ha (222/ acre): bald cypress (7%), green ash (13%), cherrybark oak (6%), water tupelo (13%), and swamp tupelo (61%) (Dulohery et al. 1995). Table 5-35 describes the planting process for each section of the stream.

Table 5-35. Description of Primary Treatment Zones, Site Preparation Techniques and Planting Scheme

Zone	Area (ha)	Description	Site Preparation	Planting
Upper Corridor	24	Mesic bottomland. Water table typically at 30 to 80 cm depth during the growing season. One or two well-defined stream channels. Initially covered by dense unbroken willow thickets.	Aerial herbicide application to control willows in September 1993. Burned to improve access for planting crews in November 1994	Planted 747 trees/ha in December 1993 and January 1994. Planted an additional 1078 trees/ha in January 1995 to compensate for loss.
Lower Corridor	16	Poorly drained bottomland. Water table within 20 or 30 cm of the soil surface during the growing season. Braided stream with up to four or five water courses. Initially covered by willow thickets and grassy openings.	None	Planted 747 trees/ha in February and March 1993. Planted an additional 549 trees/ha in January and February 1995.
Delta	46	Swamp. Continuously flooded, except on sandy ridges near the mouth of streams, where water table remains within 20 cm of the soil surface. Initial cover was about two-thirds cattail and one-third scattered willow ridges.	Herbicide application to control willow on levees and alluvial deposits (12 ha) in September 1994.	Planted 1078 trees/ha with 4.9 ha planted at about 500 trees/ha due to deep muck and standing water in January and February 1995.

5.5.2.3 Recovery of the Wetland Ecosystem

The remainder of this section describes various studies of the reforestation as of 2000.

The Pen Branch reforestation offers many opportunities to study the dynamics of a wetland ecosystem and apply what is learned to future wetland restoration projects. Annual progress is documented in annual reports prepared by the U.S. Forest Service. A workshop on the overall Pen Branch restoration effort was held at Clemson University in April of 1999 to highlight the results of the many research projects that utilized the restoration as a research vehicle. The proceedings were published as a refereed documentation of the mitigation effort (Nelson, Kolka, et al. 2000). Many of those presentations are abstracted below. The summary of the meeting and the design for future assessments of success were also published as part of the proceedings (Barton et al. 2000; Kolka, Nelson, and Trettin 2000).

A number of MS and PhD research projects were associated with the Pen Branch restoration, and aided in understanding many of the ecological dynamics that were at work during the early reforestation effort (Funderburk 1995; Buffington l996; Bowers 1997; Rozelle 1997; Parker 1998; Landman 2000; Wigginton 2000; Giese 2001).

5.5.2.3.1 <u>Hydrology</u>

Intensive monitoring between 1991 and 1995 characterized the hydrology of Pen Branch, Fourmile Branch, and Steel Creek (Dulohery et al. 1995). The objective was to determine the influence of pumping less Savannah River water through the system on the hydrology of SRS streams and swamp, and to determine suitable tree species and management practices based on the expected hydrology. Results indicate that:

- Water pumped from K Reactor flooded the Pen Branch corridor and saturated the soils as late as the summer of 1992. Pumping at that level limits the tree species that could establish themselves in the corridor.
- A few continuous recording water-level monitors are adequate to maintain long-term monitoring of the hydrology. There is a strong correlation among water table depths in the monitoring wells and surface water levels.

5.5.2.3.2 <u>Soils</u>

Subsequent monitoring was conducted to determine the influence of hydrology on restoration success (Kolka, Singer, et al. 2000).

Three studies were examining different aspects of the wetland soils: one was looking at the development of the soil organic matter, one was looking at the distribution and function of the organic matter pools among different successional stages, and one was looking at the comparison of carbon and nutrient fluxes among different successional stages.

Soil organic matter (SOM) is critical for the exchange of nutrients between vegetation and soil and is directly linked to forest productivity. Research has been conducted on SOM in upland soils, but not on the formation of SOM in wetland systems. This research studies forest floor development and SOM formation in four seral stages of floodplain forest to determine the rate of conversion of litter to SOM, the importance of the labile fraction, and the amount of forest floor mass and carbon and the carbon:nitrogen ratios in the different stages.

Forest floor mass increased rapidly during early succession, reaching a maximum in early mid-succession, then declined in late succession forests. Differences in the composition of the forest floor fraction between the various stages were noted: the herbaceous fraction declined through succession (from 74% in the earliest stages to <1% in the latest stages) and woody foliage increased from 6.7% in the earliest stages to >70% in late succession. Carbon and nitrogen concentrations increase during early succession and reach equilibrium during late succession. Carbon:nitrogen ratios were relatively stable throughout all stages of succession, with ratios ranging from 41 to 48. The rates of transformation of litter to SOM as measured by the lignocellulose index were not significantly different between stages of succession; however, the hydrologic dynamics of floodplains and the warm climate of the southeastern U.S. may render this method invalid in floodplain forests (Lockaby and Wigginton 1997;Wiggington et al. 2000).

Carbon and nitrogen pools and fluxes are being studied in Pen Branch, Fourmile Branch, and Meyers Branch forests to understand the dynamic processes that affect carbon and nitrogen allocation and transport in bottomland hardwood wetlands at various successional stages. The goals of the studies are to characterize the mass balance for organic carbon and nutrient pools, assess the influence of organic carbon on the transport of forest nutrients, and establish indicator relationships among and within wetland forests (Kolka and Trettin 1997; Aust and Giese 1997; Giese et al. 2000).

5.5.2.3.3 Vegetation

Following planting, vegetation surveys were conducted to monitor survival and growth (Dulohery et al. 1995). In 1996, a systematic survey was conducted of seedling establishment (Table 5-36). Results indicated good survival of planted seedlings with means in corridor planted areas of 666 trees/ha (270 trees/acre) and in delta areas of 1360 trees/ha (550 trees/acre). Approximately 12% of the seedlings were volunteers from species that had not been planted (Kolka and Trettin 1997).

Table 5-36. Results of 1996 Seedling Establishment Survey

	Mean ±SE (trees/acre[a])	N
Upper Corridor, planted	290.2 ± 6.2	51
Upper Corridor, control	211.5 ± 51.6	13
Lower Corridor, planted	225.0 ± 44.0	24
Lower Corridor, control	63.3 ± 21.5	15
Upper Delta, planted	550.0 ± 80.0	48

Source: Kolka and Trettin 1997.
[a]To convert to trees/ha, divide by 0.4047.

A long-term study assessed the physiological and morphological responses of four species – bald cypress, water tupelo, swamp tupelo, and green ash – to flooding. These species were chosen because of their high flood tolerance and similarity to species in the original forest. The soil in the delta was saturated for most of the two-year study. Seedlings were planted in four different microhabitats: one, in the forb layer, was cleared with lawn maintenance equipment. In a second, the grass remained. A third was dominated by willows, and the fourth was mucky and wetter than the other sites. Periodically over two years, seedlings were collected and measured; the viability of their root tips determined; the activity of the enzyme alcohol dehydrogenase (ADH) was measured; and their leaf area and the fresh and dry weights of leaves, stems, and roots were determined (Hook and Rozelle 1997).

The level of ADH activity and root viability quantify a seedling's capacity for anaerobic metabolism. The capacity for anaerobic metabolism has some bearing on a seedling's survival in flooded wetlands. A computer model is expected to be developed to show the relative responses of the various species over time. Early results indicate that green ash seedlings are stressed in all four habitat types, but that the other three species are not (Hook and Rozelle 1997).

The effect of root pruning and tree shelters on seedling growth and survival also is being studied in areas that are continually saturated. Differences between root-pruned and non-root-pruned seedlings were variable, depending on the species, but moderate root pruning was not detrimental to seedling survival. Tree shelters increased seedling height and survival. The amount of herbaceous vegetation around the seedling affected the quantity of light a seedling received. Because root-pruned seedlings are easier to plant in the swamp, this information will be useful in future wetland restorations. The impacts of root pruning on long-term growth and survival require further study (Conner 1997; Conner et al. 2000).

A study determined the effects of overstory removal on the environmental factors influencing the growth and survival of seedlings (McKevlin and Dulohery 1997; Dulohery et al. 2000). Specific objectives were to determine the optimum overstory condition for planted seedlings, based on seedling growth and survival; the effect of overstory on microhabitat factors such as light intensity, soil temperature, depth to the water table, and herbaceous competition; and the influence of these environmental characteristics on seedling survival, growth and biomass allocations. Four species – bald cypress, water tupelo, swamp chestnut oak, and green ash – planted in a variety of flood and shade conditions were treated to one of four overstory conditions. These included no competition control, partial removal of overstory with the stems left in place, complete removal of the overstory with the stems left in place, and clearcut.

There are significant differences among treatments in the diurnal fluctuations of the depth to the water table, the quantity and quality of light available to seedlings and biomass of herbaceous competition. The large diurnal fluctuations in the depth of the water table occurred in the treatments where the willow canopy was undisturbed. Greater light transmittance in the clearcut plots resulted in greater herbaceous competition. Initial results suggest that there are both height growth and survivorship differences among species and among treatments. Sparse to moderate willow canopy can ameliorate the stresses of growth-limiting hydrology and herbaceous competition and be beneficial to the establishment, growth, and survival of bottomland hardwood species (McKevlin and Dulohery 1997).

5.5.2.3.4 Fish

Studies of differences in stream morphology and fish community characteristics among Pen Branch, Meyers Branch, Fourmile Branch, and Upper Three Runs will allow scientists to determine how the morphology of a stream influences its fish community. Many aspects of fish assemblage structure (e.g., species richness, disease incidence, taxonomic composition at the family level) did not differ between disturbed and undisturbed streams; however, the disturbed streams were characterized by higher densities of a number of species. These differences were successfully detected with the multivariate statistical methods; whereas, the IBI did not differ between most recovering and undisturbed sampling sites. Because fish assemblages are strongly influenced by instream habitat, and because instream habitat is strongly influenced by the riparian zone, fish assemblages can be used to measure restoration success (Reichert and Dean 1997; Paller et al. 2000).

Scientists are examining the effects of past effluent releases on the physiology and behavior of individual fish, the demography and habitat segregation of populations, and the structure and function of the entire community. Results from Fourmile Branch and Pen Branch studies indicate that streams formerly impacted by reactor operations have two to five times the densities and at least as many species as streams that did not experience similar perturbations. Although species richness is similar, evenness differs greatly. A few fish taxa (suckers [Catastomidae], mosquitofish [*Gambusia* spp.], minnows, and sunfishes [*Lepomis* spp.]) dominate the impacted streams. The unimpacted streams have a more even distribution of numbers among species. The community composition differs among the streams, suggesting a change in the functional organization of the fish communities (Fletcher et al. 1997).

The preliminary results of one study indicate that dusky shiners (*Notropis cummingsae*) spawn on the nests of redbreast sunfish (*L. auritus*). Spawning on redbreast nests is probably obligatory for the shiners, which feed on sunfish larvae and embryos, selectively eating the offspring of their host. The research is expanding to study nesting microhabitats and the selection by the fish of their location in the streams (Fletcher et al. 1997).

5.5.2.3.5 Invertebrates

A study examined the recovery of the aquatic invertebrates in Pen Branch by investigating the invertebrate community and stream characteristics that may influence insect distribution and abundance. The effect of the reforestation efforts on the invertebrate community, the periphyton, and the macrophytes was evaluated. Disparate instream habitat structural components and stream physical changes in the post-thermal and reference systems drive functional differences in the macroinvertebrate community. The post-thermal stream is physically and biologically structured by high densities of aquatic macrophytes, while the reference system is driven by high concentrations of coarse woody debris. Consequently, the abundant, diverse macroinvertebrate communities in both systems illustrate a post-thermal shift in energy source from a reliance on allocthonous to autochthonous inputs. Biotic indices such as taxa richness, a family level index, and similarity index may not be sufficient to determine functional changes as a result of thermal impacs. However, the distribution of diverse functional feeding groups across streams was successful at characterizing divergence in resource utilization and processing (McArthur and Lakly 1997; Lakly and McArthur 2000).

5.5.2.3.6 <u>Birds</u>

Populations of Neotropical migrants have declined over the last decades due to reductions in the breeding and overwintering habitats. Many Neotropical migrants breed in southeastern late successional bottomland hardwood forests. Although efforts are being made to restore bottomland forests, no attempt has been made to determine if the restored forests serve the same function for birds as natural forests. By studying the birds in the different successional stages of the Pen Branch forest, scientists may determine if the community in a restored forest is similar to that in a natural forest, and if so, how long it takes for the bird community to develop. Miller and Chapman (1997) examined the differences between communities in early, mid, and late successional forests. The study sites were an early successional forest at Pen Branch, a mid-successional forest at Steel Creek, and a late successional forest at Tinker Creek.

Results are that although there are few differences in the avian community composition in the different forest restoration treatments, those plots that were herbicided, burned, and planted tended to have greater species richness in 1994 and greater abundance in 1995 ($P<0.05$) than the control plots. Steel Creek bottomland forests had fewer individuals than Pen Branch, but there was no difference between Pen Branch and Tinker Creek. Species diversity was greater at Tinker Creek than at Pen Branch. Short-distance migrants and species associated with forest edge/scrub habitats were more common in the early successional bottomland of Pen Branch than at the other sites (Table 5-37). Neotropical migrants were more common in the mature forest associated with Tinker Creek (Miller and Chapman 1997; Buffington et al 2000).

The foraging behavior of hooded warblers (*Wilsonia citrina*), white-eyed vireos (*Vireo griscus*), and parula warblers (*Paula americana*) were examined. Each species appears to occupy a slightly different foraging niche differentiated by foraging maneuver and the position of the bird relative to the trunk and the top of the tree (Miller and Chapman 1997).

5.5.2.3.7 <u>Mammals</u>

During the summer of 1996, the small mammal population in the Pen Branch corridor was monitored (Wike 1997). Three habitats – wooded upland, streambank, and islands (often no more than sand bars) – were sampled. Preliminary results suggest that there are substantial populations of rice rats (*Oryzomus palustris*), cotton rats (*Sigmodon hispidus*), and cotton mice (*Peromyscus gossypinus*) at Pen Branch. The Lincoln-Peterson method for estimating populations estimated the populations of each species in the 40 ha (100 acre) study area (Table 5-38).

Several other species were trapped, but in smaller numbers: Southern short-tailed shrew (*Blarina carolinensis*), star-nosed mole (*Condylura cristata*), wood rat (*Neotoma floridana*), and golden mouse (*Ochrotomys nuttalli*). Virginia opossums (*Didelphis virginiana*) and a racoon (*Procyon lotor*) were trapped in rabbit boxes and several swamp rabbits (*Sylvilagus aquaticus*) were seen (Wike 1997; Wike et al. 2000).

Table 5-37. Birds that were Detected at Pen Branch, 1994-1995

Common Name	Scientific Name
Green Heron	*Butorides striatus*
Wood Duck	*Aix sponsa*
American Woodcock	*Scolopax minor*
Mourning Dove	*Zenaida macroura*
Yellow-billed Cuckoo	*Coccyzus americanus*
Ruby-throated Hummingbird	*Archilochus colubris*
Downy Woodpecker	*Picoides pubescens*
Acadian Flycatcher	*Empidonax virescens*
Great-crested Flycatcher	*Myiarchus crinitus*
Fish Crow	*Corvus ossifragus*
Carolina Chickadee	*Puecile carolinensis*
Tufted Titmouse	*Baculophus bicolor*
Carolina Wren	*Thryothorus ludovicianus*
Blue-gray Gnatcatcher	*Polioptila caerulea*
White-eyed Vireo	*Vireo griseus*
Red-eyed Vireo	*Vireo olivaceous*
Northern Parula	*Parula americana*
Black-and-white Warbler	*Mniotilta varia*
Common Yellowthroat	*Geothlypis trichas*
Hooded Warbler	*Wilsonia citrina*
Yellow-breasted Chat	*Icteria virens*
Summer Tanager	*Piranga rubra*
Northern Cardinal	*Cardinalis cardinalis*
Blue Grosbeak	*Guiraca caerulea*
Indigo Bunting	*Passerina cyanea*
Painted Bunting	*Passerina ciris*
Rufous-sided Towhee	*Pipilo erythrophthalmus*
Red-winged Blackbird	*Agelaius phoeniceus*
Brown-headed Cowbird	*Molothrus ater*
Orchard Oriole	*Icterus spurius*

Source: Buffington 1996.

Table 5-38. Small Mammal Population Estimates at Pen Branch, Summer 1996

Species	Number of Individual Trapped	Estimated Population Size	Females[a]
P. gossypinus	44	161	13
O. palustris	47	186	19
S. hispidus	66	224	12

Source: Wike 1997.
[a]Some animals could not be sexed.

5.5.2.3.8 Reptiles and Amphibians

The reptile and amphibian populations in the Pen Branch corridor were monitored from January 1, 1995, to September 30, 1996, with drift fences and pitfall traps, coverboards, aquatic turtle traps, and modified minnow traps (Hanlin and Guynn 1997). All animals were identified, sexed if possible, marked, and released at their point of capture. The animals were collected in eleven of the planting strips, with the traps lines divided between the planted zones and the control zones. A total of 11,802 individuals representing 70 species were captured in 13,834 captures over 221,126 trap nights (12% were recaptures and 3% escaped before being marked). The most frequently captured species was the narrow-mouthed toad (*Gastrophryne carolinensis*; 30.5% of captures) followed by southern toad (*Bufo terrestris*; 19.1%), southern leopard frog (*Rana utricularia*; 16.7%), marbled salamander (*Ambystoma opacum*; 6.7%), and slimy salamander (*Plethodon glutinosus*; 6.0%). These five species represented approximately 79% of the total captures.

Twenty-four species of snakes (524 animals), 16 species of anurans (8281 animals), 13 species of salamanders (1818 animals), 9 species of turtles (459 animals), 8 species of lizards (718 animals), and 2 alligators were collected (Table 5-39) (Hanlin and Guynn 1997; Bowers et al. 2000).

5.5.2.3.9 Evaluation

Finally, a technique for evaluating the success of the Pen Branch restoration was developed using appropriate parts of existing wetland assessment methodologies. In addition to developing an assessment system uniquely suited to the condition of the Pen Branch wetland, researchers compiled an extensive annotated bibliography of all information relevant to the restoration. The bibliography identified data gaps and in the future should provide scientists with information to prevent the collection of redundant data sets.

Table 5-39.   Reptile and Amphibian Species Captured in Pen Branch Corridor, 1995-1996

Common Name	Scientific Name
Salamanders	
Spotted Salamander	*Ambystoma maculatum*
Marbled Salamander	*A. opacum*
Mole Salamander	*A. talpoideum*
Two-Toed Amphiuma	*Amphiuma means*
Southern Dusky Salamander	*Desmognathus auriculatus*
Southern Two-Lined Salamander	*Eurycea cirrigera*
Three-Lined Salamander	*E. longicauda guttolineata*
Dwarf Salamander	*E. quadridigitata*
Eastern Red-Spotted Newt	*Notophthalmus viridescens*
Slimy Salamander	*Plethodon glutinosus*
Mud Salamander	*Pseudotriton montanus*
Lesser Siren	*Siren intermedia*
Greater Siren	*S. lacertina*
Frogs and Toads	
Southern Cricket Frog	*Acris gryllus*
Southern Toad	*Bufo terrestris*
Eastern Narrowmouth Toad	*Gastrophryne carolinensis*
Bird-Voiced Treefrog	*Hyla avivoca*
Cope’s Gray Treefrog	*H. chrysoscelis*
Green Treefrog	*H. cinerea*
Pine Woods Treefrog	*H. femoralis*
Squirrel Treefrog	*H. squirella*
Spring Peeper	*Pseudacris crucifer*
Southern Chorus Frog	*P. nigrita*
Little Grass Frog	*P. ocularis*
Ornate Chorus Frog	*P. ornata*
Bullfrog	*Rana catesbeiana*
Bronze Frog	*R. clamitans*
Southern Leopard Frog	*R. utricularia*
Eastern Spadefoot Toad	*Scaphiopus holbrookii*
Turtles	
Common Snapping Turtle	*Chelydra sepentina*
Spotted Turtle	*Clemmys guttata*
Striped Mud Turtle	*Kinosternon baurii*
Eastern Mud Turtle	*K. subrubrum*
Eastern River Cooter	*Pseudemys concinna*
Florida Cooter	*P. floridana*
Common Musk Turtle	*Sternotherus odoratus*
Eastern Box Turtle	*Terrapene carolina*
Yellowbelly Slider	*Trachemys scripta*
Crocodilians	
American Alligator	*Alligator mississippiensis*

Table 5-39. Reptile and Amphibian Species Captured in Pen Branch Corridor, 1995-1996 - continued

Common Name	Scientific Name
Lizards	
Green Anole	*Anolis carolinensis*
Six-Lined Racerunner	*Cnemidophorus sexlineatus*
Five-Linked Skink	*Eumeces fasciatus*
Southeastern Five-Lined Skink	*E. inexpectatus*
Broad-Headed Skink	*E. laticeps*
Slender Glass Lizard	*Ophisaurus attenuatus*
Eastern Glass Lizard	*O. ventralis*
Ground Skink	*Scincella lateralis*
Eastern Fence Lizard	*Sceloporus undulatus*
Snakes	
Eastern Cottonmouth	*Agkistrodon piscivorus*
Eastern Worm Snake	*Carphophis amoenus*
Scarlet Snake	*Cemophora coccinea*
Black Racer	*Coluber constrictor*
Timber Rattlesnake	*Crotalus horridus*
Southern Ringneck Snake	*Diadophis punctatus*
Corn Snake	*Elaphe guttata*
Rat Snake	*E. obsoleta*
Mud Snake	*Farancia abacura*
Rainbow Snake	*F. erytrogramma*
Eastern Hognose Snake	*Heterodon platirhinos*
Southern Hognose Snake	*H. simus*
Eastern Kingsnake	*Lampropeltis getula*
Scarlet Kingsnake	*L. triangulum elapsoides*
Redbelly Water Snake	*Nerodia erythrogaster*
Banded Water Snake	*N. fasciata*
Brown Water Snake	*N. taxispilota*
Rough Green Snake	*Opheodrys asetivus*
Brown Snake	*Storeria dekayi*
Redbelly Snake	*S. occipitomaculata*
Southeastern Crowned Snake	*Tantilla coronata*
Eastern Ribbon Snake	*Thamnophis sauritus*
Eastern Garter Snake	*T. sirralis*
Rough Earth Snake	*Virginia striatula*

Source: Hanlin and Guynn 1997.

Restored sites must be compared to healthy and functional reference ecosystems to determine the success of rehabilitation (Kolka et al. 2002). For restoration to be considered a success, wetland function needs to be restored or the community must be developing in the direction of the restoration of function. Easily measured indicators should be developed and interactions between biotic and abiotic factors need to be understood. To date, the information collected from Pen Branch indicates the following (Trettin et al. 1997):

- The four parameters measured in the aquatic macroinvertebrate community (mean number of taxa per sampler, mean density, mean biomass, and total taxa collected) are higher in the reforested wetland than in the reference community. Moving from the era of thermal impacts to postreforestation, all four indicator parameters have increased in value.
- Fish communities in the reforested wetland are more diverse, with higher densities and more sensitive species than the undisturbed reference site. There appears to be a higher level of biotic integrity and freedom from ecosystem disturbance in the reforested site compared to the pristine site.
- Water quality monitoring at Pen Branch indicates decreases in water temperature and velocity, and increases in conductivity. The pH, dissolved oxygen, and hardness at Pen Branch and the control site are comparable and unchanged.
- Bird and reptile and amphibian communities resemble those of early successional systems.
- Vegetation communities are the most distinctly different between the two sites. The diversity and net primary production are greater at the restored site, but the desirable species have not yet established themselves as the dominant vegetation.

It appears that Pen Branch is functioning as a viable wetland. For some faunal communities, it may provide greater opportunities for establishment and survival than later successional forests.

Based on the research as of the date of the revision of the document, several valuable conclusions regarding vegetation restoration are already evident. Seedling establishment appears to be hampered in open conditions because of herbaceous competition and herbivory. The best chance for seedling survival is when a shrub cover or nursery crop is present. Shading slows seedling growth somewhat; however, the effects are offset by the protection from herbaceous competition and herbivory the larger plants afford the seedlings. Future restoration plans should consider minimal site preparation. Tree tubes and tree shelters ensure greater survival, although they would be cost-prohibitive for large scale restorations. Root pruning makes planting in muck easier and does not appear to have a detrimental effect on seedling survival of the species planted in Pen Branch. Green ash is more susceptible to prolonged flooding than the other experimental species.

5.6 CAROLINA BAYS OF SRS

5.6.1 General Characteristics of Carolina Bays

Carolina bays are shallow, poorly drained, oval, or elliptical depressions found throughout the southeastern Coastal Plain. Bennett and Nelson (1991) described their abundance and distribution in South Carolina, excluding SRS. Much of this chapter was taken from the National Environmental Research Park (NERP) report of the Carolina bays of SRS (Schalles et al. 1989). Carolina bays are a common feature of the SRS landscape (Figure 5-23). The 194 bays Shields et al. (1982) identified support a variety of aquatic and wetland communities. Most of the bays have limited development of organic or peat substrates, and the soils are typically sandy clay loam underlain by a clay hardpan. Many were ditched and drained for agricultural use prior to the acquisition of the land for the SRS (Christel-Rose 1993). Few have been disturbed since the early 1950s; therefore, most of the altered bays have undergone successional revegetation (Schalles et al. 1989). In recent years, SRS has begun a program to restore some bays to their former hydrology. The uniqueness of these habitats has been recently described by Sharitz (2003).

Several physical characteristics of these wetlands dictate the development and status of their biota. Carolina bays are typically isolated wetlands that are largely fed by rainfall or shallow, low-solute groundwater (Schalles et al. 1989; Lide 1991; Lide 1997). Thus, they have a nutrient-poor, softwater, acidic chemistry that, in turn, restricts primary and secondary productivity and use of these systems to tolerant species. In addition, fluctuations of their hydrology make these bays relatively unpredictable habitats. Interpretations of successional status or development of the biota must take this unpredictability of hydrology into account and long-term observations are necessary to understand the role of these bays in supporting aquatic and wetland organisms. Most of the bays contain water, at least seasonally (Kirkman 1992; Schalles et al. 1989).

Carolina bays occur throughout the upper Coastal Plain of Georgia and the Carolinas. Their origin is unknown, but because they are seasonally inundated and isolated wetlands, they provide valuable habitat. Carolina bays on SRS have remained largely undisturbed since the advent of SRS in the early 1950s and are valuable examples of these ecosystems.

5.6.2 Previous Research on SRS Carolina Bays

Much of the research on the Carolina bays of SRS has focused on certain species or on environmental features. Different levels of detail exist for different groups of organisms and reflect the diverse interests of previous investigators. This chapter summarizes aspects of research to date and presents data from numerous studies, but it does not attempt to synthesize. The most complete ecosystem study and synthesis of the biotic and abiotic properties of a single bay is a study of Thunder Bay by Schalles and Shure (1989). The most extensive comparison of SRS bays with those found throughout the Southeast is provided by Sharitz and Gibbons (1982) (Schalles et al. 1989).

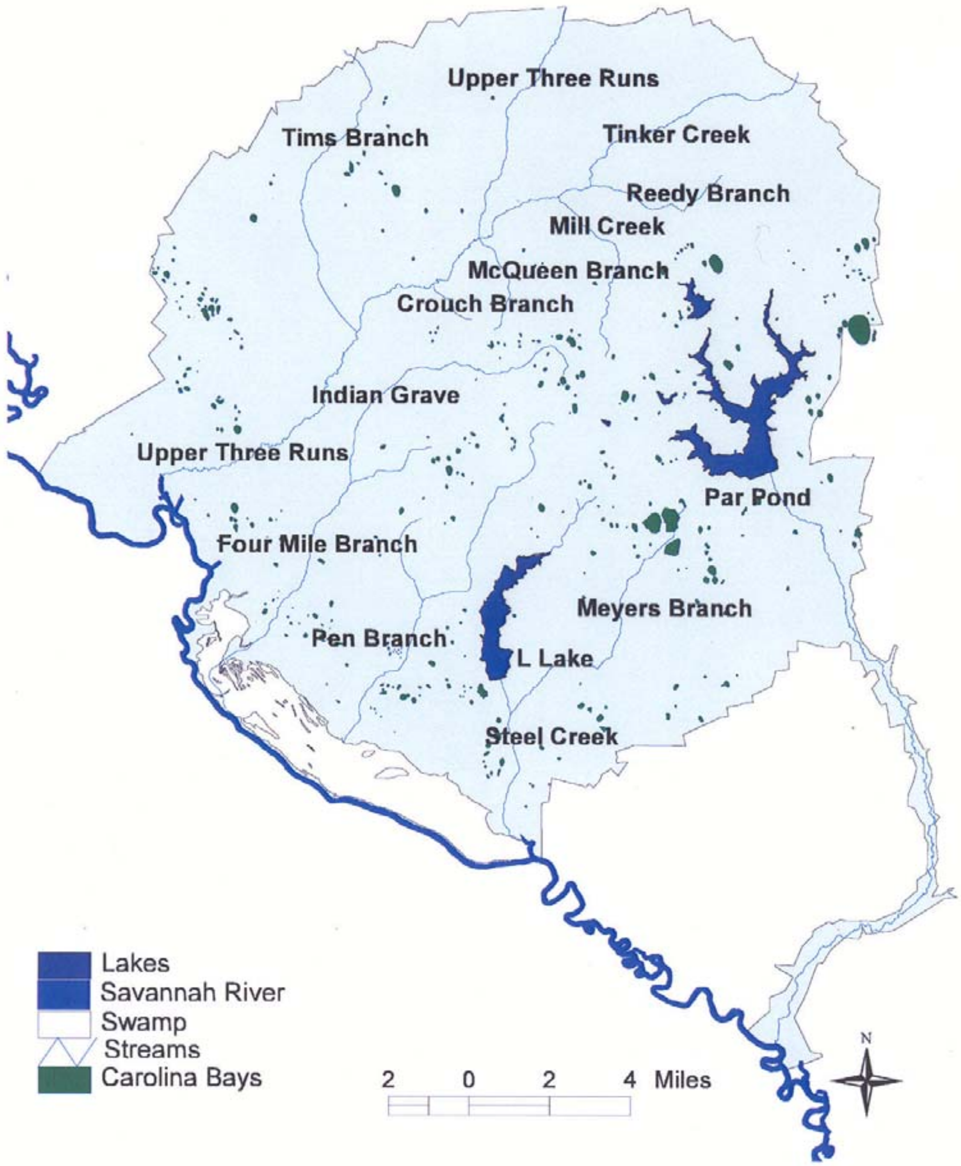


Figure 5-23. Location of Carolina Bays on SRS (Kirkman et al. 1996)

5.6.3 Size and Distribution of Carolina Bays on SRS

An inventory of the Carolina bays on SRS was made by examining false-color infrared photography (scale 1:15,840) (Shields et al. 1982). This inventory identified 194 confirmed or suspected bays; each bay was assigned a number, and its position was located on a topographic map of SRS (USGS 1:48,000). The identification number, name, location, wetland surface area, and habitat type of each bay are presented in *Locations and Areas of Ponds and Carolina bays at the Savannah River Plant* (Shields et al. 1982). A more recent survey by Kirkman et al. (1996) identified 299 Carolina bays and bay-like wetlands on SRS (Figure 5-23).

Carolina bays are distributed in clusters and broad bands across SRS (Figure 5-23). The bays occur at elevations ranging from 36 to 104 m (118 to 341 ft) above mean sea level. The surface areas of bays on SRS range from less than 0.1 ha (0.2 acres) to about 50 ha (125 acres). Aerial photography from the 1940s reveals that three large bays southwest of Par Pond, at the headwaters of Meyers Branch, may be remnants of a large bay covering about 220 ha (545 acres). The median size of SRS bays is about 0.8 ha (2 acres); only 15 sites exceed 4 ha (10 acres) (Shields et al. 1982; Schalles et al. 1989).

5.6.4 Hydrology

Water chemistry of undisturbed Carolina bays on SRS is typical of precipitation-dominated systems (Schalles et al. 1989). Surface inflow channels generally are absent. Drainage channels are common and many are man-made. Today, none of these channels is maintained; most are partially filled with sediments and discharge only during periods of high water.

Although the water levels of these bays generally were related to the amount of precipitation, the amplitude and timing of changes differed. For example, Ellenton Bay and Thunder Bay have similar overall patterns; whereas, Rainbow Bay has greater water-level fluctuation. Schalles (1979) found that maximum water-level fluctuation over an annual cycle in 1974-1975 was between 35 and 83 cm (14 and 33 in.) in six local bays. Water level changes in excess of 50 cm (20 in.) from the summer of 1990 through the summer of 1992 were common at Lost Lake. Continuous or temporary connection to near-surface groundwater is probably a common feature of Carolina bays (Lide 1991). Comparisons of surface-water levels to the piezometric levels in four adjacent monitoring wells (Schalles et al. 1989) revealed conditions favorable to almost continuous subsurface seepage loss and periodic groundwater recharge at Thunder Bay. Later work with a series of 34 shallow piezometers in Thunder Bay monitored the hydrology for 5 years (Lide et al. 1995). This work indicates that Thunder Bay is not a perched system, but a surface expression of the water table. Schalles (1979) proposed that most groundwater surface-water interactions occur laterally, around the margins of the depressions, and that these connections are often lost during periods of low water levels.

An impervious clay lens appears to underlie many of the SRS Carolina bays. Soils in the center of the bays contain higher percentages of clays and silts than those closer to the rims. Consequently, soils in the center are less permeable and more poorly drained. Many Carolina bays on SRS dry periodically. Many of the smaller bays contain surface water only during wet seasons; whereas some of the larger depressions dry only during prolonged drought (e.g., Craigs Pond and Ellenton Bay). Ellenton Bay experienced severe drying with only a few deep holes holding water during droughts in 1968, 1981, 1987, and 1988 (Sharitz and Gibbons 1982; Schalles et al. 1989). Craigs Pond was dry to at least 20 cm (7.8 in.) below the soil surface in 1988 (Schalles et al. 1989).

5.6.5 Water Chemistry

5.6.5.1 General Chemical Characteristics

Newman and Schalles (1990) made several surveys of surface water chemistry in Carolina bays of SRS. The surface waters of the surveyed bays were acidic (pH 3.8-5.5) with low levels of calcium and total inorganic solutes (conductivities of 20-40 µS/cm). Bay waters had low to moderate color and dissolved organic carbon (mean = 22 mg/l). The moderate levels of color and dissolved organic carbon (DOC) in the bays can be attributed to the low calcium levels, abundance of living and decaying plant materials, and the shallow depths of the ponds. No single element dominates cations in the bay waters. In 1980, calcium was the most abundant cation (25% of total meq/l). However, sodium, magnesium, and hydrogen ions were also significant (Table 5-40). The relatively high monovalent/divalent cation ratios, low total inorganic solutes, and occurrence of moderate acidity and dissolved organic carbon in the bays are probably the result of sea salt contributions to atmospheric chemistry in the region; restricted watersheds with sandy, leached soils; periodic exchanges with low solute-strength shallow groundwater, and high nutrient retention by vegetation (Schalles et al. 1989). Overall, the SRS bays had lower total cation levels than other Coastal Plain wetlands (Table 5-40). Manganese concentrations in the bays on SRS were about one order of magnitude greater than the freshwater global average (0.0013 meq/l) reported by Livingston (1963). A possible source of the manganese is conifer litter (Wetzel 1983) from marginal pine forests; thus manganese concentrations in the bays may attest to the importance of exchange pathways between these bays and adjacent terrestrial habitats (Schalles et al. 1989).

Table 5-40. Cation Proportions for Various Southeastern Coastal Plain Surface Waters (Softwater, Lentic Systems)

Cation (% meq/l)[a]	SRS Carolina Bay[1]	SRS Farm Ponds[2]	North Carolina Pocosins[3]	Georgia Okefenokee Swamp[4]	Florida Cypress Dome[5]	Virginia-Lake Drummond, Dismal Swamp[6]
Ca++	24.4	18.6	34.9	7.6	25.4	38.2
Mg++	17.4	21.0	16.6	9.4	20.1	16.9
Na+	23.7	51.6	36.6	45.9	38.3	31.3
K+	5.6	7.4	2.6	2.0	1.6	9.4
H+	18.2		9.2	32.3	5.7	1.8
Fe++	5.9			2.6	3.4	2.4
Mn++	4.9		<0.1	1.4	1.4	
S(meq/l)	0.261		0.573	0.392	0.561	0.875

Sources: [1]Schalles et al. 1989; [2]Tilly 1973; [3]Daniel 1981; [4]Abule 1984; [5]Dierberg and Brezonik 1984; [6]Lichtler and Walker 1979.
[a]Iron and manganese probably were present as colloids and thus do not contribute to total cation charge.

5.6.5.1.1 Detailed Chemical Analyses of Bays of SRS

Detailed chemical analyses of bays on or in the vicinity of SRS were made as part of a 1988 regional survey of 53 sites (Table 5-41). Overall, solute levels were higher than levels seen in previous surveys of bays on SRS. Potassium levels were notably higher and hydrogen-ion levels lower. A dry period during the early and mid-1980s and corresponding ecosystem responses may account for these differences. Chloride was the dominant inorganic anion, with sulfate second in abundance (Table 5-41). Dissolved organic carbon averaged 14.1 mg/ l and accounted for 39% of the total anionic charge. Dissolved silica values were moderate, but quite variable. The dilute acidic chemistry is a probable indicator of moderate to severe nutrient limitations in the bays. The acidic nature of the surface waters suggests a dystrophic condition. The acidity seems largely related to biological phenomena and low regional alkalinities. Interestingly, sphagnum moss, often implicated in bog acidity (Clymo 1964), is uncommon or absent from bay communities on SRS (Schalles et al. 1989).

Table 5-41. Detailed Chemical Analysis, Including Anion/Cation Charge Balance, for Surface Waters in Six Carolina Bays Sampled as Part of a Regional Survey in January 1988[a]

Variable	$\bar{x}$	range (mg/l)	x (meq/l)	x (% meq)	Variable
DOC[b]	14.09	(8.08-21.71)	0.155	39.0	DOC[b]
Cl-	4.94	(3.44-7.99)	0.139	35.0	Cl-
SO_4--	3.32	(0.50-10.34)	0.069	17.4	SO_4--
HCO_3-	2.07	(0.13-6.89)	0.034	8.6	HCO_3-
Anions(Σ)	--		0.397	100.0	Anions(Σ)
Na+	3.08	(0.82-6.64)	0.134	32.8	Na+
Ca++	2.12	(0.72-4.53)	0.106	26.0	Ca++
K+	3.83	(1.09-14.5)	0.098	24.0	K+
Mg++	0.78	(0.49-1.25)	0.064	15.7	Mg++
H+	0.006	(0.001-0.013)	0.006	1.5	H+
Cations (Σ)	--		0.408	100.0	Cations (Σ)
Sp. Conductance[c]	47.4	(28.6-98.2)			Sp. Conductance[c]
pH	5.2	(4.9-6.1)			pH
SiO_2--	2.82	(0.10-9.24)			SiO_2--
Fe (reactive)[d]	0.35	(0.28-0.63)			Fe (reactive)[d]
Mn (reactive)[d]	0.18	(0.09-0.32)			Mn (reactive)[d]

Source: Schalles et al. 1989.
[a]The sites were Flamingo Bay, Enchantment Bay, Thunder Bay, Mathis Lake in Aiken County, and Sister Lake and an unnamed site near Williston in Barnwell County. Four replicates were collected per site. Anions were determined with ion chromatography, metals with atomic absorption spectrophotometry, and silica with molybdenum blue method.
[b]Dissolved organic carbon, charge estimated from the analysis of Perdue et al. (1984).
[c]µS/cm.
[d]From acid-pretreated samples; may be largely colloidal; values were not used in the charge balance analysis.

5.6.5.1.2 Variation in Oxygen and Temperature

Spatial and temporal variability in oxygen and temperature were found in the bays. Strong oxygen and temperature stratification often existed when emergent or floating-leaf vegetation was present, even in shallow waters. Bottom strata exhibited low oxygen concentrations (less than 0.5 mg/l) during most of the year. Stratification and destratification can occur almost daily. Horizontal patterns were demonstrated with *in situ* measurements made in December 1979 in Dry Bay. The highest oxygen concentrations were found in shallow water with abundant filamentous algae, while the lowest concentration was found in a macrophyte-shaded area with abundant detritus. In general, bay margins had the greatest overall physical-chemical variability. Thunder Bay displayed marked seasonal patterns (Schalles et al. 1989). Average water-column oxygen concentrations ranged from about 7 to 8 mg/l in mid-winter to about 1.5 to 2 mg/l in late summer. Average water column temperatures varied from approximately 7°C (44.6°F) in mid-winter to 27°C (80.6°F) in mid-summer.

5.6.6 Soils

Bay soils generally grade from well-drained sands on the xeric rims to consolidated sandy loams in the wetland centers. Unpublished research by Hodge (unpublished, cited in Schalles et al. 1989) documented two conditions in sandy surface soils of the bay rims and adjacent interbay areas on or near SRS. In one condition, the surface sand was 75-150 cm (29.5-59 in.) thick and was underlain by a sandy clay loam (Blanton series). In the second condition, the surface layer was excessively drained sand with depths exceeding 2 m (6 ft) (Lakeland series). Interior to the bay rims, Hodge (unpublished, cited in Schalles et al. 1989) found a narrow zone with loamy surface sands 15-35 cm (6-14 in.) thick overlying a sandy clay loam horizon about 45 cm (18 in.) thick and a third horizon of about 75 cm (29.5 in.) composed of sandy loams or loamy sands.

The central floors of most bays on or near SRS have shallow, consolidated loamy soils that vary from 15-75 cm (6-29.5 in.) in thickness. A consolidated, gray clay hardpan is consistently found below the loamy stratum. Hodge (unpublished, cited in Schalles et al. 1989) determined that these hardpans averaged about 70 cm (27.5 in.) thick and that soils immediately below the hardpans were sandy clay loams. Organic horizons are generally thin, but often thicken with increasing water depths and hydroperiods. The surface mineral soils of the bay interiors are typically dark and contain numerous fine charcoal fragments indicating earlier fires (Schalles 1979). Most soils occurring in the interiors of bays on SRS and vicinity fit an Ochraquult classification. Ochraquult soils have thin, dark peptones, thin to moderately thick argillic horizons, and base saturations of less than 50%. Such soils are inundated for at least three months of the year and have poor drainage. Soils of the SRS bays are largely Rembert and Ogeechee series loams, but also include Williman and Lumbee loamy sands. Duplin, Plummer, Faceville, Orangeburg, and Johnston soil series are found less frequently inside the sandy bay rims.

Many bays of SRS have surface organic layers of less than 15 cm (6 in.). However, the maximum thickness of peat in Peat Bay exceeds 1 m (3 ft). The occurrence of significant peat in Peat Bay could reflect a more stable hydrology with almost continual groundwater recharge that reduces exposure to the atmosphere and enhances peat development. This bay is between 42.7-45.9 m (140-150.5 ft) above mean sea level and is relatively close to Steel Creek and the Savannah River floodplain. However, other SRS bays with similar locations near streams or the floodplain lack significant peat buildup. Hodge (unpublished, cited in Schalles et al. 1989) found several Carolina bays on SRS and in adjacent Barnwell and Aiken Counties with peat layers of 50-100 cm (20-39 in.).

5.6.7 Vegetation

5.6.7.1 Introduction

Several wetland community types typical of undrained coastal plain sites are found in SRS. Topographical relief and hydrology are the principal determinants of vegetation composition in the bays. The duration and magnitude of inundation creates a range of conditions favoring different vegetation associations. Many Carolina bays are dominated by grasses and sedges that generally occur in monospecific stands. These stands change in area and in community dominance as water conditions change (Kirkman 1992; Schalles et al. 1989; Kirkman and Sharitz 1994; Kirkman et al. 1996).

5.6.7.2 Vegetation Pattern Control

The hydrologic regime of Carolina bays is one of the most important factors controlling patterns of vegetation in the bay. Kirkman (1992) concluded that it was during extremes of the hydrologic regime (i.e., very wet or very dry conditions) that recruitment from the seed bank becomes a more significant factor influencing vegetation change. Species diversity and density of seed banks of Carolina bays are among the highest reported for wetlands; however, these seed banks do not necessarily reflect standing vegetation (Kirkman 1992; Schalles et al. 1989; Kirkman and Sharitz 1994).

5.6.7.3 Vegetation Zones

A xeric to hydric gradient occurs from the peripheral sand rim to the center of the bays. Kelley and Batson (1955) described several concentric vegetational zones in Craigs Pond. The outermost zone lies along the sandy rim of the bay and is dominated by trees such as loblolly (*Pinus taeda*) and longleaf pines (*P. palustris*), black gum (*Nyssa sylvatica*), blackjack oak (*Quercus marilandica*), turkey oak (*Q. laevis*), and sweetgum (*Liquidambar styraciflua*). Several shrubs, such as sumac (*Toxicadendron copallina*), gallberry (*Ilex glabra* and *I. coriacea*), and red bay (*Persea borbonia*) also occur here. Inside this zone of woody species are several bands of herbaceous vegetation, each of which is dominated by grass species. The driest zone is characterized by broomsedge (*Andropogon virginicus*), but also contains numerous herbs including pitcher plants (*Sarracenia* spp.). Inside this zone, closer to the bay's center, is a band of vegetation dominated by three awn grass (*Aristida affinis*), and in deeper water areas, surrounding the central pool of water, species of maidencane (*Panicum* spp.) are abundant. The pond in the middle of the bay contains typical floating-leaved aquatic plants such as the water lilies (*Nymphaea odorata* and *Nymphoides aquaticum*). In a subsequent floristic study of Craigs Pond, Hodge (unpublished, cited in Schalles et al. 1989) found similar patterns.

5.6.7.4 Community Types

Seventeen herbaceous community types were found in the eight Carolina bays studied by Hodge (unpublished, cited in Schalles et al. 1989). As many as six types were found in one bay (Craigs Pond). Figure 5-24 and Figure 5-25 illustrate the composition and distribution of herbaceous species in community types along the hydrologic gradient from the rim to the hydric center at Craigs Pond and Ellenton Bay (Schalles et al. 1989).

5.6.7.5 Short-Term Succession

Field observations and the results of the study by Hodge (unpublished, cited in Schalles et al. 1989) suggest that short-term succession of herbaceous to woody-dominated communities in bays of the upper Coastal Plain occurs when water levels are low. After a bay has been ditched and drained buttonbush (*Cephalanthus occidentalis*), persimmon *(Diospyros virginiana*), or sweetgum commonly germinate on the exposed soil. A woody-dominated community soon becomes established. In undisturbed bays, organic material accumulates faster in the semipermanently to permanently inundated areas where conditions are at or approaching anoxia throughout the year. In these deeper areas of the bays, peat may accumulate until it is exposed during periods of low water levels. During these periods, seeds of woody species may become established and initiate the development of a woody-dominated community (Schalles et al. 1989).

5.6.7.6 Effect of Previous Land Use on Bay Recovery

About 25% of the 299 bays or bay-like depressions on SRS were either pasture or cultivated in 1951. By 1992, most had reverted to mixed hardwood and pine or had been converted to pine plantations. No distinctively different patterns in vegetative recovery could be associated with cultivation versus pasture.

Many of the depression wetlands at SRS once were disturbed by agricultural practices or ditched prior to 1951, implying considerable resilience in the recovery to a functioning wetland if hydrologic regimes are restored. Although the longevity of seeds is unknown, the presence of persistent soil seed banks (including rare species) in depression wetlands (Kirkman and Sharitz 1994) may greatly contribute to the restoration potential of the vegetation.

Herb-dominated wetlands are relatively stable. Based on the results of Kirkman et al. (1996), an herbaceous bay may not necessarily be a successional stage toward an eventual hardwood forest, but a climax wetland. After 1951, upland uses adjacent to depression wetlands undoubtedly influenced recovery processes following disturbances. A better understanding of the role of adjacent land uses on wetland vegetative recovery dynamics is clearly needed, particularly in regard to seed and nutrient inputs, implications for fire corridors, and potential hydrologic modifications (Kirkman et al. 1996).

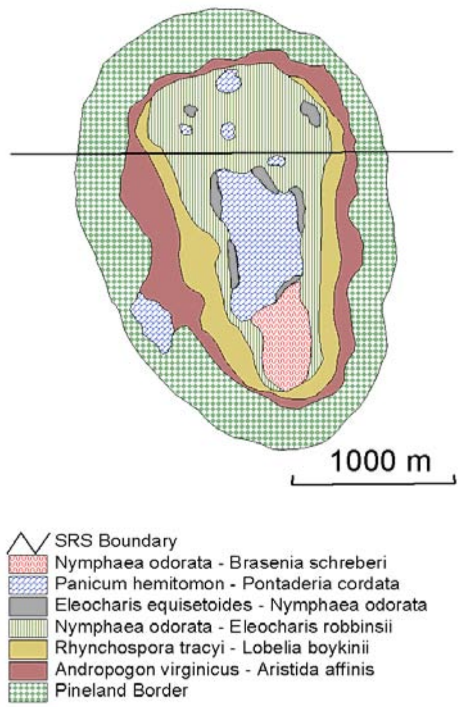


Figure 5-24. Wetland Vegetation Community Types at Craigs Pond (Site 77) (Source: Schalles et al. 1989)

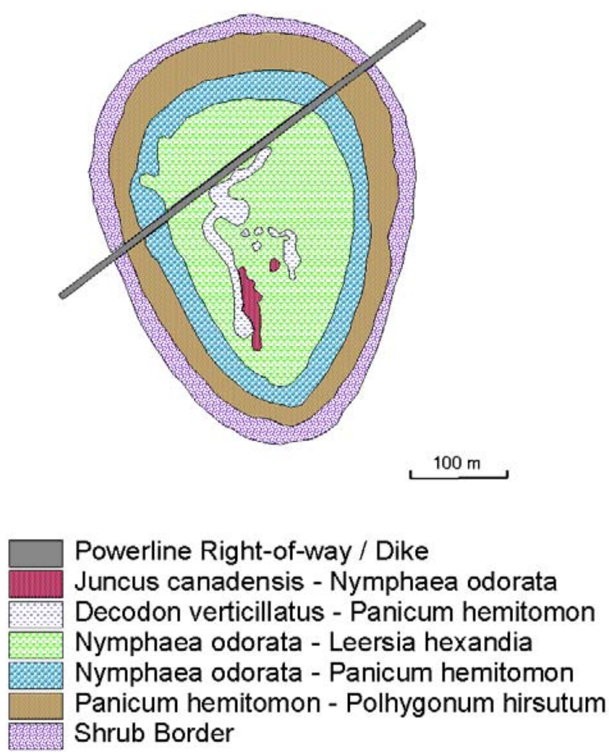


Figure 5-25. Wetlands Vegetation Community Types at Ellenton Bay (Site 176) (Source: Schalles et al. 1989)

5.6.8 Invertebrate Fauna

5.6.8.1 Introduction

The invertebrate fauna from only a few Carolina bays on SRS has been described. Cross (1955) surveyed Odonata distributions in Carolina bays and other aquatic habitats of SRS. Invertebrates were intensively surveyed in 1979 at Rainbow Bay and Sun Bay (no longer in existence), with detailed listings of taxa and their relative abundances (SREL 1980). Intensive work at Sun Bay disclosed a diverse insect assemblage with 119 families from 14 orders identified. Dipterans were the most abundant taxa at both Sun Bay and Rainbow Bay. Oligochaetes and isopods were relatively common in Rainbow Bay, but were not collected in Sun Bay (Table 5-42) (Schalles et al. 1989).

Table 5-42. Density of Certain Insect Orders, Oligochaetes, and Isopods (Number of Individuals/m^2) Determined by Artificial Substrate Sampling at Rainbow Bay and Sun Bay

Microhabitat	Ephemeroptera	Coleoptera	Diptera	Hemiptera	Odonata	Oligochaeta	Isopoda
Rainbow Bay							
Rainbow Bay deep open water	6.25	0	111.25	1.25	7.5	41.25	26.25
shallow water in buttonbush	11.25	3.25	2.4	8.25	4	12.5	38.25
Sun Bay							
Sun Bay open disturbed pond	0	3.75	76.25	2.5	0	0	0
open weed-filled pond	0	5	147.5	2.5	1.25	0	0
pond in buttonbush	0	16.5	102.5	0	0	0	0
drainage ditch	7.5	2.5	96.25	1.25	1.25	0	
drainage ditch flowing	0	12.5	252.5	0	0	0	0

Source: SREL 1980.

5.6.8.2 Macroinvertebrates

Macroinvertebrates were quantified from 1975-1977 at Thunder Bay (Schalles and Shure 1989). Four insect orders dominated the invertebrates: odonates, dipterans, hemipterans, and coleopterans. Macroinvertebrates in Thunder Bay were taxonomically similar to the macroinvertebrates of an abandoned SRS farm pond studied by Benke (1976), but had only about 20% of the benthic biomass of the farm pond. The dystrophic bog chemistry and periodic drying apparently prevent or severely restrict the occurrence of several freshwater invertebrate groups in the Thunder Bay wetland community. Ephemeropterans, megalopterans, and trichopterans were infrequent, and plecopterans, amphipods, isopods, decapod crustaceans, gastropods (except the limpet *Ferrisia*), bivalves, and oligochaetes were absent during that study. The low calcium levels in undisturbed, upper coastal plain bays may be the primary limiting factor for molluscs, decapods and other malacrustaceans, and, perhaps, annelids. Snails frequently were observed in two nearby Carolina bays at the Barnwell County Industrial Park. The bays had received runoff and sediments from a construction area and had higher calcium levels (averages of 9.5 and 14 mg/l for the two sites) (Schalles et al. 1989).

5.6.8.3 Zooplankton

The zooplankton of Carolina bays on SRS are diverse, abundant, and at least moderately productive (Taylor et al. 1989). Calanoid and cyclopoid copepods, cladocerans, and rotifers are ubiquitous. Anostracans and conchostracans are sporadically distributed, but may be abundant where they occur. The Rainbow Bay community showed marked changes in species composition during the wet season. In such bays, which function as temporary ponds, all of the zooplankton have resting stages and lie dormant in the sediments during the dry season. Varied times of emergence from these resting stages contribute to the succession of species in Rainbow Bay. Zooplankton are an important part of the diets of larval salamanders (Taylor et al. 1988). Insect larvae may also prey heavily on the zooplankton (Schalles et al. 1989).

5.6.9 Vertebrate Fauna

5.6.9.1 Introduction

Vertebrates are conspicuous and relatively abundant members of the fauna of Carolina bays. Perhaps because of the water-level oscillations and dry periods, no vertebrates found in SRS bays are considered strictly endemic to these habitats. All aquatic and semiaquatic vertebrates, except fish, apparently use migration or aestivation strategies during dry periods. For example, sirens (*Siren intermedia* and *Siren lacertina*) form cocoons and aestivate during dry-outs (Conant and Collins 1991). The mole salamander (*Ambystoma talpoideum*) is commonly terrestrial as an adult, but is paedogenic in situations where water is usually permanent. It may have evolved this pattern of metamorphosis in response to unpredictable water levels that may result in potentially ephemeral aquatic habitats becoming permanent ponds with no fish predators (Patterson 1978; Semlitsch 1985; Schalles et al. 1989).

5.6.9.2 Fishes

Fishes have been observed in several Carolina bays on SRS (Bennett and McFarlane 1983). The following fish were observed in four Carolina bays on SRS during 1978-1983: redfin pickerel (*Esox americanus*), mud sunfish (*Acantharchus pomotis*), sunfish (*Lepomis* spp.), lake chubsucker (*Erimyzon sucetta*), and mosquitofish (*Gambusia affinis*). Fewer than 10% of the Carolina bays on SRS are known to have permanent fish populations, although over-wash from neighboring swamps or streams may reestablish the ichthyofauna of formerly dry basins (Schalles et al. 1989).

5.6.9.3 Amphibians in Carolina Bays

Although fishes are not a dominant feature in most bays, other vertebrates are diverse. Many species of reptiles and amphibians are associated with Carolina bays on SRS (Gibbons and Patterson 1978; Gibbons and Semlitsch 1990). Gibbons (1970) observed more than 30 species of amphibians and reptiles in and around Ellenton Bay. The use of bays by vertebrates is sometimes astonishing, as revealed by the high number of semiaquatic animals migrating to and from the water. Rainbow Bay, which has an aquatic perimeter of less than 450 m (1476 ft), had approximately 10,000 individuals of the southern leopard frog (*Rana utricularia*) migrating to or from this bay in one year (Schalles et al. 1989). This is an average of one frog for every 2 cm of pond margin. A similar calculation for Ellenton Bay, which is larger, indicates that one adult mole salamander (*Ambystoma talpoideum*) enters to breed each winter per 20 cm (7.8 in.) of perimeter (Patterson 1978) and as many as 11,000 metamorphosed individuals may exit during one week. Schalles and Shure (1989) obtained *in situ* estimates of salamander density and biomass in the aquatic area of Thunder Bay. Over an annual cycle in a 1-ha (2.5-acre) sampling grid, *Siren intermedia, Notophthalmus viridescens,* and *Ambystoma talpoideum* populations averaged 0.15, 1.18, and 1.46 individuals/m^2 and 8.03, 3.12, and 1.23 kg dry wt/ha, respectively. During the same period, anuran larvae (primarily Ranidae) averaged 1.03 kg dry wt/ha. (Schalles et al. 1989).

5.6.9.4 Abundance in Altered Bays

The abundance of amphibians in Carolina bays altered by agricultural, forest management, or construction activities (e.g., Sun Bay, Lost Lake), may be higher than expected (Bennett et al. 1979). In 1979, more than 500 ornate chorus frogs (*Pseudacris ornata*), 5000 southern leopard frogs, and 500 mole salamanders entered or left Sun Bay, a bay of less than 1 ha (2.5 acres) which had been drained by construction activity in the previous year. Similarly, Lost Lake on SRS had been altered by agricultural practices prior to the 1950s and later by the release of industrial by-products into the lake (Bennett et al. 1979). Extrapolation of captures by intermittent fencing and pitfall traps to the shoreline length bordered by a pine forest around the bay yielded estimates of 5000 southern toads (*Bufo terrestris*), 2000 mole salamanders, and 1000 spadefoot toads (*Scaphiopus holbrooki*) entering or leaving Lost Lake in one summer (Bennett et al. 1979).

5.6.9.5 Amphibian Community Dynamics in a Carolina Bay

The amphibian community of Rainbow Bay, a Carolina bay with a widely variable hydroperiod and a surface area of 1 ha (2.5 acres), was studies for 16 years. Results of the study are that the hydroperiod is the primary determinant of amphibian community reproduction. Competition and predation also have an influence, but theirs is mediated by pond hydroperiod. However, the effects were difficult to separate. All 13 amphibian species studied experienced episodic reproduction, with most of the larvae produced in only a few (1-7) of the 16 years. Not all species reproduced in all years. Temporal variation in hydroperiod may favor the reproductive success of different species in different years. Juvenile recruitment was limited for all species by a short hydroperiod during the driest years. In years with longer hydroperiods, competition influenced the density of metamorphosing juveniles. Apparently community structure of a temporary pond is regulated by an interaction of rainfall, timing of the hydroperiod, competition and predation (Semlitsch et al. 1995).

5.6.9.6 Other Vertebrate Species that use Carolina Bays

Although amphibians are the prevalent terrestrial vertebrates using Carolina bays (Patterson 1978; Bennett et al. 1979; Semlitsch 1981) and a major contributor to secondary productivity, other vertebrates may be important in these communities. The American alligator (*Alligator mississippiensis*), six species of turtles, and several species of snakes are reptiles common to bays (Table 5-43; Gibbons 1970; Gibbons et al. 1977; Gibbons and Patterson 1978; Gibbons and Semlitsch 1990). Though quantitative data are unavailable, mammals such as deer, raccoons, skunks, and opossums may use bays for water or feeding sites. Beaver (*Castor canadensis*) have been found in Thunder Bay and several other sites and could be an important agent in hardwood species composition and abundance. In the sandhills regions of the Carolinas, many bird species including hawks, egrets, and migratory water fowl use the bays at least part of the year. Wood storks, an endangered bird species, have been observed foraging in Ellenton Bay. In bays with standing water and mature trees with cavities for nesting sites, wood ducks (*Aix sponsa*) may also be found (Mayer et al. 1986). The use of wood duck boxes as nesting sites in Carolina bays is common in some years (Schalles et al. 1989).

Quantitative data are available for many small mammals using the periphery of Carolina bays (Table 5-43). Though shrews (*Blarina brevicauda* and *Sorex longirostris*) and small rodents (*Sigmodon hispidus*, *Peromyscus gossypinus*, and *Microtus pinetorum*) may be abundant, only certain species, e.g., the rice rat (*Oryzomys palustris*), actually inhabit the marshy areas. Many small mammals captured by drift fences and pitfall traps around Carolina bays are equally abundant in strictly terrestrial habitats in the region (Briese and Smith 1974; Brown 1980; Gibbons and Semlitsch 1982; Schalles et al. 1989).

Table 5-43. Use of Carolina Bay Habitats by Small Vertebrates[a]

	Rainbow Bay				Sun Bay			
	Entering		Exiting		Entering		Exiting	
Species	**Adult**	**Juvenile**	**Adult**	**Juvenile**	**Adult**	**Juvenile**	**Adult**	**Juvenile**
Class Amphibia								
Order Caudata								
Ambystoma talpoideum	1,750	154	499	3,856	6,028	0	938	0
A. tigrinum	129	46	42	992	57	1	4	1
Notophthalmus viridescens	1,625	968	609	15,013	3,452	5	2,100	23
total of all salamanders	3,953	1,201	1,212	19,874	9,595	6	3,087	24
Order Anura								
Scaphiopus holbrooki	**69**	**33**	**39**	**34**	**1,803**	**134**	**483**	**58**
Bufo terrestris	424	644	79	689	580	375	98	622
Hyla crucifer	346	212	205	1,329	594	12	239	50
Pseudacris ornata	235	28	89	1,158	392	9	79	18
Gastrophryne carolinensis	1,122	18	418	15	887	1	420	0
Rana clamitans	27	30	19	1,136	27	35	1	7
R. utricularia	699	2,024	610	52,287	154	29	24	7
total of all frogs	3,197	3,053	1,569	57,106	4,486	680	1,355	767
Class Reptilia								
Order Chelonia								
Kinosternon subrubrum	29	6	25	6	49	59	14	11
Kinosternon subrubrum	29	6	25	6	49	59	14	11
Deirochelys reticularia	8	9	10	2	14	14	4	1
total of all turtles	43	16	39	9	70	74	19	14
Order Squamata								
Suborder Sauria								
Anolis carolinensis	26	2	19	2	5	0	12	0
Sceloporus undulatus	18	1	8	3	9	3	5	6
Cnemidophorus sexlineatus	2	2	1	0	19	7	19	2
total of all lizards	53	7	43	5	36	11	40	9
Suborder Ophidia								
Storeria occipitomaculata	26	1	37	0	4	0	2	0
Diadophis punctatus	7	2	10	0	7	1	15	3
Tantilla coronata	17	0	11	0	42	0	46	0
total of all snakes	92	7	88	2	68	5	85	5
Class Mammalia								
Blarina brevicauda	68	1	40	0	26	0	20	0
Reithrodontomys humulis	16	0	146	8	1	0	0	0
Sigmodon hispidus	7	0	14	0	5	0	18	0
total of all mammals	168	3	251	9	76	1	63	1
total of all species	**7,506**	**4,287**	**3,202**	**77,005**	**14,331**	**777**	**4,649**	**820**

Source: Gibbons and Semlitsch 1982.

[a] Numbers indicate selected vertebrate species captured (original and recaptured) in drift fences with pitfall at Rainbow Bay and Sun Bay, for one year, March 1979-March 1980.

5.6.10 Lost Lake Restoration

5.6.10.1 Introduction

Before 1943 and until the early l950s, a ditch to the south drained the Carolina bay known as Lost Lake for agriculture use. After the land was removed from farming in the early 1950s, the watershed above the lake was planted in loblolly pine (*Pinus taeda*) for erosion control. Without ditch maintenance, Lost Lake began to refill and function as a wetland. Impacts to the watershed occurred as the nearby M-Area industrial facility was constructed with associated roads, drainage ditches, railroads, and soil-fill areas. In addition, Lost Lake received overflow from the M-Area seepage basin until 1984 (Figure 5-26), contaminating it over the years with heavy metals, solvents, and cleaning fluids (Figure 5-26 and Figure 5-27). Restoration of the 10-ha (25-acre) bay to a "natural wetland system" was required as part of the Resource Conservation and Recovery Act (RCRA) closure plan for the M-Area seepage basin. The closure plan was approved in July 1987 (DOE 1992).

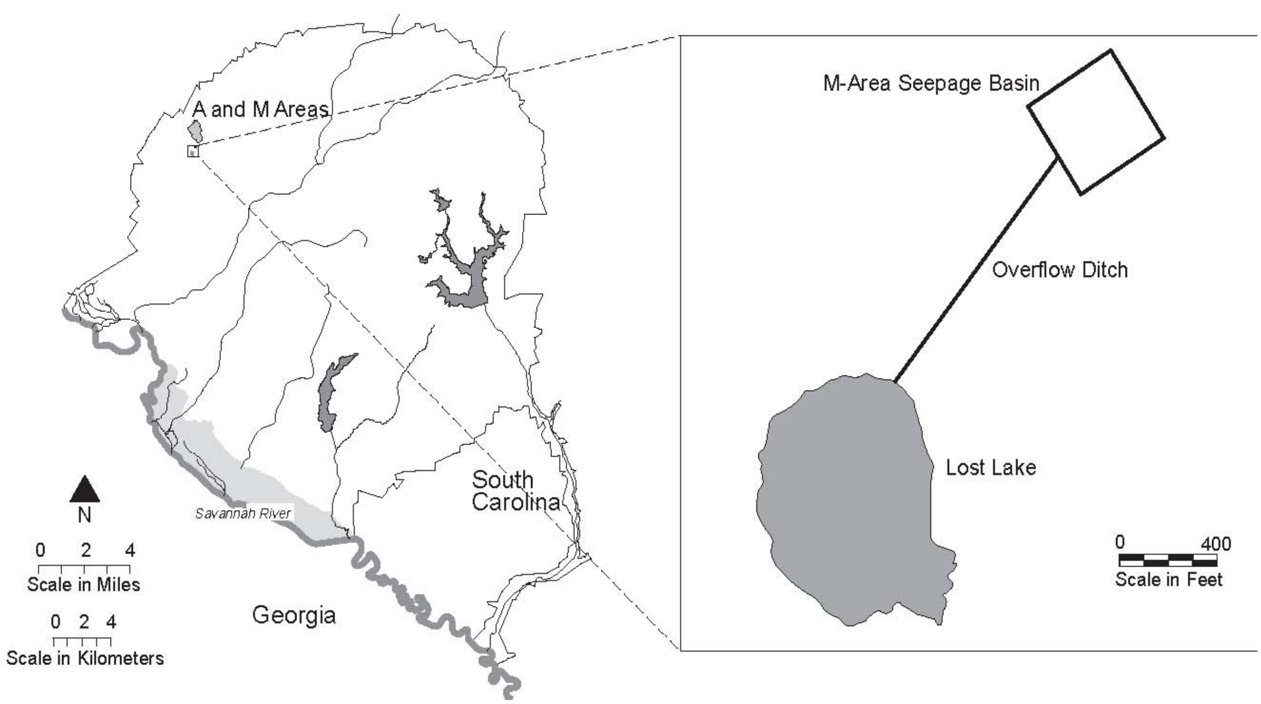


Figure 5-26. Location of Lost Lake and the M-Area Seepage Basin on SRS

Vertical

Oblique

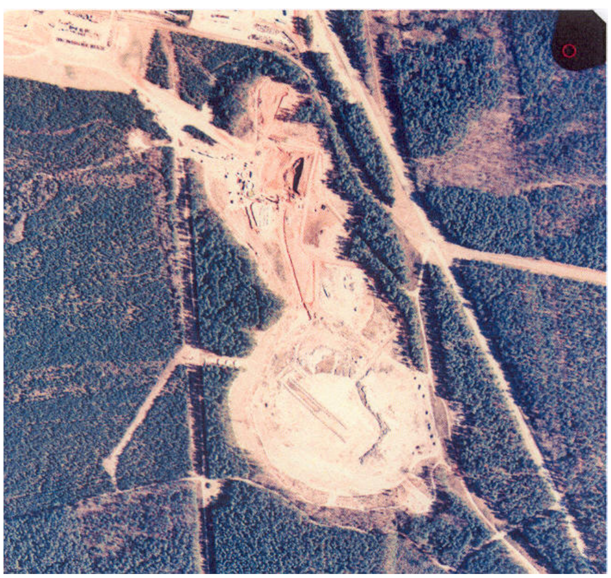
Figure 5-27. Lost Lake and the M-Area Seepage Basin Prior to Cleanup (Vertical and Oblique Photography)

5.6.10.2 Restoration Plan

The reclamation of Lost Lake was an opportunity to restore a degraded natural area to a functional wetland; however, the closure plan did not include a specific plan for the restoration. The restoration was to be coordinated with the Natural Resources Conservation Service and the U.S. Forest Service and was to produce low maintenance, self-sustaining natural vegetation. Despite the removal of up to 30 cm (12 in) of soil, a sufficient clay layer remained to retain water (Figure 5-28); therefore, reclamation as a wetland was considered feasible (DOE 1992). The project strategy was to stabilize surrounding areas, use only native plant species, and fill an old drainage ditch at the south end of the bay to restore hydrology, thus creating Carolina bay-like conditions. The restoration was divided into two parts: upland planting and wetland restoration. An extremely wet fall in 1990 delayed soil preparation and partially refilled the basin. The water level was lowered in December 1990 to facilitate soil treatment in January 1991. Trees were planted in the upland areas during the winter of 1991. Macrophyte planting was staggered from early February through mid-April 1991. Erosion control was improved in the ditch leading from the M-Area Basin to Lost Lake in late April 1991 (DOE 1992).

1988 Vertical

1988 Oblique



1989 Vertical

1989 Oblique

Figure 5-28. Lost Lake and the M-Area Seepage Basin During Cleanup (Vertical and Oblique Photography)

5.6.10.3 Restoration Objectives

There were two major objectives in the reclamation plan for Lost Lake. First, and most important, was to restore the wetland ecosystem following hazardous waste cleanup. The second goal was to study and evaluate a restoration project. To this end, a research design was developed that would allow the evaluation of several wetland restoration levels-of-effort to determine minimum requirements to restore a disturbed Carolina bay. A third goal of the project was an opportunistic one. The scientific community is developing aerial imagery as a tool for evaluating changes to landscapes over time. This project also was used to study the success of using aerial imagery to monitor the re-establishment of the wetland community (Mackey 1993).

5.6.10.4 Strategy Considerations

5.6.10.4.1 Treatment Scheme

A four-treatment scheme was developed to determine how much manipulation was needed to successfully restore a functioning wetland. The bay was divided into eight treatment zones (Figure 5-29), with four treatments applied in duplicate. One of the treatments was no treatment. The initial treatment zones were rearranged when a sensitive plant species, little burhead (*Echinodorus tenellus*), was found in significant numbers in one quadrant of the bay (Zone IIB, Figure 5-29). This plant does not grow well in fertile soils, so the area it occurred in received no treatment (DOE 1992).

The four treatments zones are shown in Figure 5-29 and outlined as follows:

- no treatment (IIA, IIB) (i.e., controls)
- addition of fertilizer, gypsum, and plantings (IVA, IVB)
- subsoiling, disking, fertilizer, gypsum, and plantings (IIIA, IIIB)
- subsoiling, disking, gypsum, topsoiling, fertilizer, and plantings (IA, IB)

The area of the lakebed classified as A zone had more extensive soil removal during remediation than the B zone area.

Gypsum (calcium sulfate dihydrate) was added to all the zones that received any treatment because the pH of the bay was approximately 6.0 and needed to be lowered slightly to mimic the acidic nature of natural bays in the region. There were two replicates of each treatment. Planting plots were sized and arranged within each treatment zone to facilitate future monitoring and to test the aerial photography monitoring techniques.

5.6.10.4.2 Soil Conditions

In designing the restoration project, several factors had to be considered. Contaminated soils had been removed from the bay. The soil had been somewhat compacted from heavy equipment, and the lack of organic matter and the presence of debris in the subsoil caused concern. To improve soil conditions, topsoil was added to two of the treatment areas, and four of the treatment areas were disked. When spreading the topsoil, care was taken to minimize compaction from trucks and earth moving equipment (DOE 1992).

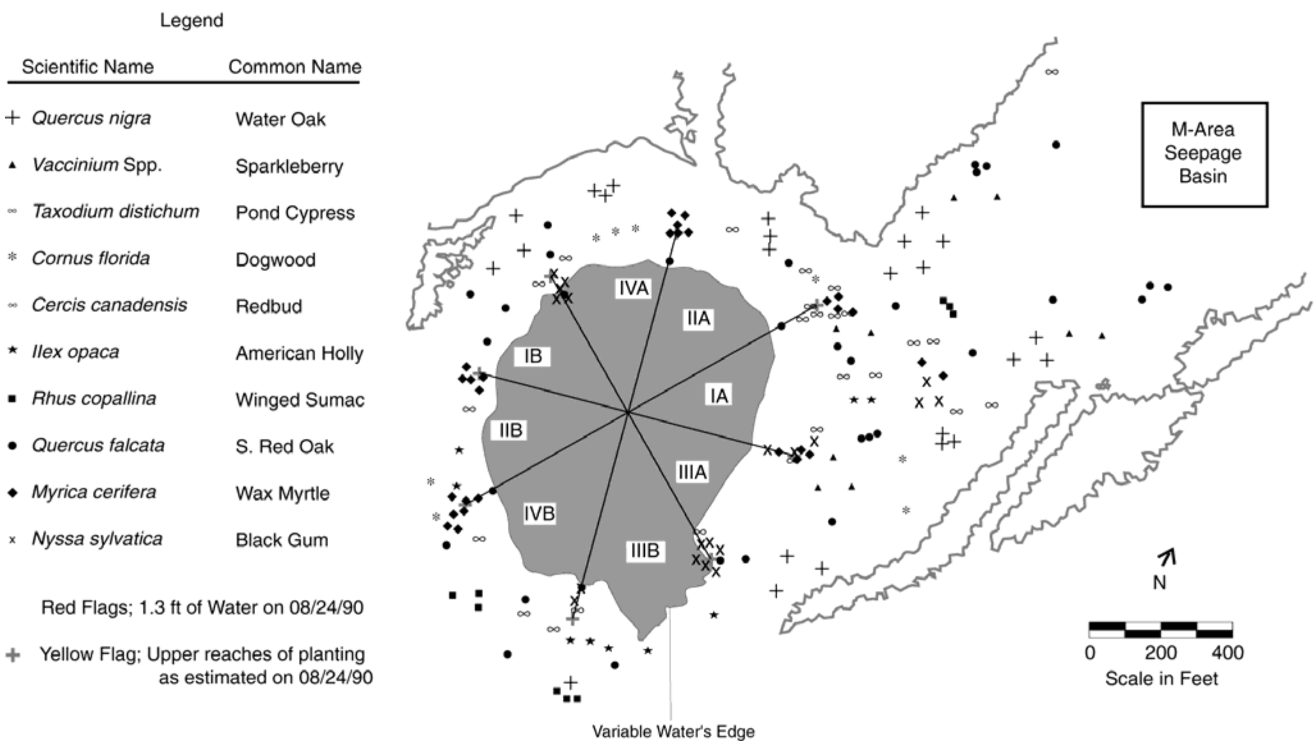


Figure 5-29. Planting Plan at the Lost Lake/M-Area Seepage Basin Restoration Site

5.6.10.4.3 <u>Hydrology</u>

A significant factor in the restoration of Lost Lake to a functional wetland was the decision not to control the hydrologic regime, but to let it fluctuate naturally after initial planting of the vegetation in early 1991 (DOE 1992).

5.6.10.4.4 <u>Monitoring</u>

A final consideration in the plan was the ability to monitor the program of the restoration and apply the information to future restorations. Low-altitude aerial photography, airborne multispectral scanner data, and, later, satellite imagery will be used to monitor the successful growth of the vegetation. The location and placement of plots were designed to aid in the interpretation of future photographs (DOE 1992). In addition to remote sensing and vegetation monitoring, a cooperative program is in place with the University of South Carolina-Aiken to monitor and evaluate reptile and amphibian recolonization at Lost Lake.

5.6.10.5 Plantings

Ten tree and shrub species were planted on the upland areas. Regional nursery stock was used for these plantings. Five species of shallow water emergent herbaceous vegetation were planted. All the herbaceous plants were taken from aquatic habitats on SRS. Adequate numbers of all plants except duck potato (*Sagittaria latifolia*) were available at SRS to allow transplanting without depleting the donor stock. Lotus seeds (*Nelumbo lutea*) and water lily (*Nymphaea odorata*) were planted in the deeper plots. Because of the configuration of the treatment zones and the size of the bay, the planned plot sizes and arrangements had to be slightly modified.

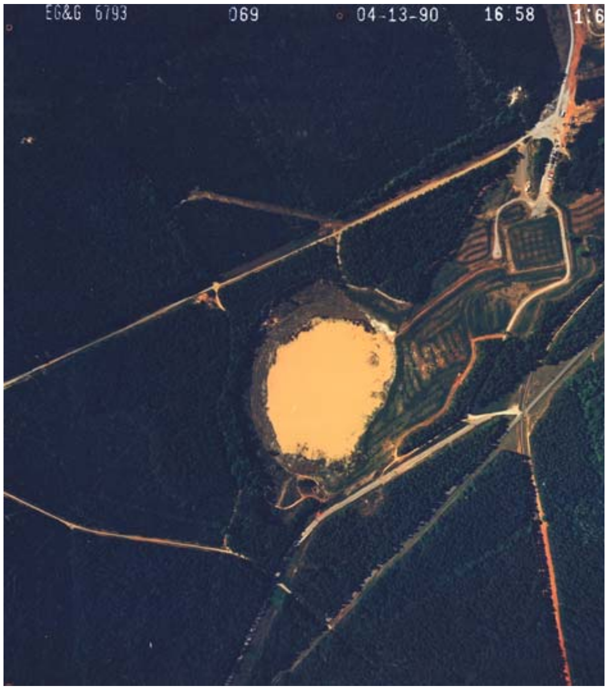
5.6.10.6 Initial Results

5.6.10.6.1 <u>1991 Results</u>

In 1991, it was too early to determine the success of the wetlands restoration. Despite the unanticipated problems and delays in implementation, Lost Lake was beginning to resemble a natural Carolina bay (Figure 5-30). Monitoring efforts started in the fall of 1991 and included measurements within each of the eight treatment zones of percent cover, density, and percent survival of wetland plants in the experimental plots. Preliminary results from the fall of 1991 showed an 80-90% survival rate of the deep water species and 20-30% for the emergent species. Cattails invaded heavily in the areas with soil amendments and fertilizer. Of the macrophyte species planted, three were the most successful (*Panicum hemitomon*, spike rush, and pickerelweed). Successful naturally invading species included spike rush, dogfennel, cattail, knotweed, *Panicum dichotomiflorum,* and foxtail grass (*Setaria* sp.). Woody species (e.g., buttonbush) also occurred in some areas.

5.6.10.6.2 <u>1992 Results</u>

Subsequent monitoring in 1992 of percent cover, density, and percent survival indicate that *Panicum* continues to be the most successful of the introduced species, with a density increase of 3184% ±1598%. Other successful plants include spike rush and pickerelweed, with density increases of 1838% ± 435% and 1016% ± 412%, respectively (Youngblood et al. 1993a, b; Youngblook and Ornes 1994). Analysis of hydrology data show that several periods of low water probably resulted in lotus not establishing from the germinated seeds and the continued low occurrence of water lilies.



1990 Vertical

1990 Oblique

1991 Vertical

1991 Oblique

Figure 5-30. Lost Lake and the M-Area Seepage Basin During Early Restoration Activities (Vertical and Oblique Photography)

5.6.10.6.3 1994 and 1995 Results

Panicium hemitomon continued to be the most successful planted species in 1994; however, its percent cover was much reduced (from a high of 57% in 1992 to a low of 0.4% in 1994 across all treatments). Percent cover ranged from 0.4% to 12% in 1994. Other successful planted species were rushes, *Scirpus* spp., and pickerelweed, although, again, densities were lower than in previous years. In 1994, *Typha* spp. averaged less than 1% cover. More common species in 1994 included dog fennel, *Erigeron* sp., briars, and *Digitaria* sp., all facultative or facultative upland plants.

The plant community at Lost Lake appears to be composed of more upland species. Water levels dropped from 1991 to 1992 to 1993 and 1994. In 1995, water level returned to 1991 levels, so the community composition could change.

Based on these results, revegetation strategies should be based on the potential for extreme hydrologic conditions and be a mix of species adapted to drought and wet conditions. Under natural conditions, many rare and aquatic plants persist in the seed bank. Since Lost Lake's topsoil was removed to a depth of 30 cm (12 in.), the Lost Lake seed bank was lost, which is evident by the species mix now seen at the bay (Ornes and Youngblood 1995).

5.6.10.6.4 Recolonization by Reptiles and Amphibians

The reptile and amphibian populations have been monitored around Lost Lake to study their recolonization of a restored wetland. Fifty species were observed or collected at the bay between May 1993 and December 1995 (Table 5-44). Missing from this list and perhaps significant, are the snakes most often associated with aquatic environments (e.g., most of the genus *Nerodia*, the mud snake [*Farancia abacura*] and the rainbow snake [*F. erytrogramma*] and aquatic salamander (e.g., the genus *Eurycea*) known to inhabit Carolina bays on the SRS (Hanlin et al. 1996).

5.6.11 Restoration of Other SRS Wetlands

The Savannah River Natural Resource Management and Research Institute and SREL developed a cooperative research program to evaluate the effects of restoring the hydrology of a degraded Carolina bay and the potential of other treatments that might be necessary to restore wetland function. Aerial photography from 1951 indicated that a 4-ha (10-acre) bay currently supporting a pine-sweetgum forest had supported an herbaceous wetland at one time. In November 1993, the ditch draining Carolina bay 93 was plugged, approximately 50% of the timber was removed, and portions of the timbered and untimbered sections were burned to remove litter. Water levels the first year after plugging the ditch were higher than in previous years, but lower than expected due to unseasonably dry conditions. Upland species dominated vegetation. During the second year, the bay had more water and the plant community was characterized by more wetland species. Preliminary results indicate that part of the wetland seed bank may have survived the drier hydrologic regime in existence since 1951. Increased light and soil disturbance created by the clearing and burning stimulated the germination of the seeds (Sharitz and Wein 1995).

Table 5-44. Amphibian and Reptile Species Collected or Observed at Lost Lake, May 1993 - December 1995

Species	Number Collected
Class Amphibia	
Order Caudata - Salamanders	
Ambystoma opacum (marbled salamander)	29
[1]*A. talpoideum* (mole salamander)	3,506
[1]*A. tigrinum* (tiger salamander)	417
[1]*Notophthalmus viridescens* (eastern newt)	3,183
Order Anura – Frogs and Toads	
[1]*Acris gryllus* (southern cricket frog)	763
Bufo quercicus (oak toad)	47
[1]*B. terrestris* (southern toad)	55,916
[1]*Gastrophryne carolinensis* (narrow-mouthed toad)	6,414
Hyla chrysoscelis (Cope's gray treefrog) (observed only)	0
[1]*H. cinerea* (green treefrog)	170
[1]*H. gratiosa* (barking treefrog)	1,910
[1]*H. squirella* (squirrel treefrog)	229
[1]*Pseudacris crucifer* (spring peeper)	30
P. nigrita (southern chorus frog)	4
[1]*P. ornata* (ornate chorus frog)	89
[1]*Rana catesbeiana* (bullfrog)	2,633
R. clamitans (green frog)	3
[1]*R. utricularia* (southern leopard frog)	939
Scaphiopus holbrooki (eastern spadefoot toad)	69
CLASS REPTILIA	
Order Crocodilia - Crocodilians	
Alligator mississippiensis (American alligator)	1
Order Chelonia - Turtles	
Chelydra serpentina (common snapping turtle)	1
Chrysemys picta (painted turtle)	1
[1]*Deirochelys reticularia* (chicken turtle)	29
Kinosternon subrubrum (eastern mud turtle)	7
Pseudemys floridana (Florida cooter)	1
[1]*Trachemys scripta* (slider turtle)	102
Order Squamata - Lizards and Snakes	
Suborder Lacertilia - Lizards	
Anolis carolinensis (green anole)	89
Cnemidophorus sexlineatus (six-lined racerunner)	4
[1]*Eumeces fasciatus* (five-lined skink)	2
[1]*E. inexpectatus* (southeastern five-lined skink)	2
[1]*E. laticeps* (broadhead skink)	28
[1]*Sceloporus undulatus* (eastern fence lizard)	6
[1]*Scincella lateralis* (ground skink)	52
Suborder Serpentes - Snakes	
[2]*Cemophora coccinea* (scarlet snake)	5
[1, 2]*Coluber constrictor* (racer/black racer)	44
[2]*Crotalus horridus* (canebrake rattlesnake)	4
[2]*Diadophis punctatus* (ringneck snake)	2
[2]*Elaphe guttata* (corn snake)	4

Source: Hanlin et al. 1996.
[1]Successful reproduction documented by presence of larvae, recent metamorphs, hatchlings, or newborns.
[2]Species is terrestrial and associated with the periphery of bays.

5.7 WETLAND MITIGATION BANK AND CAROLINA BAY RESTORATION PROJECT

5.7.1 Introduction

A Wetlands Mitigation Bank was established at the Savannah River Site (SRS) in 1997 as a compensatory alternative for unavoidable wetland losses associated with future authorized construction and environmental restoration projects in SRS wetlands (DOE 1997). The Bank was intended not only to hasten mitigation efforts with respect to regulatory requirements and implementation, but also to provide onsite and fully functional compensation of impacted wetland acreage prior to any impact. Restoration and enhancement of small isolated wetlands, as well as major bottomland wetland systems scattered throughout the nonindustralized area of SRS were designated for inclusion in the Bank. A project to restore degraded Carolina bays on SRS was undertaken to serve as the initial “deposit” in The Bank. Over 300 Carolina bays or bay-like depression wetlands occur on the SRS, of which an estimated two-thirds were ditched or disturbed prior to federal occupation of the Site (Kirkman et al. 1996). Historical impacts to the Carolina bays at SRS were primarily associated with agricultural activities. The bays for restoration were drained for agricultural use. The consequence was a loss in the wetland hydrologic cycle, the native wetland vegetation, and associated wildlife.

The purpose of this mitigation was to restore the functions and vegetation typical of intact depression wetlands and, in doing so, to enhance habitat for wetland-dependent wildlife on SRS. Twenty Carolina bays in the non-industrialized management area of SRS were identified as candidates for restoration (Figure 5-31). All twenty bays possessed an active drainage ditch and nearly all had a vegetation composition characteristic of a disturbed wetland system. Pre-restoration characterizations of soil, hydrology, vegetation and wildlife were performed within each site, to be used as a baseline for evaluating restoration success. Of the twenty bays, sixteen were initially being restored and the remainder were planned to serve as unrestored controls. Undisturbed bays of similar size have also been selected for use as reference sites. The use of reference and control systems will enhance the ability to assess response in the wetlands due to restoration treatment. Details of the design and Bay designations are presented in Barton and Singer (2000).

The project is a collaborative effort that was designed jointly by researchers and the management staff of the US Forest Service, Westinghouse Savannah River Corporation – Environmental Protection Division, Savannah River National Laboratory, and the Savannah River Ecology Laboratory. Additionally, cooperators from the University of Kentucky, US Fish & Wildlife Service, Clemson University, the University of South Carolina at Aiken, the University of West Virginia, and the University of Georgia are participating in studies examining the responses of soils, hydrology, vegetation and animal communities.

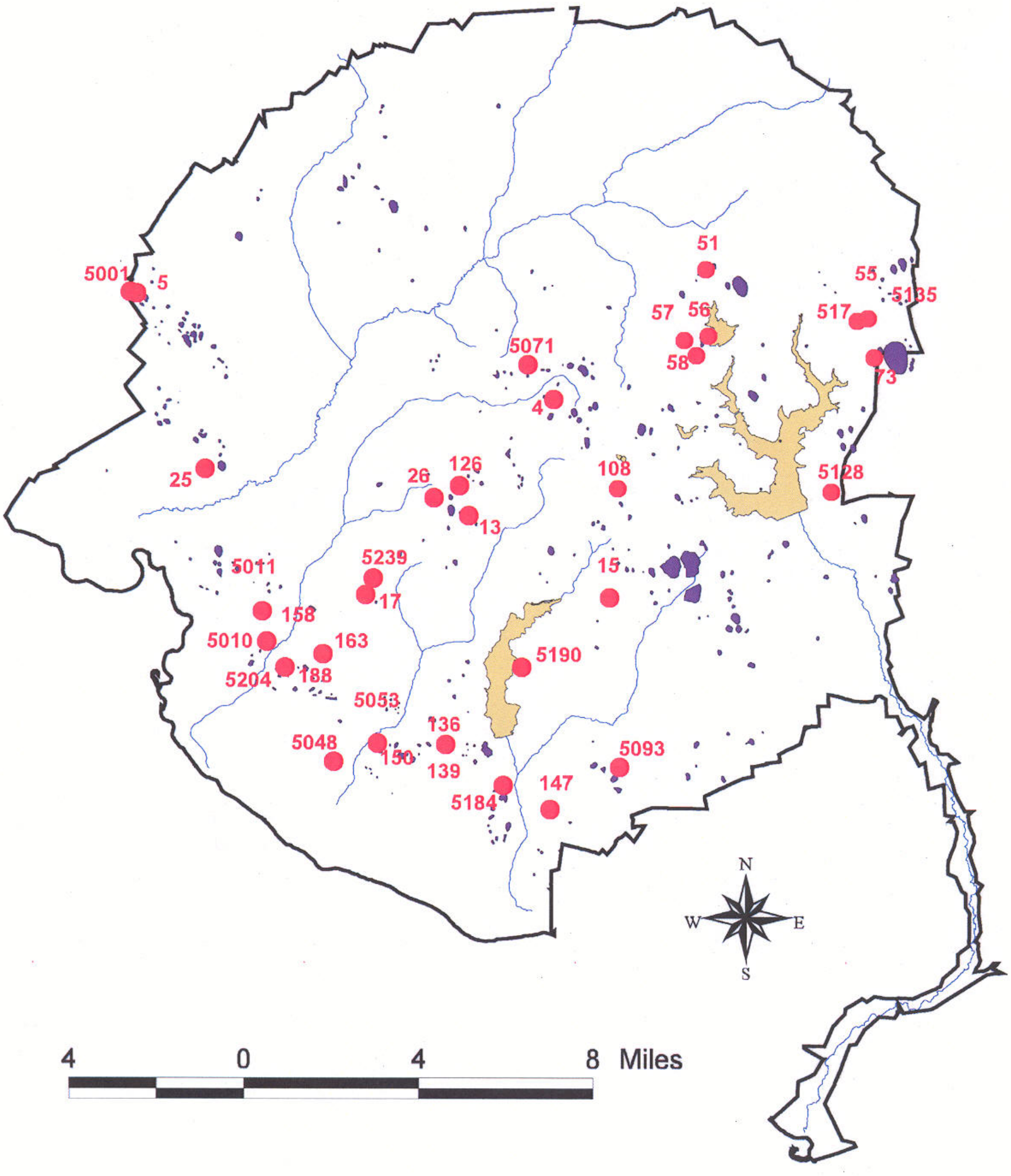


Figure 5-31. Location of SRS Mitigation Bank Carolina Bay Restoration Sites

5.7.2 Restoration Design

To restore the wetlands, trees in the bay interior were harvested and drainage ditches were plugged with low permeable clay to re-establish prior hydrological conditions. Several strategies for restoring the vegetation in replicated sets of these bays are being examined. Planned endpoints or treatments included forested and herbaceous bay interiors. In bays that are being restored as herbaceous communities, test plots were planted with obligate wetland grass species (*Panicum hemitomon* and *Leersia hexandra)*. The majority of the area within these herbaceous bays was not planted, but efforts were taken to encourage natural succession through soil scarification. Bays intended for restoration to a forested community were planted on 4.5 m centers throughout the interior with swamp tupelo (*Nyssa sylvatica* var. *biflora*) and baldcypress (*Taxodium distichum*). The role of the seed bank on revegetation and natural succession is also being examined in all bays to evaluate the need for out planting of wetland species and for further development of planting strategies in disturbed Carolina bays and similar depression wetlands.

To gain a better understanding of the relationship between buffer-zone management and wetland properties, two upland management alternatives are being examined as bay margin treatments and as expected endpoints for the uplands surrounding the bays. The two principal upland landscapes on the SRS that are commonly associated with Carolina bays are: 1) fire-managed, open-canopy pine forest savannas, and 2) closed canopy mixed pine-hardwood forests. Bay margin treatments were applied to a 100-m buffer from the edge of each bay into the upland. Selective harvesting of hardwoods and some pines was performed in the open-canopy pine forest savanna margins to reduce the basal area to approximately 5 m2 ha-1. Prescribed burning of the margins began in 2003 and will be repeated as dictated by fuel levels (approximately once every 3 to 4 years). Margins within the closed canopy mixed pine-hardwood forests were left unthinned.

Determination of whether restored systems and their accompanying buffers are moving toward planned endpoints will be accomplished by assessing trends and rates of change in biotic and abiotic metrics and comparing these to undisturbed reference bays and/or unrestored control bays. The monitoring program will record the progress of the restoration for five years after the treatment manipulations (2001 - 2005), and will be used as a guide for determining the final net improvement displayed for each individual wetland. A Carolina bay restoration will be deemed a success when the restored hydrologic regime has stabilized and the associated wetland community is dominated by hydrophytic vegetation more commonly found in wetlands than in the community occupying the site immediately before restoration (DOE 1997). Specific criteria for determining restoration success have been defined (Osteen 2003).

5.7.3 Preliminary Results

By the end of 2002, most restoration treatments were successfully imposed. Pre-restoration monitoring ended and post restoration monitoring began as harvesting activities in the bay interiors began. The total interior harvest for the 16 restoration bays was targeted at 15.5 hectares, and ultimately 19.6 ha. were cleared. Efforts to thin the margins in the open-canopy, pine savanna margin treatments were successful in sites that contained a mature forested stand. Ultimately, over 126 hectares were included in the study areas (interior + margin). Planting of the two forested species and the transplanting of wetland grass species was successful. The exact number of either *Nyssa sylvatica* or *Taxodium distichum* that were initially planted in the bays was difficult to ascertain due to methods employed by the contracted planting crew. The total number of trees planted at each site was estimated by the number of seedling bags utilized at the site (50 and 100 seedlings per bag of cypress and tupelo, respectively) and the number of seedlings claimed planted by the contractor. Subsequently, field surveys were performed to evaluate the accuracy of these numbers. From these surveys it was estimated that approximately 2700 *Nyssa sylvatica* and 1900 *Taxodium distichum* seedlings were planted in the eight bays. One hundred seedlings of each species per bay (where available) were marked and measured and will be utilized throughout the study to evaluate survivability and growth. Wetland grass species were located at donor sites on SRS and transplanted to test plots that ranged in size from 100 – 300 m2, scaled to correspond to the size of the wetland. On 0.75 and 0.6 meter centers, respectively, 2198 plugs of *Panicum hemitomon* and 3021 plugs *Leersia hexandra* were transplanted. Annual surveys will also be performed in these plots to evaluate transplant survival and growth.

Efforts to curtail stump sprouting immediately following the interior harvest were not undertaken. However, new shoots originating from the stumps were treated with a foliar herbicide (Garlon® 4) during the summer of 2001 using backpack sprayers. Dieback of the sprouts was apparent within a week of the applications, but the treatment proved ineffective as evident by the numerous shoots that reappeared, and persisted in subsequent growing seasons. Efforts to control some of the sprouts, particularly those of sweetgum (*Liquidambar styraciflua*), may be necessary in the near future.

The filling of drainage ditches was intended to begin immediately after the planting had been completed; however, plug installation was delayed approximately eight months due to permitting constraints. Most of the sites were “effectively” plugged by harvesting activities, where native soil was dozed into the ditch and compacted so as to facilitate movement of mechanical harvesters and skidders in the wetland interiors. With the verification of the Corps of Engineers 404 permit (Nationwide Permit 27), received December 18, 2001, actions to plug the drainage ditches began. A clay plug was installed by excavating an area perpendicular to the drainage ditch at the location of the historical wetland boundary (rim). The excavated site was at least twice the width and depth of the original drainage ditch and extended two to three meters into the upland. The material removed from the ditch was set aside and reused as a surface cover on the impermeable clay plug.

Once the excavated area was established, subsoil clays obtained from SRS borrow areas were dumped into the pits and compacted using a backhoe. Erosion control practices (seeded annual ryegrass and installed coconut/straw stitched erosion control blankets) were implemented at each site with the completion of the plug installation. Water levels rose during the winter/spring of 2003 and no leaks or undercutting of the plugs have been detected thus far.

Planned burning of the open-canopy, pine savanna margin bays was postponed in both 2001 and 2002 due to a variety of reasons that included a national ban on prescribed burning following a wildfire incident at the Los Alamos National Lab in NM, a Site burning ban in response to terrorist activities of September, 2001, extreme drought and unfavorable burning conditions. The consequence of these delays on the vegetation and overall restoration response in difficult to ascertain at this time, though possibly it contributed to the lack of early control of woody resprouts. After soil moisture levels increased in response to rainfall in 2003, site conditions improved and prescribed burning operations were re-initiated. The eight bays will be re-burned as soon as fuel levels are re-established to a point that will support the activity (approx. 3 years).

The hydrological response to the restoration treatments was complicated by the regional drought. All treatment and reference bays were dry for most of 2002. Surprisingly, however, a change in hydroperiod (% time ponded per year) was detected in many of the treatment bays and a subsequent response by faunal communities was noted. Details on the response of hydrology, vegetation and faunal communities to the restoration activities are reported in the annual status report (Barton 2003). Post restoration monitoring of biotic and abiotic metrics will continue through 2005.

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6.0 SUPPLEMENTAL STUDIES

6.1 INTRODUCTION

Previous chapters have summarized available information for specific habitat or resource types. This chapter summarizes the results of several initiatives and studies that address specific issues with SRS-wide and /or regional importance. The following sections summarize:

- Data available from the SRS aerial Remote Sensing program
- Aquatic toxicity and alternate test species development
- Aquatic Rapid Bioassessment methods development
- Characterization of environmental mercury concentrations in SRS streams and the Savannah River

Many recent reports are available through the DOE Office of Scientific and Technical Information (www.osti.gov)

6.2 REMOTE SENSING DATA

Remote sensing data have been used to evaluate SRS's natural resources and to monitor the environmental effects of operations since the early 1950s. From the beginning, the U.S. Forest Service used vertical aerial photography to support SRS timber resource management. Numerous other overflights have been conducted, such as those by the National High Altitude Photographic Program (NHAP) and the DOE Remote Sensing Laboratory (RSL). These programs documented facilities and operations with low altitude oblique and video photography. Low altitude gamma overflights have been flown every 5 to 10 years from 1974 to 1998, providing data on areas of radioactive contamination on SRS. More recently, specialized airborne remote sensing scanners (multispectral scanners [MSS]) have provided special interest coverage, such as documenting the effects of thermal releases to SRS wetlands. Satellite data (SPOT and Thematic Mapper Landsat) provide large-scale synoptic views of the site. Much of the remote sensing data is now available in digital format for Geographic Information Systems (Mackey and Riley 1996). Table 6-1 summarizes available aerial data.

Table 6-1. Aerial Coverage Available for the SRS

Type	Dates Available	Purpose	Specifications
Aerial oblique photography	1971 - Jan 1974 - June 1975 - Dec 1979 - June 1981 - Mar, Sept, Oct 1982 - Aug, Sept 1983 - Mar, Aug 1984 - Mar, May - Nov 1985 - Feb - Jun, Aug 1986 - Mar, Apr, Jun, Aug 1987 - Feb, Mar, Jun 1988 - Mar 1990 - Apr 1991 - May, Jun 1994 – Apr 1998 – Aug	Document major operating and construction activities; areas of interest, including waste units and natural areas	altitude: 30-2,300 ft size: 4x5 Original proof boxes are in vaults at the Remote Sensing Laboratory.
Vertical aerial photography	1938, 1943, 1951, 1955, 1956, 1966, 1973, 1974, 1979, 1981, 1982, 1986, 1989, 1992, 1994, 1996, 1998, 1999, 2001; partial coverage in other years		b&w prior to 1974; color after 1974 (normal or False Color Infrared) altitude: 10,000 ft. quality: fair to good
SPOT satellite data	1987 through 1996	Land use / cover	single band, panchromatic (10x10), and 3-band multi-spectral (20x20)
Multispectral Scanner (MSS) data	1981-1985 after 1985 through 1996	Document thermal impacts and vegetation changes	Daedalus 1260 Daedalus 1268 kept at DOE Remote Sensing Laboratory
Hyperspectral Scanner	1996, 1999, 2002, 2005	Change detection, minerals, vegetation	High and low altitude, various systems
Multispectral Thermal Imager	2001 through 2004	Temperature retrieval, Vegetation Analysis	Satellite imager
Gamma surveys	1958-1991, 1998	Map natural and manmade gamma fields	available in digital format

Source: Mackey and Riley 1996.

6.2.1 Aerial Oblique Photographic Coverage

The RSL recorded aerial oblique photographs of the SRS and surrounding areas in 1971, 1974, 1975, 1979, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1990, 1991, and 1994. The purpose of the oblique photographic coverage was to provide SRS personnel with a catalogue of aerial oblique scenes of the major operating areas, construction projects (e.g., DWPF and L Lake), and other areas of interest (Mackey and Riley 1996).

6.2.2 Vertical Aerial Photography

An extensive collection of vertical aerial photographs exists for the SRS. Most of the photographs prior to 1974 are black and white, while those after 1974 are color, either normal color or false color infrared (FCIR). The most common altitude and scale are 10,000 feet above ground level and 1:20,000, respectively. The U.S. Forest Service photographed the site in 1955, 1956, 1966, 1973, 1974, 1979, 1982, 1986, 1989, 1992, and 1996, to assist with timber management. The site also was imaged under the NHAP program in 1981, 1989, and 1994. From 1981 to 2001, part or all of the site has been flown almost annually by RSL. Nearly sitewide coverage is available for most years since 1973 (Mackey and Riley 1996).

Two sets of sitewide vertical photographs taken in 1938 and 1943 predate the establishment of the SRS in the early 1950s. These provide a record of the land use patterns on SRS area prior to establishment of the site (Mackey and Riley 1996).

Several sets of photographs were taken in the 1950s. Two sets were taken in 1951 at 2,000 and 10,000 foot altitudes, during early construction of the SRS, documenting the land cover of the site at that time in good detail. Photographs of the northern half of the site are available as a digital orthographic file. The 1955 and 1956 black and white coverages are of fair quality, but only prints have been located. Much of the photography in the 1950s and 1960s has the areas surrounding the operating areas removed from the prints and/or negatives as part of the security practices at that time, thus their utility to review history of selected locations on the SRS is limited. The construction activities of Par Pond are covered in low and high altitude sets of photography from 1958.

The coverage flown by the DOE Remote Sensing Laboratory started in 1974 and was extensive, particularly after 1981. It supported a variety of SRS projects, most often related to reactor operations, National Environmental Policy Act (NEPA) activities, and evaluation of thermal impacts to wetlands.

In addition to supporting the development of sitewide GIS databases, representative historical photography of the SRS has been incorporated into a series of image browse files available through SRNL or the WSRC Environmental and Geographical Information Systems.

6.2.3 SPOT Satellite Data

Acquisition of SPOT satellite data coverage of the SRS began in 1987. Coverage was repeated almost annually between 1987 and 1995. SPOT satellite data are especially useful for habitat and land use mapping of the general landscape at a reasonable cost (Mackey and Riley 1996).

6.2.4 TM Landsat Satellite Data

Thematic Mapper (TM) Landsat satellite coverage exists for the SRS and surrounding region. As with SPOT data, Landsat data are particularly good for habitat and land use mapping of the general landscape (Mackey and Riley 1996).

6.2.5 Airborne Multispectral Scanner Data

Airborne multispectral scanner (MSS) data are similar to TM satellite data with the major exception that the scanner(s) is flown at relatively low altitudes, resulting in a much higher spatial resolution than can be obtained with the current commercial satellite systems. Also, the overflights can be timed, for example, to take advantage of experimental manipulations such as thermal plume or thermal dispersion dye studies (Mackey and Riley 1996).

The vast majority of the overflights at SRS were flown after 1980, primarily to document thermal impacts of site operations on site creeks and reservoirs and to evaluate the dispersion of thermal plumes in the Savannah River (Mackey and Riley 1996).

6.2.6 Aerial Hyperspectral Scanner Data

Airborne hyperspectral scanner (HPS) data are similar to multispectral data. Exceptions are band width and number. Four data sets have been collected of selected areas of SRS (1996, 1999, 2002, 2005).

6.2.7 Multispectral Thermal Imager

DOE Satellite multispectral thermal imagery (MTI) has been collected periodically from August 2001 through 2004. The imager will produce large amounts of fairly high-resolution imagery over 15 wavebands covering the visible, near-infrared (NIR), short wave infrared (SWIR), mid-wave infrared (MWIR), and long-wave infrared (LWIR). The imagery can be used for temperature retrieval, monitoring waste sites, and vegetation health and material identification.

6.2.8 Aerial Gamma Survey Data

Aerial gamma surveys of the SRS and surrounding areas were conducted between 1958 and 1991 and again in 1998. These surveys resulted in relatively good maps of natural and manmade gamma fields. In addition to sitewide surveys, special gamma overflights were conducted from time to time to provide baseline information for selected locations or for potential project evaluations or changes in site operations (Mackey and Riley 1996).

6.3 ECOLOGICAL INVESTIGATIONS AT THE MIXED WASTE MANAGEMENT FACILITY

The Mixed Waste Management Facility (MWMF) occupies approximately 79 ha (194 acres) in the central portion of SRS. It contains active and former disposal sites for wastes generated by SRS operations, including solid metallic waste, radioactive waste, and solvents. Three separate investigations were performed in 1994 that support remedial investigation activities required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA): (a) remote sensing to develop a land-use cover map; (b) aquatic toxicity testing to determine if surface waters were toxic to aquatic biota; and (c) qualitative surveys of small mammals, reptiles, and amphibians to identify the species that inhabited the area (Friday et al. 1994). The land use and cover of the MWMF is primarily grassy (46%) or industrial (45%). It includes upland pine plantations and several small creeks bordered by mixed hardwood or bottomland hardwood forest. Grassy habitat is relatively uncommon on SRS.

Aquatic toxicity tests indicate that although some of the surface water leaving the MWMF is toxic (Table 6-2), it does not appear to be causing toxicity in either Upper Three Runs or Fourmile Branch. Toxicity in three of four seeps tested in 1993 and 1994 declined over the year. The fourth seep had a fairly constant toxicity over the interim (Table 6-3).

Eight areas and five habitats were surveyed for small mammals, reptiles, and amphibians. The habitats were old field, early successional, mixed hardwood and pine, upland pines, and bottomland hardwoods. Early successional habitat type was more or less typical of its type on the SRS. The southern short-tailed shrew (*Blarina carolinensis*) was the most frequently captured mammal (Table 6-4), followed by the cotton rat (*Sigmodon hispidis*). The early successional habitat had more than 35% of the total catch, and 7 species. The old field and bottomland hardwood habitats had high catch rates, but low species diversity (four species in the old field and two in the hardwood forest). Animals other than those trapped use the MWMF (Table 6-5). Reptiles and amphibians observed, collected, or heard during the study are shown in Table 6-6. The greatest number of species were observed in the early successional and hardwood areas, which are adjacent to each other. All species of vertebrates captured or observed were generally those expected to frequent the type habitat where they were encountered.

Investigations in 2000 and 2002 using aerial remote sensing data at the MWMF were conducted to evaluate assessment techniques for capping system performance monitoring. These investigations were focused on identifying potential surface indicators that are indicative of system performance. An integrating characteristic of the capping system is the ability of the surface vegetation to minimize infiltration and prevent surface erosion. Both investigations used the NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) hyperspectral instrument that collected imagery over the entire MWMF site. The 2000 investigation (Kelch, et. al. 2001) highlighted the conclusion that capping system performance analysis using aerial remote sensing data relies on evaluation of indirect surface indicators (e.g., vegetative cover layer quality and soil-vegetation moisture differences). These surface indicators temporally integrate the effects of system performance.

Technical results identified the ability to correlate capping system subsidence activity to vegetation indices. The hyperspectral analysis correlated small changes (<15 cm) in ground elevation to vegetation spectral characteristics. Meaningful differences in the vegetative cover layer quality were detected by discriminating between healthy and stressed vegetative cover layer. These differences are indicative of moisture availability in the soil-vegetation component of the capping system. Moisture availability is an indirect measure of the capping system performance and its efficiency to remove water through evapotranspiration. Evapotranspiration is an important capping system performance characteristic and is a major the function of the vegetative cover layer to control moisture.

Table 6-2. Results of Toxicity Tests at the MWMF Study Area, 1994

Location[a]	No Observable Effects Concentration	Lowest Observable Effects Concentration
UTR-022	50%	100%
UTR-029	50%	100%
UTR-116	50%	100%
FSP-012	>100%	>100%
FSP-204	25%	50%
HSP-008	>100%	>100%
HSP-103	12.5%	25%
FMC-001F	>100%	>100%
BGW-045	>100%	>100%
UTR-RR Bridge	>100%	>100%

Source: Friday et al. 1994.
[a]UTR = Upper Three Runs
FSP = F-Area Seepline.
HSP = H-Area Seepline.
FMC = Fourmile Branch.
BGW = Burial Ground.

Table 6-3. Results of Toxicity Tests Conducted at Four F-/H-Area Seeps in 1993 and 1994

Location[a]	No Observable Effects Concentration	
	1993	1994
FSP-012	10%	>100%
FSP-204	30%	25%
HSP-008	100%	>100%
HSP-103	3%	12.5%

Source: Friday et al. 1994.
[a] FSP = F-Area Seepline.
HSP = H-Area Seepline.

Table 6-4. Species, Total Captures, and Frequency of Captures for Small Mammals at the MWMF Study Area, 1994

Species	Total Captures	Frequency
Short-Tailed Shrew	52	0.351
Least Shrew	19	0.128
Golden Mouse	1	0.007
Cotton Mouse	13	0.088
Old-Field Mouse	12	0.081
Deer Mouse	1	0.007
Eastern Harvest Mouse	4	0.027
Cotton Rat	44	0.297
House Mouse	1	0.007
Southern Flying Squirrel	1	0.007

Source: Friday et al. 1994.

Table 6-5. Scientific and Common Names of Mammals Observed at the MWMF Study Area, 1994

Scientific name	Common Name	Observation
Didelphis virginiana	Opossum	Live trap
Blarina carolinensis	Short-Tailed Shrew	Trapping
Cryptotis parva	Least Shrew	Trapping
Scalopus aquaticus	Eastern Mole	Active tunnels
Sylvilagus floridanus	Eastern Cottontail	Sighting, scat
Ochrotomys nuttalli	Golden Mouse	Trapping
Peromyscus gossypinus	Cotton Mouse	Trapping
Peromyscus polionotus	Old-Field Mouse	Trapping
Peromyscus sp.	Deer Mouse	Trapping
Reithrodontomys humulis	Eastern Harvest Mouse	Trapping
Sigmodon hispidus	Cotton Rat	Trapping
Mus musculus	House Mouse	Trapping
Glaucomys volans	Southern Flying Squirrel	Trapping
Sciurus carolinensis	Gray Squirrel	Observed
Lynxs rufus	Bobcat	Tracks
Mephitis mephitis	Striped Skunk	Carcass
Procyon lotor	Raccoon	Trapping, scat
Odocoileus virginianus	White-Tailed Deer	Tracks
Sus scrofa	Wild Pig	Scat

Source: Friday et al. 1994.

Table 6-6. Scientific and Common Names of Reptiles and Amphibians Identified During the MWMF Characterization, 1994

Scientific Name	Common Name	Observation[a]
Plethodon glutinosus	Slimy Salamander	HDWD, RR
Scaphiopus holbrookii	Eastern Spadefoot Toad	ZUP
Bufo quercicus	Oak Toad	RR
B. terrestris	Southern Toad	QM, SROW, ZUP
Hyla chrysoscelis	Gray Tree Frog	FOF, SROW, ZBOT, ZUP
H. cinerea	Green Tree Frog	ESC/HDWD
H. gratiosa	Barking Tree Frog	ESC/HDWD, QM, SROW, ZBOT, ZUP
H. squirella	Squirrel Tree Frog	RR, SROW, ZBOT
Gastrophryne carolinensis	Eastern Narrowmouth Toad	ESC/HDWD
Rana catesbeiana	Bullfrog	ESC/HDWD, ZUP
R. clamitans	Bronze Frog	ESC/HDWD, ZUP
R. grylio	Pig Frog	ESC/HDWD
R. sphenocephala	Southern Leopard Frog	QM, ZUP
Terrapene carolina	Box Turtle	SROW, ZBOT
Anolis carolinensis	Green Anole	RR, ZUP
Cnemidophorus sexlineatus	Six-Lined Racerunner	ZBOT
Eumeces inexpectatus	Southeastern Five-Linked Skink	QM, RR, SROW, ZBOT
Scincella lateralis	Ground Skink	HDWD, RR, SROW, ZBOT
Elaphe obsoleta	Rat Snake	ESC

Source: Friday et al. 1994.
[a] HDWD = Upland Hardwood/Pine.
RR = Railroad Pine Forest.
ZUP = Z-Area Upland Pine.
QM = H-Area Seepline.
SROW = Steamline Right-of-way.
FOF = Old Field.
ZBOT = Z-Area Bottomland.
ESC = Early Successional.

The 2002 investigation (Gladden, et al. 2003) again focused on the MWMF site and evaluated the capping system performance using the AVIRIS hyperspectral instrument. This investigation coupled aerial remote sensing data/imagery to ground truth data obtained from a monitoring station network that was installed on the MWMF site. The conclusions were the hyperspectral analysis was able to point out differences in vegetation types along with identifying the spatial distribution and condition of the vegetation. Technical results showed definitive spectral response in varying grass types and its spatial distribution in the vegetation cover layer. The ability to identify vegetation type is an important aspect in monitoring performance because invasive vegetation types can alter the capping system performance, thus degrading system performance and durability. Another outcome from this investigation further refined the derivative spectral bands used to analyze the vegetation cover layer. This refinement was correlated to in-situ biomass and moisture data provided by the MWMF monitoring station network. Technical results illustrated refined spectral bands used for analysis produced correlation coefficients ranging from 0.74 to 0.81 for the middle-infrared region vegetation spectra and water indices. These results provide a higher level of confidence to accurately measure and monitor indicators of change in the vegetation cover layer. The indicators of change provide in-put to assess the overall performance efficiency of the capping system.

6.4 AQUATIC TOXICITY TESTS

South Carolina Department of Health and Environmental Control (SCDHEC) requires effluent toxicity testing at selected SRS National Pollutant Discharge Elimination System (NPDES) outfalls. The U.S. Environmental Protection Agency (EPA) and SCDHEC have recommended the cladoceran *Ceriodaphnia dubia* as the species of choice for effluent toxicity testing. Although other species of daphnids, such as *Ceriodaphnia reticulata* and *Daphnia ambigua*, are common in SRS ponds and reservoirs, *C. dubia* is not found on the SRS. The following discussion on the suitability of using SRS stream waters as diluents in toxicity tests is taken from Specht (1994a).

The chemical composition of surface waters in the United States varies widely with respect to water hardness and trace mineral content. In order to provide a consistent source of culture water for performing toxicity tests, the EPA and SCDHEC recommend that *C. dubia* be cultured in 20% dilute mineral water (DMW), which is a mixture of 80% deionized water and 20% Perrier mineral water. DMW has sufficient calcium and trace minerals to maintain long-term cultures of *C. dubia*. DMW has a hardness of approximately 200 mg/l as $CaCO_3$ and is considered to be moderately hard water.

In contrast, SRS stream water is extremely soft, with hardnesses ranging from approximately 2 to 30 mg/l. If mineral water is diluted to the hardness values that are typical of SRS waters, it does not contain sufficient calcium and trace minerals to support *C. dubia*. Because *C. dubia* does not occur on the SRS and the natural water chemistry of SRS surface waters differs greatly from that of DMW, *C. dubia* may not thrive when exposed to unimpacted SRS surface water. SCDHEC has specified that SRS surface waters may be used as the diluent for effluent toxicity tests. However, if *C. dubia* will not thrive in SRS surface waters, the use of SRS water as diluent may result in less than optimal conditions for the test species and produce inconclusive or erroneous test results.

In order to determine if *C. dubia* can thrive in water from SRS streams, water was collected from three unimpacted reaches of streams (Upper Three Runs at Road 8-1, Fourmile Branch at Road F, and Pen Branch at Road B). Collectively, these three streams and their tributaries are the receiving streams for approximately 70% of SRS's NPDES discharges. The three main objectives of this study were to determine if: 1) *C. dubia* is adversely affected by SRS stream waters that do not receive NPDES discharges; 2) *C. dubia* can be cultured for extended periods of time in SRS stream waters; and 3) *C. dubia* that are cultured in stream waters differ in sensitivity to a reference toxicant when compared to organisms that are cultured in 20% DMW. Increased sensitivity to a toxicant is generally an indication of stress.

Water was collected monthly from the three locations and cultures of *C. dubia* were established in all three waters in December 1993 (Specht 1994a). Once each month the percent survival and mean number of young produced during a seven-day period was determined for each water source and for 20% DMW. In addition, a reference toxicity test using sodium chloride was performed on each water source and DMW each month.

The water chemistry data confirm that SRS streams are soft, with total hardness averaging 4.4 mg/l in Upper Three Runs, 12.9 mg/l in Fourmile Branch, and 19.6 mg/l in Pen Branch (Table 6-7). The pH of the streams averaged 5.3 in Fourmile Branch, 5.7 in Upper Three Runs, and 6.7 in Pen Branch.

Table 6-7. Water Quality Data For Pen Branch, Upper Three Runs, and Fourmile Branch, 1994

Parameter	Pen Branch		Upper Three Runs		Fourmile Branch	
	Mean	Range	Mean	Range	Mean	Range
Dissolved oxygen (mg/l)	9.1	6.6 - 11.8	9.0	6.4 - 12.0	4.3	1.2 - 7.1
Hardness (mg/l)	19.6	12.0 - 30.9	4.4	1.96 - 8.0	12.9	8.0 - 23.3
Alkalinity (mg/l)	16.6	6.0 - 26.9	2.4	1.0 - 6.7	4.0	2.0 - 11.0
Dissolved organic carbon (mg/l)	5.6	2.9 - 16.9	3.7	1.1 - 11.0	12.1	5.1 - 18.0
Conductivity (µS/cm)	51.7	37.7 - 66.0	17.4	13.4 - 34.3	36.9	28.5 - 49.0

Source: Specht 1994a

C. dubia did best in water from Pen Branch and poorest in water from Fourmile Branch (Table 6-8 through Table 6-10). However, even in water from Pen Branch, reproduction was significantly lower than for organisms cultured in DMW in 5 of 11 tests. Overall, the number of young produced in Pen Branch water averaged 21.1 young/female as compared to 24.4 young/ female in DMW. Water from Pen Branch never induced acute toxicity (mortality >10%).

C. dubia cultured in water from Upper Three Runs exhibited some degree of acute toxicity in 6 of 11 tests. In the chronic tests, organisms cultured in water from Upper Three Runs had significantly lower rates of reproduction in all 11 tests. Overall, the number of young produced in Upper Three Runs water averaged 13.8 young/female as compared to 24.6 young/female in DMW.

Cultures of *C. dubia* that were established in water from Fourmile Branch in December 1993 declined in vigor so they were not sustainable by February. No further culturing was attempted with Fourmile Branch water until August. Based on results for the five months that cultures were maintained in water from Fourmile Branch, the water was acutely toxic in three of the five months; percent survival ranged from 0 to 95% and averaged 55% (Table 6-10). In the chronic tests, organisms cultured in water from Fourmile Branch had significantly lower rates of reproduction in all five months. Overall, the number of young produced in Fourmile Branch water averaged 11.1 young/female as compared to 23.8 young/female in DMW. Reproductive rates showed a continuous decline between August (22.1 young/female) and November, when no young were produced. These data indicate that Fourmile Branch is not capable of sustaining *C. dubia* long-term.

The reference toxicity tests with sodium chloride produced results similar to those of the chronic tests. In all instances, organisms cultured in SRS stream waters were more sensitive to the reference toxicant (sodium chloride) than were organisms cultured in DMW (Table 6-11). Organisms in water from Fourmile Branch were most sensitive and those from Pen Branch were least sensitive. These results suggest that *C. dubia* cultured in unimpacted SRS stream water are stressed to various degrees, and therefore, more sensitive to the added stress of a toxicant.

The results of both the reproduction tests and the reference toxicity tests indicate that none of the three SRS water sources that was tested do as well as DMW in supporting long-term cultures of *C. dubia*. Of the three water sources, Pen Branch came closest to matching the results obtained in DMW, and Fourmile Branch was the worst. These results indicate that it may not be possible to distinguish between toxicity resulting from effluent discharges and naturally occurring toxicity, except by performing toxicity tests on samples collected upstream and downstream from outfalls and comparing the results. In many instances, the use of upstream and downstream locations for toxicity testing is not feasible, because the effluent may discharge into the headwaters of a stream so that there is no upstream location for comparison. Because at least two of the three streams (Upper Three Runs and Pen Branch) support diverse macroinvertebrate communities, these results also suggest that C. *dubia* may not be an appropriate species to use for toxicity testing at the SRS.

As a follow-up to this study, a Toxicity Identification Evaluation (TIE) was performed on a sample of water collected from Fourmile Branch at Road F to determine if the poor performance of *C. dubia* in Fourmile Branch water was due to a naturally occurring toxicant or to unsuitable water chemistry (e.g., low pH, low hardness, or low levels of essential trace minerals). The results of the TIE indicate that naturally occurring iron was responsible for the observed toxicity (Specht 1996). The EPA aquatic life water quality criterion for iron is 1 mg/l. In contrast, the iron concentration in Fourmile Branch at the time of sampling was 6.2 mg/l. The source of the iron is probably the iron-rich clays in the soil. When these clays are exposed to the naturally low pH conditions that exist in blackwater streams and their watersheds, iron is leached from the clay particles.

It was ultimately determined that low hardness was responsible for the reduced survival and reproduction in SRS surface waters. Based on these findings, it was concluded that *C. dubia* was an inappropriate species to use for toxicity testing in waters with very low hardness. In 1996, research was initiated to develop a toxicity test using an indigenous species of cladoceran, *Daphnia ambigua*. Criteria for the alternate species included:

- the test species should be at least as sensitive as *C. dubia* to a broad range of toxicants
- the test species should be widely available and abundant
- the test species should be indigenous to or representative of the ecosystem receiving the impact
- the test species should be amenable to routine maintenance and culture in the laboratory

This research determined that *D. ambigua* could be cultured in the laboratory with only minimal changes to established regulatory protocol and that the life-cycle characteristics of this species were conducive to traditional acute and chronic aquatic toxicity test methods used with other daphnids. Aquatic toxicity tests showed that the sensitivity of *D. ambigua* to a broad range of toxicants (metals, surfactants, and insecticides) was similar to that of *C. dubia*. When exposed to low-hardness, low pH stream waters typical of many southeastern coastal plain streams that had depressed survival and reproduction in *C. dubia*, *D. abigua* was not adversely affected. These results suggest that *D. ambigua* is a suitable surrogate for *C. dubia* as a toxicity indicator species in these types of receiving streams (Specht and Harmon 1997; Harmon et al. 2003).

The results of this study were submitted to SCDHEC in July 1998. SCDHEC transmitted the results to U.S. EPA Region 4 in January 1999. At that time, SRS requested a modification of the existing NPDES permit to allow the use of *D. ambigua* for routine toxicity testing at the SRS. In January 2000, U.S. EPA Region 4 requested that additional testing be performed. The results of these tests were provided to U.S. EPA Region 4 in June 2000 (Specht 2000).

In September 2001, U.S. EPA Region 4 approved the use of *Daphnia ambigua* for toxicity testing of SRS outfalls, the first such approval for the use of an alternate species ever granted by the U.S. EPA for use in freshwater. The use of this species has largely eliminated toxicity failures at SRS NPDES outfalls.

Table 6-8. Reproductive Rates And Mortality In Pen Branch Water, 1994

	Reproductive Rate (young/female)			Percent Survival		
	Control	**Creek**	**Chronic Toxicity**	**Control**	**Creek**	**Acute Toxicity**
January	23.3	25.3	No	100	95	No
February	21.1	25.1	No	100	90	No
March	20.4	19.7	No	90	95	No
April	21.9	20.1	No	100	95	No
May	25.8	15.7	Yes	100	95	No
June	28.8	18.7	Yes	100	100	No
July	25.8	25.0	No	100	100	No
August	27.2	18.6	Yes	100	95	No
September	29.1	21.0	Yes	95	100	No
October	24.6	16.6	Yes	95	95	No
November	20.8	26.3	No	100	100	No

Source: Specht 1994a

Table 6-9. Reproductive Rates And Mortality In Upper Three Runs Water, 1994

	Reproductive Rate (young/female)			Percent Survival		
	Control	**Creek**	**Chronic Toxicity**	**Control**	**Creek**	**Acute Toxicity**
January	24.1	8.5	Yes	100	90	No
February	No chronic test was performed.			100	85	Yes
March	20.4	6.7	Yes	90	65	Yes
April	21.9	12.1	Yes	100	85	Yes
May	25.8	15.3	Yes	100	95	No
June	28.8	16.4	Yes	100	90	No
July	23.0	12.5	Yes	100	80	Yes
August	27.2	12.4	Yes	100	45	Yes
September	29.0	17.6	Yes	100	90	No
October	24.6	15.4	Yes	95	100	No
November	20.8	5.2	Yes	100	15	Yes

Source: Specht 1994a

Table 6-10. Reproductive Rates And Mortality In Fourmile Branch Water, 1994

	Reproductive Rate (young/female)			Percent Survival		
	Control	Creek	Chronic Toxicity	Control	Creek	Acute Toxicity
January	24.1	6.6	Yes	100	80	Yes
February	Cultures could not be maintained long-term (>1 month) in water from Fourmile Branch.					
March						
April						
May						
June						
July						
August	27.2	22.1	Yes	100	90	No
September	28.1	20.4	Yes	100	95	No
October	18.6	6.5	Yes	95	10	Yes
November	20.8	0.0	Yes	100	0	Yes

Source: Specht 1994a

6.5 RAPID BIOASSESSMENTS OF SRS STREAMS

The use of information about communities of organisms to assess environmental quality is often termed bioassessment (Plafkin et al. 1989). Bioassessment is increasingly favored by regulatory agencies because it explicitly evaluates effects on receptor organisms and reflects the cumulative effects of ecological disturbances. Rapid bioassessment methods can be used to accurately and quickly evaluate the health of aquatic ecosystems within realistic time and budget constraints. Among the most widely used rapid bioassessment methods in the United States are multimetric indices that are composed of a number of community, population, and organism level metrics that are ecologically important and sensitive to environmental disturbances of various types. These metrics are measured at assessment sites, compared to those in a range of similar but undisturbed benchmark streams, and the results summarized in a single number that reflects the extent to which the assessment site resembles the benchmarks. Multimetric indices for streams are often based on macroinvertebrate or fish data. Several such bioassessment methods have been developed for southeastern Coastal Plain streams and have been used to address important environmental issues on the SRS.

6.5.1 Rapid Bioassessment Methods for Assessing Stream Macroinvertebrate Communities

As part of a program to extend the use of rapid bioassessment methods to SRS streams, SRNL scientists developed a multimetric index termed the HDMI (Hester-Dendy Multimetric Index) based on the use of macroinvertebrate data collected with Hester-Dendy multiplate artificial substrates. Initial research and development was based on Hester-Dendy multiplate data collected from 16 locations in SRS streams in 1994 and 24 locations in 1993 (Specht 1994b). Sampling stations that were unperturbed, as well as stations that were downstream from industrial, sanitary, and thermal or post-thermal discharges were included in the study, and more than one type of perturbation impacted several of the sites.

Table 6-11. Results of Reference Toxicant Toxicity Tests Conducted With Sodium Chloride, 1994

	LC_{50}[a] (g NaCl/l)				Survival NOEC[b] (g NaCl/l)				Reproductive NOEC (g NaCl/l)			
	Control	**Pen Branch**	**Upper Three Runs**	**Four-mile Branch**	**Control**	**Pen Branch**	**Upper Three Runs**	**Four-mile Branch**	**Control**	**Pen Branch**	**Upper Three Runs**	**Four-mile Branch**
January	2.08	1.22	<0.2	<0.2	1.5	0.8		<0.2	0.4	0.4	<0.2	<0.2
February[c]	2.08	1.13			1.5	0.8			0.4	0.8		
March[c]	2.08	1.22			1.5	0.4			0.4	0.4		
April[c]	2.08	1.19	<0.0625		1.5	0.8	<0.0625		0.4	0.8	<0.0625	
May[c]	2.08	2.07	0.128		1.5	1.5	0.13		0.4	0.8	0.03	
June[c]	2.08	1.92	0.18		1.5	1.5	0.032		0.4	0.8	0.032	
July[c]	2.08	1.55	<0.03		1.5	1.5	0.06		0.4	0.8	0.06	
August	2.08	1.43	<0.03	<1.0	1.5	1.5		<0.02	0.4	0.8		<1
September	2.11	1.43	>0.25	0.26	1.5	1.5	0.25	<0.06	0.4	0.4	0.0125	0.26
October	2.2	1.41	0.11	0.62	1.5	0.8	>0.02		0.8	0.8	>0.02	0.62
November[c]	2.2	1.11	0.16		1.5	0.8	0.01		0.4	0.8	<0.005	

Source: Specht 1994a.
[a]Lethal concentration 50 = the concentration that kills 50% of the test organisms in a given time period.
[b]No Observable Effects Concentration.
[c]Some fields contain no data because a toxicity test could not be performed due to high mortality.

The index proved more useful than the EPA Rapid Bioassessment Protocol (Plafkin et al. 1989) in assessing impacts in SRS Coastal Plain streams. It included community structure variables (taxa richness; Ephemeroptera, Plecoptera, Trichoptera [EPT] richness), community balance variables (percent Tanytarsini, percent Trichoptera, percent Ephemeroptera, community similarity (Pearson-Pinkham community similarity index, Pinkham and Pearson 1976), and community function variables (density and Pearson-Pinkham similarity index with respect to functional feeding groups). Table 6-12 summarizes the index metrics and the scoring criteria for each metric. The rationale used in developing the index can be found in Specht and Paller (1995) and Paller and Specht (1997).

Table 6-12. Metrics And Scoring Criteria Used In The Macroinvertebrate Biotic Index, September 1994

	Scoring Criteria		
	1	**3**	**5**
Number of taxa	<35	35-45	>45
Standardized density[a]	>2.5	>1.5-2.5	<1.5
Number EPT[b] taxa	<10	10-14	>15
%Tanytarsini	<10	10-25	>25
%Trichoptera	0 or >10		>0-10
%Ephemeroptera	<2	2-7	>7
Taxonomic similarity[c]	<0.25	0.25-0.45	>0.45
Functional group similarity[d]	<0.45	0.45-0.55	>0.55

Source: Specht and Paller 1995.
Note: Individual metrics are assigned scores of 1, 3, or 5. The biotic index is calculated by summing the scores for the individual metrics.
[a]Standardized density = (X-M)/SD where X = density, M = average density for the unimpacted stations, and SD = standard deviation of the mean for the unimpacted stations.
[b]Ephemeroptera, Plecoptera, and Trichoptera.
[c]Similarity to the average taxonomic composition at the unimpacted stations (calculated with Pinkham and Pearson Index).
[d]Similarity to the average functional group composition at the unimpacted stations (calculated with Pinkham and Pearson Index).

The HDMI has been used to assess stream health as part of two important stream sampling programs conducted on the SRS: the instream biological assessment of NPDES point discharge sources program required by SCDHEC and the Integrator Operable Unit (IOU) assessment program conducted by the SRS Environmental Restoration Department. The objective of the first program was to determine the effects of discharges from SRS NPDES outfalls on biological communities in SRS streams. Results can be found in Specht and Paller (1998 and 2001). The second program was part of a larger effort to assess the cumulative effects of contaminants from hazardous waste sites on SRS watersheds. Results can be found in Paller and Dyer (1999 and 2003).

6.5.2 Rapid Bioassessment Methods for Assessing Stream Fish Communities

Paller et al. (1996) adapted the index of biotic integrity (IBI), a multimetric index based on fish community data, for use in streams in the upper southeastern Coastal Plain. Biotic integrity is the ability of a stream to support self-sustaining biological communities and ecological processes typical of undisturbed, natural conditions (Angermeier and Karr 1994). The IBI uses species richness, abundance, and percent composition variables that reflect important aspects of community structure and function. As with other multimetric indices, metrics are measured at assessment sites and compared to undisturbed benchmark streams; results are summarized in a single number that reflects the extent to which the assessment sites resemble benchmark conditions.

The IBI typically includes metrics within six categories: species richness, species composition, trophic composition, fish abundance, fish condition, and local indicator species. Because the IBI was originally developed for the midwest, SRS research emphasized the modification of these metrics to accurately characterize streams in the upper coastal region of South Carolina (Paller et al. 1996). The modified IBI consisted of 10 fish community variables: four species richness variables (total number of species, number of cyprinid species, number of darter [*Etheostoma*] species, and number of madtom [*Noturus*] species), two species composition variables (percent sunfish, primarily *Lepomis*, and percent Cyprinidae), three trophic composition variables (percent omnivores, percent specialized insectivores, and percent generalized insectivores), and a percent tolerance variable (Table 6-13). The modified IBI accurately discriminated among undisturbed and several types of disturbed streams on and near the SRS (Paller et al. 1996).

When assessing streams, sample unit size and level of effort must be matched to the needs of the study. Paller et al. (1996) found that sampling a stream reach of 150 m (492 ft) gave results with good precision, even if the reach was sampled with only one electrofishing pass. In contrast, a 50-m (164-ft) reach yielded results with poor precision, even with multiple passes. Sample lengths of 50 m (164-ft) provide only a general indication of biotic integrity in Sand Hill streams while sample lengths of 150 m (492 ft) often will yield a sample that is representative and accurate enough for most purposes.

Like the HDMI, the IBI has been used to assess stream health as part of the instream biological assessment of NPDES point source discharge program and the Integrator Operable Unit (IOU) assessment program conducted by the SRS Environmental Restoration Department.

Table 6-13. Metrics and scoring criteria used in the modified Index of Biotic Integrity (IBI)

Metrics	Scoring Criteria		
	1	**3**	**5**
Species richness			
Percentage of expected number of total species (TSP)[a]	<70	70-90	>90
Percentage of expected number of native minnow species (CSP)[a]	<55	55-80	>80
Percentage of expected number of piscivorous species (PSP)[a]	<65	65-85	>85
Percentage of expected number of madtom and darter species (BSP)[a]	<55	55-80	>80
Species composition			
Percent native minnows	<20	20-35	>35
Percent sunfish	<5 and >45	25-45	5-24
Trophic composition			
Percent generalized insectivores	>75	50-75	<50
Local indicator species			
Percent tolerant fish	>15	5-15	<5
Fish abundance (Number/100 m^2)			
Stream orders 1-3, ≥4 passes[b]	<25		≥25
Stream orders 1-3, 1 pass	<10		≥10
Stream order 4, ≥4 passes	<5		≥5
Stream order 4, 1 pass	<2		≥2
Fish condition			
Percent with disease or anomalies	>5	2-5	<2

[a] Percentage determined on the basis of sample site surface area and sampling effort (Paller et al. 1996)

[b] Passes refer to number of electrofishing passes through the sample reach

6.5.3 Other Rapid Bioassessment Initiatives on the SRS

Stream bioassessments are usually based on a single taxonomic assemblage with the assumption that this assemblage is representative of ecological conditions. However, ecological and physiological differences between taxonomic groups may result in different assessment results. The simultaneous collection of fish and benthic macroinvertebrate data from SRS streams on several occasions permitted a comparison of the response of both taxonomic groups to various stressors and an evaluation of the advantages of using both groups together. The IBI and HDMI were compared on the basis of precision, sensitivity, accuracy, and agreement (Paller 2001). The IBI was more precise than the HDMI, but the average difference between disturbed and reference sites was greater for the HDMI, resulting in equal sensitivity (i.e., ability to measure disturbance in relation to index variability). The IBI and HDMI were significantly correlated, but agreement between indices was weak for slightly and moderately disturbed sites. Analysis of species richness and abundance data indicated that fish and macroinvertebrates responded differently to some disturbances regardless of whether macroinvertebrates were collected from Hester-Dendy samplers or natural substrates. Disagreement between macroinvertebrate and fish assessments at moderately disturbed sites indicated that biological condition could not always be adequately evaluated from a single taxonomic group. Identification of disturbed sites was most accurate when based on both the HDMI and IBI suggesting the importance of using both taxonomic groups.

Although bioassessment was originally developed for streams, multimetric indices and other bioassessment protocols are now being developed for other types of aquatic ecosystems. SRNL scientists recently investigated the application of bioassessment to slope wetlands, which occur where groundwater emerges from hillsides to create shallow pools (Paller et al. 2005). Slope wetlands are the initial point of contact between biota and emerging contaminated groundwater. Slope wetlands that received contaminated groundwater from the F and H Area seepage basins were compared to undisturbed slope wetlands on the SRS. All of the wetlands supported a variety of insects and other invertebrates, especially midge larvae and other Diptera, annelid worms, and aquatic beetles, and some supported mites, copepods, and salamanders. Many of these organisms were tolerant of harsh conditions such as low dissolved oxygen and low pH. Assemblage composition varied among wetlands due to differences in hydroperiod and likelihood of being flooded by nearby streams. Also important was the lack of shading in some disturbed wetlands, which permitted the growth of filamentous algae, sphagnum moss, and other plants. Multivariate analysis of taxonomic data appeared to be useful for assessing natural slope wetland variability and discriminating this from more extreme variations indicating disturbance.

6.6 AQUATIC MERCURY STUDY

In February 2000, EPA Region 4 issued a proposed Total Maximum Daily Load (TMDL) for mercury in the middle and lower Savannah River. The TMDL, which would have imposed a 1 ng/l mercury limit for discharges to the middle/lower Savannah River, was revised to 2.8 ng/l in the final TMDL released in February 2001. Because of the environmental and economic significance of the mercury discharge limits imposed by the TMDL, the SRS initiated several studies concerning: 1) mercury in Savannah River Site streams and the Savannah River, 2) mercury bioaccumulation factors for Savannah River fish, 3) the influence of mercury from tributary streams on clams in the Savannah River, and 4) atmospheric mercury deposition.

The first study documented the occurrence, distribution and variation of total and methylmercury at SRS industrial outfalls, principal SRS streams and the Savannah River where it borders the SRS. All of the analyses were performed using the U. S. EPA Method 1630/31 ultra low-level and contaminant-free techniques for measuring total and methylmercury. Total mercury at NPDES outfalls ranged from 0.31 - 604.00 ng/l with a mean of 8.71 ng/l (Table 6-14). Mercury-contaminated groundwater was the source at outfalls with significantly elevated mercury concentrations. Total mercury in SRS streams ranged from 0.95 – 15.71 ng/l (Table 6-15). Mean total mercury levels in the streams varied from 2.39 ng/l in Pen Branch to 5.26 ng/l in Tims Branch. Methylmercury ranged from 0.002 ng/l in Upper Three Runs to 2.601 ng/l in Tims Branch (Table 6-15). Total mercury in the Savannah River ranged from 0.62 ng/l to 43.94 ng/l, and methylmercury ranged from 0.036 ng/l to 0.934 ng/l (Table 6-16). Both total and methylmercury concentrations were consistently high in the river near the mouth of Steel Creek. Total mercury was positively correlated with methylmercury (r = 0.70). Total mercury, bound to particulates ranged from 46% to 57% in the river and from 27.9% to 89.9% in the streams. Particulate methylmercury varied widely from 6.4% to 78.7%. Small temporary pools in the swamp area near and around Fourmile Branch had the highest concentrations observed in the Savannah River watershed. Total mercury in these pools reached 1890 ng/l, and methylmercury reached 34.0 ng/l (Table 6-17).

Table 6-14. Total Mercury Concentrations (ng/l) at SRS NPDES Outfalls. Samples Collected from August 1999 through September 2002

Outfall	No. of Samples	Minimum	Maximum	Mean
A-01	6	7.2	96.9	46.6
A-1A[a]	7	103.0	186.0	139.4
A-11	8	16.8	37.6	27.4
D-1A	5	9.9	107.0	54.1
F-01	5	0.6	2.6	1.3
F-02	5	3.6	7.4	4.7
F-05	5	26.5	51.3	36.3
F-08	9	1.2	10.4	3.2
G-10	7	6.4	73.7	21.7
H-02	6	6.4	8.5	7.1
H-04	3	1.1	8.0	4.1
H-07	1	7.4	7.4	7.4
H-08	6	1.1	6.6	3.5
H-12	6	2.6	6.4	4.4
H-16	2	5.7	6.6	6.2
K-04	3	8.0	24.4	16.7
K-06	3	2.3	9.8	6.0
K-12	5	3.7	16.6	7.5
K-18	6	0.9	1.7	1.3
L-07	8	1.5	6.0	2.7
L-07A	5	21.7	77.8	42.8
L-08	3	0.6	3.3	1.8
M-05[b]	6	54.1	169.0	105.1
PP-1	2	0.3	28.5	14.4
S-04	5	1.2	8.9	4.6
X-04	4	15.3	190.9	101.5
X-08	7	101.1	436.0	194.5
X-08A[c]	5	18.8	52.1	33.7
X-08B[c]	3	36.8	121.0	84.0
X-08C[c]	4	319.0	604.0	443.2

[a] flows to A-01 outfall
[b] flows to A-11 outfall
[c] flows to X-08 outfall

Table 6-15. Total Mercury and Methylmercury (ng/l) in SRS Streams

Location	Total Mercury					Methylmercury			
	Min.	Max.	Mean	Std. Dev.		Min.	Max.	Mean	Std. Dev.
Tims Branch at Steeds Pond	1.73	8.45	4.56	2.70		0.024	0.362	0.213	0.116
Tims Branch at swamp	3.41	9.54	5.26	2.19		0.159	2.601	1.048	0.731
Beaver Dam Creek at 400D	2.12	4.87	3.24	1.13		0.056	0.133	0.087	0.034
Upper Three Runs at Tyler Creek Bridge	1.37	9.40	3.50	2.34		0.002	0.255	0.123	0.078
Upper Three Runs at Rd. C	1.09	8.86	2.93	3.33		0.066	0.256	0.136	0.072
Upper Three Runs at Rt. 125	1.35	15.71	3.65	4.24		0.077	0.233	0.130	0.043
Fourmile Branch at swamp	2.03	8.52	3.95	1.90		0.039	1.500	0.400	0.456
Fourmile Branch at Rd. C	1.68	7.80	3.87	1.97		0.010	0.726	0.357	0.257
Fourmile Branch at Rt. 125	0.95	5.96	2.88	1.59		0.007	0.293	0.135	0.100
Pen Branch at Rt. 125	1.65	4.48	2.39	1.18		0.114	0.438	0.242	0.120
Pen Branch at Rt. 13.2	1.74	10.10	3.29	2.46		0.084	0.393	0.185	0.092
Meyers Branch at Rd. 9	1.47	8.40	3.81	2.76		0.117	0.886	0.419	0.368
Steel Creek at Rt. 125	1.93	4.27	2.88	0.82		0.116	0.700	0.289	0.200
Lower Three Runs at Patterson Mill Rd.	1.82	13.30	4.29	3.84		0.099	0.675	0.272	0.196

Table 6-16. Total Mercury and Methylmercury (ng/l) in the Savannah River near SRS Stream Mouths

Location	Total Mercury					Methylmercury			
	Minimum	Maximum	Mean	Std. Dev.		Minimum	Maximum	Mean	Std. Dev.
Above Upper Three Runs	1.91	3.26	2.62	0.44		0.036	0.141	0.082	0.036
At Upper Three Runs	1.04	7.36	2.71	1.70		0.063	0.357	0.176	0.102
Below Upper Three Runs	1.41	9.62	3.05	1.79		0.042	0.154	0.090	0.033
At Beaver Dam Creek	2.86	5.90	4.48	0.89		0.074	0.160	0.115	0.031
Below Beaver Dam Creek	1.38	3.67	2.40	0.53		0.041	0.119	0.077	0.030
At Fourmile Branch	1.78	10.16	3.81	2.08		0.055	0.599	0.180	0.165
Below Fourmile Branch	1.93	3.70	2.51	0.46		0.043	0.415	0.102	0.094
At Steel Creek	0.62	10.20	2.68	2.47		0.072	0.934	0.220	0.234
Below Steel Creek	1.79	5.85	3.00	1.08		0.040	0.246	0.089	0.053
At Lower Three Runs	0.96	3.74	2.44	0.88		0.092	0.735	0.272	0.196
Below Lower Three Runs	1.94	9.65	3.18	1.79		0.037	0.191	0.090	0.052

Table 6-17. Total and Methylmercury Concentrations from Small Shallow Pools in the Fourmile Branch Swamp, Savannah River Site, July 10 and 11 and August 1, 2001.

Transect Number	Total Mercury (ng/l)	Methylmercury (ng/l)
1	74.20	1.54
1	118.00	1.95
1	4.77	0.19
1	1.93	0.17
1	708.00	1.58
1	402.00	1.54
2	9.73	7.03
2	13.20	8.15
2	57.80	21.00
2	55.20	21.60
2	12.10	4.53
2	15.90	4.29
2	641.00	31.40
2	440.00	34.70
2	4.83	0.21
2	1.98	0.17
3	9.89	1.71
3	1890.00	10.91
3	96.40	2.15
3	2.73	0.62

A mercury bioaccumulation factor (BAF) is the ratio of the concentration of mercury in fish flesh to the concentration of mercury in the water. BAFs are important in the TMDL process because target concentrations for mercury in water are computed from BAFs. Mercury BAFs are known to differ substantially among fish species, water bodies, and possibly seasons. Knowledge of such variation is needed to determine a BAF that accurately represents average and extreme conditions in the water body under study. Analysis of fish tissue and aqueous methyl mercury samples collected at a number of locations and over several seasons in a 118 km reach of the Savannah River demonstrated that BAFs for each species under study varied by factors of three to eight. Influences on BAF variability were location, habitat and season related differences in fish mercury levels and seasonal differences in methyl mercury levels in the water. Overall (all locations, habitats, and seasons) average BAFs were 3.7 x 106 for largemouth bass, 1.4 x 106 for sunfishes, and 2.5 x 106 for white catfish (Figure 6-1). This study showed that determination of representative BAFs for large rivers requires the collection of large numbers of fish and aqueous methyl mercury samples over at least one complete seasonal cycle from the entire area and all habitats to be represented by the TMDL.

The third study examined the potential for using clams as an integrating biological monitor to assess mercury sources. This issue was investigated by comparing mercury levels in Asiatic clams (*Corbicula fluminea*) collected upstream from and downstream from mouths of SRS creeks and two creeks located downstream from the SRS. Asiatic clams were selected for study because their relatively sedentary behavior made them a better indicator of local mercury exposure than mobile organisms. Mercury concentrations in Asiatic clams collected from the discharge plumes of the Savannah River creeks (0.044 ug/g wet weight) were approximately 2.5 times higher than in clams collected from the Savannah River upstream from the creek mouths (0.017 µg/g wet weight). This pattern was observed for both SRS and offsite creeks (Figure 6-2). High mercury concentrations in the clams were apparently the result of elevated methylmercury levels in the creeks (0.170 ng/l), which were nearly twice as high as in the Savannah River (0.085 ng/l). All of the tributaries drained extensive wetlands that would be expected to support comparatively high rates of methylation.

The findings of the Asiatic clam study together with the finding of strongly elevated mercury levels in Fourmile Branch swamp water in the first study suggest that the floodplain swamps along the Savannah River may be important sources of methylmercury. Apart from this study, little research has been conducted on the production of methylmercury in southeastern floodplain swamps and its transport to river ecosystems.

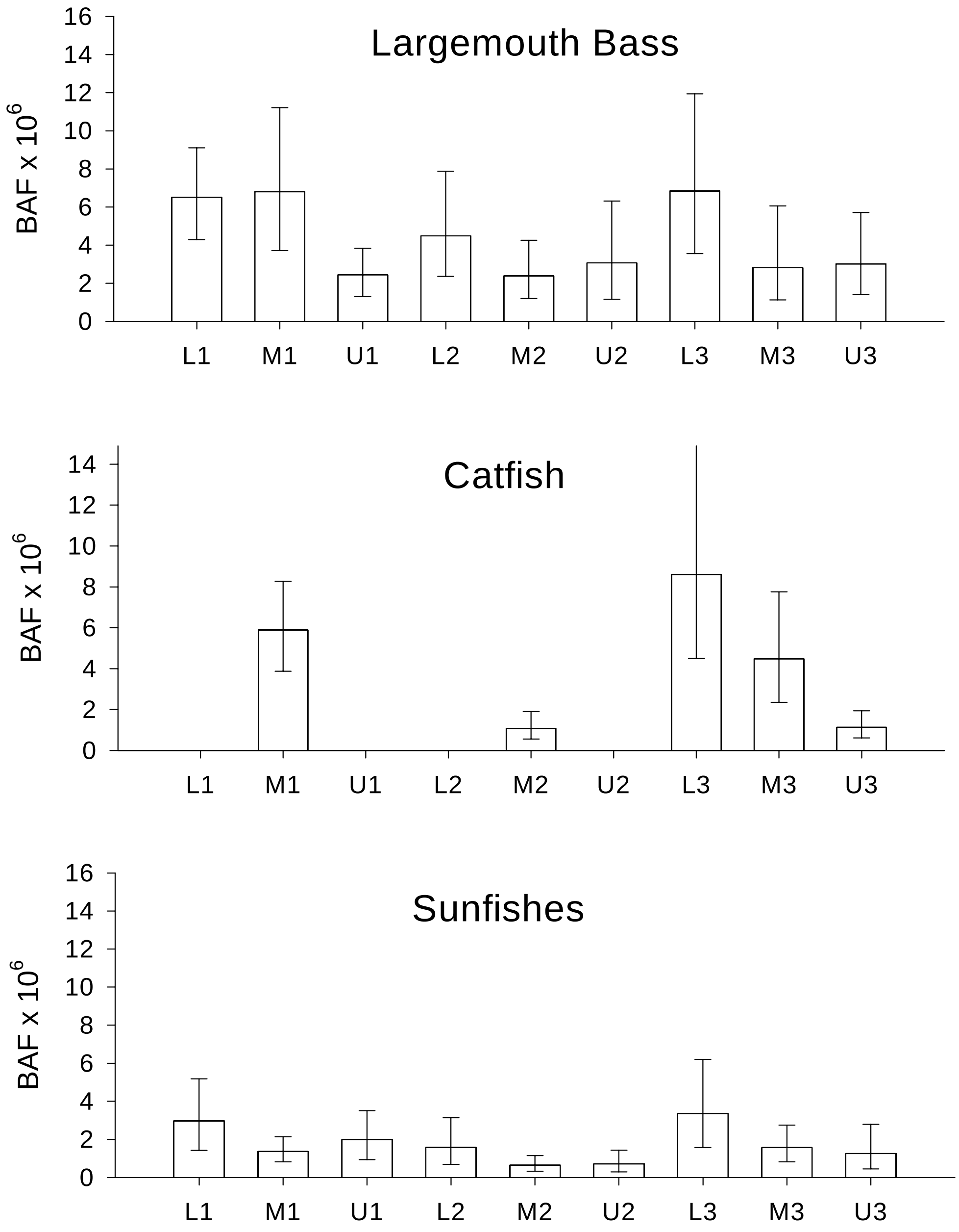

Figure 6-1. Average Mercury Bioaccumulation Factors (95% confidence intervals) for the lower (L), middle (M), and upper (U) Savannah River. Error bars represent standard errors.

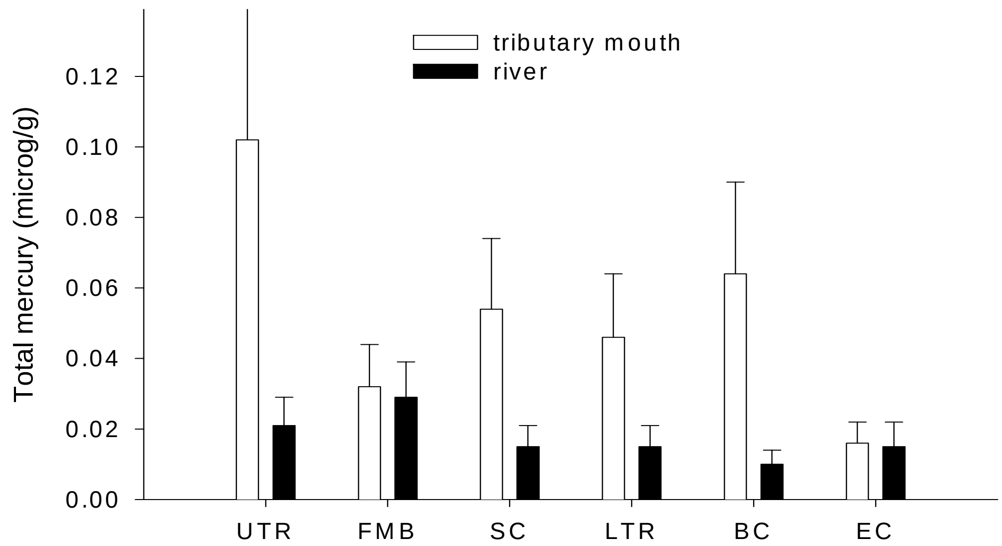

Figure 6-2. Geometric Mean Mercury Levels in Corbicula fluminea Collected from Six Savannah River Tributaries and Six Savannah River Sites Located Just Upstream from Each of the Tributaries

UTR = Upper Three Runs
FM = Fourmile Branch
SC = Steel Creek
LTR = Lower Three Runs
BC = Brier Creek
EC = Ebenezer Creek

Error bars represent 95% confidence intervals

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APPENDIX A
ACRONYMS, UNITS OF MEASURE, GLOSSARY

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ACRONYMS

ADH	alcohol hydrogenase
AFDW	ash-free dry weight
ANSP	Academy of Natural Sciences of Philadelphia
BGC	Burial Ground Complex
CCWS	Comprehensive Cooling Water Study
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
COE	U.S. Army Corps of Engineers
cms	cubic meter(s) per second
CSRA	Central Savannah River Area
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DWPF	Defense Waste Processing Facility
EAS	Environmental Analytical Section
EMS	Environmental Monitoring Section
EPA	U.S. Environmental Protection Agency
gdm	grams dry mass (grams dry weight)
RKm	River Kilometer
msl	mean sea level
MSS	multispectral scanner
MWMF	Mixed Waste Management Facility
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NTS	Nonproliferation Technology Section
NTU	Nephelometric Turbidity Units
RCRA	Resource Conservation and Recovery Act
RM	River Mile
SCDHEC	South Carolina Department of Health and Environmental Control
SCDNR	South Carolina Department of Natural Resources
SCWMRD	South Carolina Wildlife and Marine Resources Department
SREL	Savannah River Ecology Laboratory
SRS	Savannah River Site
SRFS	Savannah River Forest Station
SRNL	Savannah River National Laboratory
SWDF	Solid Waste Disposal Facility
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WSRC	Westinghouse Savannah River Company

UNITS OF MEASURE

Ci	curie
cm	centimeter
ft	feet
ft2	square feet
ft3	cubic feet
fCi	femtoCurie (10-15 curie)
g	gram
ha	hectare
ha2	square hectare
in	inch
kg	kilogram
km	kilometer
km2	square kilometer
l	liter
m	meter
m2	meter square
m3	cubic meters
meq	milliequivalent; 1/1000 of a compounds’ or an element’s equivalent weight
mg	milligram
mi	mile
ml	milliliter
mm	millimeter
mV	millivolt; a unit of potential difference equal to 1/1000 of a volt
ppb	parts per billion
ppm	parts per million
pCi	picoCurie (10-12 Curie)
µg	microgram (10-6 gram)
µS/cm	micro Seimens per centimeter; a measure of conductivity or the ratio of electric current density to the electric field in the medium

GLOSSARY

7Q10 - the expected lowest flow averaged over seven consecutive days in a 10 year period

abiotic - referring to the nonliving components of an ecosystem

aestivate - to become dormant or torpid

aestivation - the condition of dormancy or torpidity

alcohol dehydrogenase -a plant enzyme

anadromous - said of fish, such as shad or sturgeon, that ascend freshwater rivers from the ocean to spawn

anoxia - a lack of oxygen to or in living tissue

anoxic - oxygen-depleted

anuran - refers to animals in the order Anura in the Class Amphibia; specifically frogs and toads

apices - the growing tip of a stem or root

argillic horizon - argillic refers to clay and horizon is a layer of soil; ergo, a layer of clay in the soil

benthic - pertaining to, or living in or on the substrate at the bottom of a body of water

biomass - the mass of living matter

biotic index - a measure of the living community; there can be many kinds of indices composed of many different variables

bivalve - the common name for a number of bilaterally symmetrical organisms having a soft body enclosed in a calcareous two-part shell (clams and oysters for example)

braided stream - a stream with many small channels and no single main channel

canonical discriminant analysis - a way to mathematically express the similarity of independent units

canopy -the collective name for the crowns of the tallest trees in a forest

clutch - a nest of eggs or a brood of young

commensal - describing an interspecific, symbiotic relationship in which two different species are associated; one is benefited and neither is harmed

conductivity -the ratio of electric current density to the electric field in a material

cove rotenone - a method of sampling fish in a small area

curie (Ci) - a unit of radioactivity; that quantity of nuclear material that has 3.700×10^{10} disintegrations per second

deltaic - referring to an alluvial deposit, usually triangular in shape at the mouth of a river or stream

depauperate - inferiority of natural development or size; in this context, a depauperate community has few species

diel - refers to a 24-hour cycle

diurnal - active during daylight hours

dystrophic - pertaining to an environment that does not supply adequate nutrition

ectotherm - an animal that gets most of its heat from the environment (aka “cold-blooded”)

electrofishing - a sampling technique where an electric current is introduced into the water that stuns aquatic organisms, primarily fish

emergent - refers to plants such as cattails, that are rooted in an aquatic substrate, but grow above the water

endemic - peculiar to a particular region; the opposite of ubiquitous

endlap - in aerial photography refers to the amount of image repeated from one frame to the next

entrainment -the process whereby planktonic organisms or weak swimmers such as young fish are caught in a powerful current from which they cannot escape, and hence are swept into water intake structures

ephemeral -temporary; carrying or holding water only during or immediately after precipitation events

epilimnetic - refers to the epilimnion of a waterbody

epilimnion - a freshwater zone of relatively warm water in which mixing occurs as a result of wind action and convection currents; the epilimnion is the shallowest water in a lake and remains oxygenated (see hypolimnion)

eurythermal - tolerant of a wide range of temperatures

eutrophic - pertaining to a lake containing a high concentration of dissolved nutrients; often shallow, with periods of oxygen deficiency

eutrophication - the process by which a body of water becomes, either by natural means or through pollution, excessively rich in dissolved nutrients, resulting in increased primary productivity that often leads to a seasonal deficiency in oxygen

facultative - an organism that prefers or does best in one environment but can survive in others; a facultative wetland plant grows best in wetlands but will grow in dry places

fecundity - the innate potential reproductive capacity of an organism

fledged - refers to young birds’ newly acquired ability to fly

fledglings - young birds just learning to fly

forb - a broad-leaved herbaceous plant

freshet - a stream caused by heavy rains or snowmelt

fyke net - a type of net used to collect fish, consisting of several to many hoops, covered with a mesh, and wings of the mesh material that direct the fish into the opening of the net

genera - plural of genus which is a taxonomic category that includes groups of closely related species

geomorphology - the study of the origin of secondary topographic features which are carved by erosion of the primary elements and built up of erosional debris

gill net - a type of net used to collect fish where the fish swim into the net which is lowered through the water column and are trapped in the net's mesh by their gills

gonosomatic - reproductive tissue

graminoids - grasses

guilds - organisms grouped or associated due to a special mode of living (e.g., shorebirds)

hardpan - a secondary accumulation of calcareous material in layers in soil

hectare - a measure of area, 2.471 acres in size

herbivore -an animal that eats plants

herpetofauna - the term used to refer to reptiles and amphibians, collectively

Hester-Dendy multiplate sampler - a series of hardboard squares arrayed vertically along a central axis with established spacing between the squares; deployed in aquatic environments and colonized by aquatic macroinvertebrates

hoop net - yet another way to catch fish or turtles; similar in design to a fyke net but without the wings

hydric - characterized by or thriving in an abundance of moisture

hypolimnetic - referring to the hypolimnion of a lake

hypolimnion - the lower part of the water column in a stratified lake, characterized by a uniform temperature that is cooler then the epilimnion; may also have less oxygen than the epilimnion

ichthyofauna - larval fish

ichthyoplankton - larval fish

impingement -collection of debris by screens at water intakes; fish are also trapped on these screens

insectivorous - refers to animals that eat insects

invertebrate - an animal that does not have a backbone

isozymes - any of the electrophoretically distinct forms of an enzyme; having different polymeric states but performing the same functions

Jolly - a mark-multiple recapture model for estimating the size of population

lacustrine - belonging to or produced by lakes

land cover - the predominant vegetation type in an area

lentic - of or pertaining to still waters such as lakes and reservoirs

limnetic - of or pertaining to inhabiting the pelagic region of a lake

Lincoln index - a mark-recapture model for estimating the size of a population

littoral - of or pertaining to the biogeographic zone between the high and low water marks

lorica - a hard shell in certain invertebrates that functions as an exoskeleton

lotic -of or pertaining to swiftly moving waters

macrohabitat - an extensive habitat presenting considerable variation of the environment, containing a variety of ecological niches, and supporting a large number and variety of complex flora and fauna

macroinvertebrate - a large invertebrate; visible to the naked eye and collected by hand

macrophyte - an aquatic vascular plant, usually rooted in the littoral zone

macrozooplankton - the large zooplankton

malate dehydrogenase -a plant enzyme

maximum contaminant level (MDL) - a drinking water regulatory standard which is the maximum level of a contaminant which is not expected to cause adverse health effects over a lifetime of exposure and includes a margin of safety

meroplankton -plankton composed of floating developmental stages (eggs and larvae) of the benthos (bottom living) and nekton (free-swimming) organisms; temporary plankton

mesic - of or pertaining to a habitat characterized by a moderate amount of water

meso-eutrophic - moderately eutrophic

metamorphose -to change markedly structurally as an animal grows from an embryo to subadult or adult

methylation - a chemical process for introducing a methyl group (CH3—) into an organic compound; the process by which mercury is introduced into animals

microhabitat -a small, specialized and effectively isolated habitat

microzooplankton - the smaller classes of zooplankton

midstory - in a forest, trees with crowns below the canopy

monospecific -affecting or characterized by a single species

morphometry - measuring the structure of an organism

multispectral - describing the recording of images in more than the visible spectrum

obligate - restricted to a specified condition of life; an obligate wetland plant can not survive in other than a wetland

overstory -the top layer of leaves in a forest; also known as the canopy

oxic - relating to the presence of adequate oxygen

paedogenic - reproducing as a larvae; conversely, adults that retain juvenile characteristics

palustrine - being, living or thriving in a marsh

panchromatic - of a photographic film, emulsion or plate sensitive to all wavelengths in the visible spectrum

pelagic - pertaining to the open water in a body of water; beyond the outer limits of the littoral zone

peptones -a water-soluble mixture of proteoses and amino acids

perched water table - the upper surface of a body of perched water (groundwater that is unconfined and separated from an underlying main body of groundwater by an unsaturated zone); also known as apparent water table

periphyton – algae and other organisms attached to a substrate

phenological - pertaining to the local climate and seasonal changes

phenology - the science which studies periodic biological phenomena with relation to climate, especially seasonal changes

photointepretation - deciphering the images on aerial photographs

photogrammetry - the science of making accurate measurements and maps from aerial photographs

phytoplankton - planktonic algae, that is, algae that floats in the water columns

planktivorous - describing organisms that feed on plankton

ponar dredge - a device for the collection of benthic organisms; it consists of two metal jaws that are cocked open and shut on command to scoop up sediments

quadrat - a sampling plot

quiescent - inactive, latent, dormant, at rest

recruitment - when the young of a population become capable of reproduction

refugia - areas which provide conditions for relict populations to survive

revetment - a facing made on a soil or rock embankment to prevent scour by weather or water

riffle - a shallow area of stream bed over which water flows swiftly and is broken into waves by submerged obstructions

riparian - pertaining to a stream or riverbank

riverine - pertaining to a river

scalar -a single value or item; having magnitude only, no direction

sedge - a wetland plant

seed bank - the seeds that remain in the ground, and that, under the right conditions will germinate even years after the parent plant is gone

senesce - to die back

senescence - aging

Shannon-Weaver diversity -a mathematical measure of the diversity of a ecological community

sidelap - in aerial photography refers to the amount of image repeated from one flightline to the next

sp. - species singular

spp. - species plural

stoloniferous - having runners or horizontally growing adventitious roots

stump community - the plants and animals living on stumps, usually in wetland or aquatic systems

submergent - aquatic plants that do not grow on or above the water surface

synoptic - refers to the use of technical data obtained simultaneously over a wide area for the purpose of presenting a comprehensive picture of the atmosphere

taxa - the plural of taxon

taxon - a taxonomic group or entity; one of a hierarchy of levels in the biological classification scheme

thermocline - a temperature gradient in a body of water in which the temperature decrease with depth is greater than that of the overlying and underlying water; marks the transition between the epilimnion and hypolimnion

thermophilic - describing an organism that thrives at high temperatures

topographical relief -the natural features of a region, treated collectively

transect - to cut across; in this case describing a method of sampling vegetation or other biological communities by running a straight line through the community and sampling at designated points along the line or “transect”

trophic - pertaining to nutrition

unconsolidated sediments -loose or unstratified mud

understory - the trees that are naturally shorter than canopy trees

vertebrate - an animal with a backbone

xeric - of or pertaining to a habitat having a low or inadequate supply of moisture