# *5.8 Par Pond*

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# Drainage Description and Surface Hydrology

## General Description

Par Pond is a 1012-ha (2500 acre) reactor cooling reservoir that augmented the cooling requirements for P and R Reactors (Figure 5-93). 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). Table 5-171 describes the physical characteristics of Par Pond and Pond B. 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).

## 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

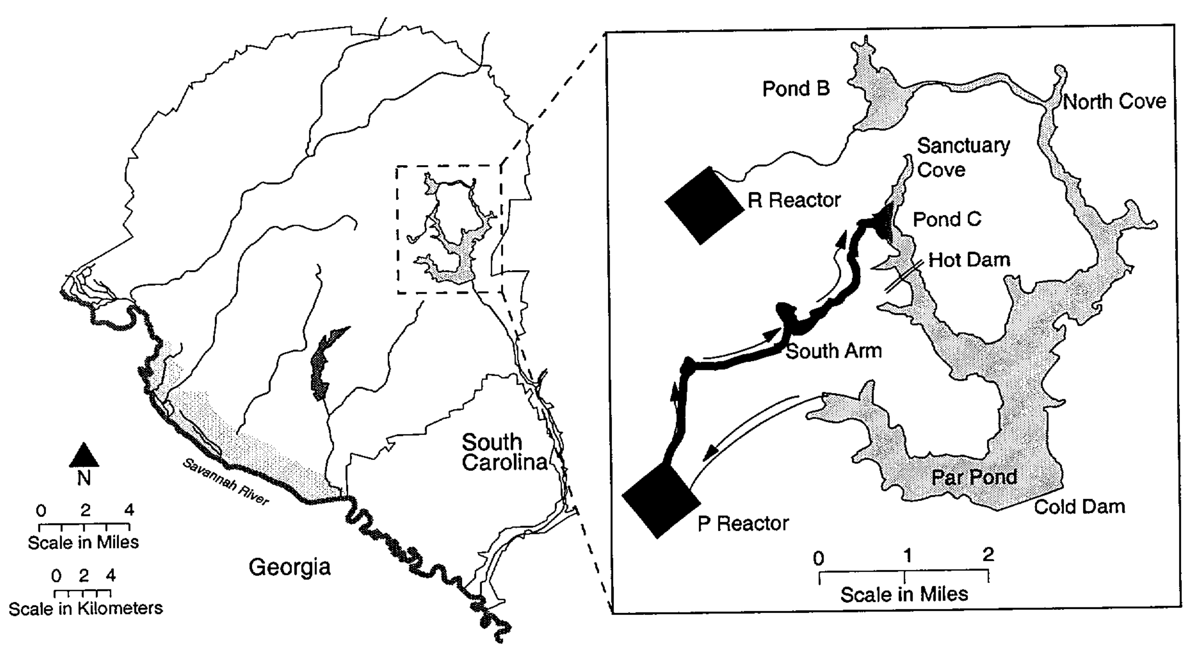


**Figure 5-93.** Location of Par Pond on SRS

**Table 5-171.** Physical Characteristics of Par Pond and Pond B

| Reservoir | Physiographic Province | Maximum Depth (m) | Mean Depth (m) | Surface Area ($km^2$) | Volume (x $10^8$ $m^3$) | Residence Time (days) | Shoreline Length (km) | Drainage Area ($km^2$) | Shoreline Development Ratio |
|---|---|---|---|---|---|---|---|---|---|
| Par Pond | Coastal Plain | 18 | 6.2 | 10.12 | 0.62 | 108.8 | 53 | 93 | 4.7 |
| Pond B | Coastal Plain | 12 | 4.2 | 0.81 | 0.034 | -- | 6.4 | -- | 2 |

Source: Bowers 1992.

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 5-93). 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 5-93).

## 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).

# Water Chemistry and Quality

## Studies and Monitoring

### 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 Comprehensive Cooling Water Study (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.

#### Comprehensive Cooling Water Study

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 5-94):

- 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)

| | Station Name |
|---|---|
| 01 | South Arm |
| 02 | near "bubble up" |
| 03 | Cold Dam |

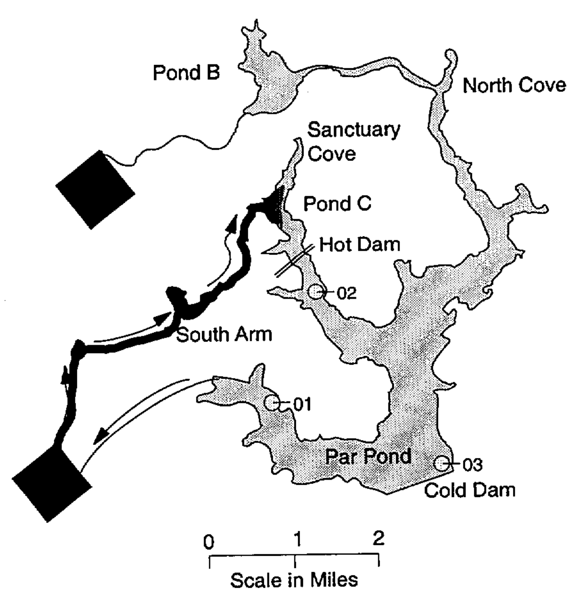


**Figure 5-94.** Location Map of Par Pond

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.

### Chemical Assessment Studies

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 5-94; point 03). These data reflect postreactor operation conditions.

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).

### Regional Lakes Study

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).

## Field Data

### Water Temperature

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 (Table 5-172). The mean water temperature of Par Pond during the L-Lake/Steel Creek Program (1985-1991) was 18.1°C (64.6°F) (Table 5-172). This difference reflects the cessation of thermal discharge into Par Pond associated with the shutdown of P Reactor in 1988.

### pH Measurements

The mean pH of Par Pond water during the CCWS ranged from 7.32 to 7.33 (Table 5-172). 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 (Table 5-172).

## Physical Characteristics and General Chemistry

### Dissolved Oxygen

During the CCWS, mean dissolved oxygen concentrations in Par Pond ranged from 6.44 to 8.20 mg/l (Table 5-173). 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 (Table 5-173).

**Table 5-172.** Par Pond Field Data

| | Water Temperature (°C) | pH |
|---|---|---|
| **Par Pond in South Arm near pumphouse intake (CCWS)[a]** | | |
| Mean | 21.5 | 7.32 |
| Range | 5.3 - 33.0 | 6.14 - 8.83 |
| Samples | 46 | 45 |
| **Par Pond "bubble-up" between Pond C and Hot Arm of Par Pond (CCWS)[a]** | | |
| Mean | 31.0 | 7.33 |
| Range | 14.8 - 43.0 | 6.75 - 8.23 |
| Samples | 46 | 46 |
| **Par Pond, 1985-1991[b]** | | |
| Mean | 18.1 | 6.33 |
| Range | 8.5 - 31 | 5.54 - 7.25 |
| Samples | 96 | 84 |

[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]Kretchmer and Chimney 1992.

**Table 5-173.** Par Pond Physical Characteristics and General Chemistry

| | Dissolved Oxygen (mg/l) | Specific Conductance (µS/cm) | Turbidity (NTU) | Total Suspended Solids (mg/l) |
|---|---|---|---|---|
| **Par Pond in South Arm near pumphouse intake (CCWS)[a]** | | | | |
| Mean | 8.20 | 62.9 | 3.4 | 3.65 |
| Range | 5.60 - 11.2 | 55.2 - 74.4 | 0.9 - 17.5 | 0.25 - 15.7 |
| Samples | 46 | 38 | 43 | 45 |
| **Par Pond "bubble-up" between Pond C and middle arm of Par Pond (CCWS)[a]** | | | | |
| Mean | 6.44 | 66.4 | 2.8 | 2.05 |
| Range | 3.50 - 10.4 | 57.0 - 77.0 | 0.55 - 23.3 | 0.25 - 14.1 |
| Samples | 46 | 38 | 43 | 43 |
| **Par Pond, 1985-1991[b]** | | | | |
| Mean | 6.01 | 70.0 | NA | 2.02 |
| Range | 0.02 - 11.6 | 46 - 126 | | 0 - 10 |
| Samples | 96 | 96 | | 96 |

NTU = Nephelometric turbidity units.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]Kretchmer and Chimney 1992.

### Suspended Solids and Turbidity

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 (Table 5-173). The mean suspended solids concentration in Par Pond during the L-Lake/Steel Creek Biological Monitoring Program was 2.02 mg/l (Table 5-173). In Par Pond, the mean turbidity ranged from 2.8 to 3.4 NTU during the CCWS.

### Conductivity

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) (Table 5-173).

## Major Anions and Cations

### Alkalinity, Chloride, and Sulfate

Table 5-174 shows alkalinity, chloride, and sulfate concentrations. 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).

### Calcium, Magnesium, Sodium, and Potassium

Table 5-175 summarizes calcium, magnesium, sodium, and potassium concentrations in Par Pond during the CCWS and the L-Lake/Steel Creek Biological Monitoring Program. 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.

### Aluminum, Iron, and Manganese

Table 5-175 summarizes the total concentrations of aluminum, iron, and manganese measured during the CCWS and the L-Lake/Steel Creek Program. 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.

## Nutrients

### Phosphorus

All measured forms of phosphorus generally indicated that Par Pond is phosphorus deficient relative to the waters of the Savannah River (Lower 1987). Table 5-176 summarizes concentrations of total phosphorus and total orthophosphate measured during the CCWS and the

**Table 5-174.** Par Pond Major Anions

| | Alkalinity ($mg\ CaCO_3/l$) | Chloride (mg/l) | Sulfate (mg/l) |
|---|---|---|---|
| **Par Pond in West Arm near pumphouse intake (CCWS)[a]** | | | |
| Mean | 14.5 | 6.05 | 4.90 |
| Range | 11.0 - 17.8 | 5.00 - 7.60 | 1.55 - 7.67 |
| Samples | 45 | 46 | 28 |
| **Par Pond "bubble-up" between Pond C and Middle Arm of Par Pond (CCWS)[a]** | | | |
| Mean | 15.6 | 6.28 | 5.12 |
| Range | 12.7 - 19.0 | 5.00 - 7.60 | 1.34 - 7.55 |
| Samples | 45 | | 28 |
| **Par Pond, 1985-1991[b]** | | | |
| Mean | 14.6 | 5.73 | 4.62 |
| Range | 6.73 - 40.3 | 3.52 - 8.0 | 3.6 - 7.8 |
| Samples | 96 | 28 | 28 |

[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]Kretchmer and Chimney 1992.

**Table 5-175.** Par Pond Major Cations (Total)

| | Calcium (mg/l) | Magnesium (mg/l) | Sodium (mg/l) | Potassium (mg/l) | Aluminum (mg/l) | Iron (mg/l) | Manganese (mg/l) |
|---|---|---|---|---|---|---|---|
| **Par Pond in South near pumphouse intake (CCWS)[a]** | | | | | | | |
| Mean | 3.58 | 1.05 | 5.24 | 0.799 | 0.287 | 0.382 | 0.041 |
| Range | 2.67 - 5.06 | 0.712 - 1.28 | 3.63 - 7.73 | <0.368 - 1.84 | <0.038 - 2.02 | <0.003 - 2.61 | <0.0004 - 0.152 |
| Samples | 38 | 39 | 39 | 39 | 39 | 39 | 16 |
| **Par Pond "bubble-up" between Pond C and Middle Arm of Par Pond (CCWS)[a]** | | | | | | | |
| Mean | 3.71 | 1.07 | 5.35 | 0.781 | 0.280 | 0.251 | 0.075 |
| Range | 0.006 - 6.02 | 0.001 - 1.24 | 0.017 - 7.43 | <0.368 - 1.86 | <0.038 - 2.38 | 0.015 - 1.05 | <0.0004 - 0.210 |
| Samples | 38 | 38 | 38 | 38 | 38 | 38 | 16 |
| **Par Pond, 1985-1991[b]** | | | | | | | |
| Mean | 3.42 | 0.84 | 6.15 | 1.04 | 0.032 | 0.517 | 0.251 |
| Range | 2.44 - 4.72 | 0.593 - 1.04 | 3.07 - 9.05 | 0.54 - 1.38 | 0.006 - 0.109 | 0.015 - 3.63 | 0.006 - 137 |
| Samples | 28 | 28 | 28 | 28 | 28 | 28 | 28 |

[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]Kretchmer and Chimney 1992.

**Table 5-176.** Par Pond Nutrients

| | Total Phosphorus (mg/l) | Total Ortho-phosphate (mg/l) | Organic Nitrogen (mg/l) | Total Kjeldhal Nitrogen (mg/l) | Ammonia (mg/l) | Nitrite (mg/l) | Nitrate (mg/l) |
|---|---|---|---|---|---|---|---|
| **Par Pond in South Arm near pumphouse intake (CCWS)[a]** | | | | | | | |
| Mean | 0.020 | 0.005 | 0.257 | 0.276 | 0.031 | 0.003 | 0.031 |
| Range | <0.010 - 0.085 | <0.001 - 0.026 | 0.025 - 0.906 | 0.020 - 0.920 | <0.005 - 0.321 | <0.001 - 0.009 | <0.001 - 0.128 |
| Samples | 45 | 39 | 45 | 46 | 46 | 44 | 43 |
| **Par Pond "bubble-up" between Pond C and Middle Arm of Par Pond (CCWS)[a]** | | | | | | | |
| Mean | 0.042 | 0.006 | 0.219 | 0.276 | 0.041 | 0.003 | 0.052 |
| Range | <0.010 - 0.692 | <0.001 - 0.026 | 0.030 - 0.657 | 0.020 - 0.920 | 0.012 - 0.281 | <0.001 - 0.005 | 0.003 - 0.163 |
| Samples | 45 | 40 | 44 | 46 | 46 | 44 | 43 |
| **Par Pond, 1985-1991[b]** | | | | | | | |
| Mean | 0.032 | 0.007 | NA | 0.302 | 0.046 | 0.003 | 0.073 |
| Range | 0.008 - 0.28 | 0 - 0.238 | | 0 - 1.03 | 0 - 0.891 | 0 - 0.026 | 0 - 0.385 |
| Samples | 1,000 | 999 | | 1,000 | 1,000 | 1,000 | 999 |

NA = Not analyzed.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]Kretchmer and Chimney 1992.

L-Lake/Steel Creek Program. 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.

### Nitrogen

Table 5-176 summarizes nitrogen concentrations for both the CCWS and the L-Lake/Steel Creek Program. 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.

## Trace Elements

Table 5-177 summarizes trace element concentrations measured in Par Pond during the CCWS. 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.

**Table 5-177.** Par Pond Trace Elements (Total)

| | Arsenic (μg/l) | Cadmium (μg/l) | Chromium (μg/l) | Copper (μg/l) | Lead (μg/l) | Nickel (μg/l) | Zinc (μg/l) |
|---|---|---|---|---|---|---|---|
| **Par Pond in South Arm near pumphouse intake (CCWS)[a]** | | | | | | | |
| Mean | 1.5 | 0.53 | 5.5 | 2.9 | 1.3 | 2.0 | 5.5 |
| Range | <0.4 - 5.7 | <0.04 - 2.70 | <0.4 - 51.0 | <0.4 - 9.3 | <0.4 - 6.7 | <0.4 - 6.0 | <0.4 - 29.2 |
| Samples | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| **Par Pond "bubble-up" between Pond C and Middle Arm of Par Pond (CCWS)[a]** | | | | | | | |
| Mean | 1.9 | 0.40 | 9.1 | 2.4 | 1.3 | 4.3 | 5.4 |
| Range | <0.4 - 15.0 | <0.04 - 1.90 | <0.4 - 93.0 | <0.4 - 6.6 | <0.4 - 3.9 | <0.4 - 28.1 | <0.4 - 31.0 |
| Samples | 16 | 16 | 16 | 16 | 16 | 16 | 16 |

[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).

## 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).

## 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.

## 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.

# Par Pond System Sediments

## 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 Wilke 1996a).

Mean concentrations of cesium-137 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 actinium-228, cobalt-60, lead-212, potassium-40, and thorium-234. These constituents had much lower concentrations than cesium-137 (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 cesium-137 occurred consistently and at levels well in excess of levels at control sites. The cesium-137 geometric mean concentration was 7.2 pCi/g; the maximum was 56.7 pCi/g. Cesium-137 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). Cesium-137 concentrations were higher in sediments with high organic content, and the patchy distribution of these sediments probably contributed to the patchy distribution of cesium-137 (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 cesium-137, promethium-146, plutonium-238, and zirconium-95 than the reference cores collected from Lake Marion and several SRS creeks (Koch et al. 1996a).

## 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 cobalt-60, cesium-137, europium-155, and americium-241. Cesium-137 was detected in all but four samples. Six samples had cobalt-60; one sample indicated the presence of europium-155; and one indicated the presence of americium-241 (Halverson and Noonkester 1996).

Cesium-137 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, cesium-137 ranged from 0.0569 pCi/g to 0.176 pCi/g. One location in Pond 2 had an americium-241 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 cesium-137, strontium-90, and plutonium. Studies indicated that, although there has been no input of cesium-137 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 cesium-137 in the surface sediments contradicts the findings of many studies of the cesium-137 deposited from weapons testing in the 1960s. Cesium-137 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 cesium-137 in the surface sediments in Pond B include the sorption of cesium-137 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 cesium-137 from the sediments during anoxia (approximately April to October of each year) and dispersed to the water column during turnover (November). Alternatively, cesium-137 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). Plutonium-239/240 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 plutonium-239/240 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 plutonium-239/240 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 cesium-137 and the only other radionuclide detected was cobalt-60.

The Pond C inventory of Cs-137 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 Cs-137 concentration observed for Pond C was 55 $\mu Ci/m^2$, which is about 10% higher than the maximum observed for Par Pond.

# Algae

## Phytoplankton

### Studies in the Par Pond System

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. 1985). 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.

### Taxonomic Groups Found In Par Pond

The 1995-1996 study (Wilde et al. 1997) identified 173 taxa. The 1984-1985 study (Chimney et al. 1985) 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) (Table 5-178). 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. 1985).

### 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. 1985). 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. (1985) 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.

### 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).

**Table 5-178.** Phytoplankton Taxa Collected from Par Pond during Monthly Sampling in 1995-1996, 1984-1985, and Quarterly Sampling in 1978

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| **Bacillariophyta** | | | |
| *Achnanthes linearis* | | x | x |
| *A. minutissima* | x | x | x |
| *Achnanthes* sp. | | x | |
| *Asterionella formosa* | x | x | x |
| *Atthea zachariasi* | x | x | x |
| *Caloneis bacillum* | | x | |
| *C. ventricosa* | | x | |
| *Caloneis* sp. | | | x |
| *Cyclotella pseudostelligera* | x | | |
| *C. stelligera* | x | x | x |
| *Cyclotella* sp. | x | x | x |
| *Cymbella lunata* | | x | |
| *C. microcephala* | x | | |
| *C. minuta* | | x | x |
| *Diploneis elliptica* | | x | |
| *Eunotia curvata* | x | x | |
| *E. dioden* | | x | |
| *E. flexuosa* | x | x | |
| *E. pectinalis* | x | x | x |
| *E. tenella* | x | | |
| *E. zazumensis* | x | x | |
| *Eunotia* sp. | | x | |
| *Fragilaria capucina* | x | x | |
| *F. crotonensis* | x | x | x |
| *F. vaucheriae* | x | x | |
| *Fragilaria* sp. | x | x | |
| *Frustrulla rhomboides* | | x | x |
| *F. vulgaris* | x | | |
| *Gomphonema acuminatum* | | x | |
| *G. clevei* | | x | |
| *G. gracile* | | x | x |
| *G. parvulum* | x | x | x |
| *Gomphonema sp.* | x | | |
| *Gyrosigma acuminatum* | | x | |
| *Gyrosigma* sp. | | x | |
| *Melosira ambigua* | x | x | x |
| *M. distans* | x | x | |
| *M. distans v. tenella* | | x | |
| *M. herzogii* | | x | |
| *M. granulata* | | x | x |
| *M. granulata v. angustissima* | | x | x |
| *M. italica* | | x | |
| *M. varians* | | x | |
| *Navicula capitata* | | x | |
| *N. cryptocephala* | | x | |
| *N. elginensis* | | x | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *N. gregaria* | x | | |
| *N. hustedtii* | | | x |
| *N. minima* | | x | |
| *N. pupula* | | x | |
| *N. radiosa* | | x | |
| *N. radiosa v. tenella* | | x | |
| *Navicula* sp. | x | x | x |
| *Nitzschia acicularis* | | x | x |
| *N. amphibia* | | x | x |
| *N. dissipata* | | | x |
| *N. frustulum* | x | | |
| *N. gracilis* | x | | |
| *N. holsetica* | | x | x |
| *N. intermedia* | | x | |
| *N. palea* | | x | x |
| *N. sigmoidea* | | x | |
| *Nitzchia* spp. | x | | |
| *Pinnularia aboujensis* | x | | |
| *P. biceps* | | x | |
| *P. major* | | x | |
| *Pinnularia* spp. | x | | |
| *Rhizosolenia eriensis* | x | x | x |
| *Rhizosolenia* sp. | | | x |
| *Stauroneis phoenicenteson* | | x | |
| *Stauroneis* sp. | | | x |
| *Surirella linearis* | | x | |
| *S. robusta* | | x | |
| *Surirella* sp. | | x | |
| *Synedra aeus* | x | | |
| *S. delicatissima* | x | x | x |
| *S. parasitica* | | x | |
| *S. planktonica* | x | x | x |
| *S. radians* | | x | |
| *S. rumpens* | x | x | x |
| *S. tenera* | x | x | |
| *S. ulna* | x | x | x |
| *S. vaucheriae* | | | x |
| *Synedra* sp. | | x | |
| *Tabellaria flocculosa* | | x | |
| *T. fenestrata* | x | | x |
| **Chlorophyta** | | | |
| *Actinastrum hantzschii* | | | x |
| *Ankistrodesmus convolutus* | x | | |
| *A. falcatus* | x | | x |
| *A. falcatus v. mirabilis* | | | x |
| *A. spiralis* | x | x | x |
| *Arthrodesmus maximum* | | x | |
| *A. octocornus* | | x | |
| *A. validus* | x | x | |
| *Arthrodesmus* sp. 1 | | x | x |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *Arthrodesmus* sp. 2 | | x | |
| *Botryococcus braunii* | | | x |
| *Carteria dissecta* | | x | |
| *C. globosa* | | x | |
| *Carteria* sp. 1 | | x | x |
| *Carteria* sp. | x | | |
| *Characium ambiguum* | | x | |
| *Characium* sp. 1 | x | x | |
| *Chlamydomonas* sp. 1 | x | x | x |
| *Chlamydomonas* sp. 2 | | x | |
| *Chlorogonium* sp. | | x | |
| *Closteriopsis longissima* | x | x | x |
| *Closteriopsis* sp. | | x | |
| *Closterium abruptum* | | x | |
| *C. acerosum* | | x | |
| *C. aciculare* | x | x | |
| *C. acutum* | x | x | |
| *C. dianae* | | x | |
| *C. gracile* | x | x | |
| *C. kuetzingii* | | x | |
| *C. parvulum* | | x | |
| *C. pseudodianae* | x | | |
| *C. venus* | | x | |
| *Closterium* sp. | | x | x |
| *Coelastrum cambricum* | | x | x |
| *C. microporum* | x | x | |
| *C. probascideum* | | x | x |
| *C. reticulatum* | | x | |
| *Cosmarium angulosum* | | x | |
| *C. biretum v. trigibberum* | | x | |
| *C. clepsydra* | | x | |
| *C. contractum* | | x | |
| *C. depressum* | x | x | |
| *C. granatum* | | x | |
| *C. impressulum* | | x | |
| *C. isthmium* | | x | |
| *C. protractum* | | x | |
| *C. pseudibroemei* | | x | |
| *C. reniforme* | | x | |
| *C. sexangulare* | | x | |
| *C. tenue* | x | x | |
| *C. tenue v. minus* | | x | |
| *C. vegnellii* | x | | |
| *Cosmarium* sp. | | x | x |
| *Cosmarium* spp. | | x | |
| *Crucigenia apiculata* | x | x | |
| *C. crucifera* | | x | |
| *C. irregularis* | | x | |
| *C. quadrata* | x | x | x |
| *C. tetrapedia* | x | x | x |
| *C. truncata* | | x | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *Desmidium aptogonum* | | x | |
| *D. baileyi* | | x | |
| *D. grevellii* | | x | |
| *Dictyosphaeium pulchellum* | x | x | x |
| *Elakatothrix gelatinosa* | | x | x |
| *E. viridis* | x | x | x |
| *Euastrum binale* | x | | |
| *E. denticulatum* | x | | |
| *E. ciastonii* | x | x | |
| *Eudorina elegans* | x | x | x |
| *Francia droescheri* | | | x |
| *F. ovalis* | x | x | x |
| *Gleocystis ampla* | | x | x |
| *G. gigas* | | x | x |
| *G. planktonica* | x | x | x |
| *G. vesiculosa* | | | x |
| *Golenkenia gigas* | | x | |
| *G. paucispina* | | x | |
| *G. radiata* | | x | x |
| *Gonatozygon brebissonii* | x | | x |
| *Gonium pectorale* | | x | x |
| *Kirchneriella contorta* | | x | |
| *K. lunata* | | x | |
| *K. lunaris* | x | x | |
| *K. obesa* | | x | |
| *K. subsolitaria* | | | x |
| *Lagerhemia chodatii* | | x | |
| *L. quadradiseta* | | | x |
| *L. subsola* | x | | |
| *Micratinium pusillum* | x | x | x |
| *Micrasterias muricata* | | x | |
| *M. radiata* | | x | |
| *Monoraphidium circinale* | x | | |
| *M. curvata* | x | | |
| *Mougeotia* sp. | x | x | x |
| *Nephrocytium acardhianum* | x | x | |
| *N. limneticum* | x | | |
| *Oedogonium* sp. | | x | |
| *Onychonema laeve v. micracanthum* | | x | |
| *Oocystis borgei* | | x | x |
| *O. lacustris* | | x | x |
| *O. parva* | x | x | |
| *O. pusilla* | | x | x |
| *O. submarina* | x | | |
| *Oocystis* sp. | x | | |
| *Palmella miniata* | x | | |
| *Pandorina charkowiensis* | x | | |
| *P. morum* | x | x | |
| *Pediastrum boryanum* | | | x |
| *P. duplex* | | x | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *P. tetras* | x | x | |
| *Phacatus lenticularis* | x | | |
| *Pleutrotaenium subcornulatum* | | x | |
| *P. tridentulum* | | | x |
| *Quadrigula chodatii* | x | | |
| *Q. closteriodes* | | x | |
| *Scenedesmus abundans* | | x | |
| *S. acuminatus* | | x | |
| *S. bernardi* | | x | |
| *S. bicaudatus* | x | | |
| *S. bijuga* | x | x | |
| *S. brasiliensis* | | x | |
| *S. brevispina* | | x | x |
| *S. denticulatus* | | | x |
| *S. dimorphus* | | x | x |
| *S. dispar* | x | | |
| *S. excavatum* | x | | |
| *S. insignis* | x | | |
| *S. intermedium* | | | x |
| *S. longiseta* | x | | |
| *S. longispina* | x | x | |
| *S. opoliensis* | x | x | x |
| *S. quadricauda* | x | x | x |
| *S. serratus* | x | | |
| *S. smithii* | x | | |
| *S. spinosus* | x | x | |
| *Scenedesmus* sp. | x | x | |
| *Schroderia judayi* | | x | |
| *S. setigera* | x | x | x |
| *Scourfieldii cordiformis* | | x | |
| *Selenastrum capricornutum* | | x | x |
| *S. gracile* | x | x | x |
| *S. minutum* | x | x | x |
| *Sorastrum americanum* | | x | |
| *S. spinulosum* | x | | |
| *Sphaerellopsis* sp. | | x | |
| *Sphaerocystis planktonica* | | x | |
| *S. schroeteri* | x | | |
| *Spirogyra* sp. | | x | |
| *Spondylosium leutkemuelleri* | | x | |
| *S. planum* | x | x | |
| *Staurastrum anatinum* | | x | |
| *S. apiculatum* | | x | |
| *S. chaetoceros* | | x | x |
| *S. cingulum* | x | | |
| *S. claviferum* | | x | |
| *S. clevei* | | x | |
| *S. curvatum* | | x | |
| *S. excavatum* | x | | |
| *S. gladiosum* | | x | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *S. gracile* | | x | |
| *S. hexacerum* | | | |
| *S. megacanthum* | x | x | |
| *S. micron* | | x | |
| *S. muticum* | x | | |
| *S. octoverrueosum* | x | | |
| *S. paradoxum* | | x | x |
| *S. pentacerum* | | x | |
| *S. pseudopelagicum* | x | | |
| *S. ravenellii* | | | x |
| *S. rotula* | | x | |
| *S. small* | | x | |
| *S. smithii* | | x | |
| *S. tetracerum* | x | x | |
| *Staurastrum* sp. 1 | | x | x |
| *Staurastrum* sp. 2 | | | x |
| *Tetraedron caudatum* | x | x | x |
| *T. constrictum* | | x | |
| *T. gracile* | x | x | x |
| *T. minimum* | x | x | x |
| *T. guadricuspidatum* | | x | |
| *T. nastatum* | x | | |
| *T. regulare* | | x | x |
| *T. staurogeniaeforme* | | | x |
| *T. trigonum* | x | x | x |
| *Tetraedron* sp. | | x | x |
| *Treubaria setigerum* | x | x | |
| *Ulothrix* sp. | | x | |
| Undetermined green flagellates | | | x |
| *Vaucheria* sp. | | x | |
| *Volvox aures* | | x | |
| *Westella botryoides* | | x | x |
| *W. linearis* | | x | |
| *Xanthidium antilopaeum* | | x | |
| *X. cristatum* | | x | x |
| *Xanthidium* sp. | | | x |
| *Zygnema* sp. | | x | |
| Unid. coccoid unicells 5-10 µm | | x | |
| Unid. coccoid unicells 11-15 µm | | x | |
| Unid. coccoid colony | | x | |
| **Chrysophyta** | | | |
| *Bitricia longspina* | x | | |
| *Bitrichia* sp. | x | x | |
| *Chromulina mikroplankton* | | x | |
| *C. minima* | | x | |
| *C. parvula* | | x | |
| *Chromulina* sp. 1 | | x | |
| *Chrysidalis* sp. 1 | x | | |
| *Chrysococcus* sp. 1 | x | | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *Chrysosphaerella longispina* | | x | |
| *Dinobryon bavaricum* | x | x | |
| *D. divergens* | x | x | x |
| *D. sertularia* | | x | |
| *Dinobryon* sp. | | x | |
| *Kephyrion ovale* | | x | |
| *Kephyrion* sp. | | x | |
| *Mallomonas acaroides* | | x | |
| *M. alpina* | | | x |
| *M. caudata* | x | x | x |
| *M. pseudocoronata* | | x | x |
| *M. tonsurata* | | x | x |
| *Mallomonas* sp. 1 | x | x | x |
| *Mallomonas* sp. 2 | | x | |
| *Mallomonas* spp. | | x | |
| *Ochromonas nonnos* | | x | |
| *Ochromonas* sp. | | x | |
| *Ophiocytium capitantum v. longispinum* | x | | x |
| *Synura caroliniana* | | x | |
| *S. petersenii* | | | x |
| *S. uvella* | | x | x |
| Unid. chrysophyte sp. 1 | | x | |
| Unid. chrysophyte sp. 2 | | x | |
| Unid. chrysophyte spp. | | x | |
| **Cryptophyta** | | | |
| *Cryptomonas caudata* | | x | |
| *C. curvata* | | x | |
| *C. erosa* | x | x | x |
| *C. marsonii* | | x | x |
| *Cryptomonas* sp. | | | x |
| *Rhodomonas minuta* | x | x | x |
| *Rhodomonas* sp. | | | x |
| **Cyanophyta** | | | |
| *Anabaena circinalis* | | x | |
| *A. planktonica* | | x | |
| *A. wisconsinense* | x | x | |
| *Anabaena* sp. | | x | x |
| *Anabaenopsis seriata* | x | | |
| *Anacystis* sp. | | | x |
| *Aphanizomenon flos-aquae* | x | x | |
| *Aphanocapsa elachista* | | x | |
| *A. elachista v. conferta* | | x | |
| *A. elachista v. planktonica* | | x | |
| *Aphanocapsa pulchra* | | x | |
| *A. rivularis* | | x | |
| *Aphanocapsa* sp. | | x | |
| *A. nidulans* | | x | |
| *Chroococcus dispersus* | x | x | |
| *C. lacustris* | | x | |
| *C. limneticus* | | x | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *C. minimus* | x | | |
| *Chroococcus* sp. | | | x |
| *Coelosphaerium kuetzingianum* | | x | |
| *C. naegelianum* | x | x | |
| *Dactylococcopsis fascicularis* | | | x |
| *Gloeothece linearis v. composita* | | x | |
| *Lyngbya aerugineo-caerulea* | x | | |
| *L. limnetica* | x | x | x |
| *Lyngbya* sp. | x | x | |
| *Mastigocladus laminosus* | | x | x |
| *Merismopedia tenuissima* | x | x | x |
| *Microcystis aeruginosa* | x | x | |
| *M. incerta* | | x | |
| *M. stagnalis* | | x | |
| *Oscillatoria amphibia* | x | x | |
| *O. angusta* | x | | |
| *O. formosa* | | x | |
| *O. geminata* | x | x | x |
| *O. limnetica* | x | | |
| *O. limosa* | | x | |
| *O. minnesotensis* | x | | |
| *O. nigra* | | x | |
| *O. splendida* | | x | |
| *O. tenuis* | | x | |
| *Oscillatoria* sp. | x | x | x |
| *Phormidium tenue* | x | | |
| *Phormidium* sp. 1 | | x | x |
| *Phormidium* spp. | | x | |
| *Spirulina major* | | x | x |
| *S. princeps* | | x | |
| *Spirulina* sp. | | x | |
| *Schizothrix* sp. | | x | x |
| *Tolypothrix* sp. | | x | |
| Unid. cyanophytes | x | x | |
| **Euglenophyta** | | | |
| *Euglena acus* | | x | |
| *E. gracilis* | | x | |
| *E. minuta* | x | x | x |
| *E. proxima* | | x | |
| *Euglena* sp. 1 | x | x | x |
| *Euglena* sp. 2 | | | x |
| *Lepocinclis* sp. | | x | |
| *Microglena cordiformis* | | x | |
| *Phacus acuminatus* | x | | |
| *P. monilatus* | | x | |
| *P. obicularis* | | x | |
| *P. suecicus* | | x | |
| *P. tortus* | | x | |
| *Phacus* sp. | | | x |
| *Trachelomonas armata* | | x | |
| *T. furcata* | | x | |

**Table 5-178. (cont)**

| Taxa | 1995-1996[a] | 1984-1985[b] | 1978[c] |
|---|---|---|---|
| *T. hispida* | x | x | |
| *T. horrida* | | | x |
| *T. oblonga* | x | x | |
| *T. volvocina* | x | x | |
| *Trachelomonas* sp. | x | x | |
| **Phytoflagellates** | | | |
| Unid. flagellate sp. 1 | | x | |
| Unid. flagellate sp. 2 | | x | |
| Unid. flagellate sp. 3 | | x | |
| Unid. flagellate sp. 5 | | x | |
| Unid. flagellate sp. 6 | | x | |
| Unid. flagellate sp. 7 | | x | |
| Unid. flagellate sp. 9 | | x | |
| Unid phytobiflagellate sp. 1 | | x | |
| Unid phytobiflagellate sp. 2 | | x | |
| **Pyrrhophyta** | | | |
| *Ceratium carolinianum* | | x | |
| *C. hirundinella* | | x | |
| *Glenodinium palustre* | | x | |
| *G. guadridens* | x | x | |
| *Glenodinium* sp. | | x | x |
| *Gymnodinium aeruginosum* | | x | |
| *G. excavatum* | | x | |
| *G. ordinatum* | x | x | |
| *G. palustre* | | x | |
| *Gymnodinium* sp. 1 | x | x | |
| *Gymnodinium* sp. 2 | x | x | |
| *Peridinium cinctum* | | x | |
| *P. cinctum v. tuberosum* | | x | |
| *P. inconspicuum* | x | x | |
| *P. pusillum* | | x | |
| *P. umbonatum* | | x | |
| *P. volzii* | x | | |
| *P. wisconsinense* | x | x | |
| *Peridinium* sp. | x | x | x |

[a]Wilde et al. 1997.
[b]Chimney et al. 1985.
[c]Wilde 1983.

### 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. (1985) included 128 of the 169 phytoplankton species identified by Wilde (1983) in a 1978 study (Table 5-178). Data from the study by Chimney et al. (1985) 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. (1985) 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.

## Periphyton

Wilde and Tilly (1985) conducted several studies of periphyton attached to glass slides at various locations in Par Pond. Table 5-179 is a species list containing the principal taxa observed in these studies. 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.

**Table 5-179.** Principal Periphyton Species Collected from Par Pond

**Bacillariophyta**
*Achnanthes affinis*
*Achnanthes lanceolata*
*Achnanthes minutissima*
*Anomoeoneis vitrea*
*Cyclotella pseudostelligera*
*Cyclotella stelligera*
*Cymbella delicatula*
*Cymbella microcephala*
*Cymbella minuta v. silesiaca*
*Fragilaria crotonensis*
*Fragilaria pinnata*
*Fragilaria vaucheriae*
*Gomphonema carolinense*
*Gomphonema grunowii*
*Gomphonema intricatum*
*Gomphonema parvuium*
*Gomphonema subccavatum*
*Melosira distans v. alpigena*
*Melosira granulata v. angustissima*
*Nitzschia frustulum*
*Nitzschia frustulum v. perminuta*
*Synedra delicatissima v. angustissima*
*Synedra minuscula*
*Synedra rumpens*
*Synedra tenera*
*Synedra ulna*
*Tabellaria fenestrata*
**Chlorophyta**
*Actinastrum hantschii*
*Ankistrodesmus falcatus*
*Arthrodesmus octocornis*
*Bulbochaeta* sp.
*Chlamydomonas* sp.
*Closterium cornu*
*Closterium* sp.
*Closterium venus*
*Cosmarium angulosum*
*Cosmarium asphaerosparum*
*Cosmarium bireme*
*Cosmarium bisphaericum*
*Cosmarium blyttii*
*Cosmarium circulare*
*Cosmarium comminsurale var crassum*
*Cosmarium dentatum*
*Cosmarium excavatum f. duplomajor*
*Cosmarium exiguum*
*Cosmarium goleritum*
*Cosmarium impressulum*
*Cosmarium margaritatum*
*Cosmarium pardalis*
*Cosmarium phaseolus*
*Cosmarium psuedoconnatum*
*Cosmarium schliephakeanum*
*Cosmarium* spp.
*Cosmarium subcrenatum*
*Cosmarium tenue*
*Dictyosphaerium pulchellum*
*Euastrum ciastonii*
*Euastrum denticulatum*
*Gonatozygon aculeatum*
*Gonatozygon brebissonii*
*Gonatozygon monotaenium*
*Mougeotia* sp.
*Oedogonium* sp.
*Oocystis borgei*
*Oscillatoria lutea*
*Oscillatoria princeps*
*Pandorina morum*
*Pediastrum duplex var recticulata*
*Pediastrum tetras var tetraedron*
*Pedidinium cinctum*
*Pedidinium excavatum*
*Pedidinium* sp.
*Pedidinium umbonatum*
*Scenedesmus armatus*
*Scenedesmus brasiliensis*
*Scenedesmus quadricanda*
*Sphaerocystis schroeteri*
*Spirogyra* sp.
*Spondylosium planium*
*Staurastrum chaetocero*
*Staurastrum clevei*
*Staurastrum dejectum*
*Staurastrum dickei*
*Staurastrum leptocladum*
*Staurastrum manfeldtii*
*Staurastrum margaritaceum*
*Staurastrum megacanthum*
*Staurastrum perundulatum*
*Staurastrum protectum*
*Staurastrum* sp.
*Staurastrum tetracerum*
*Staurastrum turgescen*
*Stigeoclonium flagelliferum*
*Stigeoclonium* sp.
*Xanthidium subhastiferum*
*Zygnema* sp.
**Cyanophyta**
*Agmenellum elegans*
*Amphidinium* sp.
*Anabaena circinalis*
*Anabaena* sp.
*Anacystis cyanea*
*Calothrix* sp.
*Gleocapsa* sp.
*Microcoleus* sp.
*Microcoleus vaginatus*
*Nostoc macorum*
*Nostoc* sp.
*Schizothrix arenaria*
*Schizothrix calcicola*
*Schizothrix* sp.
**Pyrrhophyta**
*Ceratium hirundinella*

Source: Wilde 1985.
[a]Identification made by the Academy of Natural Sciences of Philadelphia.

# Macrophytes

Par Pond aquatic macrophytes are not covered in this section but in Chapter 6—Wetlands and Carolina Bays of the SRS.

# Zooplankton

## 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).

## 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.

## 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.

## Group Densities

### Introduction

Figure 5-95 through Figure 5-98 illustrate the volumetric densities of each of the groups. Seasonal and annual fluctuations 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) as seen in Figure 5-95 and Figure 5-96 when compared to cladoceran and copepod densities.

### 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*.

### 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).

### 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.

### 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*.

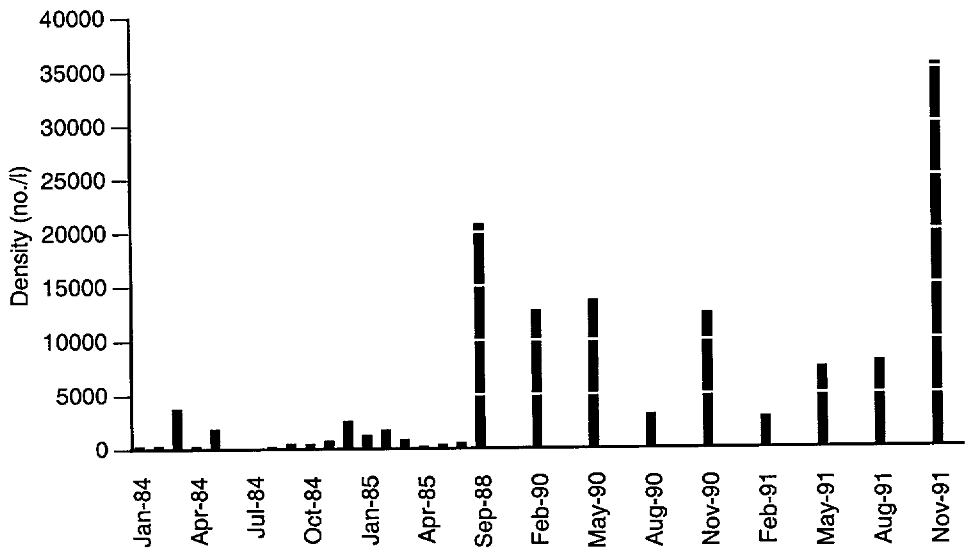


**Figure 5-95.** Mean Density of Protozoa in Par Pond (There is a difference in scale among this series of figures.)

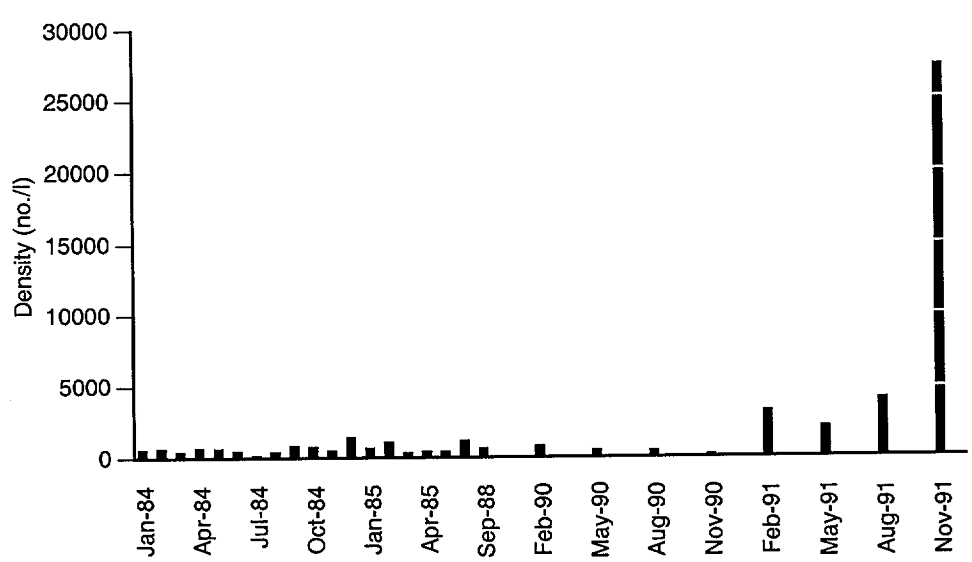


**Figure 5-96.** Mean Density of Rotifera in Par Pond

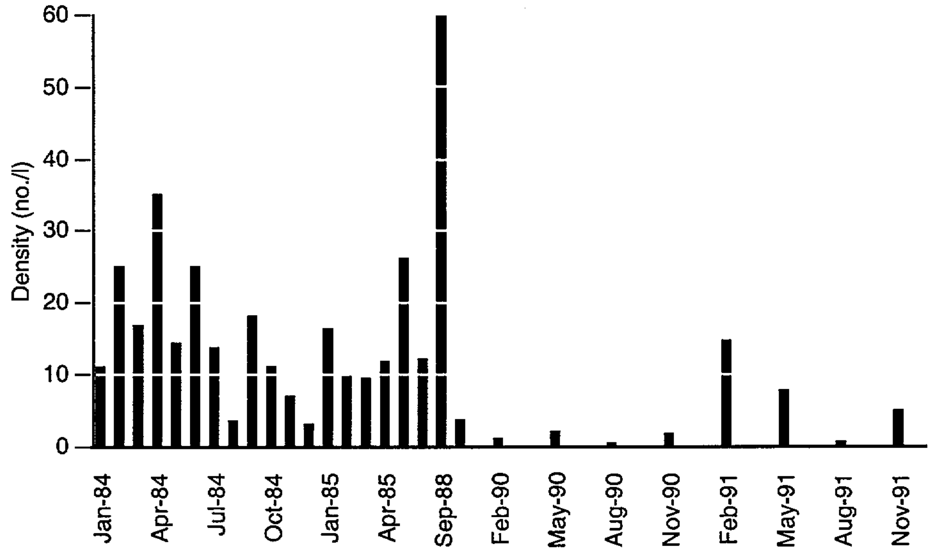


**Figure 5-97.** Mean Density of Cladocera in Par Pond

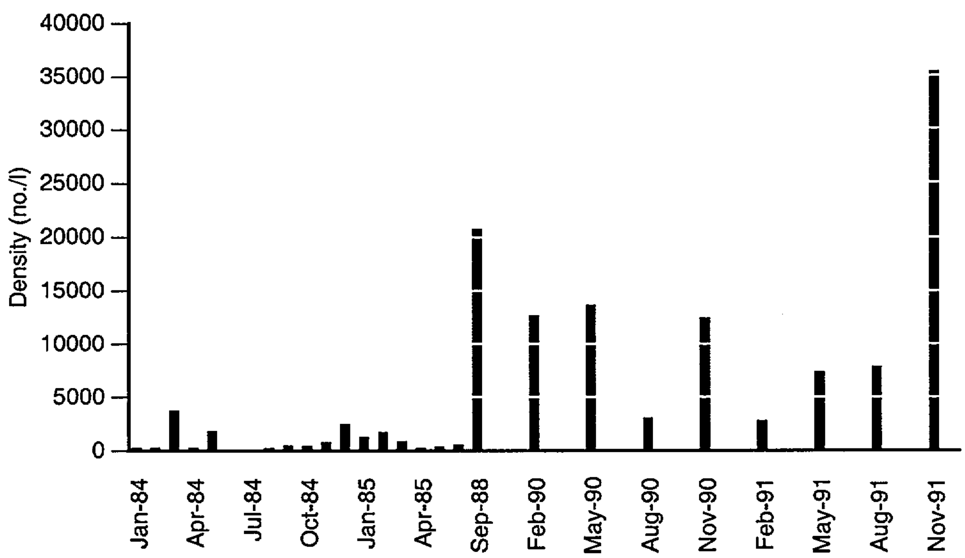


**Figure 5-98.** Mean Density of Copepoda in Par Pond

## 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 °C (113 °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).

# Macroinvertebrates

## Sampling Locations and Methods

From January 1984 through June 1985, benthic macroinvertebrates were sampled quarterly in four areas of Par Pond (Figure 5-99). 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).

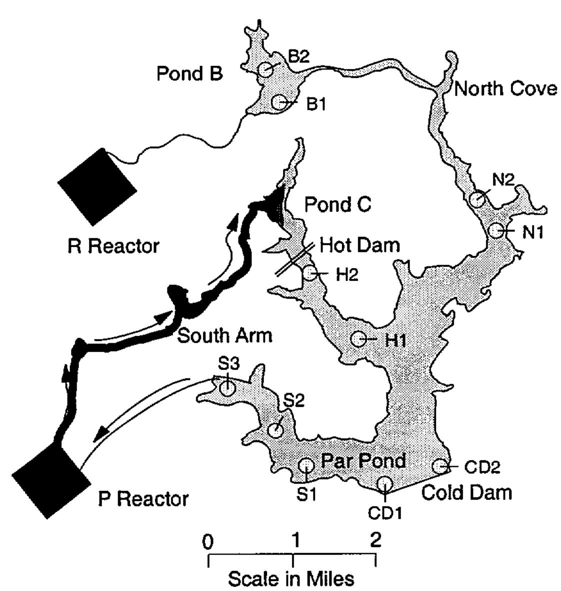


**Figure 5-99.** Macroinvertebrate Sampling Locations for Par Pond

## Results

### Number of Taxa Collected

At least 143 macroinvertebrate taxa were collected from Par Pond in 1984-1985 (Table 5-180) by all sampling methods. During the sampling in 1988 and 1989, 82 taxa were collected (Table 5-181). 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).

### 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 (Table 5-182). 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 (Table 5-183). 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 (Table 5-183). 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).

## 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 (Table 5-184). Mean species diversity was similar at all stations, ranging from 1.90 at the Cold Dam to 2.07 in the South Arm (Table 5-184). 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

**Table 5-180.** Macroinvertebrate Taxa Collected from Par Pond and Pond B, 1984-1985

| Scientific Name | Common Name | Location[a] | Sampling Method[b] |
|---|---|---|---|
| Phylum Coelenterata | | | |
| *Cordylophora lacustris* | | PP | M |
| *Craspedacusta sowerbyi* | | PP | M |
| *Hydra* sp. | hydra | PP, PB | M |
| Phylum Platyhelminthes | flatworms | | |
| Class Turbellaria | | | |
| *Dugesia tigrina* | | PP, PB | D, N, M |
| Phylum Aschelminthes | round worms | | |
| Class Nematoda | | | |
| unidentified spp. | | PP, PB | D, M |
| Phylum Annelida | | | |
| Class Oligochaeta | segmented worms | | |
| *Chaetogaster* sp. | | PB | M |
| *Nais* sp. | | PP, PB | M |
| *Stylaria lacustris* | | PP, PB | D, M |
| unidentified Naididae | | PP, PB | D, M |
| Class Hirudinea | leeches | | |
| unidentified spp. | | PP, PB | D, M |
| Phylum Mollusca | | | |
| Class Gastropoda | snails | | |
| *Amnicola limosa* | | PP | D, N, M |
| Ancylidae | | | |
| unidentified Ancyclidae | | PP | M |
| *Campeloma decisum* | | PP | D, M |
| *Ferrisia rivularis* | | PP | N, M |
| *Gyraulus parvus* | | PP | N, M |
| *Helisoma anceps* | | PP, PB | D, N, M |
| *Helisoma trivolvis* | | PP, PB | D, N, M |
| *Menetus dilitatus* | | PP, PB | D, N, M |
| *Physella heterostropha* | | PP, PB | D, N, M |
| *Pseudosuccinea columella* | | PP | N |
| Class Pelecypoda | clams | | |
| *Anodonta imbecillus* | | PP | N |
| *Corbicula fluminea* | | PP, PB | D, N, M |
| *Elliptio complanata* | | PP | M |
| Sphaeriidae | | | |
| Unidentified sphaeriidae | | PP, PB | D, N, M |
| Phylum Arthropoda | | | |
| Class Arachnoidea | | | |
| Order Hydracarina | water mites | | |
| *Albia* sp. | | PP, PB | D, M |
| *Arrenurus* sp. | | PP, PB | M |
| *Frontipoda americana* | | PP | M |

**Table 5-180. (cont)**

| Scientific Name | Common Name | Location[a] | Sampling Method[b] |
|---|---|---|---|
| Phylum Arthropoda | | | |
| *Hydrodroma despiciens* | | PP | M |
| *Koenikea* sp. | | PP | M |
| *Limnesia* sp. | | PP, PB | D, M |
| *Neumania* sp. | | PP, PB | M |
| *Piona* sp. | | PP, PB | M |
| *Unionicola* sp. | | PP, PB | D, M |
| unidentified sp. A | | PP | M |
| unidentified sp. C | | PP, PB | M |
| unidentified sp. D | | PP | M |
| unidentified spp. | | PP, PB | M |
| Class Crustacea | | | |
| Order Amphipoda | scuds | | |
| *Hyalella azteca* | | PP, PB | D, N, M |
| Order Isopoda | isopods | | |
| *Asellus* sp. | | PP | D, M |
| Order Ostracoda | seed shrimp | | |
| unidentified sp. A | | PP, PB | M |
| unidentified sp. B | | PP, PB | M |
| Order Decapoda | crayfish | | |
| *Procambarus* sp. | | PP | N, M |
| Class Insecta | | | |
| Order Collembola | springtails | | |
| *Isotomurus palustris* | | PP | M |
| Sminthuridae | | PB | N |
| unidentified spp. | | PP | D, M |
| Order Ephemeroptera | mayflies | | |
| *Baetis* spp. | | PP, PB | D, N, M |
| *Caenis diminuta* | | PP, PB | N |
| *Caenis* spp. | | PP, PB | D, N, M |
| *Callibaetis floridanus* | | PP, PB | N |
| *Callibaetis* sp. | | PP, PB | D, N, M |
| *Paraleptophlebia* sp. | | PB | N, M |
| *Stenonema* sp. | | PP | M |
| Order Odonata | dragonflies and damselflies | | |
| *Anax longipes* | | PP | N |
| *Aphylla williamsoni* | | PP | D, N, M |
| *Argia fumipennis* | | PP | M |
| *Argia* spp. | | PP, PB | N |
| *Basiaeschna janata* | | PP | N |
| *Brachymesia gravida* | | PP | N |
| *Celithemis fasciata* | | PP, PB | D, N |
| *Celithemis ornata* | | PP, PB | D, N |
| *Celithemis* sp. | | PP, PB | N, M |
| *Coryphaeschna ingens* | | PP | N, M |
| *Didymops transversa* | | PP | N |
| *Dromogomphus spinosus* | | PP | N |
| *Enallagma divagans* | | PP, PB | N, M |
| *Enallagma vesperum* | | PP | N, M |

**Table 5-180. (cont)**

| Scientific Name | Common Name | Location[a] | Sampling Method[b] |
|---|---|---|---|
| *Enallagma hageni* | | PP, PB | N, M |
| *Enallagma* sp. | | PP, PB | D, N, M |
| *Epiaeschna heros* | | PP | N |
| *Epicordulia princeps* | | PP | M |
| *Epicordulia regina* | | PP | N |
| *Erythemis simplicicollis* | | PP, PB | N |
| *Ischnura* spp. | | PP | M |
| Gomphidae | | | |
| *Gomphus exilis* | | PP, PB | N |
| *Ladona deplanata* | | PB | N |
| *Lestes vigilax* | | PP | D, N |
| *Lestes* sp. | | PP, PB | N, M |
| *Libellula auripennis* | | PP, PB | N |
| *Libellula axilena* | | PP, PB | N |
| *Libellula cyanea* | | PP, PB | N |
| *Libellula incesta* | | PP, PB | N |
| *Libellula* sp. | | PP | N |
| *Nehalennia* sp. | | PP | N |
| *Pachydiplax longipennis* | | PP, PB | D, N, M |
| *Perithemis tenera* | | PP | N, M |
| *Progomphus* prob. *obscurus* | | PP | N |
| *Tetragoneuria cynosura* | | PP, PB | D, N |
| *Tetragoneuria* sp. | | PP, PB | N, M |
| *Tramea carolina* | | PB | N |
| unidentified spp. | | PP | N |
| Order Hemiptera | true bugs | | |
| *Belostoma flumineum* | | PP | N |
| *Belostoma* sp. | | PP | D, N, M |
| *Merragata brunnea* | | PP | N |
| *Mesovelia mulsanti* | | PP, PB | D, N, M |
| *Microvelia* sp. | | PB | N |
| *Neogerris hesione* | | PB | N |
| *Neoplea striola* | | PP, PB | N, M |
| *Pelocoris femoratus* | | PP | N |
| *Ranatra nigra* | | PB | N |
| *Ranatra* sp. | | PP | N |
| *Trichocorixa macroceps* | | PP, PB | N |
| *Trichocorixa* sp. | | PP, PB | N |
| Order Plecoptera | stone flies | | |
| unidentified sp. | | PP | M |
| Order Coleoptera | beetles | | |
| *Agabus* | | PP, PB | N |
| *Bagous* sp. | | PP | N, M |
| *Berosus striatus* | | PB | N |
| *Berosus* sp. | | PP, PB | N |
| *Bidessus* sp. | | PB | N |
| *Celina* sp. | | PP, PB | D, N, M |
| *Coptotomus interrogatus* | | PB | N |
| Curculionidae | | | |

**Table 5-180. (cont)**

| Scientific Name | Common Name | Location[a] | Sampling Method[b] |
|---|---|---|---|
| *Cybister fimbriolatus* | | PP | N |
| *Derallus altus* | | PB | N |
| *Disonycha* sp. | | PP | D, M |
| Phylum Arthropoda (continued) | | | |
| *Donacia* sp. | | PP, PB | N, M |
| *Dubiraphia bivattata* | | PP | M |
| *Haliplus* prob. *americanus* | | PP | N, M |
| *Haliplus triopsis* | | PP | N |
| *Haliplus fasciatus* | | PP, PB | N |
| *Haliplus* sp. | | PP, PB | N, M |
| *Hydrochus inaequalis* | | PB | N |
| *Hydroporus* prob. *hybridus* | | PP, PB | D, N, M |
| *Hydroporus* spp. | | PP, PB | D, N, M |
| *Hydrovatus pustulatus* | | PP | N |
| *Macronychus glabratus* | | PP | M |
| *Peltodytes dietrichi* | | PP | N |
| *Peltodytes sexmaculatus* | | PP | N |
| *Peltodytes* sp. | | PP | N, M |
| *Pyrrhalta nymphaeae* | | PP | N |
| *Pyrrhalta* sp. | | PB | N |
| *Thermonectus basillaris* | | PP | M |
| unidentified sp. | | PB | N |
| Noteridae | | | |
| *Hydrocantnus* sp. | | PP | N |
| *Susphisellus bicolor punctipennis* | | PB | N |
| unidentified sp. | | PP | D |
| Order Trichoptera | caddisflies | | |
| *Agrypnia vestita* | | PB | N |
| *Banksiola* sp. | | PB | N |
| *Ceraclea maculata* | | PP | M |
| *Cernotina spicata* | | PP, PB | D, N, M |
| *Cheumatopsyche* sp. | | PP | M |
| *Cyrnellus fraternus* | | PP | M |
| *Hydropsyche* sp. | | PP | M |
| *Hydroptila* sp. | | PP | M |
| *Leptocerus americanus* | | PP, PB | D, M |
| *Oecetis inconspicua* | | PP, PB | N |
| *Oecetis* sp. 1 | | PB | D, N, M |
| *Oecetis* sp. 2 | | PP | M |
| *Orthotrichia* sp. | | PP, PB | D, N, M |
| *Oxyethira* spp. | | PP, PB | D, N, M |
| *Polycentropus* sp. | | PP, PB | N |
| *Ptilostomis* sp. | | PP | N |
| *Triaenodes* spp. | | PP | N, M |
| Order Lepidoptera | moths | | |
| *Eoparargyractis* sp. | | PP | N, M |
| *Langessa nomophilalis* | | PP, PB | N, M |
| *Munroessa gyralis* | | PP | M |
| *Munroessa* sp. | | PP, PB | N |

**Table 5-180. (cont)**

| Scientific Name | Common Name | Location[a] | Sampling Method[b] |
|---|---|---|---|
| *Neargyractis slossonalis* | | PB | N |
| *Parapoynx* spp. | | PP, PB | D, N, M |
| Pyralidae | | | |
| *Synclita* sp. | | PP, PB | N, M |
| unidentified sp. | | PB | N |
| Order Diptera | true flies | | |
| Chaoboridae | | | |
| *Chaoborus punctipennis* | | PP, PB | D, N, M |
| Culicidae | | | |
| *Anopheles* sp. | | PB | N |
| *Mansonia perturbans* | | PP | N |
| Ceratopogonidae | | | |
| *Bezzia* sp. | | PP, PB | M |
| *Forcipomyia* sp. | | PB | M |
| unidentified spp. | | PP, PB | D, M |
| Tabanidae | | | |
| *Chrysops* sp. | | PB | N |
| Empididae | | | |
| unidentified spp. | | PP | M |
| Ephydridae | | | |
| unidentified spp. | | PP | M |
| Tipulidae | | | |
| *Limonia* sp. | | PP | N |
| *Pilaria* sp. | | PB | N |
| unidentified spp. | | PP | N |
| Psychodidae | | | |
| *Psychoda alternata* | | PP | M |
| *Telamatoscopus* sp. | | PP | M |
| unidentified spp. | | PP, PB | D, M |
| Simuliidae | | | |
| *Simulium* spp. | | PP | M |
| Order Chironomidae | | | |
| Chironominae | | | |
| *Glyptotendipes* sp. | | PP, PB | M |
| *Parachironomus* sp. | | PP, PB | M |
| unidentified spp. | | PP, PB | D, N, M |
| Orthocladiinae | | | |
| unidentified spp | | PP, PB | D, N, M |
| Tanypodinae | | | |
| *Ablabesmyia* sp. | | PP, PB | M |
| *Clinotanypus* sp. | | PP, PB | M |
| *Labrundinia* sp. | | PP | M |
| *Procladius* sp. | | PP, PB | M |
| *Thienemannimyia* sp. | | PP | M |
| unidentified spp. | | PP, PB | D, N, M |

[a]P = Par Pond, PB = Pond B
[b]D = dredge (quantitative benthic) sample; N = net (qualitative benthic) sample; M = meroplankton sample

**Table 5-181.** Benthic Macroinvertebrate Taxa Collected from a Combination of Ponar and Dip Net Samples in Par Pond during the L-Lake Comparison Study, September 1988 and 1989

**Taxa**

Phylum Nematoda
unknown spp.

Phylum Platyhelminthes
Class Turbellaria
unknown spp

Phylum. Coelenterata
Class Hydrozoa.
Order Hydroida
Family Hydridae
*Hydra* sp.

Phylum Annelida
Class Oligochaeta
*Bratislavia unidentata*
*Dero digitata*
*Dero flabelliger*
*Dero nivea*
*Dero pectinata*
*Dero* sp. A
*Dero vaga*
*Haemonais waldvogeli*
*Nais communis*
*Nais pseudobtusa*
*Pristina aequiseta*
*Pristina leidyi*
*Pristinella longisoma*
*Slavina appendiculata*
*Specaria josinae*
*Stylaria lacustris*
unknown spp.
*Aulodrilus piqueti*
*Ilyodrilus templetoni*
unknown spp.

Class Hirudinea
unknown spp.

Phylum Mollusca
Class Gastropoda
Family Ancylidae
unknown spp.

Family Physidae
*Physella heterostropha*

Family Planorbidae
*Helisoma anceps*
*Helisoma trivolvus*
*Menetus dilatatus*

**Table 5-181. (cont)**

Order Mesogastropoda
Family Hydrobiidae
*Amnicola* sp.

Uncertain Affiliation
unknown spp.

Class Pelecypoda
Order Heterodonta
Family Corbiculiidae
*Corbicula fluminea*

Family Sphaeriidae
unknown spp.

Uncertain Affiliation
unknown spp.

Phylum Arthropoda
Class Arachnoidea
Order Hydracarina
unknown spp.

Class Crustacea
Order Amphipoda
Family Talitridae
*Hyalella azteca*

Uncertain Affiliation
unknown spp.

Order Decapoda
Family Cambaridae
unknown spp.

Class Insecta
Order Coleoptera
Family Curculionidae
unknown spp.

Family Dytiscidae
*Agabus* sp.
unknown spp.

Family Elmidae
*Macronychus glabratus*

Family Haliplidae
*Peltodytes* sp.

Family Hydrophilidae
*Derallus* sp.
unknown spp.

Family Noteridae
*Hydrocanthus* sp.
unknown spp.

**Table 5-181. (cont)**

Order Diptera
Family Ceratopogonidae
*Bezzia* sp.
Ceratopogoniinae
Forcypomyiinae
*Palpomyia* sp.

Family Chaoboridae
*Chaoborus punctipennis*

Family Chironomidae
Chironomini
*Chironomus* sp.
*Cladopelma* sp.
*Cryptochironomus* sp.
*Fittkauimyia* sp.
*Glyptotendipes* sp.
*Lauterborniella* sp.
*Parachironomus* sp.
*Phaenopsectra* sp.
*Polypedilum* sp.
*Pseudochironomus* sp.
*Stenochironomus* sp.
*Zavreliella* sp.
Orthocladiinae
*Corynoneura* sp.
*Cricotopus* sp.
*Nanocladius* sp.
Tanypodoninae
*Ablabesmyia* sp.
*Labrundinia* sp.
*Procladius* sp.
Tanytarsini sp.
*Rheotanytarsus* sp.
*Tanytarsus* sp.

Family Culicidae
*Culex* sp.
*Mansonia peturbans*

Family Tipulidae
*Helius* sp.
unknown spp.

Order Ephemeroptera
Family Baetidae
*Baetis* sp.
unknown spp.

Family Caenidae
*Caenis* sp.

Order Hemiptera
Family Belostomatidae
*Belostoma* sp.

**Table 5-181. (cont)**

Family Corixidae
unknown spp.

Family Gerridae
unknown spp.

Family Naucoridae
*Pelocoris* sp.

Family Pleidae
*Neoplea* sp.

Order Lepidoptera
Family Pyralidae
*Parapoynx* sp.
*Synclita* sp.
unknown spp.

Order Odonata
Family Coenagrionidae
*Basiaeschna* sp.
*Enallagma* sp.
unknown spp.

Family Corduliidae
*Tetragoneuria* sp.
unknown spp.

Family Lestidae
*Lestes* sp.

Family Libellulidae
*Brachymesia* sp.
*Erythemis simplicicollis*
*Sympetrum* sp.
unknown spp.

Uncertain Affiliation
Anisoptera sp.

Order Trichoptera
Family Hydropsychidae
*Hydropsyche* sp.

Family Hydroptilidae
*Orthotrichia* sp.
*Oxyethira* sp.

Family Leptoceridae
*Oecetis* sp.
*Trianodes* sp.

Family Polycentropodidae
*Cernotina* sp.
unknown spp.

**Table 5-182.** Relative Abundance (Percent Composition) of Major Macroinvertebrate Meroplankton Taxa Collected in Par Pond and Pond B, January 1984-June 1985

| | Sampling Locations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Par Pond | | | | | | | | | Pond B | |
| **Taxa** | **H1** | **H2** | **N1** | **N2** | **CD1** | **CD2** | **S1** | **S2** | **P** | **B1** | **B2** |
| Diptera | 63.4 | 58.0 | 53.0 | 35.9 | 60.2 | 90.6 | 41.1 | 28.9 | 32.4 | 66.5 | 49.5 |
| Trichoptera | 3.6 | 5.9 | 2.3 | 1.6 | 1.3 | 1.2 | 2.2 | 4.3 | 45.5 | 0.6 | 1.5 |
| Odonata | 0.3 | 0.3 | 0.5 | 0.3 | 0.3 | 0.1 | 0.9 | 1.2 | 0.1 | 0.2 | 0.3 |
| Ephemeroptera | 0.2 | 0.1 | 0.2 | 0.2 | 0.4 | 0.1 | 0.5 | 0.8 | 0.2 | 0.1 | 0.1 |
| Amphipoda | 0.7 | 0.3 | 1.3 | 2.0 | 0.7 | 0.1 | 2.5 | 3.5 | 0.9 | 6.6 | 21.3 |
| Gastropoda | 0.5 | 2.8 | 0.3 | 0.3 | 0.8 | 0.1 | 0.9 | 8.7 | 0.8 | 0.1 | 0.2 |
| Pelecypoda | 2.5 | 1.6 | 0.8 | 2.6 | 3.2 | 0.2 | 15.8 | 0.9 | 0.5 | 0.0 | 0.0 |
| Oligochaeta | 22.6 | 25.7 | 26.9 | 41.3 | 28.5 | 2.7 | 25.2 | 41.7 | 8.6 | 3.2 | 18.9 |
| Turbellaria | 0.2 | 0.9 | 0.2 | 0.7 | 0.2 | 0.0 | 0.6 | 2.5 | 1.5 | 0.6 | 1.4 |
| Nematoda | 1.8 | 1.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.2 | 0.2 | 0.2 | 0.0 | 0.0 |
| Hydracarina | 2.8 | 1.2 | 13.8 | 12.8 | 4.5 | 3.6 | 6.4 | 3.8 | 8.8 | 21.7 | 6.3 |
| Ostracoda | 1.3 | 1.6 | 0.3 | 0.2 | 0.5 | 0.9 | 0.9 | 2.2 | 0.2 | 0.2 | 0.4 |
| Other | 0.1 | 0.6 | 0.3 | 2.0 | 0.5 | 0.2 | 2.8 | 1.3 | 0.2 | 0.2 | 0.1 |

H = Hot Dam.
N = North Cove.
CD = Cold Dam.
S = South Arm.
P = Pumphouse.
B = Pond B.

**Table 5-183.** Mean Species Richness (Number of Taxa) and Mean Density of Organisms in Par Pond and Pond B Macroinvertebrate Meroplankton Samples, January 1984-June 1985

| **Sampling Location** | **Mean Species Richness (SE)** | **Mean Density as Organisms/1000 $m^3$ (SE)** |
|---|---|---|
| **Par Pond** | | |
| Hl | 4.7 (0.5) | 191.3 (48.7) |
| H2 | 6.0 (0.6) | 292.1 (69.7) |
| Nl | 6.7 (0.5) | 368.1 (85.6) |
| N2 | 6.9 (0.7) | 573.7 (286.9) |
| CDl | 5.6 (0.6) | 320.9 (86.4) |
| CD2 | 4.7 (0.4) | 425.2 (218.3) |
| Sl | 5.4 (0.5) | 144.6 (52.3) |
| S2 | 10.1 (0.8) | 339.9 (74.6) |
| P | 13.6 (0.8) | 711.5 (194.1) |
| Mean | 7.1 (0.4) | 374.1 (59.3) |
| **Pond B** | | |
| Bl | 6.9 (0.5) | 577.1 (114.6) |
| B2 | 6.7 (0.6) | 693.3 (168.4) |
| Mean | 6.8 (0.5) | 635.2 (58.1) |

H = Hot Dam.
N = North Cove.
CD = Cold Dam.
S = South Arm.
P = Pumphouse.
B= Pond B.

**Table 5-184.** Mean Species Richness, Mean Density, and Mean Species Diversity for Benthic Macroinvertebrates from Par Pond and Pond B, February 1984-May 1985

| Sampling Area | Mean Species Richness (SE)[a] | Mean Density as No./m$^2$ (SE) | Mean Species Diversity (SE) | Mean Biomass as Ash-Free Dry Weight (g/m$^2$) |
|---|---|---|---|---|
| Hot Arm | 11.6 (0.6) | 7224.8 (1272.3) | 1.97 (0.07) | 41.76 |
| North Arm | 12.5 (1.3) | 3814.8 (357.2) | 1.96 (0.09) | 6.76 |
| Cold Dam | 11.5 (1.1) | 4090.2 (448.2) | 1.90 (0.09) | 8.12 |
| South Arm | 12.2 (1.0) | 2416.0 (207.4) | 2.07 (0.06) | 26.76 |
| Par Pond Mean | 12.0 (0.2) | 4385.6 (424.1) | 1.98 (0.04) | 20.85 |
| Pond B | 9.4 (1.2) | 3421.6 (303.7) | 1.60 (0.08) | 0.542 |

[a]S.E. = standard error.

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 (Table 5-185 and Table 5-186).

Macroinvertebrate densities ranged from 2416.0 organisms/m$^2$ in the South Arm to 7224.8 organisms/m$^2$ in the Hot Arm (Table 5-184). Mean ash-free dry weight biomass ranged from 6.76 to 41.76 g/m$^2$ (Table 5-184). 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 macroinvertebrate taxa, including 66 taxa that were not collected in either the macroinvertebrate meroplankton or Ponar dredge samples (Table 5-180). 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).

## 1988–1989 Sampling

Eighty-two macroinvertebrate taxa were collected from dredge samples and dip net samples in Par Pond in September 1988 and 1989 (Table 5-181). The most abundant groups of organisms in the dredge samples included oligochaetes, snails, clams, chironomids, and the phantom midge *(Chaoborus punctipennis)* (Table 5-187).

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 (Table 5-185 and Table 5-187). 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).

**Table 5-185.** Relative Abundance (Percent Composition) of Major Benthic Macroinvertebrate Taxa Collected in Par Pond and Pond B, February 1984-May 1985

| | Sampling Area[a] | | | | |
|---|---|---|---|---|---|
| **Taxon** | **H** | **N** | **CD** | **S** | **Pond B** |
| Diptera | 29.0 | 58.6 | 64.4 | 47.0 | 83.8 |
| Trichoptera | 0.3 | 1.2 | 1.3 | 1.4 | 1.0 |
| Odonata | <0.1 | 0.3 | 0.5 | 0.7 | 0.4 |
| Amphipoda | 3.6 | 3.8 | 0.8 | 1.3 | 5.9 |
| Gastropoda | 0.7 | 5.8 | 2.6 | 7.1 | 0.3 |
| Pelecypoda | 12.7 | 3.5 | 5.0 | 10.6 | <0.1 |
| Oligochaeta | 21.5 | 20.9 | 23.0 | 23.6 | 6.0 |
| Turbellaria | 13.0 | 2.8 | 0.5 | 5.0 | 1.1 |
| Nematoda | 16.0 | 1.0 | 1.2 | 2.0 | 0.4 |
| Hirudinea | 2.6 | 0.5 | 0.2 | 0.2 | 0.1 |
| Ostracoda | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 |
| Other | 0.5 | 1.6 | 0.4 | 1.1 | 0.8 |

[a]H = Hot Dam.
N = North Arm.
CD = Cold Dam.
S = South Arm.

**Table 5-186.** Composition of Benthic Macroinvertebrate Community Presented as Mean Densities (organisms/$m^2$) from Par Pond and Pond B, February 1984-May 1985

| | Sampling Area | | | | |
|---|---|---|---|---|---|
| **Taxa** | **H** | **N** | **D** | **I** | **Pond B** |
| Coelenterata | 0.0 | 0.0 | 10.9 | 10.3 | 1.2 |
| Turbellaria | 940.2 | 105.7 | 29.6 | 120.8 | 38.7 |
| Nematoda | 1158.9 | 38.0 | 68.8 | 47.7 | 12.1 |
| Annelida | | | | | |
| Oligochaeta | 798.3 | 1056.8 | 569.5 | 205.9 | 1557.4 |
| Hirudinea | 188.4 | 21.7 | 12.1 | 4.8 | 4.2 |
| Ostracoda | 0.0 | 0.0 | 4.8 | 0.0 | 3.6 |
| Crustacea | | | | | |
| Isopoda | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 |
| Amphipoda | 257.9 | 143.7 | 44.1 | 32.6 | 201.1 |
| Decapoda | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydracarina | 27.2 | 19.9 | 6.7 | 7.8 | 11.5 |
| Insecta | | | | | |
| Collembola | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Odonata | 1.8 | 13.3 | 10.3 | 16.9 | 15.1 |
| Ephemeroptera | 1.2 | 25.9 | 0.6 | 1.2 | 5.4 |

**Table 5-186. (cont)**

| | Sampling Area | | | | |
|---|---|---|---|---|---|
| **Taxa** | **H** | **N** | **D** | **I** | **Pond B** |
| Plecoptera | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hemiptera | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 |
| Neuroptera | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Trichoptera | 21.7 | 45.9 | 35.6 | 33.8 | 35.0 |
| Lepidoptera | 0.0 | 0.6 | 1.2 | 1.8 | 0.6 |
| Coleoptera | 0.6 | 7.3 | 2.4 | 1.2 | 6.6 |
| Diptera | 2097.3 | 2236.8 | 2372.1 | 1134.7 | 2868.5 |
| Gastropoda | 51.3 | 222.8 | 147.4 | 171.5 | 11.5 |
| Pelecypoda | 920.9 | 133.5 | 285.0 | 255.4 | 0.6 |
| Totals | 7224.8 | 3814.6 | 4090.2 | 2416.0 | 3421.6 |

H = Hot Arm.
N = North Arm.
CD = Cold Dam.
S = South Arm.

**Table 5-187.** Relative Abundance (Percent Composition) of Major Groups of Macroinvertebrates in Ponar Dredge Samples Collected from Par Pond, September 1988 and 1989

| **Taxon** | **1988** | **1989** |
|---|---|---|
| Nematoda | 5.4 | 4.8 |
| Turbellaria | 15.4 | 4.4 |
| Oligochaeta | 28.0 | 48.5 |
| Hirudinea | 0.1 | 0.1 |
| Gastropoda | 16.9 | 2.8 |
| Pelecypoda | 2.6 | 10.7 |
| Hydracarina | 2.5 | 0.4 |
| Amphipoda | 0.2 | 5.0 |
| Ephemeroptera | 0.1 | 0.3 |
| Coleoptera | 0.1 | 0.0 |
| Hemiptera | 0.0 | 0.6 |
| Lepidoptera | 0.3 | 0.0 |
| Odonata | 0.5 | 0.6 |
| Trichoptera | 1.2 | 0.3 |
| Diptera | 26.6 | 21.4 |
| Chaoboridae[a] | (17.1) | (12.6) |
| Chironomidae | (9.5) | (8.7) |
| Other Diptera | (0.0) | (0.1) |
| Total[b] | 99.9 | 99.9 |

[a]Numbers in parentheses are included in the percentage reported for Diptera.
[b]Totals may not equal 100%, due to rounding.

# Fish

## Introduction

The fishes of Par Pond have been extensively studied (Table 5-188). 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).

## Species Composition and Abundance

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 (Table 5-189). Of these species, 17 also were reported from Pond C and 14 from Pond B (Figure 5-93). 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 mosquitofish (*Gambusia affinis*). Largemouth bass and bluegill were more abundant in Par Pond than in most other reservoirs.

### 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).

**Table 5-188.** Principal Reports Describing Fish Studies in the Par Pond System

| **Author(s) and Major Topics[a] Covered** | |
|---|---|
| Bennett (1971) (3) | Quinn et al. (1978) (3) |
| Gibbons and Bennett (1971) (2,3) | Beisser (1978) (4) |
| Bennett (1972) (4) | Hazen (1978) (6) |
| Gibbons et al. (1972) (2) | Hazen et al. (1978a) (6) |
| Bennett and Gibbons (1972) (4) | Hazen et al. (1978b) (6) |
| Clugston (1973) (1,2,3,4,5) | Hazen et al. (1978c) (6) |
| Holland et al. (1974) (3) | Hazen et al. (1978d) (6) |
| Ferens and Murphy (1974) (3,4) | Esch and Hazen (1978) (6) |
| Falke and Smith (1974) (4) | Belk and Hales (1993) (4,5) |
| Bennett and Gibbons (1974) (4) | Hazen and Fliermans (1979) (6) |
| Eure (1974) (7) | Hazen and Esch (1978) (7) |
| Eure and Esch (1974) (7) | Hazen (1979) (6) |
| Smith and Scott (1975) (3) | Huizinga et al. (1979) (6) |
| Bennett and Gibbons (1975) (4) | Aho (1979) (7) |
| Siler and Clugston (1975) (2,3,4,5) | Martin (1980) (2,3,4) |
| Johnson (1975) (4) | Esch and Hazen (1980) (6) |
| Siler (1975) (1,2) | Camp (1980) (7) |
| McFarlane (1976) (1) | Ross (1980) (3) |
| Murphy et al. (1976) (3) | Gilbert and Hightower (1981) (2) |
| Eure (1976a) (7) | Hazen et al. (1981) (6) |
| Eure (1976b) (7) | Aho et al. (1982) (7) |
| Aho et al. (1976) (7) | Camp et al. (1982) (7) |
| Esch et al. (1976) (6) | Rice et al. (1983) (4) |
| Du Pont (1976) (1,3) | Bennett and McFarlane (1983) (1,2) |
| Hogan (1977) (2,4) | Janssen and Giesy (1984) (4) |
| Fliermans et al. (1977) (6) | Belk and Hales (1993) (4, 5) |
| Gibbons et al. (1978) (4) | |

[a](1)species richness.
(2)abundance, species composition.
(3)movements, body temperatures, thermal tolerance limits.
(4)feeding habits, growth, condition factors.
(5)reproduction.
(6)red sore disease (*Aeromonas*).
(7)parasitic worms.

**Table 5-189.** Species of Fish in Par Pond, Pond B, and Pond C[a]

| Scientific Name | Common Name |
|---|---|
| *Alosa aestivalis* | blueback herring (C) |
| *Amia calva* | bowfin |
| *Anguilla rostrate* | American eel |
| *Aphredoderus sayanus* | pirate perch (C) |
| *Dorosoma cepedianum* | gizzard shad (B, C) |
| *Elassoma zonatum* | banded pygmy sunfish (C) |
| *Erimyzon sucetta* | lake chubsucker (C) |
| *Esox americanus* | redfin pickerel (B, C) |
| *Esox niger* | chain pickerel |
| *Etheostoma fusiforme* | swamp darter (B, C) |
| *Gambusia affinis* | mosquitofish (B, C) |
| *Ameiurus natalis* | yellow bullhead (B, C) |
| *Ameiurus nebulosus* | brown bullhead |
| *Ameiurus platycephalus* | flat bullhead |
| *Ameiurus punctatus* | channel catfish |
| *Labidesthes sicculus* | brook silversides (B) |
| *Lepomis auritus* | redbreast sunfish (B, C) |
| *Lepomis gulosus* | warmouth (B, C) |
| *Lepomis macrochirus* | bluegill (B, C) |
| *Lepomis marginatus* | dollar sunfish (B, C) |
| *Lepomis microlophus* | redear sunfish (C) |
| *Lepomis punctatus* | spotted sunfish (B) |
| *Micropterus salmoides* | largemouth bass (B, C) |
| *Minytrema melanops* | spotted sucker |
| *Notemigonus crysoleucas* | golden shiner (C) |
| *Notropis petersoni* | coastal shiner |
| *Noturus gyrinus* | tadpole madtom |
| *Perca flavescens* | yellow perch (B) |
| *Pomoxis nigromaculatus* | black crappie (B, C) |
| *Pylodictus olivaris* | flathead catfish |

[a]All species on the list have been collected from Par Pond. Species also collected from Ponds B and C are noted by B and C (in parentheses), respectively.

## 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 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).

## 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 (Table 5-190). In addition, two other species (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 (Table 5-190). 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-Weaver diversity (1.01 in Pond B compared to 1.78 in Par Pond).

Fish community structure differed among locations in Par Pond (Table 5-191). 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 sam-

**Table 5-190.** Species Relative Abundance (Percent Composition and Percent Total Weight) of Adult Fishes Collected From Par Pond and Pond B[a], January 1984-June 1985

| | Par Pond[b] | | Pond B | |
|---|---|---|---|---|
| **Fish** | **Percent number** | **Percent weight** | **Percent number** | **Percent weight** |
| **Game Fish** | | | | |
| largemouth bass | 17.9 | 31.7 | 17.7 | 23.9 |
| black crappie | 1.5 | 3.4 | 1.0 | 2.6 |
| white crappie | <0.1 | <0.1 | 0.0 | 0.0 |
| bluegill | 14.1 | 2.8 | 4.9 | 2.6 |
| redoreast | 0.5 | 0.1 | 0.0 | 0.0 |
| pumpkinseed | <0.1 | <0.1 | 0.0 | 0.0 |
| dollar sunfish | 0.1 | <0.1 | 0.0 | 0.0 |
| spotted sunfish | 0.1 | <0.1 | 0.0 | 0.0 |
| warmouth | 0.4 | 0.2 | 1.6 | 1.0 |
| unidentified sunfish | <0.1 | <0.1 | 12.4[c] | 0.1 |
| yellow perch | 0.8 | 0.3 | 0.1 | 0.4 |
| **Forage Fish** | | | | |
| lake chubsucker | 18.0 | 45.1 | 0.0 | 0.0 |
| brook silversides | 37.8 | 0.2 | 34.1 | 0.2 |
| blueback herring | <0.1 | <0.1 | 0.0 | 0.0 |
| gizzard shad | 0.9 | 6.4 | 15.9 | 45.5 |
| golden shiner | 2.4 | 0.7 | 0.0 | 0.0 |
| shiners (*Notropis* spp.) | 2.6 | <0.1 | 1.3 | <0.1 |
| mosquitofish | -[d] | - | <0.1 | <0.1 |
| darters (*Etheostoma* spp.) | - | - | <0.1 | <0.1 |
| **Rough Fish** | | | | |
| bowfin | 0.3 | 2.9 | 0.0 | 0.0 |
| chain pickerel | 1.2 | 1.3 | 0.0 | 0.0 |
| redfin pickerel | <0.1 | <0.1 | 0.0 | 0.0 |
| yellow bullhead | 0.3 | 1.3 | 7.4 | 16.3 |
| brown bullhead | 0.2 | 0.6 | 0.4 | 1.1 |
| flat bullhead | 0.9 | 2.9 | 3.0 | 6.2 |
| white catfish | <0.1 | 0.1 | 0.0 | 0.0 |
| Total percent | 100.0 | 100.0 | 99.8 | 99.9 |
| Total number | 13,166 | | 1,336 | |
| Total weight (Kg) | | 2,491.7 | | 230.9 |
| Total number species | 25 | | 13 | |

[a]Collection methods include electrofishing, gill netting, hoopnetting and angling.
[b]Catch from the Cold Dam, Hot Arm, South Arm and North Arm combined.
[c]Most were probably juvenile bluegill.
[d]Observed but not collected by any of the four collection techniques.

**Table 5-191.** Species Relative Abundance as Percent Composition (and number) of Adult Fishes Collected From Par Pond, January 1984-June 1985

| Species | Cold Dam | Hot Arm | South Arm | North Arm |
|---|---|---|---|---|
| **Game Fish** | | | | |
| largemouth bass | 19.9 (438) | 19.9 (879) | 22.8 (684) | 9.8 (350) |
| black crappie | 1.6 (36) | 2.8 (122) | 0.7 (22) | 0.5 (17) |
| white crappie | <0.1 (1) | <0.1 (1) | 0.0 (0) | 0.0 (0) |
| bluegill | 21.1 (463) | 14.6 (643) | 8.5 (254) | 13.8 (491) |
| redbreast sunfish | 0.4 (8) | 0.9 (42) | 0.4 (12) | 0.2 (9) |
| pumpkinseed | <0.1 (1) | 0.0 (0) | 0.0 (0) | 0.0 (0) |
| dollar sunfish | 0.0 (0) | <0.1 (2) | 0.1 (3) | 0.1 (3) |
| spotted sunfish | 0.4 (9) | 0.0 (0) | 0.1 (3) | <0.1 (1) |
| warmouth | 0.8 (18) | 0.2 (8) | 0.5 (16) | 0.1 (5) |
| unidentified sunfish | 0.0 (0) | 0.0 (0) | 0.0 (0) | <0.1 (1) |
| yellow perch | 1.0 (22) | 0.3 (13) | 0.6 (17) | 1.7 (61) |
| **Forage Fish** | | | | |
| lake chubsucker | 30.1 (661) | 11.4 (504) | 17.1 (514) | 19.5 (693) |
| brook silverside | 4.0 (88) | 46.3 (2045) | 41.1 (1231) | 45.2 (1607) |
| blueback herring | 0.2 (5) | 0.0 (0) | 0.0 (0) | <0.1 (1) |
| gizzard shad | 0.6 (13) | 1.5 (67) | 0.5 (16) | 0.6 (20) |
| golden shiner | 5.9 (129) | 0.5 (20) | 3.4 (103) | 1.9 (66) |
| shiner (*Notropis* spp.) | 8.5 (186) | 0.4 (17) | 1.3 (38) | 2.7 (95) |
| darter (*Etheostoma* spp.) | <0.1 (0) | 0.0 (0) | 0.0 (0) | 0.0 (0) |
| **Rough Fish** | | | | |
| bowfin | 0.5 (11) | 0.2 (8) | 0.4 (13) | 0.2 (9) |
| chain pickerel | 2.5 (55) | 0.2 (10) | 1.3 (39) | 1.6 (57) |
| yellow bullhead | 0.9 (20) | 0.1 (5) | 0.1 (4) | 0.5 (17) |
| brown bullhead | 0.1 (3) | 0.2 (9) | <0.1 (1) | 0.2 (8) |
| flat bullhead | 1.3 (28) | 0.5 (24) | 0.8 (24) | 1.3 (45) |
| white catfish | 0.0 (0) | 0.0 (0) | 0.1 (2) | 0.0 (0) |
| Total percent | 99.8 | 100.0 | 99.8 | 99.9 |
| Total nunber | 2,195 | 4,419 | 2,996 | 3,556 |

ple 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.

## Ichthyoplankton Surveys

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.

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.

### 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" on page 5-450). Other possible thermal effects include reduced condition of largemouth bass ("Growth and Condition" on page 5-444 and "Diet" on page 5-447) 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.

### Comparison of Par Pond and Other United States Reservoirs

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.

## Growth and Condition

### Largemouth Bass

Bennett and Gibbons (1974) 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 large-mouth 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 zoo-plankton 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. 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.

## 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 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).

### Mosquitofish

Mosquitofish (*Gambusia affinis*) 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 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 mosquitofish bearing eyed embryos in Par Pond.

## 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 large mouth bass ate fish (primarily mosquitofish and small sunfish) throughout the year. Pond C largemouth bass ate fish (primarily 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.

## 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 (Table 5-192) 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 mosquitofish on SRS liver at temperatures greater than (up to 44°[111°F]) the CTM reported for northern populations. Mosquitofish have reportedly been dipnetted from portions of Pond C at temperatures greater than 40°C (104°F).

**Table 5-192.** Critical Thermal Maxima Estimates for Bluegill from Two Locations at Different Acclimation Temperatures

| | Acclimation Temperature, °C[a] | | |
|---|---|---|---|
| **Sample Location** | **16°** | **24°** | **32°** |
| Pond C | 31.5 (9) | 37.5 (10) | 41.4 (10) |
| Par Pond | 31.4 (8) | 35.6 (10) | 38.5 (10) |
| Difference | 0.1 (NS) | 1.9[b] | 2.9[b] |

[a]Means at each acclimation temperature were significantly different from each other at both localities (P <0.01). Numbers in parentheses are sample size. NS is not significant.
[b]Overall f test for locality differences was significant (P <0.001); Tukey's HSD test demonstrated significant differences among locality means at 24°C (75°F) and 32°C (90°F) (P <0.05).

## 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 1979) 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.

## Reproduction

### 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).

### 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.

## Disease and Parasitism

### Red-Sore Disease

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 (Table 5-193). 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).

## 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.

## 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

**Table 5-193.** Seasonal Distribution of *A. Hydrophila*-Like Bacteria at Selected Stations in Par Pond

| | **Station 5 (Near Cold Dam)** | | | **Station 3 (Middle of Hot Arm)** | | | **Station 1 (Near Hot Dam)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **X[a]** | **SD** | **N** | **X[a]** | **SD** | **N** | **X[a]** | **SD** | **N** |
| August 1975[b] | 0.39 | 0.54 | 114 | 0.24 | 0.38 | 72 | ND[c] | | |
| September 1975[d] | 1.51 | 1.42 | 56 | 3.01 | 1.06 | 33 | ND[c] | | |
| October 1975 | 5.22 | 1.86 | 57 | 6.02 | 1.84 | 33 | ND[c] | | |
| November 1975 | 3.14 | 1.93 | 50 | 14.62 | 7.96 | 39 | 9.58 | 3.78 | 30 |
| December 1975 | 1.47 | 1.10 | 27 | 1.13 | 0.65 | 18 | 1.21 | 0.73 | 18 |
| January 1976 | 3.55 | 1.65 | 15 | 16.18 | 8.20 | 11 | 17.71 | 6.36 | 12 |
| February 1976 | 2.54 | 1.07 | 33 | 5.20 | 3.56 | 26 | 3.22 | 2.71 | 26 |
| March 1976 | 154.57 | 176.31 | 44 | 141.85 | 96.78 | 32 | 27.37 | 34.63 | 30 |
| April 1976 | 32.83 | 14.76 | 18 | 147.80 | 71.25 | 15 | 99.20 | 67.74 | 15 |
| May 1976 | 18.00 | 16.25 | 24 | 21.86 | 17.69 | 14 | 51.47 | 50.57 | 15 |
| June 1976 | 300.09 | 147.01 | 27 | 20.25 | 30.42 | 15 | 0.44 | 1.37 | 27 |
| July 1976 | 67.04 | 89.42 | 47 | 25.67 | 43.91 | 25 | 41.92 | 72.82 | 27 |
| August 1976 | 7.94 | 6.19 | | 18.33 | 8.89 | 15 | 12.67 | 9.96 | 15 |

Source: Fliermans et al. (1977)

[a] X = Mean values of *A. hydrophila*-like bacteria per milliter.

[b]Experiments with reactor not operating.

[c]ND = Not determined.

[d]Experiments with reactor operating.

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.

### Strigeid Trematodes

Two parasitic worms, both strigeid trematodes (*Ornithodiplostomum ptychocheilus* and *Diplostomum scheuring*), have been collected from 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 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.

## Contaminant Levels in Par Pond Fish

Fish from Par Pond were sampled in 1995 for mercury and cesium-137 concentrations. The geometric mean total mercury concentration in largemouth bass (whole fish) was

581 μg/kg (Table 5-194). This mean concentration was greater than that reported in L-Lake largemouth bass (351 μg/kg; Paller 1996). Total mercury concentration increased significantly ($P \leq 0.001$) with fish size (Figure 5-100), 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).

The geometric mean mercury concentrations in bluegill and lake chubsucker from Par Pond averaged 154 and 133 μg/kg, respectively (Figure 5-101), 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 (Table 5-194), nearly an order of magnitude higher than in L-Lake largemouth bass (0.62 pCi/g; Paller 1996). Body burden of cesium-137 increased significantly ($P \leq 0.001$) with fish size (Figure 5-101). Geometric mean concentrations of cesium-137 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 cesium-137 body burdens than bluegill from L-Lake (chubsuckers were not analyzed for cesium-137 in L-Lake). Greater cesium-137 body burdens in Par Pond fish probably reflect greater contamination of Par Pond with cesium-137 as a result of releases from P and R Reactors (Paller and Wike 1996a).

Largemouth bass condition factors were significantly ($P \leq 0.05$) related to tissue concentrations of total mercury, but not to tissue concentrations of cesium-137.

## 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

**Table 5-194.** Average Total Mercury (µg/kg) and Cesium-137 (pCi/g) Burdens in Fishes Collected from Par Pond, October 1995

| Species | Number | Mean total length (mm) | Geometric mean (95% confidence interval) | Arithmetic mean | Median | Maximum |
|---|---|---|---|---|---|---|
| | | | **Total mercury (µg/kg wet tissue)** | | | |
| Largemouth bass | 38[a] | 347 | 581 (493-687) | 673 | 576 | 3180 |
| Lake chubsucker | 4[a] | 309 | 133 (108-164) | 140 | 125 | 216 |
| Bluegill | 14[b] | 128 | 154 (136-175) | 157 | 159 | 203 |
| | | | **Cesium-137 (pCi/g wet tissue)** | | | |
| Largemouth bass | 38[a] | 347 | 4.61 (4.11-5.15) | 4.84 | 4.69 | 8.57 |
| Lake chubsucker | 4[a] | 309 | 3.27 (2.57-4.10) | 3.41 | 3.73 | 4.38 |
| Bluegill | 14[b] | 128 | 1.70 (1.56-1.86) | 1.71 | 1.62 | 2.29 |

[a]Most samples consisted of individual fish, except for small speciments, which were composited.
[b]Most samples were composites of a number of individuals.

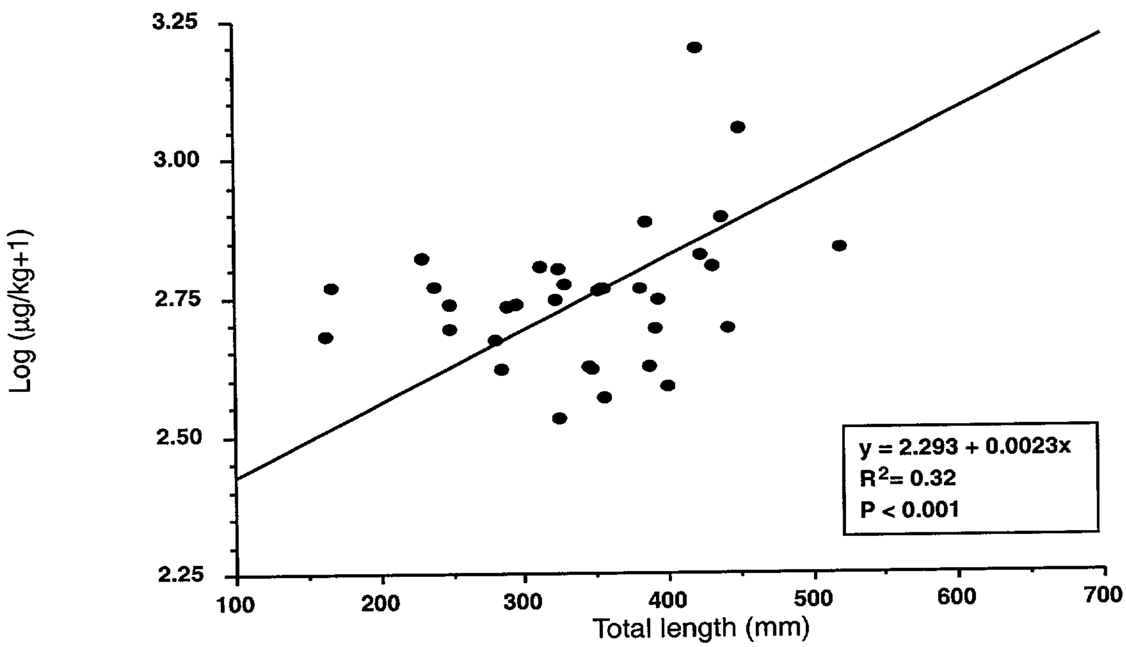


**Figure 5-100.** Regression of mercury concentration (µg/kg) in largemouth bass of various sizes (total length in millimeters) collected from Par Pond. October 1995.

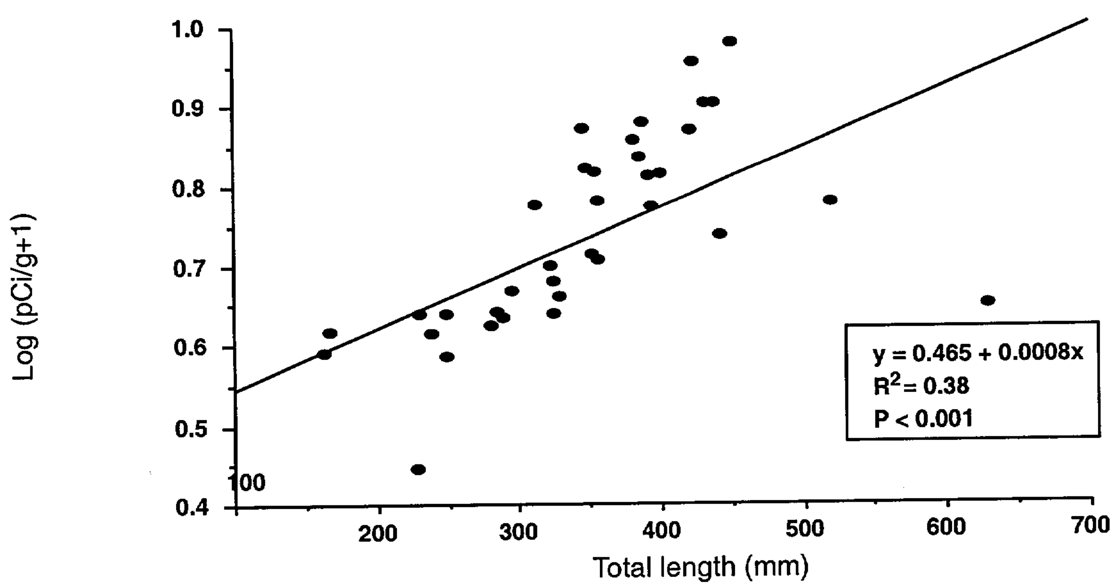


**Figure 5-101.** Regression of cesium-137 concentration (pCi/g) in largemouth bass of various sizes (total length in millimeters) collected from Par Pond. October 1995.

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-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.

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.

# 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 1997).

## 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 6—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 postrefill samples.

The average number of species collected from Par Pond declined significantly during the first and second years of the drawdown (Figure 5-102). The number of individual fish declined even more, reaching levels approximately an order of magnitude lower than before the drawdown (Figure 5-102). 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 postrefill) indicated significant increase to predrawdown levels for both species number and number of individuals. The fall postrefill sample indicated additional

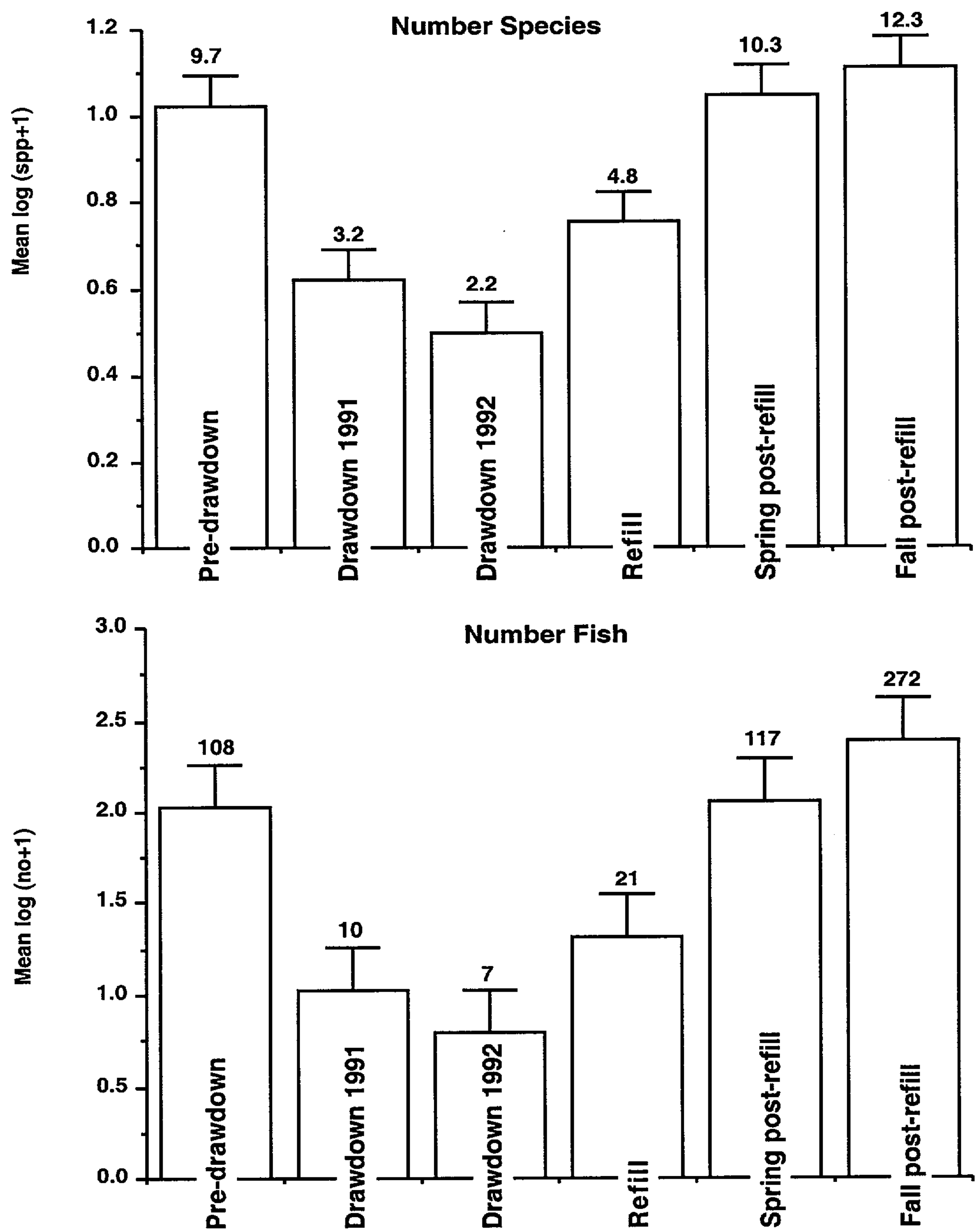


**Figure 5-102.** Average Log $_{10}$-Transformed Number of Fish Species (top figure) and Number of Fish (bottom figure) During Sample Periods in Par Pond. Means with Comparison Intervals that do not Overlap are Significantly Different ($P \leq 0.05$). Numbers Above Comparison Interval Bars are Arithmetic Averages (Source: Paller and Wike 1996a)

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 ($P \leq 0.05$) 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 (Figure 5-103 through Figure 5-105).

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.

## 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 6—Wetlands and Carolina Bays of the SRS.

## 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.

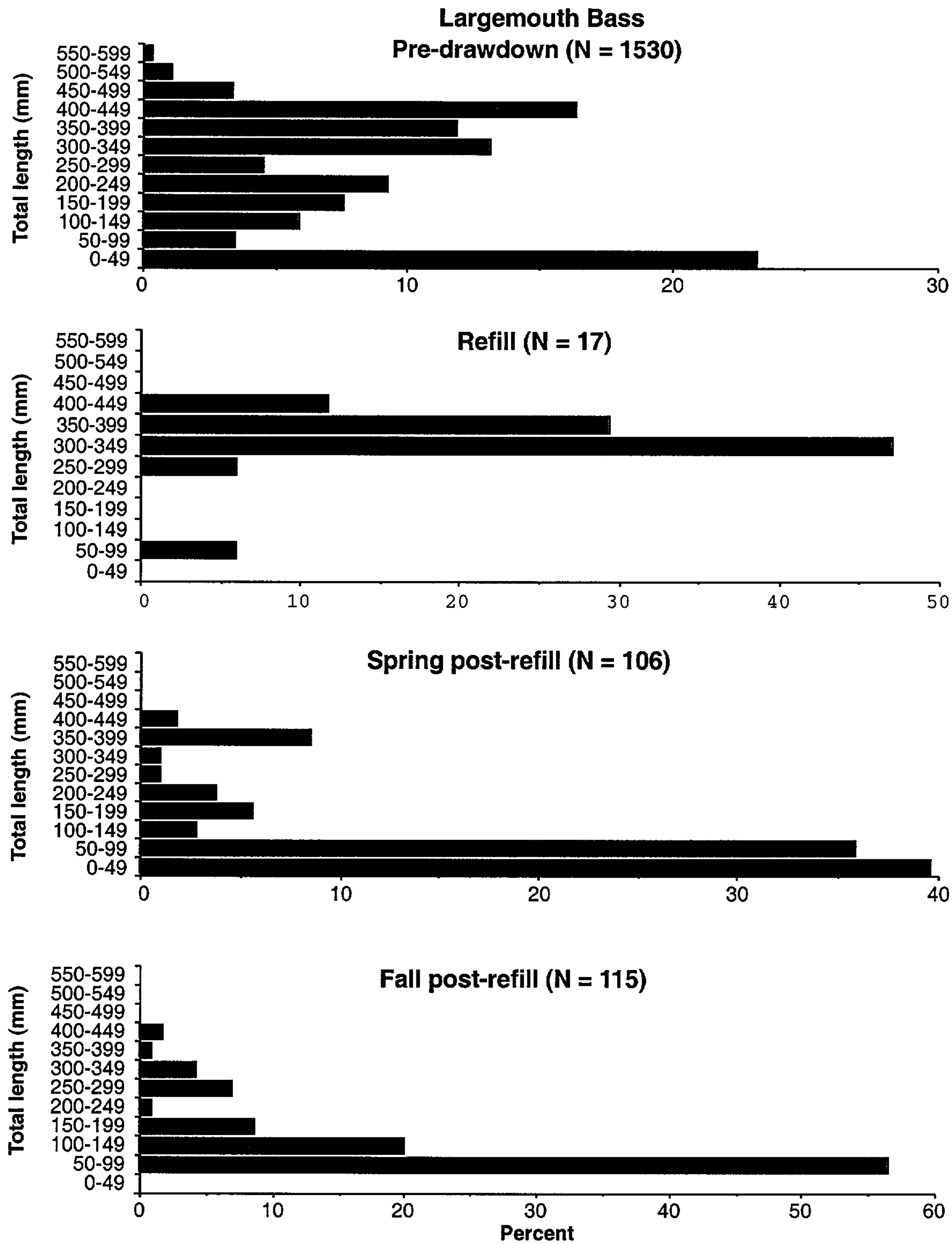


**Figure 5-103.** Length-Frequency Distributions of Largemouth Bass in Par Pond During Pre-drawdown (January 1984-January 1985), Refill (January 1985), Spring Post-Refill (May and June 1995), and Fall Post-Refill (September and October 1995) (Source: Paller and Wike 1996a)

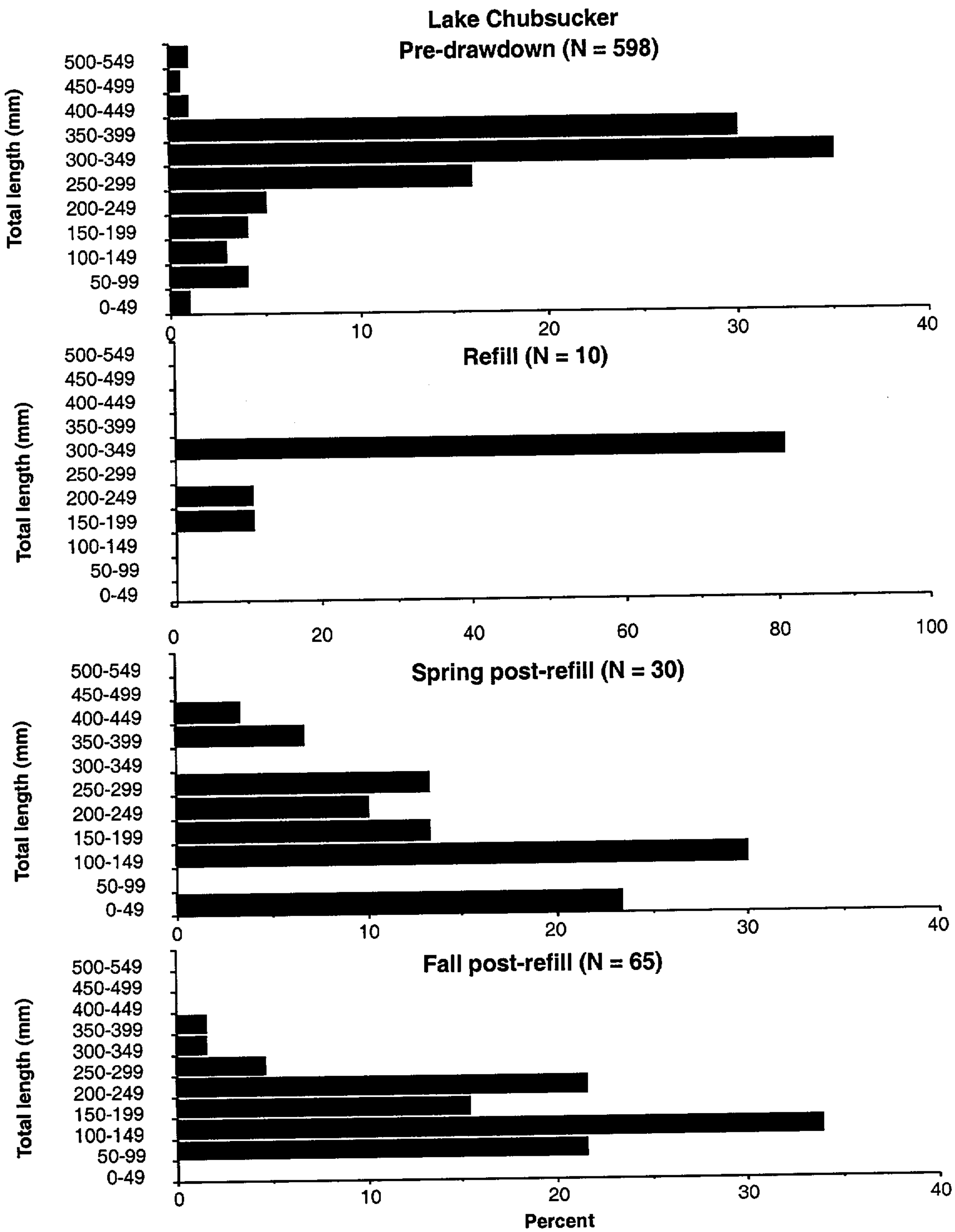


**Figure 5-104.** Length-Frequency Distributions of Lake Chubsuckers in Par Pond During Pre-Drawdown (January 1984-January 1985), Refill (January 1985), Spring Post-Refill (May and June 1995), and Fall Post-Refill (September and October 1995) (Source: Paller and Wike 1996a)

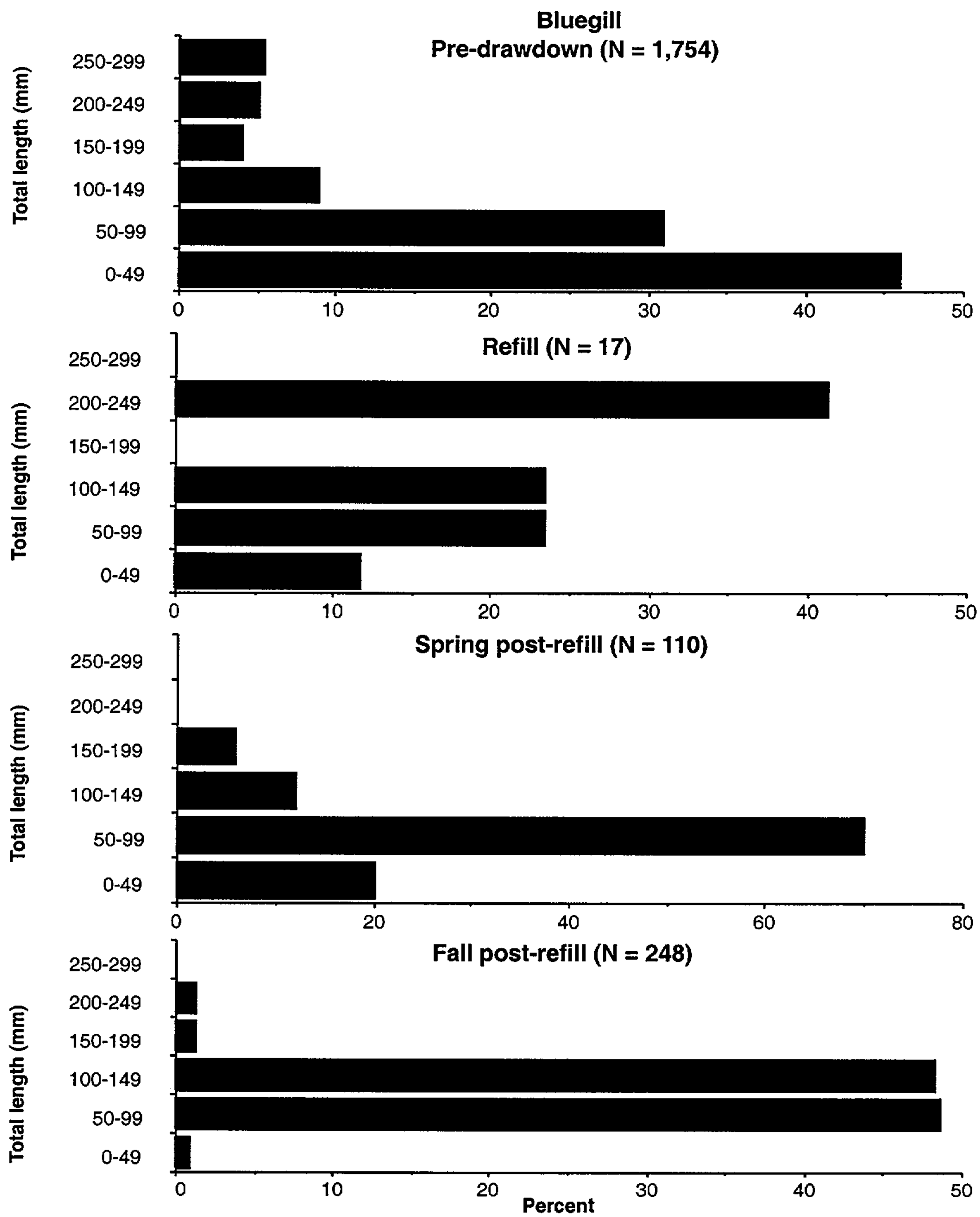


**Figure 5-105.** Length-Frequency Distributions of Lake Chubsuckers in Par Pond During Pre-Drawdown (January 1984-January 1985), Refill (January 1985), Spring Post-Refill (May and June 1995), and Fall Post-Refill (September and October 1995) (Source: Paller and Wike 1996a)

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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## *5.9 Savannah River*

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# Drainage Description and Surface Hydrology

## 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 5-106). 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).

### Physiography

#### 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).

#### 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 large reservoirs as the river flows through the Piedmont (Bauer et al. 1989).

#### 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).

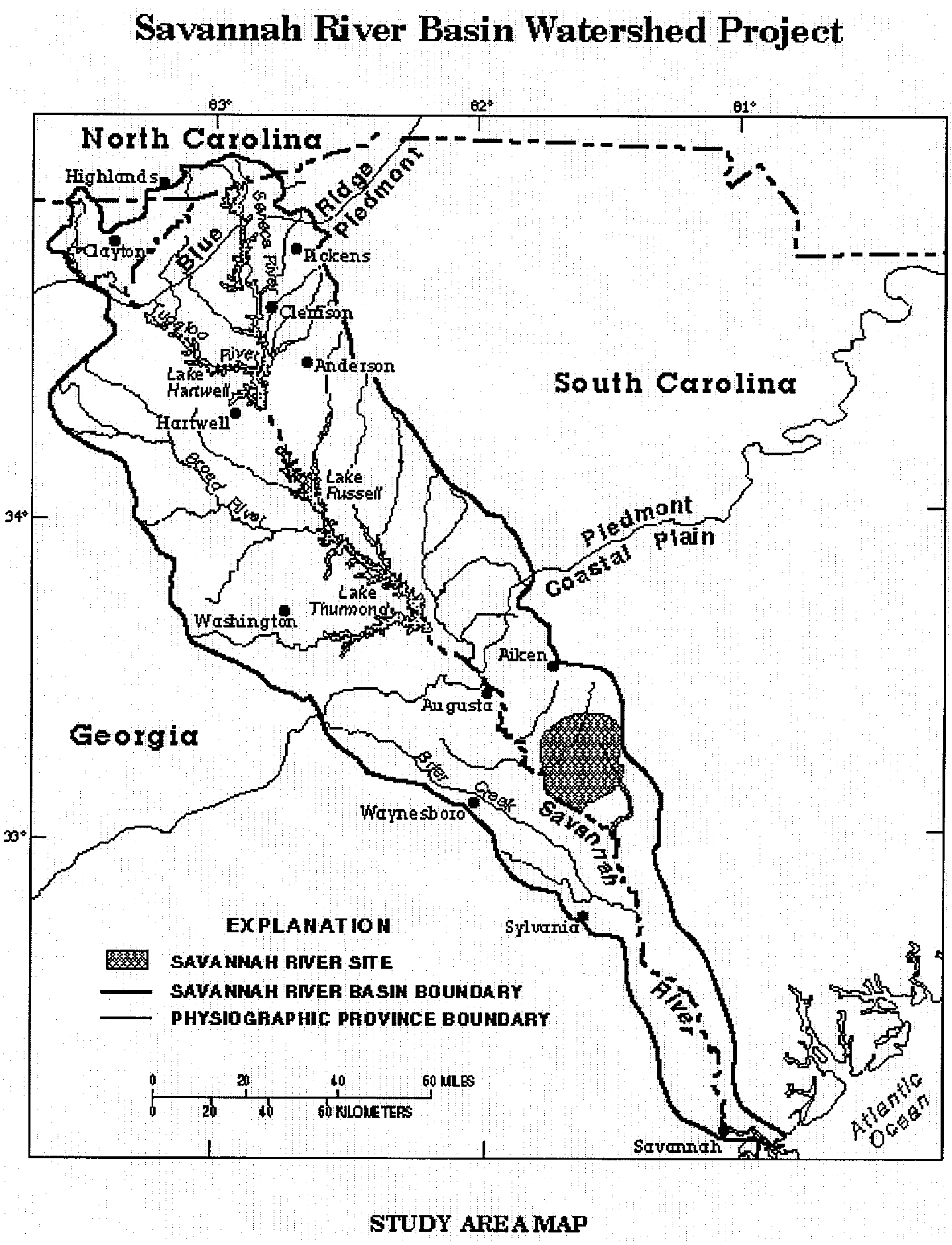


**Figure 5-106.** Map of the Savannah River Watershed

### 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).

### 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).

## 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.

# Flow Measurements

## Droughts

### 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).

### 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.

### Flow Requirements

During the 1985-1989 drought, the U.S. Army Corps of Engineers maintained minimum water releases from the 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 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).

The U.S. Geologic Survey measures flow at several locations on the Savannah River. Table 5-195 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 maximum, minimum, and mean daily flows for the four stations are shown in Figure 5-107 through Figure 5-110.

**Table 5-195.** Flow Summary for the Savannah River

| | | | Range | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | | Low | | High | | 7Q10 | | 7-Day Low Flow | |
| Station Name | Station Number | Period of Record | cms[a] | cfs[b] | cms | cfs | cms | cfs | cms | cfs | cms | cfs |
| Augusta, Georgia | 02197000 | 1954-1995 | 269 | 9,394 | 80 | 2,810 | 2,393 | 84,500 | 122 | 4,291 | 106 | 3,746 |
| near Jackson, South Carolina (SRS Boat Dock)[c] | 02197320 | 1972-1995 | - | - | 91 | 3,220 | - | - | 118 | 4,154 | 107 | 3,773 |
| Burtons Ferry Bridge near Millhaven, South Carolina (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, Georgia | 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.

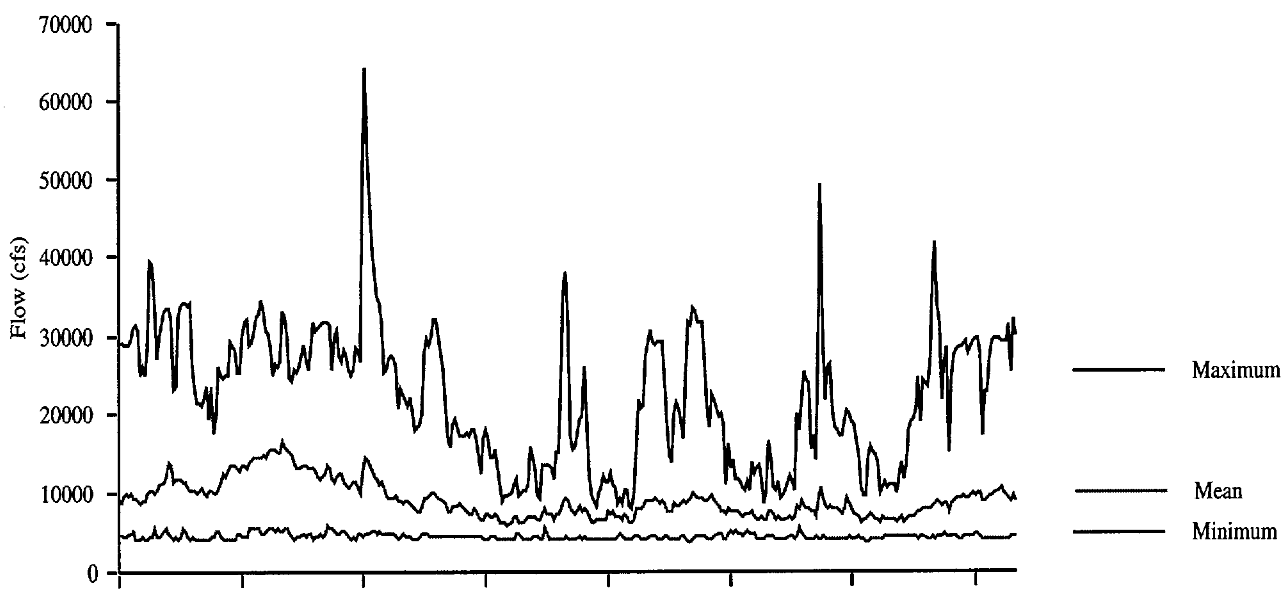


**Figure 5-107.** Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Augusta, Georgia, October 1982-September 1995

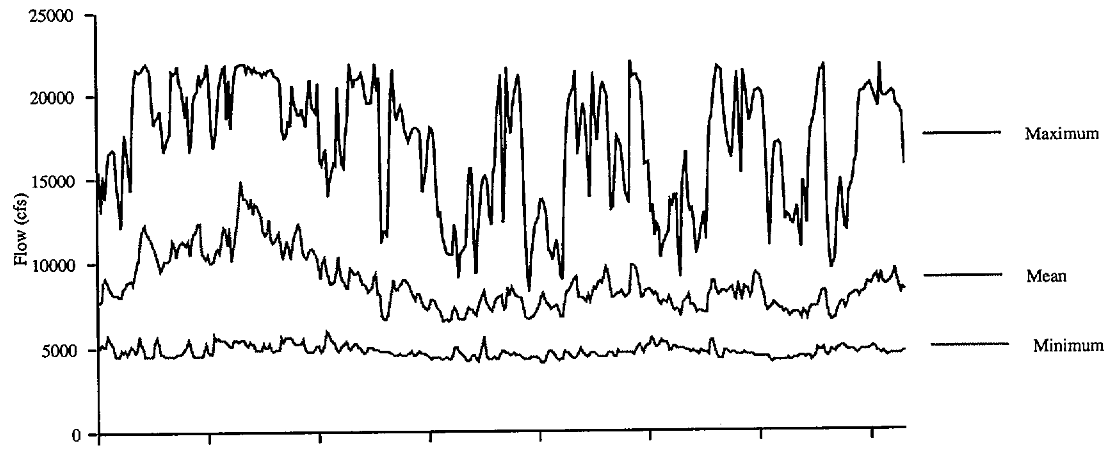


**Figure 5-108**. Maximum, Mean, and Minimum Flow Measurements for the Savannah River near Jackson, South Carolina, October 1982-September 1995

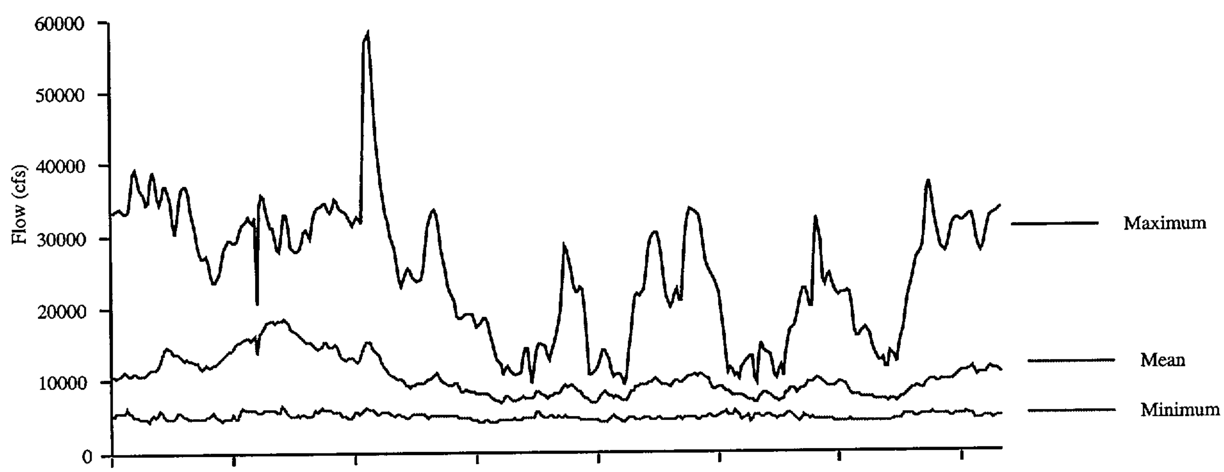


**Figure 5-109**. Maximum, Mean, and Minimum Flow Measurements for the Savannah River at the South Carolina Highway 301 Bridge, October 1982-September 1995

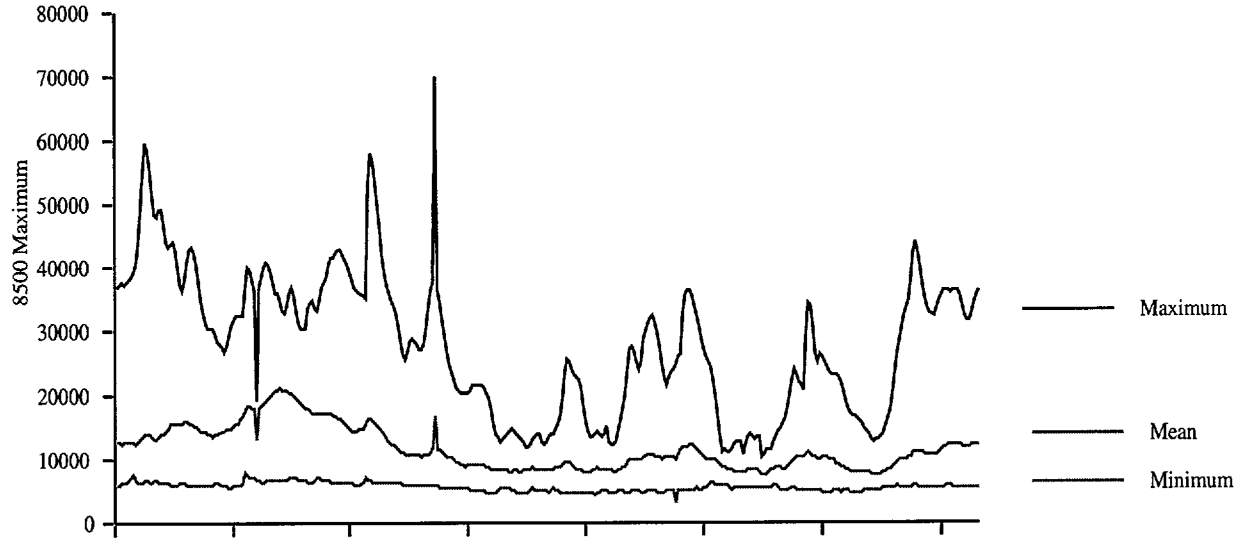


**Figure 5-110.** Maximum, Mean, and Minimum Flow Measurements for the Savannah River near Clyo, Georgia, October 1982-September 1995

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 J. Strom Thurmond (formerly Clarks Hill) 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).

# Water Chemistry and Quality

## Studies and Monitoring

### Water-Quality Monitoring

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 5-111).

### Monitoring Data

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.

### Comprehensive Cooling Water Study

In July 1983, the Comprehensive Cooling Water Study (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 5-111) 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).

### 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).

### 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 sta-

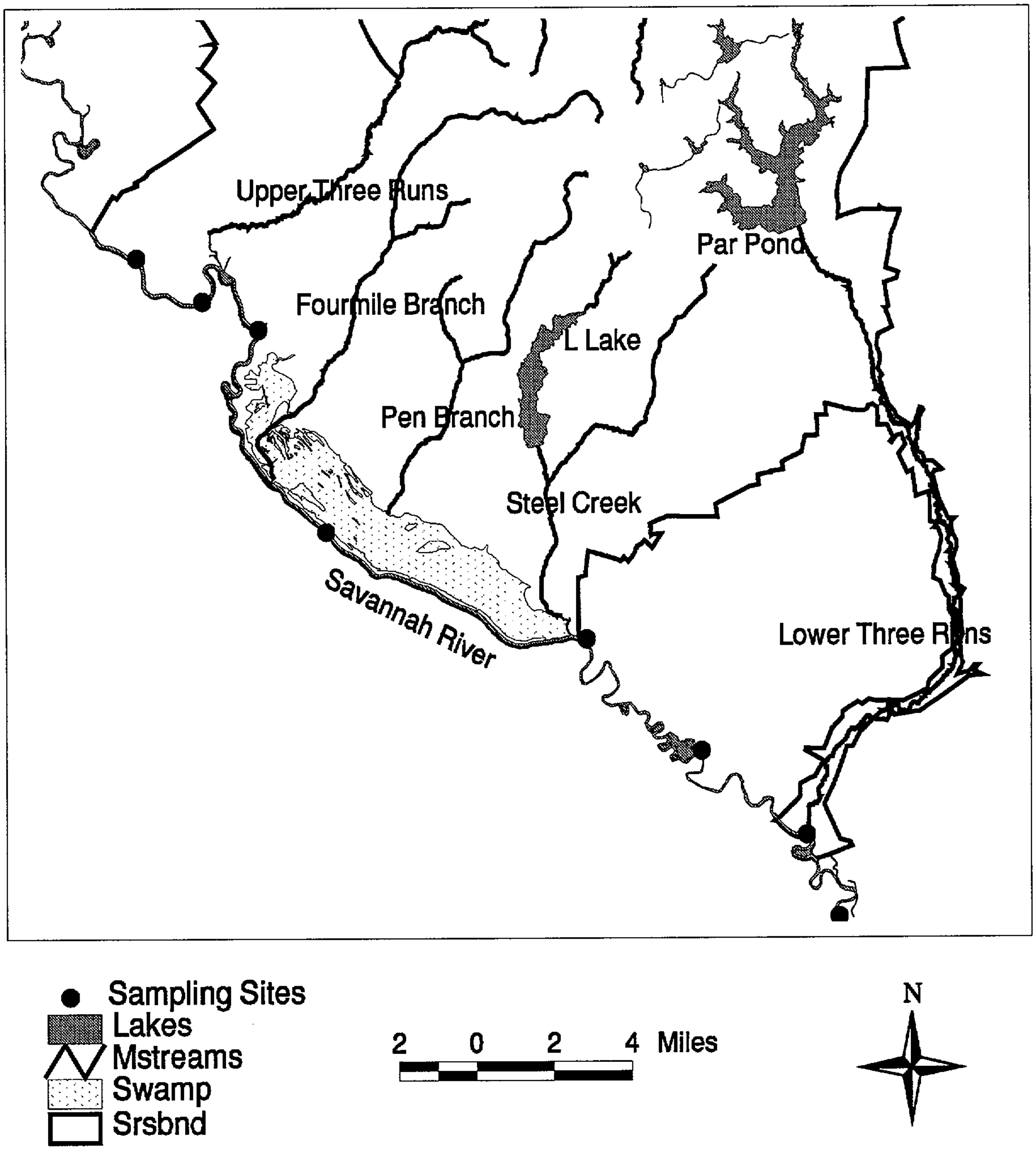


**Figure 5-111.** Water Quality Sampling Stations for the Savannah River. Sampling locations from upstream to downstream: River-2, RM 160, 3G Pumphouse, River-3, Steel Creek landing, downstream of Steel Creek landing, mouth of Lower Three Runs, River-10

tistically significant changes were evident for the tested parameters between the Savannah River water quality stations upstream and downstream of SRS.

## Field Data

### 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) (Table 5-196). 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.

### 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 (Table 5-196).

## Physical Characteristics and General Chemistry

### Dissolved Oxygen

Mean dissolved oxygen concentrations in the Savannah River (for all studies) ranged from 7.19 to 8.78 mg/l (Table 5-197). The CCWS found that percentage of oxygen saturation varied seasonally and was lowest during the autumn (Newman et al. 1986).

### 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 (Table 5-197).

### Conductivity

Mean specific conductivity values range from 68.2 to 84.8 µS/cm (Table 5-197). 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).

**Table 5-196.** Savannah River Field Data

| | Water Temperature (°C) | pH | Stream Velocity (cm/sec) |
|---|---|---|---|
| **Savannah River, upriver of SRS near Jackson, SC (CCWS)a** | | | |
| Mean | 15.9 | 6.88 | 86 |
| Range | 4.3 - 24.0 | 5.90 - 7.80 | 40 - 115 |
| Samples | 46 | 46 | 39 |
| **Savannah River at pumphouse 3G intake canal (CCWS)a** | | | |
| Mean | 15.8 | 6.98 | 67 |
| Range | 3.8 - 23.5 | 5.90 - 8.05 | 32 - 100 |
| Samples | 46 | 46 | 38 |
| **Savannah River downriver of Steel Creek Landing (CCWS)a** | | | |
| Mean | 17.1 | 6.94 | 84 |
| Range | 4.6 - 26.0 | 6.30 - 7.90 | 23 - 160 |
| Samples | 45 | 45 | 39 |
| **River-2, upriver of SRS (1987- 1991)b** | | | |
| Mean | 18.2 | 0 | |
| Range | 9.0 - 28.0 | 5.8 - 8.0 | NA |
| Samples | 60 | 60 | |
| **River-3B, adjacent to SRS (1987- 1991)b** | | | |
| Mean | 17.4 | 0 | |
| Range | 8.5 - 28.0 | 5.5 - 7.8 | NA |
| Samples | 60 | 60 | |
| **River-10, downriver of SRS (1987- 1991)b** | | | |
| Mean | 18.2 | 0 | |
| Range | 8.0 - 27.0 | 4.8 - 8.2 | NA |
| Samples | 60 | 60 | |
| **River-2, upriver of SRS (1992 - 1995)[c]** | | | |
| Mean | 17.5 | 6.4 | NA |
| Range | 8.0 - 24.8 | 5.7 - 7.8 | |
| Samples | 48 | 48 | |
| **River-3B, adjacent to SRS (1992 - 1995)[c]** | | | |
| Mean | 17.8 | 6.4 | NA |
| Range | 8.1 - 25.5 | 5.7 - 7.6 | |
| Samples | 48 | 48 | |
| **River-10, downriver of SRS (1992 - 1995)[c]** | | | |
| Mean | 17.9 | 6.4 | NA |
| Range | 8.4 - 26.2 | 4.9 - 7.2 | |
| Samples | 48 | 48 | |

NA = not analyzed.
Blank Spaces = Mean not calculated due to insufficient data in report.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]1987-1991 = Data taken from Arnett et al. 1992; Cummins et al. 1990, 1991; Davis et al. 1989; Mikol et al. 1988
[c]1992-1995 = Data taken from Arnett 1993, 1994, 1995, and 1996.

**Table 5-197.** Savannah River Physical Characteristics and General Chemistry

| | Dissolved Oxygen (mg/l) | Specific Conductivity (µS/cm) | Turbidity (NTU) | Total Suspended Solids (mg/l) |
|---|---|---|---|---|
| **Savannah River, upriver of SRS, near Jackson, SC (CCWS)[a]** | | | | |
| Mean | 7.60 | 79.4 | 20.2 | 10.1 |
| Range | 5.20 - 11.4 | 47.3 - 98.3 | 5.1 - 80.2 | 0.25 - 54.0 |
| Samples | 46 | 38 | 43 | 45 |
| **Savannah River at pumphouse 3G intake canal (CCWS)[a]** | | | | |
| Mean | 7.38 | 68.2 | 18.3 | 9.47 |
| Range | 3.80 - 11.3 | 36.7 - 90.3 | 4.9 - 81.0 | 0.25 - 43.9 |
| Samples | 46 | 38 | 43 | 45 |
| **Savannah River, downriver of Steel Creek Landing (CCWS)[a]** | | | | |
| Mean | 7.19 | 77.0 | 21.0 | 12.6 |
| Range | 4.70 - 10.9 | 50.9 - 93.7 | 1.4 - 90.9 | 2.00 - 70.0 |
| Samples | 46 | 38 | 43 | 45 |
| **River-2, upriver of SRS (1987-1991)[b]** | | | | |
| Mean | 8.2 | 75 | 10.4 | 13.8 |
| Range | 4.5 - 12.0 | 0.11 - 137 | 1.0 - 110 | 3.0 - 108 |
| Samples | 60 | 60 | 60 | 60 |
| **River-3B, adjacent to SRS (1987-1991)[b]** | | | | |
| Mean | 8.1 | 76 | 10.1 | 12.8 |
| Range | 4.5 - 12 | 0.12 - 141 | 1.0 - 110 | 3.0 - 98 |
| Samples | 60 | 60 | 60 | 60 |
| **River-10, downriver of SRS (1987-1991)[b]** | | | | |
| Mean | 7.7 | 76 | 9.08 | 12.1 |
| Range | 4.5 - 12 | 0.12 - 136 | 1.0 - 110 | 1.0 - 64 |
| Samples | 60 | 60 | 60 | 60 |
| **River-2, upriver of SRS (1992-1995)[c]** | | | | |
| Mean | 8.78 | 81 | 10.6 | 9.6 |
| Range | 6.4 - 11.6 | 54 - 107 | 2.22 - 33 | 3 - 18 |
| Samples | 48 | 48 | 48 | 48 |
| **River-3B, adjacent to SRS (1992-1995)[c]** | | | | |
| Mean | 8.32 | 83 | 9.9 | 10.6 |
| Range | 5.3 - 11.5 | 5.4 - 109 | 2.54 - 27 | 3 - 26 |
| Samples | 48 | 48 | 48 | 48 |
| **River-10, downriver of SRS (1992-1995)[c]** | | | | |
| Mean | 7.7 | 84.8 | 9.4 | 11.4 |
| Range | 5.8 - 10.7 | 54 - 114 | 5.6 - 32.4 | 3 - 48 |
| Samples | 48 | 48 | 48 | 48 |

NTU = Nephelometric Turbidity Units.
NA = Not Analyzed.
Blank Spaces = Mean not calculated due to insufficient data in report.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]1987-1991 = Data taken from Arnett et al. 1992; Cummins et al. 1990, 1991; Davis et al. 1989; Mikol et al. 1988.
[c]1992-1995 = Data taken from Arnett, 1993, 1994, 1995, and 1996.

## Major Anions and Cations

### 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 (Table 5-198).

Mean concentrations of chlorides and sulfates have been slightly higher during routine monitoring than during the CCWS (Table 5-198). 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.

### 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 (Table 5-199). 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 (Table 5-199).

### 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 (Table 5-199).

## Nutrients

### 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).

### 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 (Table 5-200). 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.

**Table 5-198.** Savannah River Major Anions

| | Alkalinity (mg $CaCO_3$/l) | Chloride (mg/l) | Sulfate (mg/l) |
|---|---|---|---|
| **Savannah River, upriver of SRS near Jackson, SC (CCWS)[a]** | | | |
| Mean | 19.6 | 6.29 | 6.00 |
| Range | 12.3 - 28.5 | 2.90 - 8.90 | 2.90 - 9.17 |
| Samples | 45 | 46 | 28 |
| **Savannah River at pumphouse 3G intake canal (CCWS)[a]** | | | |
| Mean | 16.5 | 5.53 | 5.26 |
| Range | 5.63 - 24.0 | 2.60 - 8.40 | 2.13 - 8.99 |
| Samples | 45 | 46 | 28 |
| **Savannah River, downriver of Steel Creek Landing (CCWS)[a]** | | | |
| Mean | 18.7 | 6.00 | 5.26 |
| Range | 11.6 - 24.5 | 2.70 - 8.20 | 1.77 - 8.48 |
| Samples | 45 | 45 | 28 |
| **River-2, upriver of SRS (1987-1991)[b]** | | | |
| Mean | 21 | 7.8 | 8.1 |
| Range | 7.0 - 31 | 3.2 - 13 | 4.0 - 22 |
| Samples | 60 | 60 | 60 |
| **River-3B, adjacent to SRS (1987-1991)[b]** | | | |
| Mean | 21 | 8.0 | 8.5 |
| Range | 8.0 - 31 | 3.9 - 13 | 5.0 - 22 |
| Samples | 60 | 60 | 60 |
| **River-10, downriver of SRS (1987-1991)[b]** | | | |
| Mean | 21 | 8.2 | 8.2 |
| Range | 10 - 31 | 2.8 - 12 | 4.0 - 22 |
| Samples | 60 | 60 | 60 |
| **River-2, upriver of SRS (1992-1995)[c]** | | | |
| Mean | 18.5 | 7.67 | 6.8 |
| Range | 13 - 23 | 4 - 13 | 4 - 11 |
| Samples | 48 | 48 | 48 |
| **River-3B, adjacent to SRS (1992-1995)[c]** | | | |
| Mean | 19.1 | 7.85 | 7.0 |
| Range | 12 - 25 | 4 - 12 | 4 - 11 |
| Samples | 48 | 48 | 48 |
| **River-10, downriver of SRS (1992-1995)[c]** | | | |
| Mean | 19.2 | 8.05 | 7.69 |
| Range | 13 - 24 | 4 - 12 | 4 - 11 |
| Samples | 48 | 48 | 48 |

NA = not analyzed.
Blank Spaces = Mean not calculated due to insufficient data in report.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]1987-1991 = Data taken from Arnett et al. 1992; Cummins et al. 1990, 1991; Davis et al. 1989; and Mikol et al. 1988.
[c]1992-1995 = Data taken from Arnett 1993, 1994, 1995, and 1996.

**Table 5-199.** Savannah River Major Cations (Total)

| | Calcium (mg/l) | Magnesium (mg/l) | Sodium (mg/l) | Potassium (mg/l) | Aluminum (mg/l) | Iron (mg/l) | Manganese (mg/l) |
|---|---|---|---|---|---|---|---|
| **Savannah River, upriver of SRS near Jackson, SC (CCWS)[a]** | | | | | | | |
| Mean | 3.34 | 1.34 | 7.63 | 1.10 | 0.983 | 0.956 | 0.057 |
| Range | 2.61 - 4.39 | 1.03 - 1.73 | 3.77 - 10.8 | <0.368 - 1.86 | 0.208 - 2.92 | 0.274 - 3.27 | <0.0004 - 0.115 |
| Samples | 39 | 39 | 39 | 39 | 39 | 39 | 18 |
| **Savannah River at pumphouse 3G intake canal (CCWS)[a]** | | | | | | | |
| Mean | 3.07 | 1.21 | 6.62 | 0.995 | 0.996 | 0.915 | 0.059 |
| Range | 1.75 - 4.02 | 0.488 - 1.49 | 1.35 - 10.3 | <0.368 - 2.12 | 0.290 - 5.41 | 0.140 - 3.27 | <0.0004 - 0.126 |
| Samples | 39 | 39 | 39 | 39 | 39 | 39 | 18 |
| **Savannah River, downriver of Steel Creek Landing (CCWS)[a]** | | | | | | | |
| Mean | 3.42 | 1.32 | 7.15 | 1.04 | 1.06 | 1.08 | 0.040 |
| Range | 2.76 - 4.65 | 0.83 - 1.74 | 3.10 - 10.4 | <0.368 - 1.86 | 0.115 - 3.99 | 0.477 - 4.01 | <0.0004 - 0.085 |
| Samples | 39 | 39 | 39 | 39 | 39 | 39 | 18 |
| **River-2, upriver of SRS (1987-1991)[b]** | | | | | | | |
| Mean | | | | | | | |
| Range | 2.6 - 6.0 | 1.1 - 1.7 | 6.7 - 17 | NA | <0.01 - 1.6 | 0.17 - 2.6 | <0.01 - 0.16 |
| Samples | 20 | 20 | 19 | | 19 | 20 | 20 |
| **River-3B, adjacent to SRS (1987-1991)[b]** | | | | | | | |
| Mean | | | | | | | |
| Range | 2 - 6.5 | 1.1 - 1.7 | 5.2 - 17 | NA | <0.05 - 1.2 | 0.03 - 2.5 | <0.01 - 0.16 |
| Samples | 18 | 18 | 19 | | 19 | 20 | 18 |
| **River-10, downriver of SRS (1987-1991)[b]** | | | | | | | |
| Mean | | | | | | | |
| Range | 0.26 - 6.1 | 0.63 - 1.6 | 7.5 - 17 | NA | <0.01 - 1.1 | 0.05 - 1.8 | <0.01 - 0.13 |
| Samples | 18 | 18 | 19 | | 19 | 20 | 18 |
| **River-2, upriver of SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | 3.6 | 1.33 | 9.12 | NA | 0.394 | 0.62 | 0.08 |
| Range | 3.10 - 4.24 | 0.98 - 1.55 | 4.87 - 11.60 | | 0.081 - 0.946 | ND - 1.39 | 0.058 - 0.11 |
| Samples | 16 | 16 | 16 | | 16 | 16 | 16 |
| **River-3B, adjacent to SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | 3.99 | 1.32 | 9.12 | NA | 0.33 | 0.66 | 0.08 |
| Range | 2.97 - 4.52 | 0.894 - 1.51 | 5.04 - 12.10 | | ND - 0.745 | 0.39 - 1.26 | 0.0575 - 0.125 |
| Samples | 16 | 16 | 16 | | 15 | 16 | 16 |
| **River-10, downriver of SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | 4.17 | 1.32 | 9.74 | NA | 0.41 | 0.82 | 0.07 |
| Range | 3.25 - 5.09 | 0.917 - 1.52 | 5.28 - 13.00 | | ND - 0.838 | 0.49 - 1.32 | ND - 0.11 |
| Samples | 16 | 16 | 16 | | 14 | 16 | 15 |

NA = not analyzed.
ND = none detected.
Blank Spaces = Mean not calculated due to insufficient data in report.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]1987-1991 = Data taken from Arnett et al. 1992; Cummins et al. 1990, 1991; Davis et al. 1989; Mikol et al. 1988
[c]1992-1995 = Data taken from Arnett 1993, 1994, 1995, and 1996
[d]All nondetectable quantities were excluded from the calculations of means.

**Table 5-200.** Savannah River Nutrients

| | Total Phosphorus (mg/l) | Total Orthophosphate (mg $PO_4$/l) | Organic Nitrogen (mg/l) | Total Kjeldhal Nitrogen (mg/l) | Ammonia (mg $NH_3$/l) | Nitrite (mg $NO_2$/l) | Nitrate (mg $NO_3$/l) |
|---|---|---|---|---|---|---|---|
| **Savannah River, upriver of SRS near Jackson, SC (CCWS)[a]** | | | | | | | |
| Mean | 0.109 | 0.081 | 0.144 | 0.306 | 0.183 | 0.014 | 0.289 |
| Range | 0.037 - 0.224 | 0.035 - 0.167 | <0.010 - 0.650 | 0.110 - 0.750 | 0.015 - 0.480 | <0.001 - 0.046 | 0.129 - 0.424 |
| Samples | 44 | 41 | 41 | 46 | 46 | 44 | 43 |
| **Savannah River at pumphouse 3G intake canal (CCWS)[a]** | | | | | | | |
| Mean | 0.104 | 0.068 | 0.158 | 0.277 | 0.155 | 0.012 | 0.262 |
| Range | 0.040 - 0.200 | 0.021 - 0.154 | <0.010 - 0.690 | 0.073 - 0.900 | 0.019 - 0.360 | 0.002 - 0.041 | 0.067 - 0.485 |
| Samples | 45 | 41 | 41 | 46 | 46 | 44 | 41 |
| **Savannah River, downriver of Steel Creek Landing (CCWS)[a]** | | | | | | | |
| Mean | 0.107 | 0.075 | 0.170 | 0.282 | 0.138 | 0.012 | 0.293 |
| Range | 0.040 - 0.184 | 0.023 - 0.181 | <0.010 - 0.917 | 0.087 - 0.970 | 0.011 - 0.440 | <0.001 - 0.047 | 0. 090 - 0.439 |
| Samples | 45 | 41 | 41 | 46 | 46 | 44 | 42 |
| **River-2, upriver of SRS (1987-1991)[b]** | | | | | | | |
| Mean | 0.094 | | | | 0.148 | | 0.312 |
| Range | 0.02 - 0.25 | NA | NA | NA | <0.01 - 0.84 | NA | 0.07 - 0.82 |
| Samples | 60 | | | | 60 | | 60 |
| **River-3B, adjacent to SRS (1987-1991)[b]** | | | | | | | |
| Mean | 0.118 | | | | 0.128 | | 0.334 |
| Range | 0.03 - 0.25 | NA | NA | NA | <0.01 - 0.28 | NA | 0.08 - 1.2 |
| Samples | 60 | | | | 60 | | 60 |
| **River-10, downriver of SRS (1987-1991)[b]** | | | | | | | |
| Mean | 0.104 | | | | 0.095 | | 0.320 |
| Range | 0.03 - 0.39 | NA | NA | NA | <0.01 - 0.30 | NA | 0.06 - 0.76 |
| Samples | 20 | | | | 20 | | 20 |
| **River-2, upriver of SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | 0.06 | NA | NA | NA | 0.082 | NA | 0.265 |
| Range | ND - 0.09 | | | | ND - 0.27 | | 0.02 - 0.45 |
| Samples | 12 | | | | 41 | | 48 |
| **River-3B, adjacent to SRS (1992 - 1995)[c]** | | | | | | | |
| Mean[d] | 0.06 | NA | NA | NA | 0.10 | NA | 0.31 |
| Range | ND - 0.11 | | | | ND - 0.25 | | 0.14 - 0.48 |
| Samples | 12 | | | | 47 | | 48 |
| **River-10, downriver of SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | 0.06 | NA | NA | NA | 0.12 | NA | 0.31 |
| Range | ND - 0.1 | | | | ND - 0.55 | | 0.11 - 0.47 |
| Samples | 12 | | | | 38 | | 48 |

NA = not analyzed.
ND = none detected.
Blank Spaces = Mean not calculated due to insufficient data in report.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]1987-1991 = Data taken from Arnett et al. 1992; Cummins et al. 1990, 1991; Davis et al. 1989; and Mikol et al. 1988.
[c]1992-1995 = Data taken from Arnett 1993, 1994, 1995, and 1996.
[d]All nondetectable quantities were excluded from the calculation of means.

### Nitrogen

Nitrogen concentrations are in Table 5-200. 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 (Table 5-200).

## 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. All trace element monitoring data are in Table 5-201. 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.

## 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.

## 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.

## 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).

**Table 5-201.** Savannah River Trace Elements (Total)

| | Arsenic (µg/l) | Cadmium (µg/l) | Chromium (µg/l) | Copper (µg/l) | Lead (µg/l) | Nickel (µg/l) | Zinc (µg/l) |
|---|---|---|---|---|---|---|---|
| **Savannah River, upriver of SRS near Jackson, SC (CCWS)[a]** | | | | | | | |
| Mean | 2.6 | 0.51 | 7.1 | 2.3 | 1.9 | 3.7 | 4.6 |
| Range | <0.4 - 16.2 | <0.04 - 2.90 | <0.4 - 52.0 | <0.4 - 5.7 | <0.4 - 9.0 | <0.4 - 13.6 | <0.4 - 17.8 |
| Samples | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| **Savannah River at pumphouse 3G intake canal (CCWS)[a]** | | | | | | | |
| Mean | 2.5 | 0.36 | 9.3 | 2.5 | 1.7 | 3.1 | 4.8 |
| Range | <0.4 - 21.1 | <0.04 - 1.70 | <0.4 - 57.0 | <0.4 - 5.6 | <0.4 - 5.3 | <0.4 - 12.0 | <0.4 - 14.0 |
| Samples | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| **Savannah River, downriver of Steel Creek Landing (CCWS)[a]** | | | | | | | |
| Mean | 2.5 | 0.21 | 10.5 | 2.5 | 2.0 | 2.4 | 8.0 |
| Range | <0.4 - 19.2 | <0.04 - 1.38 | <0.4 - 67.0 | <0.4 - 8.3 | <0.4 - 6.3 | <0.4 - 9.8 | <0.4 - 58.0 |
| Samples | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| **River-2, upriver of SRS (1987–1991)[b]** | | | | | | | |
| Mean | | | | | | | |
| Range | NA | <10 | <10 - <50 | <10 - <50 | 3 - <100 | <10 - <50 | <10 - <20 |
| Samples | | 20 | 20 | 20 | 20 | 19 | 20 |
| **River-3B, adjacent to SRS (1987-1991)[b]** | | | | | | | |
| Mean | | | | | | | |
| Range | NA | <10 - 10 | <10 - <50 | <10 - <50 | <3 - <100 | <10 - 870 | <10 - 30 |
| Samples | | 20 | 20 | 20 | 20 | 19 | 20 |
| **River-10, downriver of SRS (1987-1991)[b]** | | | | | | | |
| Mean | | | | | | | |
| Range | NA | <10 | <10 - <50 | <10 - 40 | <3 - <100 | <10 - <50 | <10 - 20 |
| Samples | | 20 | 20 | 20 | 20 | 19 | 20 |
| **River-2, upriver of SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | NA | <10 | <15 | <10 | <4 | <30 | <17 |
| Range | | ND - <10 | ND - <20 | ND - 20 | ND - 40 | ND - <50 | ND - 210 |
| Samples | | 4 | 4 | 7 | 5 | 4 | 9 |
| **River-3B, adjacent to SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | NA | <10 | <15 | <10 | <4 | <30 | 14 |
| Range | | ND - <10 | ND - <20 | ND - 20 | ND - <10 | ND - <50 | ND - 25 |
| Samples | | 4 | 4 | 7 | 5 | 4 | 11 |
| **River-10, downriver of SRS (1992-1995)[c]** | | | | | | | |
| Mean[d] | NA | <10 | <15 | <15 | <4 | <30 | <15 |
| Range | | ND - <10 | ND - <20 | ND - 30 | ND - <10 | ND - <50 | ND - 43 |
| Samples | | 4 | 4 | 7 | 6 | 4 | 9 |

NA = not analyzed.
ND = none detected.
Blank Spaces = Mean not calculated due to insufficient data in report.
[a]CCWS = Comprehensive Cooling Water Study (Newman et al. 1986).
[b]1987-1991 = Data taken from Arnett et al. 1992; Cummins et al. 1990, 1991; Davis et al. 1989; Mikol et al. 1988.
[c]1992-1995 = Data taken from Arnett 1993, 1994, 1995, and 1996.
[d]All nondetectable quantities were excluded from the calculation of means.

# Chemical, Including Radionuclide, and Toxicity Assessment Studies

No toxicity studies of Savannah River water have been done by the Savannah River Site.

## 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.

### 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 (Figure 5-112). Cobalt-60 in Savannah River sediments increases in the vicinity of the SRS (Figure 5-113). By examining recent data for cobalt-60, it is apparent that concentrations of this radioisotope were highest between 1992 and 1994 (Figure 5-114 and Figure 5-115) (WSRC 1996). The elevated concentrations occurred between June 1993 and July 1994 and coincided with elevated releases from Plant Vogtle.

Ratiometric 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 (Winn and Sundaram 1993; Winn 1995).

### Alpha, Nonvolatile Beta, Tritium

Most of the tritium in the Savannah River is from SRS (Figure 5-116). Fish caught in the vicinity of SRS have elevated tritium concentrations (Figure 5-117), and those caught since 1992 do not show a trend of decreasing concentrations (Figure 5-118). However, as Figure 5-119, illustrates, 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,

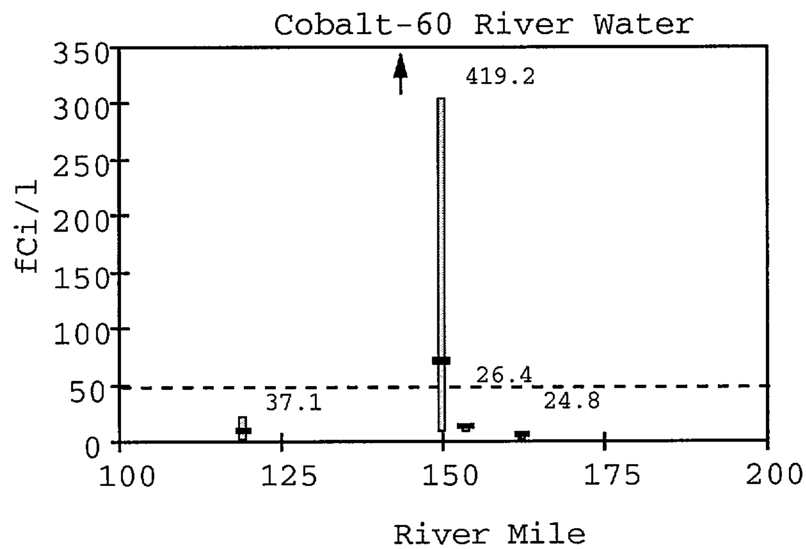


**Figure 5-112.** Mean (horiztontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Cobalt-60 in the Savannah River in the Vicinity of SRS (Source: WSRC 1996)

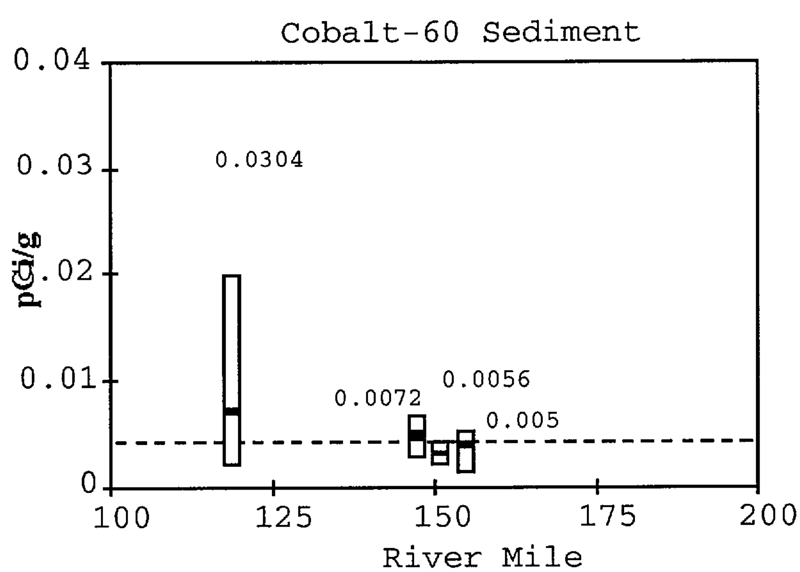


**Figure 5-113.** Mean (horizontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Cobalt-60 in Savannah River Sediments in the Vicinity of SRS (Source: WSRC 1996).

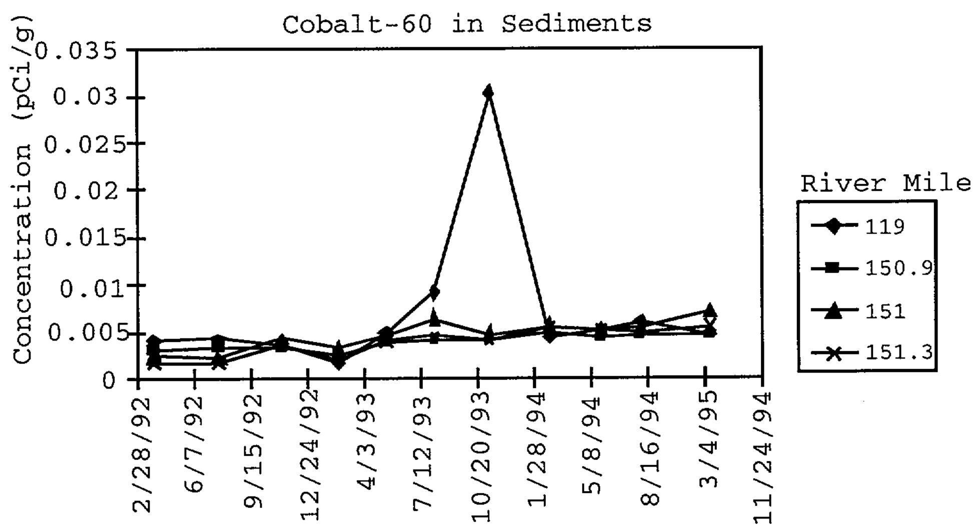


**Figure 5-114**. Mean Cobalt-60 Concentration in Savannah River Sediments, 1992-1995 (Source: WSRC 1996)

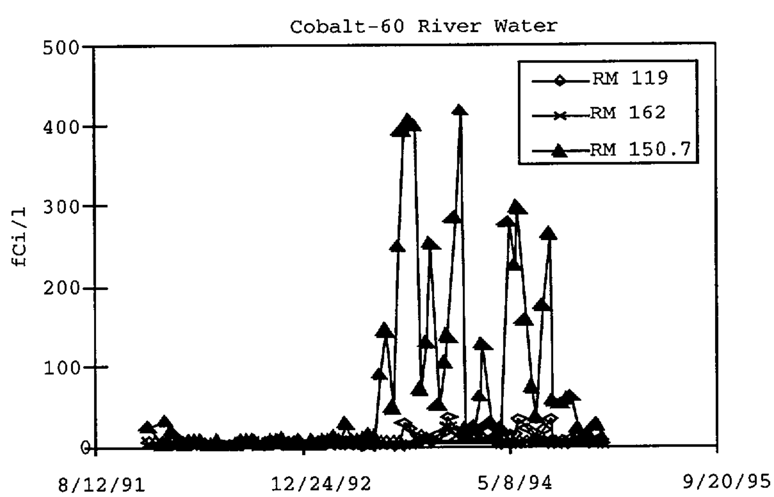


**Figure 5-115**. Mean Cobalt-60 Concentration of Savannah River Water, 1991-1994

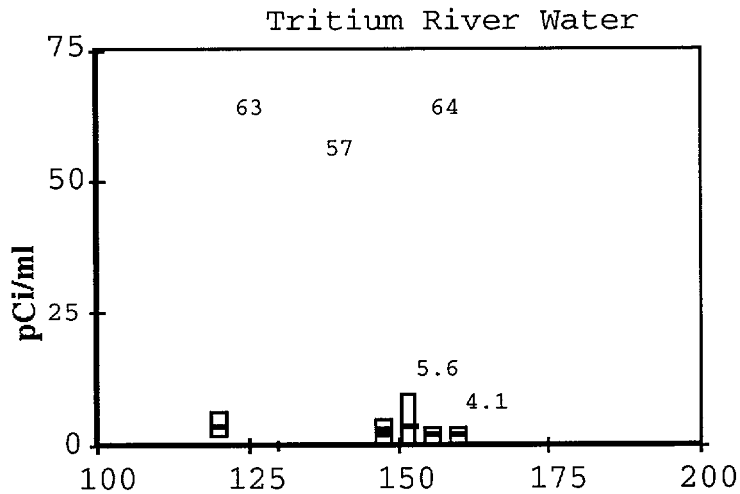


**Figure 5-116.** Mean (horizontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Tritium in Savannah River in the Vicinity of SRS (Source: WSRC 1996)

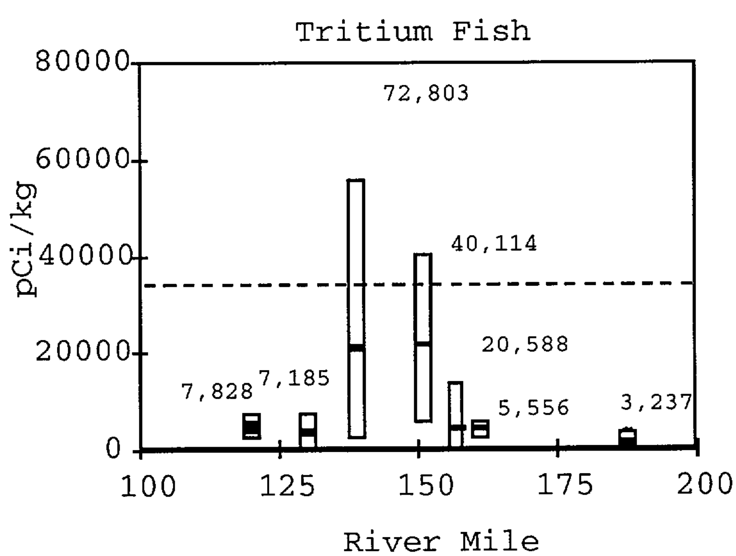


**Figure 5-117.** Mean (horizontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Tritium in Fish Caught in the Savannah River in the Vicinity of SRS (Source: WSRC 1996)

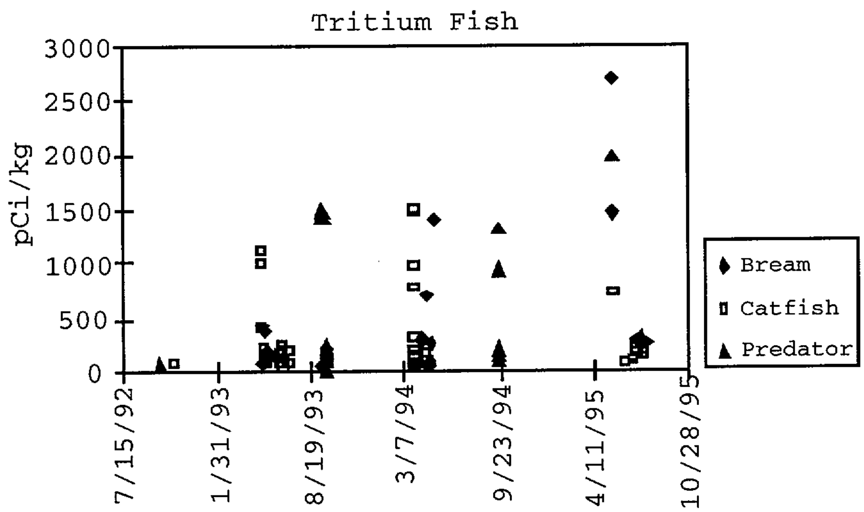


**Figure 5-118.** Mean Tritium Concentration in Fish Collected From the Savannah River, 1992-1995 (Source: WSRC 1996)

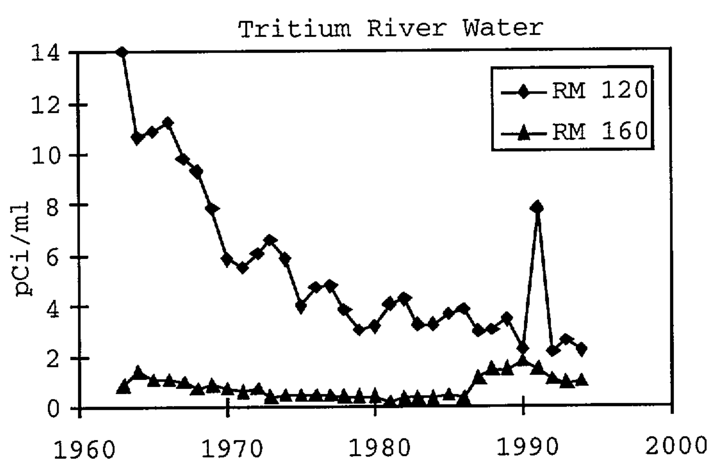


**Figure 5-119.** Mean Tritium Concentrations in Savannah River, 1960-1994 Water (Source: WSRC 1996)

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

Cesium-137 has elevated concentrations in Savannah River sediments in the vicinity of SRS (Figure 5-120). Fish taken in the vicinity of the SRS exhibit elevated concentrations of the isotope (Figure 5-121). When samples collected over time are examined, it is apparent that neither the sediments (Figure 5-122) nor the fish (Figure 5-123) 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.

Strontium-90

Strontium-90 was examined only in fish. Fish taken in the vicinity of the SRS exhibit elevated concentrations of the isotope (Figure 5-124). When fish collected over time are examined, no trend in strontium-90 concentrations is apparent (Figure 5-125) (WSRC 1996).

Mercury

From the available data on fish (Figure 5-126), the source of mercury is unclear. However, when the data are examined over time (Figure 5-127), there appears to be a trend of decreasing concentrations (WSRC 1996).

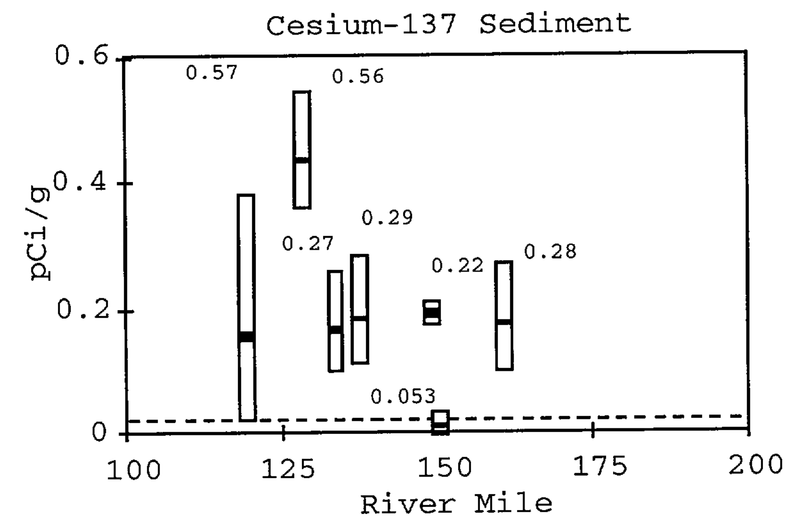


**Figure 5-120.** Mean (horizontal bar), 5th Percentile, 95th Percentile (Ends of Vertical bar), and Maximum Concentration of Cesium-137 in Savannah River Sediments in the Vicinity of SRS (Source: WSRC 1996)

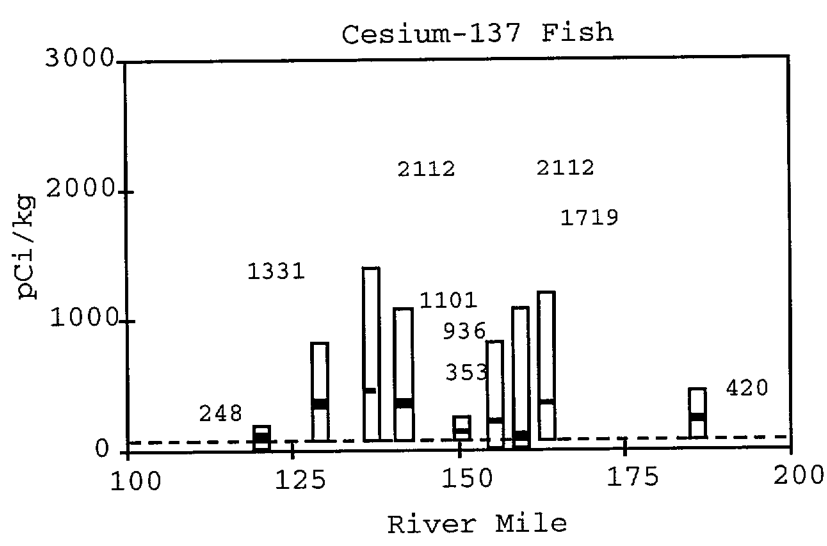


**Figure 5-121.** Mean (horizontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Cesium-137 in Savannah River Fish Collected from the Savannah River in the Vicinity of SRS (Source: WSRC 1996)

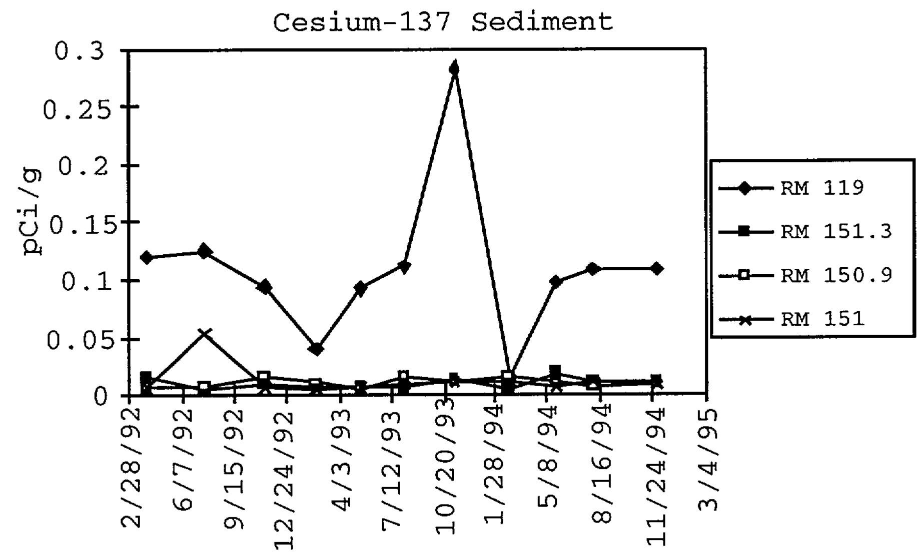


**Figure 5-122.** Mean Cesium-137 Concentration in Savannah River Sediments, 1992-1994 (Source: WSRC 1996)

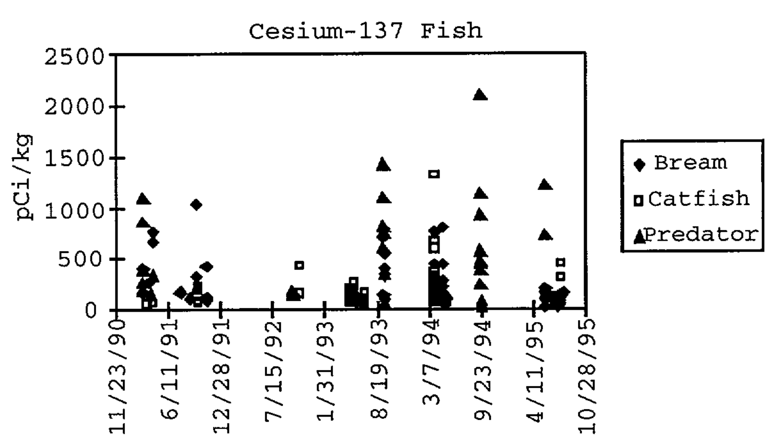


**Figure 5-123.** Mean Cesium-137 Concentration in Fish Collected from the Savannah River, 1990-1995 (Source: WSRC 1996)

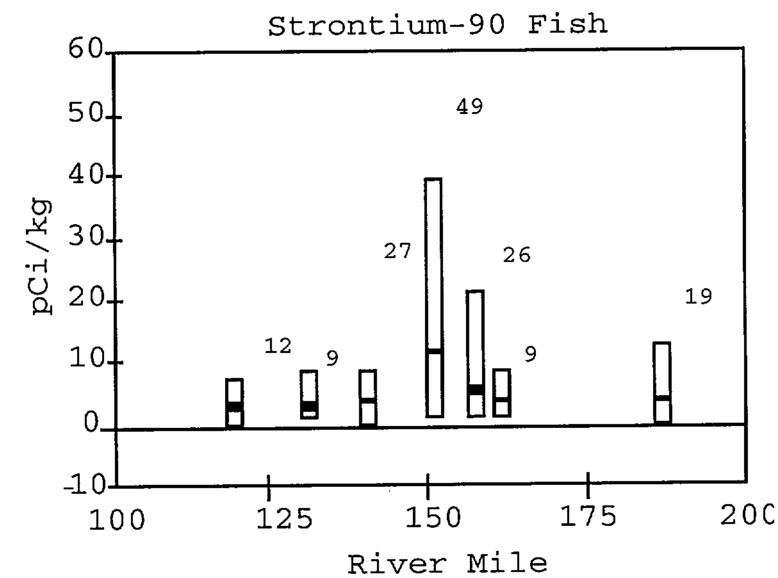


**Figure 5-124**. Mean (horizontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Strontium-90 in Fish Collected from the Savannah River in the Vicinity of SRS (Source: WSRC 1996)

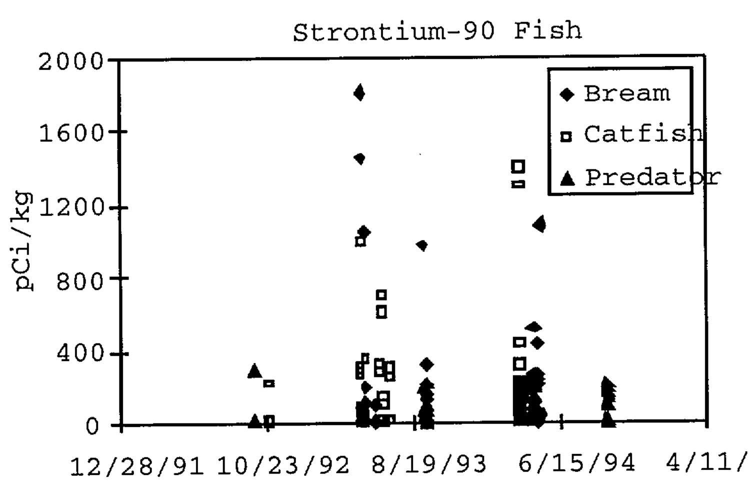


**Figure 5-125**. Mean Strontium-90 Concentration in Fish Collected from the Savannah River, 1991-1994 (Source: WSRC 1996)

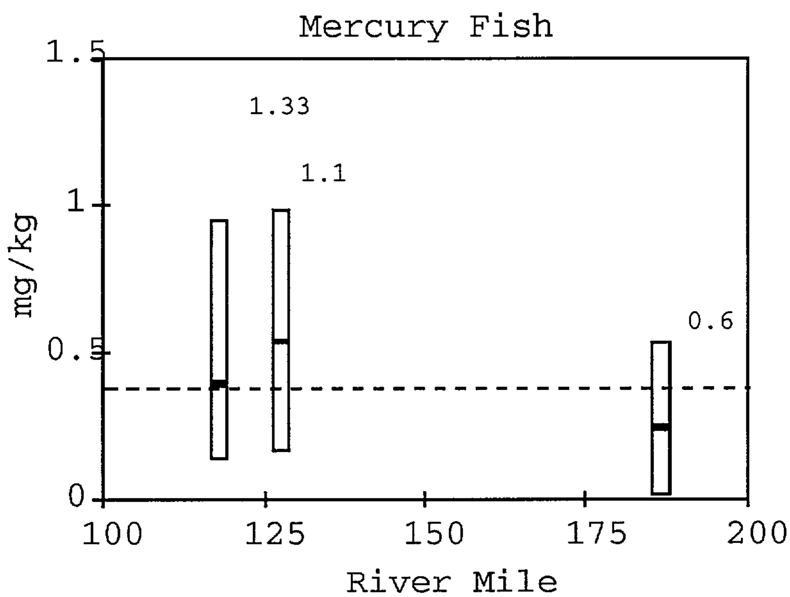


**Figure 5-126.** Mean (horizontal bar), 5th Percentile, 95th Percentile (ends of vertical bar), and Maximum Concentration of Mercury in Fish Collected from the Savannah River (Source: WSRC 1996)

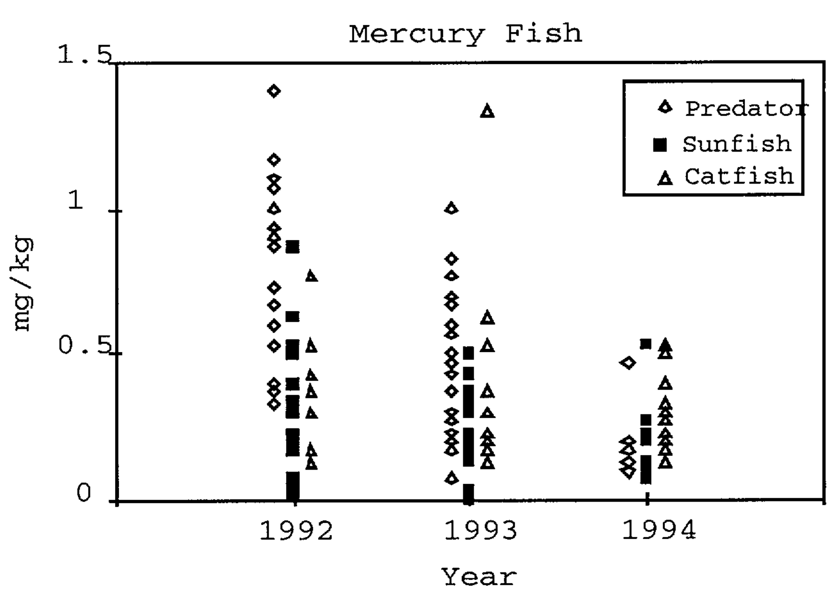


**Figure 5-127.** Mean Mercury Concentration in Fish Collected from the Savannah River, 1992-1994 (Source: WSRC 1996)

# Algae

## 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 5-128). 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 indi-


**Figure 5-128.** ANSP Sampling Stations for the Savannah River

vidual 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 (Table 5-202). The average numbers of species were greater during the fall surveys than the spring surveys for all stations.

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.

## 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.

**Table 5-202.** Number Per Year and Average Number of Non-diatom Algal Taxa Collected During Spring and Fall Surveys at ANSP Stations 1, 5, and 6 on the Savannah River 1989-1995

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **SPRING SURVEYS** | | | | |
| **Station 1** | 12 | 12 | 10 | 9 | 10 | 9 | 10 | 8 | 9 | 13 | 10 |
| **Station 5** | 12 | 8 | 9 | 10 | 7 | 10 | 11 | 9 | 14 | 13 | 13 |
| **Station 6** | 13 | 9 | 13 | 10 | 14 | 7 | 13 | 10 | 9 | 14 | 13 |
| | | | | | | | **FALL SURVEYS** | | | | |
| **Station 1** | 19 | 10 | 14 | 12 | 11 | 13 | 14 | 8 | 15 | 12 | 15 |
| **Station 5** | 8 | 11 | 15 | 12 | 13 | 14 | 17 | 8 | 12 | 15 | 14 |
| **Station 6** | 14 | 15 | 13 | 14 | 10 | 12 | 13 | 7 | 14 | 18 | 12 |

**Average (1985-1995)**

| | Spring | Fall |
|---|---|---|
| **Station 1** | 10.2 | 13 |
| **Station 5** | 10.5 | 12.6 |
| **Station 6** | 11.4 | 12.9 |

Source: ANSP 1992, 1996.

# 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.

# Zooplankton

No studies have been performed to assess the zooplankton population in the Savannah River.

# Macroinvertebrates

## Sampling Locations and Methods

Since 1951 the Academy of Natural Sciences of Philadelphia (ANSP) has sampled the insect community of the Savannah River at three stations (Figure 5-128; 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 multiplate 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).

## Results

### ANSP Studies

#### Qualitative Results

Table 5-203 lists all species collected qualitatively during surveys of the Savannah River since 1989. Table 5-204 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.

#### Quantitative Results

A summary of the statistical analyses of six community variables is presented in Table 5-205. 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-

**Table 5-203.** List of species by order found in hand collections on the Savannah River during March, June, September and December 1993-1995 surveys

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| **Phylum Arthropoda** | | | | |
| **Class Insecta** | | | | |
| **Order Odonata** | | | | |
| **Suborder Anisoptera** | | | | |
| **Family Aeshnidae** | | | | |
| *Basiaeschna janata* | | | x | |
| *Boyeria vinosa* | x | x | x | x |
| *Nasiaeschna pentacantha* | x | x | x | x |
| **Family Corduliidae** | | | | |
| *Epitheca (=Epicordulia) princeps* | | x | | |
| *Neurocordulia alabamensis* | | x | | |
| *N. molesta* | | x | x | x |
| **Family Gomphidae** | | | | |
| *Dromogomphus spinosus* | | x | | |
| *Gomphus dilatatus* | | x | | x |
| *G.* spp. | | | x | |
| *Hagenius brevistylus* | | x | x | x |
| *Stylurus* spp. | x | x | x | x |
| *S. plagiatus* | | x | x | x |
| **Family Macromiidae** | | | | |
| Macromiidae immature nymph | | | x | |
| *Macromia* spp. | x | x | x | x |
| *M. illinoiensis georgina* | | x | x | |
| *M. taeniolata* | | x | | |
| *Didymops transversa* | x | | | |
| **Suborder Zygoptera** | | | | |
| **Family Calopterygidae** | | | | |
| *Calopteryx dimidiata* | x | x | | |
| *Calopteryx* spp. | | | x | x |
| *Hetaerina* spp. | | | x | |
| **Family Coenagrionidae** | | | | |
| *Argia bipunctulata* | x | | | |
| *Argia* spp. | x | x | x | x |
| *Enallagma* spp. | x | x | x | x |
| *Ischnuria* spp. | | x | | |
| **Order Ephemeroptera** | | | | |
| **Family Baetidae** | | | | |
| *Acentrella* spp. | x | | | |
| *Baetis* spp. | x | x | | |
| *B. bimaculatus/punctiventris* | | x | | |
| *B. anniliatus* | | | | x |
| *B. ephippiatus* | x | | | |
| *B. punctiventris* | | | x | x |
| *B. intercalaris* | x | x | x | x |
| *B. propinquus* grp. | x | x | x | x |
| *Centroptilum/Procleon* spp. | | x | | |
| *Centroptilum* spp. | x | | | |
| *Heterocloeon curiosum* | | | | x |
| *Procloeon* spp. | | | | x |
| **Family Baetiscidea** | | | | |
| *Baetisca rogersi* | | x | | |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| **Family Caenidae** | | | | |
| *Amercaenus carolina* | | | x | |
| *A. ridens* | x | x | | |
| *Caenis dimutata* | | x | | |
| *C. dimutata* spp. grp. | | x | | x |
| *C. hilaris* | x | | | x |
| *C. hilaris* spp. grp. | | | | x |
| *C. punctata* | | | | x |
| **Family Ephemerellidae** | | | | |
| Ephemerellidae immature spp. | | | x | x |
| *Ephemerella* spp. | x | | x | x |
| *E. argo* | x | x | x | x |
| *E. dorothea* | x | x | x | x |
| *Eurylophella temporalis* | x | | | |
| *Eurylophella* spp. | | x | x | x |
| *E. temporalis* | | x | x | x |
| *Serratella serratoides* | | | x | |
| **Family Heptageniidae** | | | | |
| *Heptagenia flavescens* | x | x | x | x |
| *Stenacron interpunctatum* | | | x | |
| *Stenonema exiguum* | x | x | x | x |
| *S. exiguum/tenninatum* | | | | x |
| *S. mexicanum integrum* | x | x | x | x |
| *S. modestum* | x | x | x | x |
| *S. terminatum* | x | x | x | |
| *Stenonema* spp. | x | x | | |
| **Family Neoephemeridae** | | | | |
| *Neoephemera youngi* | | | | x |
| **Family Leptophlebiidae** | | | | |
| *Leptophlebia* spp. | | x | x | |
| **Family Metretopodidae** | | | | |
| *Siphloplecton basale* complex | | x | | |
| **Family Oligoneuriidae** | | | | |
| *Isonychia spp.* | x | x | x | x |
| **Family Tricorythidae** | | | | |
| *Leptohyphes dolani* | | x | | |
| *Tricorythodes* spp. | x | x | x | x |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| **Order Plecoptera** | | | | |
| **Family Perlidae** | | | | |
| *Agnetina annulipes* | | x | | |
| *Neoperla* spp. | x | x | x | x |
| *Paragnetina kansensis* | x | x | x | x |
| *Perlesta* spp. complex | x | x | x | x |
| **Family Perlodidae** | | | | |
| *Clioperia clio* | x | | x | |
| *Helopicus bogaloosa* | | | x | |
| *Hydroperla phormidia* | x | x | x | x |
| *Isoperla* spp. | x | | x | x |
| **Family Pteronarcyidae** | | | | |
| *Pteronarcys dorsata* | x | x | x | x |
| **Family Taeniopterygidae** | | | | |
| *Taeniopteryx* spp. | x | x | x | x |
| **Order Heteroptera** | | | | |
| **Family Belostomatidae** | | | | |
| *Belostoma* spp. | | x | | |
| *B. flumineum* | | | | x |
| *B. lutarium* | | | x | |
| **Family Corixidae** | | | | |
| *Corixidae* spp. immature | x | x | | x |
| *Palmacorixa* spp. | x | x | | |
| *Sigara hydatotrephes* | | | | x |
| *Sigaria* spp. | x | | x | |
| *Trichocorixa* spp. | x | x | x | x |
| **Family Notonectidae** | | | | |
| *Buenoa* spp. | x | | | |
| **Family Gelastocoridae** | | | | |
| *Gelastocoris oculatus oculatus* | x | | x | x |
| **Family Gerridae** | | | | |
| *Gerridae* immature spp. | | x | x | x |
| *Aquarius nebularis* | x | | | |
| *Metrobates hesperius* | x | | | |
| *Trepobates subnitidris* | x | | | |
| *Gerris argenticolis* | | | | x |
| *Limnoporus canaliculatus* | | | x | |
| *Metrobates hesperius* | | x | x | x |
| *Rheumatobates tenuipes* | x | x | | |
| *Rheumatobates* spp. | | | x | |
| *R. rileyi* | | | x | |
| *R. trulliger* | | | x | |
| *Trepobates* spp. | x | x | x | |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| **Family Naucoridae** | | | | |
| *Pelocoris femoratus* | x | x | | x |
| *Pelocoris* spp. (nymph) | | | x | x |
| **Family Nepidae** | | | | |
| *Ranatra buenoi* | x | x | | x |
| **Family Veliidae** | | | | |
| *Mesovelia* spp. | | x | x | |
| *Microvelia* spp. | | | | x |
| *M. paludieola* | x | | | |
| **Family Saldidae** | | | | |
| *Pentacora hirta* | x | | | |
| **Order Megaloptera** | | | | |
| **Family Corydalidae** | | | | |
| Corydalidae spp. immature | | | | x |
| *Corydalus cornutus* | x | x | x | x |
| *Chauliodes rastricornis* | x | x | | x |
| **Order Neuroptera** | | | | |
| **Family Sisyridae** | | | | |
| Sisyridae immature spp. | | | x | |
| *Climacia areolaris* | x | x | x | x |
| *Sisyra vicaria* | x | | | |
| **Order Lepidoptera** | | | | |
| **Family Pyralidae** | | | | |
| *Parapoynx* spp. | x | x | x | |
| **Order Trichoptera** | | | | |
| **Family Brachycentrida** | | | | |
| *Brachycentrus* spp. | | x | x | x |
| *Micrasema* spp. | | x | x | x |
| **Family Hydropsychidae** | | | | |
| *Cheumatopsyche* spp. | x | x | x | x |
| *Hydropsyche mississippiensis* | x | x | x | x |
| *H. rossi* | x | x | x | x |
| *Hydropsyche* spp. | x | | x | |
| *Macrostemum carolina* | x | x | x | x |
| *Macrostemum* spp. | | | x | |
| **Family Hydroptilidae** | | | | |
| *Hydroptila* spp. | x | x | x | x |
| *Neotrichia* spp. | | | | x |
| **Family Leptoceridae** | | | | |
| *Ceraclea* spp. | | x | x | x |
| *C. diluta* | x | x | x | x |
| *C. flava* | | x | | |
| *C. caceliata/maculata* | | x | | x |
| *C. tarsipunctata* grp. | x | | | |
| *C. maculata* | x | x | x | x |
| *C. nepha/protnepha* | | x | x | |
| *C. resurgens* | | x | | |
| *C. tarsipunctata* | | x | | |
| *Nectopsyche* spp. | x | x | x | x |
| *N. candida* | x | | | |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| *N. exquisita* | x | | | |
| *Oecetis* spp. | x | | x | x |
| *Triaenodes* spp. | | x | x | |
| *T. (injustus)* | | x | x | x |
| *T. tardus* | x | x | x | x |
| **Family Limnephilidae** | | | | |
| *Ironoquia* spp. | | | x | |
| *Pycnopsyche* spp. | | x | x | |
| **Family Philopotamidae** | | | | |
| *Chimarra mosleyi* | x | x | x | x |
| **Family Polycentropodidae** | | | | |
| *Cyrnellus fraternus* | | | | x |
| *Neureclipsis* spp. (pupae) | x | | | |
| *N. crepuscularis* | x | x | x | x |
| *Polycentropus* spp. | | x | | |
| **Order Coleoptera** | | | | |
| **Suborder Adephaga** | | | | |
| **Family Haliplidae** | | | | |
| *Peltodytes sexmaculatus (A)* | x | | | |
| **Family Dytiscidae** | | | | |
| *Bidessonotus longovalis* | x | | | |
| *B. pulicarius* | | x | | |
| *B. (A)* inconspicuus | | | | x |
| *Bidessonotus spp.* | | | x | |
| *Copelatus glyphicus (A)* | | | x | |
| *Copelatus spp.* | x | | | |
| *Coptotomus loticus (A)* | | | | x |
| *Coptotomus spp.* | | x | x | |
| *Cybister fimbriolatus crotchi (A)* | | x | | x |
| *Hydrovatus pustulatus compressus (A)* | | | x | x |
| *Neoporus (=Hydroporus)* spp. *(L)* | | | | x |
| *N. (=Hydroporus)* spp. *(A)* | x | x | x | x |
| *N. (=Hydroporus) (blanchardi?) (A)* | | | x | |
| *N. (=Hydroporus) clypealis (A)* | | x | x | x |
| *N. (=Hydroporus) mellitus? (A)* | | | x | x |
| *Sperchopsis tesselatus (A)* | x | | | |
| *S. tesselatus (L)* | x | | | |
| **Family Elmidae** | | | | |
| *Ancyronyx variegatus (A)* | x | x | x | x |
| *A. variegatus (L)* | x | x | x | x |
| *Dubiraphia vittata* | | x | | |
| *Dubiraphia spp. (A)* | | | x | x |
| *D. vitiata(?) (A)* | | | x | |
| *Macronychus glabratus (A)* | x | x | x | x |
| *M. glabratus (L)* | x | x | x | x |
| *Stenelmis spp. (A)* | x | x | x | x |
| *Stenelmis spp. (L)* | x | x | x | x |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| **Family Gyrinidae** | | | | |
| *Dineutus carolinus* | x | | x | |
| *D. discolor (A)* | x | x | x | x |
| *D. emarginatus (A)* | | x | | x |
| *D. serrulatus serrulatus (A)* | x | x | x | x |
| *Dineutus* spp. *(L)* | x | x | x | x |
| *Gyrinus* spp. *(A)* | x | x | x | x |
| *Gyrinus* spp. *(L)* | | | | x |
| **Family Haliplidae** | | | | |
| *Haliplus triopsis (A)* | | x | | |
| *Peltodytes bradleyi (A)* | | x | | x |
| *P. oppositus* | | x | | |
| *P. sexmaculatus (A)* | | x | x | x |
| *P. lengi (A)* | | | x | |
| *Peltodytes* spp. *(A)* | | x | | |
| **Family Hydraenidae** | | | | |
| *Hydraena marginicollis* | | x | | x |
| *H. spp. (A)* | | | | x |
| **Family Hydrophilidae** | | | | |
| *Anacaena limbata* (A) | | | | x |
| *Berosus aculeatus (A)* | | x | | x |
| *B. (peregrinus?) (A)* | | x | x | |
| *Enochrus ochracens* | x | | | |
| *E. sublongus (A)* | | | | x |
| *Enochrus* spp. *(A)* | | x | x | |
| *Hydrobius* spp. *(L)* | | x | | x |
| *Hydrochus* spp. *(A)* | | | x | x |
| *Hydrochus excavatus (A)* | x | | | |
| *Laccobius* spp. *(A)* | | | | x |
| *Sperchopsis tessallatus (A)* | | x | x | x |
| *Sperchopsis tessallatus (L)* | | x | x | x |
| *Tropisternus natator (A)* | x | | | |
| *T. lateralis nimbatus (A)* | | | | x |
| *T. collaris striolatus* | | x | x | |
| *Tropisternus* spp. *(L)* | | x | | |
| **Family Noteridae** | | | | |
| *Hydrocanthus irricolor (A)* | x | | | |
| *Hydrocanthus* spp. (A) | | | x | x |
| *Suphisellus gibbulus (A)* | | x | x | |
| *S. puncticollis (A)* | | x | x | x |
| *S, bicolor punctipennis (A)* | x | | | |
| **Family Scirtidae** | | | | |
| *Cyphon* spp. (L) | x | x | x | x |
| **Order Diptera** | | | | |
| **Family Tabanidae** | | | | |
| *Chlorotabanus* spp. | x | | | |
| **Family Ceratopogonidae** | | | | |
| Forcipomyiinae immature spp. | | x | | |
| *Palpomyia* spp. complex | | x | | x |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| **Family Culicidae** | | | | |
| *Anopheles* spp. | | | | x |
| **Family Empididae** | | | | |
| Empididae immature spp. | x | | x | x |
| *Hemerodromia* spp. | x | x | x | x |
| *Hemerodromia/Chelifera* spp. | x | x | | |
| **Family Sciomyzidae** | | | | |
| *Tetanocera* spp. | | | | x |
| **Family Simuliidae** | | | | |
| *Ectemnia (taeniatifrons?)* | | | | x |
| *Simulium* spp. (larvae) | | | x | x |
| *S. (podostemi?)* (pupae) | | | x | |
| *S. taxodium* | x | x | x | x |
| **Family Tabanidae** | | | | |
| *Chlorotabanus* spp. | | | x | x |
| **Family Chironomidae** | | | | |
| **Subfamily Tanypodinae** | | | | |
| *Ablabesmyia mallochi* | x | | x | x |
| *A. rhamphe*-grp spp. | x | x | x | x |
| *Hayesomyia (=Thienemannimyia) senata* | | x | x | x |
| *Labrundinia pilosella* | x | | x | |
| *Nilotanypus americanus* | | x | | |
| *N. fimbriatus* | | x | x | x |
| *Nilotanypus* sp. near *fimbriatus* | x | x | x | |
| *Pentaneura inconspicua* | | | x | x |
| *Pentaneurini* spp. | x | | x | |
| **Subfamily Ordiocladiinae** | | | | |
| *Thienemannimyia* spp. | x | | | |
| *Corynoneura* sp. near *celeripes* | x | | x | x |
| *Corynoneura* sp. near *taris* | x | x | x | x |
| *Cricotopus* spp. | | | x | x |
| *C. bicinctus*-grp. sp 1 | x | x | x | x |
| *C. bicinctus*-grp. sp. 2 | | x | | |
| *C. festivellus*-grp. spp. | | x | | x |
| *C. fuscus*-grp. spp. | | x | | x |
| *C. sylvestrus*-grp. spp. | | x | | |
| *Cricotopus spp.* immature | | x | | |
| *Eukiefferiella* grp. ? spp. | x | x | x | |
| *E. devonica* group spp. | x | | x | x |
| *E. gracei* group spp. | | | | x |
| *E. brevicalcar* group sp. | x | | x | x |
| *Gymnometriocnemus* spp. | x | x | | x |
| *Hydrobaenus* sp. of. *johannseni* | | x | | |
| *Nanocladius* sp. near *distinctus* | | | | x |
| *Nanocladius* sp. near *alternantheraa* | x | x | x | |
| *N.* sp. near *rectininervis* | | | | x |
| *N.* sp. near *spiniplenus* | x | x | x | |
| *Mesosmittia* | x | | | |
| *Orthocladius* sp. near *carlatus* | x | x | x | x |
| *Orthocladius* sp. near *obumbratus* | | | x | x |
| *Orthocladius* spp. | x | x | | |

**Table 5-203. (cont)**

| Taxa | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| *Parakiefferiella* sp. 1 | | | x | |
| *Parakiefferiella* sp. 3 | | | x | |
| *Parakiefferiella* sp. 4 | | | x | |
| *Parakiefferialla* sp. | x | | | |
| *Paratrichocladius* sp. (?) | x | x | x | x |
| *Psectrocladius* spp. | x | x | | x |
| *Rheocricotopus* sp. near *robacki* | x | x | x | x |
| *Rheosmittia* sp. | x | | x | |
| *Thienemanniella* sp. near *fusca* | x | x | x | x |
| *Thienemanniella* sp. near *xena* | x | x | x | x |
| *Thienemanniella* sp. | x | | | |
| *Thienemanniella* sp. 1 | | | | x |
| *Thienemanniella* sp. 2 | | | x | x |
| *Thienemanniella spp. immature* | | x | | |
| *Tvetenia discoloripes*-grp. spp. | x | x | x | x |
| Unknown Genera | x | x | | |
| **Subfamily Chironominae** | | | | |
| *Tribe Chironomini* | | | | |
| *Chironominae* | x | | | |
| *Chironomini* spp. (possibly *Dicrotendipes)* | | x | x | |
| *Chironomus* spp. | | x | | x |
| *Paralauterborniella nigrohalteralis* | | x | x | |
| *Paralauterborniella* sp. | x | | | |
| *Cryptochironomus* spp. | | x | x | x |
| *Glyptotendipes* spp. | x | x | | |
| *Dicrotendipes neomodestus* | x | x | | x |
| *Endochironomus nigricans* | x | x | | |
| *Goeldichironomus fluctuans* | | x | x | x |
| *Parachironomus carinatus (=arcuatus* group) | | | x | |
| *P. arcuatus* | | x | | |
| *Polypedilum convictum* grp. sp. | | | x | |
| *Polypedilum* cf. *tritum* | | | x | x |
| *P. fallax grp.* spp. | | x | x | |
| *P.* sp. near *fallax* | x | | | x |
| *P. (Polypedilum) convictum* grp. sp. | | | x | |
| *Polypedilum* spp. | x | x | x | |
| *P. (Tripodura) scalaenum* grp. sp. | | | x | |
| *Polypedilum (Tripodura)* sp. | x | x | | |
| *Stenochironomus* spp. | x | x | x | x |
| *Strictochironomus devinctus* | | x | | |
| *Xenochironomus xenolabis* | | | x | x |
| *X. subletti* | | x | | x |
| *Tribelos fuscicorne* | x | | | x |
| *Tribe Tanytarsini* | | x | | |
| *Paratanytarsus* sp. 1 | | x | | |
| *Rheotanytarsus* spp. | x | x | x | x |
| *Tanytarsus* sp. 1 | | x | x | x |
| *Tanytarsus* sp. 2 | | x | x | |
| *Tanytarsus* sp. 4 | | x | | |
| *Tanytarsus* sp. 5 | | | x | |

**Table 5-204.** Number of insect species found in qualitative collections on the Savannah River in March, June, September and December 1989-1995.

| | Survey Period & 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 | | | | | 36.9 | | | 41.6 | | | 41.4 | |

[a]ANSP (1996).
[b]ANSP (1995b).
[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 5-205.** 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—Wiener 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<br>D1>D5 | J1>J6<br>D1>D6 | J6>J6 |

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.

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-Wiener 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-Wiener 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 5-129 presents the relative abundances of the most abundant taxa in the quantitative samples during the past six years of surveys. The patterns in Figure 5-129 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*..

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.

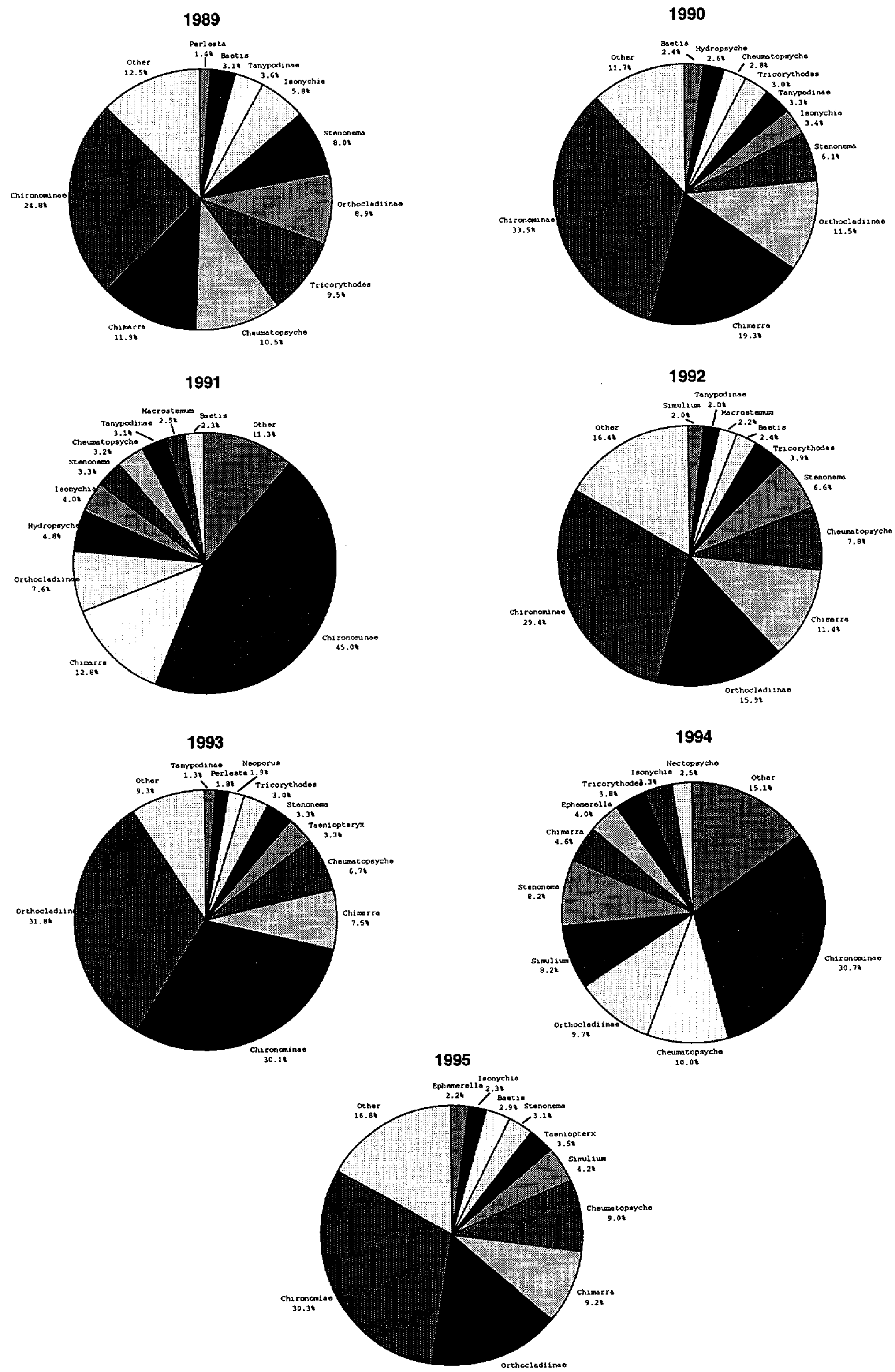


**Figure 5-129.** Percent Abundance of Insect Taxa Collected in Traps During 1990-1995 Surveys on the Savannah River. The most abundant taxa are labeled.

## CCWS Studies

### Number of Taxa Collected

During the two-year study, a total of 146 macroinvertebrate taxa were collected from the Savannah River (Table 5-206). 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.

### 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 (Table 5-207). 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%; Table 5-207). Oligochaetes and amphipods were also locally abundant at one or more stations (Table 5-207). *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).

### Taxa Richness

On the multiplate samplers, the mean number of taxa per sampler ranged from 12.0 to 21.5 (Table 5-208). Taxa richness at all stations was higher in 1984-1985 than in 1983-1984.

### Densities

The mean density of organisms on the multiplates ranged from 2751.2 organisms/$m^2$ to 7986.0 organisms/$m^2$ (Table 5-208). 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]; Table 5-208). 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 $m^3$ (Table 5-209). Drift densities were higher at all stations in 1984-1985 than in 1983-1984 (Table 5-209). 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).

## Biomass

Mean biomass on the multiplate samplers ranged from 0.387 to 0.805 $g/m^2$ (Table 5-208). No distinct spatial or temporal trends were observed for biomass.

**Table 5-206.** Macroinvertebrate Taxa Collected from Hester-Dendy Multiplate Samplers and Drift in the Savannah River, 1983-1985

| Taxon | Hester-Dendy | Drift |
|---|---|---|
| Turbellaria | X | X |
| Nematoda | X | X |
| Oligochaeta | X | X |
| Hirudinea | X | X |
| Gastropoda | | |
| *Ferrissia rivularis* | X | X |
| *Laevapex fuscus* | X | X |
| *Amnicola* | X | X |
| *Pseudosuccinea columnella* | | X |
| *Physella heterostropha* | X | X |
| *Gyraulus parvus* | X | X |
| *Helisoma trivolvis* | X | X |
| *Menetus dilatatus* | X | X |
| *Campeloma decisum* | X | |
| unidentified gastropods | | X |
| Pelecypoda | | |
| *Corbicula fluminea* | X | X |
| unidentified Sphaeriidae | X | X |
| Isopoda | | |
| *Asellus* | | X |
| Amphipoda | | |
| *Gammarus fasciatus* | X | X |
| *Hyalella azteca* | X | X |
| Decapoda | | |
| *Palaemonetes paludosus* | X | X |
| *Procambarus* | | X |
| Hydracarina | X | X |
| Collembola | | X |
| Isotomidae | | X |
| Ephemeroptera | | |
| *Baetis* | X | X |
| *Callibaetis* | | X |
| *Heterocloeon* | | X |
| *Pseudocloeon parvulum* | X | X |
| *Baetisca* | | X |
| *Caenis* | X | X |
| *Danella simplex* | X | X |
| *Ephemerella invaria* | X | X |
| *Eurylophella temporalis* | X | X |
| *Hexagenia* | | X |
| *Heptagenia* | X | X |
| *Pseudiron* | X | X |
| *Spinadis* | | X |

**Table 5-206. (cont)**

| Taxon | Hester-Dendy | Drift |
|---|---|---|
| *Stenacron interpunctatum* | X | X |
| *Stenonema modestum* | X | X |
| *Paraleptophlebia* | | X |
| *Neoephemera youngi* | X | X |
| *Isonychia* | X | X |
| *Tricorythodes* | X | X |
| *Leptohyphes* | X | |
| Odonata | | |
| *Boyeria vinosa* | X | X |
| *Neurocordulia molesta* | X | X |
| Gomphidae | X | X |
| *Macromia* | X | X |
| *Libellula* | | X |
| Zygoptera | | X |
| *Calopteryx* | | X |
| *Argia* | X | X |
| *Enallagma* | X | X |
| *Hetaerina* | X | X |
| *Lestes* | | X |
| Plecoptera | | |
| *Nemocapnia carolina* | X | X |
| *Alloperla furcula* | X | X |
| *Acroneuria abnormis* | X | |
| *Agnetina annulipes* | X | |
| *Paragnetina fumosa* | X | |
| *Perlesta placida* | X | X |
| *Perlinella* | X | |
| *Clioperla clio* | X | |
| *Helopicus bogaloosa* | X | |
| *Hydroperla* | X | |
| *Isoperla* | X | X |
| *Pteronarcys dorsata* | X | X |
| *Shipsa* | | X |
| *Taeniopteryx longicera* | X | |
| *Taeniopteryx robinae* | X | X |
| Hemiptera | | |
| Corixidae | X | |
| *Palmacorixa* | | X |
| *Sigara* | | X |
| *Trichocorixa* | | X |
| *Belostoma* | | X |
| Gerridae | | X |
| *Hydrometra* | | X |
| *Mesovelia* | | X |
| Nepidae | | X |
| *Neoplea* | | X |
| Coleoptera | | |
| Curculionidae | | X |
| Elmidae | | |

**Table 5-206. (cont)**

| Taxon | Hester-Dendy | Drift |
|---|---|---|
| *Ancyronyx variegatus* | X | X |
| *Dubiraphia* | X | X |
| *Macronychus glabratus* | X | X |
| *Microcylloepus pusillus* | X | X |
| *Stenelmis* | X | X |
| *Dineutes* | X | X |
| *Gyrinus* | X | X |
| *Haliplus* | | X |
| *Peltodytes* | X | X |
| *Hydrochus* | | X |
| *Berosus* | X | X |
| *Tropisternus* | | X |
| Noteridae | X | X |
| Dytiscidae | | X |
| *Coptotomus* | | X |
| *Dytiscus* | | X |
| *Hydroporus* | | X |
| *Hygrotus* | | X |
| *Liodessus* | | X |
| Megaloptera | | |
| *Chauliodes* | X | X |
| *Corydalus cornutus* | X | X |
| *Nigronia* | X | |
| Neuroptera | | |
| *Climacia* | | X |
| *Sisyra* | | X |
| Trichoptera | | |
| *Brachycentrus* | X | X |
| *Micrasema* | X | X |
| *Cheumatopsyche* | X | X |
| *Hydropsyche* | X | X |
| *Macrostemum carolina* | X | X |
| *Hydroptila* | X | X |
| *Ochrotrichia* | | X |
| *Orthotrichia* | X | |
| *Oxyethira* | X | X |
| *Lepidostoma* | | X |
| *Ceraclea* | X | X |
| *Leptocerus americanus* | | X |
| *Nectopsyche candida* | X | X |
| *Oecetis* | X | X |
| *Triaenodes* | | X |
| *Ironoquia* | | X |
| *Pycnopsyche* | | X |
| *Chimarra* | X | X |
| *Cernotina* | | X |
| *Cyrnellus* | X | X |
| *Neureclipsis* | X | X |
| *Nyctiophylax* | | X |
| *Phylocentropus* | X | X |

**Table 5-206. (cont)**

| Taxon | Hester-Dendy | Drift |
|---|---|---|
| *Polycentropus* | X | X |
| *Lype diversa* | X | X |
| Lepidoptera | | |
| *Munroessa* | | X |
| *Neargyractis* | | X |
| *Parapoynx* | X | X |
| *Synclita* | X | X |
| *Petrophila* | X | |
| Diptera | | |
| Ceratopogonidae | | X |
| Ceratopogoniinae | X | X |
| Forcipomyiinae | X | X |
| *Chaborus punctipennis* | X | X |
| Chironomidae | X | X |
| Chironomini | X | X |
| Orthocladiinae | X | X |
| Tanytarsini | X | X |
| Tanypodinae | X | X |
| Culicidae | | |
| *Aedes* | | X |
| *Anopheles* | | X |
| *Culex* | | X |
| *Uranotaenia* | | X |
| Empididae | X | X |
| Ephydridae | | X |
| Psychodidae | | X |
| *Bittacomorpha* | | X |
| Simulidae | | |
| *Simulium* | X | X |
| Tabanidae | | |
| *Chrysops* | | X |
| Tipulidae | | X |
| *Tipula* | X | |

**Table 5-207.** Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates on Hester-Dendy Multiplate Samplers in the Savannah River, 1984-1985

| | Station (River Mile) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Taxon** | **152.2** | **152.0** | **150.8** | **150.4** | **141.7** | **141.5** | **137.7** | **129.1** | **128.9** |
| Oligochaeta | 2.4 | 2.0 | 0.4 | 0.2 | <0.1 | 0.2 | 4.2 | 0.8 | 0.3 |
| Amphipoda | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 1.4 | 0.2 | <0.1 | <0.1 |
| Ephemeroptera | 6.0 | 5.6 | 6.1 | 5.2 | 8.5 | 10.2 | 13.4 | 17.3 | 16.3 |
| Plecoptera | 1.2 | 1.5 | 1.3 | 1.2 | 1.2 | 1.6 | 3.1 | 1.9 | 2.0 |
| Trichoptera | 25.6 | 22.4 | 27.5 | 18.5 | 29.8 | 30.3 | 29.6 | 30.0 | 22.1 |
| Diptera | 63.2 | 66.3 | 63.6 | 73.8 | 59.5 | 54.8 | 46.5 | 48.7 | 58.0 |
| Other[a] | 1.6 | 2.2 | 1.1 | 1.1 | 1.0 | 1.5 | 3.0 | 1.3 | 1.3 |

Source: Chimney and Cody 1986.
[a]Includes taxa that each made up <1% of the organisms collected at a station. These taxa included Turbellaria, Nematoda, Hirudinea, Gastropoda, Pelecypoda, Hydracarina, Decapoda, Collembola, Odonata, Hemiptera, Coleoptera, and Lepidoptera.

**Table 5-208.** Mean Number of Taxa Per Sampler, Density, and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in the Savannah River, 1983-1984

| **Station [a]** | **Mean No. Taxa/ Sampler** | **Mean Density ( Mean No. Taxa/m2)** | **Mean Biomass (g/m2)** |
|---|---|---|---|
| | **October 1983-September 1984** | | |
| 152.2 | 17.0 | 4968.5 | 0.403 |
| 152.0 | 16.8 | 5242.4 | 0.735 |
| 150.8 | 17.6 | 6174.0 | 0.753 |
| 150.4 | 17.2 | 5868.9 | 0.755 |
| 145.7 | 13.5 | 4542.7 | 0.511 |
| 141.7 | 14.6 | 2922.5 | 0.390 |
| 141.5 | 15.7 | 3171.4 | 0.387 |
| 129.1 | 14.5 | 3892.7 | 0.496 |
| 128.9 | 12.0 | 3736.9 | 0.398 |
| | **October 1984-September 1985** | | |
| 152.2 | 20.2 | 6218.7 | 0.628 |
| 152.0 | 20.3 | 5823.6 | 0.586 |
| 150.8 | 20.9 | 7083.5 | 0.706 |
| 150.4 | 21.4 | 7986.0 | 0.805 |
| 145.7 | 20.7 | 3270.8 | 0.518 |
| 141.7 | 17.2 | 5046.6 | 0.708 |
| 141.5 | 21.5 | 2751.2 | 0.419 |
| 129.1 | 18.9 | 3665.1 | 0.679 |
| 128.9 | 18.2 | 3420.5 | 0.533 |

Source: O'Hop et al. 1985; Chimney and Cody 1986.
[a] River Mile.

**Table 5-209.** Macroinvertebrate Drift Density (no./1000 $m^3$) in the Savannah River, October 1983-July 1985

| Station[a] | Oct 1983-July 1984 | Oct 1984-July 1985 |
|---|---|---|
| 157.3 | 1157.7 | 7298.7 |
| 152.2 | 1186.4 | 1953.3 |
| 152.0 | 1037.0 | 1901.2 |
| 150.8 | 927.1 | 1933.3 |
| 150.4 | 1070.0 | 2184.5 |
| 145.7 | - | 2588.5 |
| 141.7 | 1182.5 | 3235.6 |
| 141.5 | 1242.3 | 1729.5 |
| 137.7 | 1340.8 | 1949.7 |
| 129.1 | 1070.2 | 1354.2 |
| 128.9 | 1303.6 | 1516.8 |

Source: Chimney and Cody 1986.
[a]River Mile.

# Fish

## Introduction

The Academy of Natural Sciences of Philadelphia (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 5-128) 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 4—Threatened and Endangered Species.

## ANSP Surveys

Between 1980 and 1995, 59 species have been collected in the annual program (Table 5-210; Table 5-211 provides the scientific and common names of all fish collected) 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.

**Table 5-210.** Occurrence of Fish Species at Three Stations in the Savannah River from 1980 to 1995

| | 1980 | | | 1981 | | 1984 | | | 1985 | | 1986 | | | 1987 | | | 1988 | | | 1989 | | | 1990 | | | 1991 | | | 1992 | | | 1993 | | | | 1994 | | | | 1995 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 5 | 6 | 1 | 6 | 1 | 5 | 6 | 5 | 6 | 1 | 5 | 6 | 1 | 5 | 6 | 1 | 5 | 6 | 1 | 5 | 6 | 1 | 5 | 6 | 1 | 5 | 6 | 1 | 5 | 6 | 1A | 1 | 5 | 6 | 1A | 1 | 5 | 6 | 1 | 5 | 6 |
| *Lepisosteus osseus* | X | - | - | - | - | X | - | - | - | X | - | - | - | X | - | X | - | - | - | X | - | - | - | X | X | - | - | - | - | X | X | X | - | X | - | - | X | X | X | X | X | - |
| *Lepisosteus platyrhincus* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - |
| *Amia calva* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | X | X | - | - |
| *Anguilla rostrata* | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - |
| *Alosa aestivalis* | - | - | X | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | X | - | - | X | X | - | - | - |
| *Alosa sapidissima* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | X | X | - | - | - |
| *Dorosoma cepedianum* | - | X | - | - | X | X | - | - | - | X | - | - | X | - | - | X | - | - | - | X | - | - | X | X | X | - | - | - | - | X | - | - | X | X | X | X | - | X | X | - | X | - |
| *Dorsoma petenense* | - | - | X | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | X | - | - | X | - | - | - | - |
| *Cyprinella leedsi* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - |
| *Cyprinella nivea* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | X | - | - | - | - | - | - | - | X | - |
| *Hybognathus regius* | - | - | X | - | - | X | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | X | X | - | - | X | - | - | X | X | - | X | X |
| *Notropis chalybaeus* | X | X | X | - | - | - | X | X | X | X | X | - | - | - | - | - | - | - | - | X | - | - | - | X | X | - | X | X | - | - | - | - | - | - | - | X | - | X | X | X | - | - |
| *Notemigonus crysoleucas* | X | - | - | - | - | X | X | X | - | X | X | X | X | X | - | - | - | - | X | - | X | X | - | X | X | X | X | X | - | X | X | X | - | X | X | X | X | X | - | X | X | - |
| *Notropis cummingsae* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - |
| *Notropis hudsonius* | - | X | X | - | X | - | - | - | X | X | X | - | X | - | - | X | - | - | X | - | - | - | X | - | X | X | - | X | - | X | X | X | - | - | X | - | - | X | X | - | X | X |
| *Notropis maculatus* | - | X | - | - | X | X | X | X | X | X | X | - | X | X | - | X | X | - | X | X | - | X | - | X | X | X | - | X | - | X | X | - | X | X | X | X | X | X | X | - | - | - |
| *Notropis petersoni* | - | - | - | - | - | X | - | - | - | - | - | - | X | X | X | X | - | - | - | - | - | - | X | - | X | - | - | X | - | X | X | X | - | - | X | - | - | X | X | - | X | X |
| *Notropis rubescens* | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | X | - | X | - |
| *Opsopoedus emiliae* | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | X | X | - | - | - | - | - | - | - | X | - | X | X |
| *Erimyzon oblongus* | X | - | - | - | - | - | - | - | - | - | X | X | X | - | - | - | X | X | - | - | - | - | - | X | X | - | X | - | - | X | X | X | X | X | - | - | - | X | - | - | X | - |
| *Erimyzon sucetta* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | X | - | - | - | - | - | - | X | - | X | X | - | - | X | - | - | - | X | - | - | - | - |
| *Minytrema melanops* | X | X | X | - | X | X | X | - | X | X | - | - | X | X | X | X | - | - | X | - | - | - | X | X | X | - | - | X | - | X | X | X | X | X | X | X | X | X | X | X | - | X |
| *Moxostoma anisurum* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | X |
| *Ameiurus brunneus* | - | X | - | X | - | - | - | - | - | - | X | X | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Ameiurus catus* | - | - | - | - | - | - | - | - | - | - | X | - | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - |
| *Ameiurus natalis* | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | X | X | X | - | - | - | - | - | - | - | X | - | - | - | - | - | - | X | - | - | - | - | - |
| *Ameiurus nebulosus* | - | - | - | - | - | - | - | - | - | - | X | X | X | - | - | - | X | - | X | X | - | X | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - |
| *Ameiurus platycephalus* | - | - | - | - | X | - | - | - | X | X | - | - | - | - | - | - | X | X | X | - | - | - | X | X | X | - | - | - | X | X | - | X | X | X | X | X | - | - | X | - | - | X |
| *Ictalurus punctatus* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - |
| *Noturus gyrinus* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | X | - | - | - | - | - | - |
| *Noturus insignis* | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Noturus leptacanthus* | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Esox americanus* | X | - | - | - | - | X | - | - | - | - | X | - | X | - | X | - | X | X | - | X | - | - | - | X | X | - | - | - | X | X | X | X | - | X | - | - | - | - | - | X | - | X |
| *Esox niger* | X | X | X | - | - | - | - | - | - | - | X | X | - | - | - | X | X | X | - | X | - | - | - | X | X | - | X | - | - | - | X | X | X | X | X | X | X | X | - | X | - | - |
| *Aphredoderus sayanus* | X | X | X | - | - | X | - | - | - | - | X | X | X | X | X | X | X | X | X | X | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | - | - | - | X | X | X |
| *Strongylura marina* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Fundulus chrysotus* | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | X | X | - | X | X | - | X | - | - | X | - | - | - | - | X | - | - | X | - | - | - | - |
| *Fundulus lineolatus* | X | - | - | - | - | - | X | X | X | X | X | - | X | - | - | - | - | - | - | X | - | - | - | X | X | - | - | X | - | - | - | - | - | - | X | - | - | X | X | - | - | - |
| *Gambusia holbrooki* | X | X | - | X | - | X | X | X | - | - | X | X | X | X | X | X | X | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Labidesthes sicculus* | - | X | X | - | X | X | X | X | - | X | X | - | - | X | X | X | X | - | - | - | - | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Morone americana* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - |
| *Centrarchus macropterus* | X | - | - | - | - | X | - | - | - | - | - | X | X | - | - | - | - | - | - | X | - | - | - | X | - | - | X | - | - | X | X | - | - | X | - | X | - | - | - | - | - | - |
| *Enneacanthus gloriosus* | X | - | - | - | - | X | - | - | - | - | X | - | X | X | X | X | X | X | - | X | X | X | - | X | - | - | X | X | - | X | X | - | - | X | - | X | X | X | - | X | - | - |
| *Lepomis auritus* | - | X | - | X | - | X | - | X | X | X | X | X | X | - | X | X | X | X | - | X | - | X | X | X | X | X | - | X | - | X | X | - | X | X | - | X | X | X | X | X | X | X |
| *Lepomis gibbosus* | - | X | X | - | - | - | X | - | X | - | X | - | X | - | - | X | - | - | X | X | - | X | X | - | X | - | - | X | X | X | - | X | X | X | X | X | - | X | X | X | X | X |
| *Lepomis gulosus* | X | X | - | - | - | X | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Lepomis* hybrid | X | X | X | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | X | - | - | - | X | X | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Lepomis macrochirus* | X | X | X | X | X | X | X | - | X | X | X | X | X | X | X | X | X | - | X | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Lepomis marginatus* | X | X | - | - | - | X | X | - | X | X | X | X | X | - | X | X | X | X | X | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | - | X | X | X | X | X |
| *Lepomis microlophus* | X | X | X | X | X | X | X | - | X | X | X | X | X | X | - | X | X | X | X | X | - | X | X | X | X | X | X | X | - | X | X | - | X | X | X | X | X | X | X | X | X | X |
| *Lepomis* species | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | X | X | - | - | X | - | - | - | X | X | - | - |
| *Lepomis punctatus* | X | - | - | - | - | - | - | X | X | X | X | X | X | X | X | - | X | X | - | X | - | X | - | X | X | - | X | X | X | X | X | X | X | X | X | X | - | X | X | X | X | X |
| *Micropterus salmoides* | X | X | X | - | - | - | - | - | X | - | X | X | X | X | - | X | X | - | - | X | X | X | X | X | X | - | - | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *Pomoxis nigromaculatus* | X | X | - | - | X | X | - | - | X | X | - | - | X | - | X | - | X | - | X | X | - | X | X | X | X | - | - | X | - | X | X | X | - | X | X | X | X | X | - | X | - | X |
| *Elassoma zonatum* | - | - | - | - | - | - | X | - | - | - | X | X | X | X | X | X | X | X | - | X | X | - | - | X | X | X | X | X | X | X | - | - | - | - | X | - | - | X | - | - | - | - |
| *Etheostoma fusiforme* | - | X | X | X | - | - | - | - | X | - | X | X | X | X | - | X | X | X | - | X | - | - | - | X | X | - | X | - | - | X | X | X | X | X | X | X | - | X | - | - | - | - |
| *Etheostoma olmstedi* | - | X | X | X | X | - | - | - | - | - | X | - | - | - | X | - | X | - | - | X | - | - | X | - | X | - | - | X | X | X | - | - | X | X | X | X | - | - | X | - | - | X |
| *Perca flavescens* | - | X | X | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | X | X | X | - | - | - | - | X | - | - | - | X | X | - | - | X | - | - | - |
| *Percina nigrofasciata* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | X | - | - | - |
| *Mugil cephalus* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Trinectes maculatus* | - | - | - | - | - | - | X | - | - | - | - | - | - | X | - | - | - | - | - | - | - | - | X | X | X | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Number of Species | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Station Total | 19 | 23 | 16 | 8 | 13 | 19 | 14 | 9 | 17 | 18 | 27 | 18 | 27 | 18 | 15 | 20 | 21 | 15 | 14 | 26 | 9 | 17 | 20 | 31 | 36 | 13 | 17 | 24 | 13 | 33 | 27 | 21 | 23 | 27 | 28 | 25 | 15 | 36 | 30 | 20 | 23 | 21 |
| Year Total | 34 | | | 18 | | 25 | | | 22 | | 33 | | | 27 | | | 27 | | | 30 | | | 40 | | | 30 | | | 36 | | | 40 | | | | 48 | | | | 33 | | |

**Table 5-211.** Scientific and common names of fishes collected from the Savannah River during 1980-1995 cursory studies and fall 1989 and 1993 comprehensive studies at Stations 1A, 1, 5 and 6.

| Scientific Name | Common Name |
|---|---|
| **Lepistoseteidae (gars)** | |
| *Lepisosteus osseus* | Longnose gar |
| *Lepisosteus platyrhincus* | Florida gar |
| | |
| **Anguillidae (eels)** | |
| *Anguilla rostrata* | American eel |
| | |
| **Amiidae (bowfins)** | |
| *Amia calva* | Bowfin |
| | |
| **Clupeidae (herrings)** | |
| *Alosa aestivalis* | Blueback herring |
| *Alosa sapidissima* | American shad |
| *Dorosoma cepedianum* | Gizzard shad |
| *Dorosoma petenense* | Threadfin shad |
| | |
| **Cyprinidae (minnows)** | |
| *Cyprinella leedsi* | Bannerfin shiner |
| *Cyprinella nivea* | Whitefin shiner |
| *Hybognathus regius* | Eastern silvery minnow |
| *Notemigonus crysoleucas* | Golden shiner |
| *Notropis chalybaeus* | Ironcolor shiner |
| *Notropis cummingsae* | Dusky shiner |
| *Notropis hudsonius* | Spottail shiner |
| *Notropis maculatus* | Taillight shiner |
| *Notropis petersoni* | Coastal shiner |
| *Notropis rubescens* | Rosyface chub |
| *Opsopoeodus emiliae* | Pugnose shiner |
| | |
| **Catostomidae (suckers)** | |
| *Erimyzon oblongus* | Creek chubsucker |
| *Erimyzon sucetta* | Lake chubsucker |
| *Minytrema melanops* | Spotted sucker |
| *Moxostoma anisurum* | Silver redhorse |
| | |
| **Ictaluridae (bullhead catfishes)** | |
| *Ameiurus brunneus* | Snail bullhead |
| *Ameiurus catus* | White catfish |
| *Ameiurus natalis* | Yellow bullhead |
| *Ameiurus nebulosis* | Brown bullhead |
| *Ameiurus platycephalus* | Flat bullhead |
| *Ictalurus punctatus* | Channel catfish |
| *Noturus gyrinus* | Tadpole madtom |
| *Noturus insignis* | Margined madtom |
| *Noturus leptacanthus* | Speckled madtom |
| | |
| **Esocidae (pikes)** | |
| *Esox americanus* | Redfin pickerel |
| *Esox niger* | Chain pickerel |

**Table 5-211. (cont)**

| Scientific Name | Common Name |
|---|---|
| **Aphredoderidae (pirate perches)** | |
| *Aphredoderus sayanus* | Pirate perch |
| | |
| **Belonidae (needlefishes)** | |
| *Strongylura marina* | Atlantic needlefish |
| | |
| **Cyprinodontidae (topminnows)** | |
| *Fundulus chrysotus* | Golden topminnow |
| *Fundulus lineolatus* | Lined topminnow |
| | |
| **Poeciliideae (livebearers)** | |
| *Gambusia holbrooki* | Mosquitofish |
| | |
| **Atherinidae (silversides)** | |
| *Labidesthes sicculus* | Brook silverside |
| | |
| **Moronidae (temperate basses)** | |
| *Morone americana* | White perch |
| | |
| **Centracrchidae (sunfishes)** | |
| *Centrarchus macropterus* | Flier |
| *Enneacanthus gloriosus* | Bluespotted sunfish |
| *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 nigromaculatus* | Black crappie |
| | |
| **Elassomatidae (pygmy sunfishes)** | |
| *Elassoma zonatum* | Banded pygmy sunfish |
| | |
| **Percidae (darters):** | |
| *Etheostoma fricksium* | Savannah darter |
| *Etheostoma fusiforme* | Swamp darter |
| *Etheostoma olmstedi* | Tesselated darter |
| *Perca flavescens* | Yellow perch |
| *Percina nigrofasciata* | Blackbanded darter |
| | |
| **Mugilidae (mullets)** | |
| *Mugil cephalus* | Striped mullet |
| | |
| **Soleidae (soles)** | |
| *Trinectes maculatus* | Hogchoker |

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 1970's.

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).

## 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.

## 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 (Table 5-212, Table 5-213, and Table 5-214). 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. How-

**Table 5-212.** Number and Percent Composition of Fish Larvae and Eggs Collected in the Savannah River and Tributary Creeks, February-July 1983

| Taxa | Total of All River Transects | | Total of All Creek Transects | |
|---|---|---|---|---|
| | Number | Percent | Number | Percent |
| **Larvae** | | | | |
| Atlantic sturgeon | 6 | <0.1 | 0 | 0.0 |
| shortnose sturgeon | 4[a] | <0.1 | 0 | 0.0 |
| gar | 6 | <0.1 | 3 | 0.1 |
| blueback herring | 4484 | 12.1 | 1164 | 20.4 |
| American shad | 512 | 1.4 | 141 | 2.5 |
| other shad | 7338 | 19.9 | 896 | 15.7 |
| unidentified clupeids | 2469 | 6.7 | 488 | 8.5 |
| suckers | 310 | 0.8 | 11 | 0.2 |
| spotted sucker | 1860 | 5.0 | 53 | 0.9 |
| pirate perch | 2940 | 8.0 | 165 | 2.9 |
| unidentified centrarchids | 420 | 1.1 | 146 | 2.6 |
| sunfish | 781 | 2.1 | 431 | 7.5 |
| crappie | 6126 | 16.6 | 1131 | 19.8 |
| yellow perch | 1278 | 3.5 | 380 | 6.7 |
| darters | 950 | 2.6 | 85 | 1.5 |
| mudminnow | 6 | <0.1 | 0 | 0.0 |
| swamp fish | 7 | <0.1 | 0 | 0.0 |
| needle fish | 6 | <0.1 | 0 | 0.0 |
| unidentified cyprinids | 5170 | 14.0 | 387 | 6.8 |
| carp | 1336 | 3.6 | 34 | 0.6 |
| catfish | 25 | 0.1 | 2 | <0.1 |
| mosquitofish | 2 | 0.0 | 2 | <0.1 |
| pickerel | 113 | 0.3 | 16 | 0.3 |
| silverside | 87 | 0.2 | 73 | 1.3 |
| striped bass | 88 | 0.2 | 0 | 0.0 |
| unidentified | 617 | 1.7 | 106 | 1.9 |
| Subtotal | 36,941 | 99.9 | 5714 | 100.2 |
| **Eggs** | | | | |
| American shad | 3557 | 56.4 | 55 | 6.8 |
| blueback herring | 304 | 4.8 | 113 | 14.0 |
| striped bass | 852 | 13.5 | 0 | 0.0 |
| perch and darter | 301 | 4.8 | 8 | 1.0 |
| other[b] | 1294 | 20.5 | 1248 | 78.3 |
| Subtotal | 6308 | 100.0 | 1424 | 100.1 |
| Total | 43,249 | | 7138 | |
| Total ichthyoplankton | | 50,387 | | |

[a]Three additional sturgeon larvae were collected during diurnal samples not included in this report.
[b]Primarily other shad.

**Table 5-213.** Ichthyoplankton Taxa Collected from the Savannah River, Tributaries, Oxbows, and the Savannah River Plant Intake Canals, February-July 1984[a]

| Taxa | Number | Percent |
|---|---|---|
| **Larvae** | | |
| American shad | 196 | 0.7 |
| blueback herring | 1574 | 5.7 |
| gizzard and threadfin shad | 5800 | 21.0 |
| unidentified clupeids | 3987 | 14.4 |
| striped bass | 199 | 0.7 |
| spotted sucker | 913 | 3.3 |
| unidentified suckers | 163 | 0.6 |
| pirate perch | 60 | 0.2 |
| yellow perch | 223 | 0.8 |
| darter | 887 | 3.2 |
| sunfish (genus *Lepomis*) | 3437 | 12.4 |
| unidentified sunfish | 1361 | 4.9 |
| crappie | 4236 | 15.3 |
| largemouth bass | 13 | <0.1 |
| mudminnow | 1 | <0.1 |
| swampfish | 8 | <0.1 |
| minnow (family Cyprinidae) | 3060 | 11.1 |
| carp | 690 | 2.5 |
| mosquitofish | 2 | <0.1 |
| topminnow | 4 | <0.1 |
| needlefish | 9 | <0.1 |
| brook silverside | 92 | 0.3 |
| catfish and bullhead | 7 | <0.1 |
| pickerel | 34 | 0.1 |
| sturgeon | 9 | <0.1 |
| gar | 8 | <0.1 |
| bowfin | 2 | <0.1 |
| unidentified larvae | 670 | 2.4 |
| Total | 27,643 | 99.6 |
| | | |
| **Eggs** | | |
| American shad | 2520 | 51.3 |
| blueback herring | 191 | 3.9 |
| gizzard and threadfin shad | 225 | 4.6 |
| striped bass | 1182 | 24.1 |
| yellow perch | 63 | 1.3 |
| minnow | 27 | 0.6 |
| other eggs | 708 | 14.4 |
| Total | 4916 | 100.2 |

[a]Study area was between RMs 29.6 and 187.1 (RKms 48 and 301) and included two intake canals, the mouths of 28 tributary creeks and 6 oxbows.

**Table 5-214.** Ichthyoplankton Taxa Collected from the Savannah River, Tributaries, Oxbows, and the Savannah River Intake Canals, February-July 1985[a]

| Taxa | Number | Percent |
|---|---|---|
| **Larvae** | | |
| sturgeon | 6 | <0.1 |
| gar | 1 | <0.1 |
| unidentified clupeidae | 2522 | 12.7 |
| blueback herring | 1076 | 5.4 |
| American shad | 361 | 1.8 |
| gizzard and threadfin shad | 7070 | 35.5 |
| mudminnow | 1 | <0.1 |
| pickerel | 8 | 0.1 |
| needlefish | 2 | <0.1 |
| minnow (family Cyprinidae) | 856 | 4.3 |
| carp | 1109 | 5.6 |
| unidentified Suckers | 111 | 0.6 |
| spotted sucker | 2142 | 10.7 |
| catfish and bullhead | 3 | <0.1 |
| swampfish | 1 | <0.1 |
| pirate perch | 17 | 0.1 |
| topminnow | 4 | <0.1 |
| mosquitofish | 7 | <0.1 |
| brook silverside | 144 | 0.7 |
| striped bass | 134 | 0.7 |
| unidentified sunfish | 298 | 1.5 |
| sunfish (*Lepomis*) | 2337 | 11.7 |
| crappie | 373 | 1.9 |
| darter | 675 | 3.4 |
| yellow perch | 387 | 1.9 |
| unidentified larvae | 281 | 1.4 |
| Total | 19,926 | 100.0 |
| | | |
| **Eggs** | | |
| blueback herring | 491 | 3.1 |
| American shad | 11,494 | 73.0 |
| gizzard and threadfin shad | 339 | 2.2 |
| minnow | 39 | 0.2 |
| striped bass | 1132 | 7.2 |
| yellow perch | 48 | 0.3 |
| other eggs | 2206 | 14.0 |
| Total | 15,749 | 100.0 |

[a]Study area was between RM 89.3 and 187.1 (RKm 143.6 and 301) and included 22 river transects, 2 intake canals, the mouths of 14 tributary creeks, and 5 oxbows.

ever, 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 $10.0 \times 10^6$ eggs and $18.8 \times 10^6$ 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%.

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