SRS Ecology

Environmental Information Document

JAN 24 1994
OSTI

L. D. Wike, R. W. Shipley, J. A. Bowers, C. L. Cummins, B. R. del Carmen, G. P. Friday, J. E. Irwin, J. J. Mayer, E. A. Nelson, M. H. Paller, V. A. Rogers, W. L. Specht, and E. W. Wilde

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U. S. Department of Energy Under Contract No. DE-AC09-89SR18035

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Lead Scientist

L. D. Wike

Managing Editor

R. W. Shipley

Authors*Part I—Terrestrial Resources*

E. A. Nelson, volume coordinator; J. J. Mayer;
and V. A. Rogers

Part II—Wetland Resources

H. E. Mackey, volume coordinator; and J. E. Irwin

Part III—Aquatic Resources

L. D. Wike, volume coordinator; J. A. Bowers;
C. L. Cummins; B. R. del Carmen; M. H. Paller;
W. L. Specht; and E. W. Wilde

Part IV—Threatened and Endangered Species

G. P. Friday, volume coordinator; J. J. Mayer; E. A. Nelson;
and L. D. Wike

Management Review

D. B. Moore-Shedrow and J. B. Gladden

Editorial Review

J. S. Hammond and B. S. Strack

Production Support*Document Composition*

D. C. Beckett, C. S. Damiano, P. R. Dominey, B. Hobbs,
D. A. Nobles, C. P. Rogers, J. L. Stratton

Graphics

C. S. Attaway, D. W. Hendrix, H. S. Thomas

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Introduction

Soils are a basic terrestrial resource because they exert influences on nearly all other environmental aspects of the flora and fauna and can affect the decisions made in many disciplines. Foresters and agronomists use soils information as a guide to production potential; while planners, engineers, research scientists, and waste management and environmental compliance personnel have to consider the limitations of soils characteristics. Soil is the natural, three-dimensional body of the earth's surface, which contains mineral and organic matter and air. The integrated effect of climate and living matter acting on soil and conditioning over time affect its properties. The Soil Survey of Savannah River Plant Area (Rogers 1990) is the best source for information on soils on SRS.

Contents

Introduction lxxi

Soils 1-1

Introduction 1-3

SRS Soils 1-5

Geological Origin 1-5

Soil Texture 1-6

SRS Soil Survey 1-7

General Characteristics of SRS Soils 1-7

Soil Maps 1-7

Tabular Data 1-7

Soil Groups 1-9

Introduction 1-9

Chastain-Tawcaw-Shellbluff Association 1-9

Rembert-Hornsville Association 1-10

Blanton-Lakeland Association 1-10

Fuquay-Blanton-Dothan Association 1-10

Orangeburg Association 1-11

Vaucluse-Ailey Association 1-11

Troup-Pickney-Lucy Association 1-11

References 1-13

Vegetation 2-1

Introduction 2-3

Terrestrial Land Cover Types 2-5

Introduction 2-5

Non-Forested Cover Types	2-5
Industrial/Transportation Related Land Cover Types	2-5
Grassland/Forb/Scrub-Shrub	2-5
Open Water	2-5
Forested Cover Types	2-5
Evergreen Forests	2-5
Deciduous Forests	2-6
Bottomland Hardwood Forests	2-6
Swamp Forests	2-7
Carolina Bays	2-7
Landcover Maps	2-7

Successional Patterns **2-25**

Commercially and Recreationally Valuable Biota **2-27**

Timber Acreage	2-27
Timber Commercial Value	2-27

Set-Aside Areas **2-31**

References **2-33**

Wildlife 3-1

Introduction **3-3**

Herpetofauna	3-5
Introduction	3-5
Carolina Bays	3-5
Stee! Creek and L Lake	3-5
Par Pond	3-5
Pen Branch	3-6

Avifauna **3-23**

Birds Found on SRS	3-23
Waterfowl	3-32
Introduction	3-32
Effects of Wetlands Drainage	3-33
Studies of Waterfowl Populations on SRS	3-33
Introduction	3-33
Par Pond System	3-34
L Lake	3-35
Nest Box Surveys	3-37

Upland Game Birds	3-37
Threatened and Endangered Birds	3-37
Mammals	3-39
Introduction	3-39
Studies Of Mammal Populations on SRS	3-39
Commercially and Recreationally Valuable Biota	3-47
Unexploitable Resources	3-47
Introduction	3-47
Wild Turkeys	3-47
Mammals	3-48
Exploitable Resources	3-49
Introduction	3-49
White-Tailed Deer	3-49
Feral Swine	3-49
References	3-53
 <i>Sitewide Wetland Resources</i>	 <i>4-1</i>
Introduction	4-3
Recent Site-Wide Wetland Distribution	4-5
Pre-SRS Wetland Distribution	4-23
References	4-39
 <i>SRS Savannah River Swamp</i>	 <i>5-1</i>
Introduction	5-3
General Wetland Patterns of the SRS Savannah River Swamp	5-7
Pre-SRS Logging of the Swamp	5-7
Wetland Communities of the SRS Savannah River Swamp	5-12
Wetlands Classification Scheme	5-15

Long-Term Trends and Effects of Cooling-Water Releases on SRS Streams and the SRS Savannah River Swamp 5-19

Introduction 5-19

Photographic Surveys 5-20

Introduction 5-20

Summary of Photographic Surveys, 1951-1985 5-21

Multispectral Scanner Surveys of the SRS Swamp Delta Areas 5-21

Comparison of the Photographic and MSS Surveys, 1981-1985 5-22

Beaver Dam Creek 5-23

Beaver Dam Creek Watershed Characteristics 5-23

Beaver Dam Creek Delta Characteristics 5-23

Beaver Dam Creek Delta Trends 5-24

MSS Surveys of the Beaver Dam Creek Delta, 1981-1985 5-24

Fourmile Branch 5-27

Fourmile Branch Watershed Characteristics 5-27

Fourmile Branch Corridor and Delta 5-28

Fourmile Branch Delta—MSS Surveys 1981-1984 5-28

Fourmile Branch Ground Surveys 1982, 1987, 1989, 1990 5-33

Overstory Stratum 5-34

Understory Stratum 5-34

Shrub Stratum 5-34

Ground Cover Stratum 5-34

Pen Branch 5-35

Pen Branch Watershed Characteristics 5-35

Pen Branch Corridor and Delta Trends 5-35

Wetland Characteristics of the Pen Branch Delta Area, Early 1980s 5-39

MSS Surveys—Pen Branch Delta 5-40

Central Portion MSS Surveys, 1981-1984 5-40

Tail Portion MSS Surveys, 1981-1985 5-40

Pen Branch Ground Surveys 1990 5-41

Indian Grave Branch Section 5-41

Introduction 5-41

Overstory Stratum 5-41

Understory Stratum 5-42

Shrub Stratum 5-42

Ground Cover Stratum 5-42

Mid-Corridor Section 5-42

Introduction 5-42

Overstory Stratum 5-42

Understory Stratum 5-42

Shrub Stratum 5-43

Ground Cover Stratum 5-43

Lower Pen Branch Corridor 5-43

Introduction 5-43

Overstory Stratum 5-43

Understory Stratum 5-43

Shrub Stratum 5-43

Ground Cover Stratum 5-43

Upper Delta Area 5-44

Introduction 5-44

Overstory Stratum 5-44

Understory Stratum	5-44
Shrub Stratum	5-44
Ground Cover Stratum	5-44
Mid-Delta Area	5-44
Introduction	5-44
Overstory Stratum	5-44
Understory Stratum	5-45
Shrub Stratum	5-45
Ground Cover Stratum	5-45
Pen Branch "Tail" Area	5-45
Introduction	5-45
Overstory Stratum	5-45
Understory Stratum	5-45
Shrub Stratum	5-45
Ground Cover Stratum	5-46
Summary of 1990 Pen Branch Ground Survey	5-46
Steel Creek	5-46
Steel Creek Watershed Characteristics	5-46
Steel Creek Corridor and Delta Trends	5-46
Wetland Characteristics of the Steel Creek Drainage Area, Early 1980s	5-49
Steel Creek Delta MSS Surveys, 1981–1985	5-50
MSS Surveys Below L Lake, 1985–1987	5-52

References 5-55

Pen Branch Wetland Changes, 1987-1992 6-1

Introduction 6-3

Wetland Community Patterns, SPOT Data 1987-1992 6-5

Introduction 6-5

Changes in the Pen Branch Wetlands 6-7

Cover Types Found in the Pen Branch Wetlands 6-7

Effects of Decreased Operation of K Reactor 6-7

Effects of the Shutdown of K Reactor 6-7

Wetlands Change Detection from 1987-1991 in the Pen Branch Corridor and Delta Using Airborne MSS Data 6-9

Introduction 6-9

Methodology 6-9

Wetlands Classification 6-9

Introduction 6-9

Factors Affecting Wetlands Classification 6-9

Pen Branch Wetland Classifications 6-10

1987 Classification 6-10

1988 Classification 6-11

1989 Classification 6-11

1990 Classification	6-11
1991 Classification	6-12
Summary of Changes	6-12

References	6-19
------------	------

Wetlands of L Lake 7-1

Introduction	7-3
--------------	-----

Habitat Formers	7-5
Introduction	7-5
Plant Community Composition	7-5
Areal Cover and Expansion	7-6
Line Transects vs. Plots	7-6
Littoral-Zone Change	7-6

Macrophyte Planting Program	7-7
Introduction	7-7
Submersed and Floating-leaved Zone (30 to 100-cm Water Depth)	7-7
Emergent Zone (Waterline to 30-cm Water Depth)	7-7
Upper Emergent/Shrub Zone (Waterline to 30-cm Above Waterline)	7-8

References	7-11
------------	------

Wetlands of the Par Pond System 8-1

Introduction	8-3
--------------	-----

Macrophyte Distributions	8-5
Introduction	8-5
Scrub-Shrub Communities	8-6
Cattails	8-6
Non-Persistent Macrophytes	8-6
Comparison of Par Pond Macrophyte Communities to Regional Reservoirs	8-8

Thermal Effects on Par Pond Vegetation	8-9
Changes in Phenological Cycle	8-9
Floating-Leaved and Emergent Macrophytes	8-9
Community Alterations	8-9
Flora Tolerant to Thermal Conditions	8-9
 Changes in Par Pond Macrophyte Growth	 8-11
Introduction	8-11
Photographic Studies, 1958 - 1990	8-11
Introduction	8-11
Macrophyte Classification	8-11
Introduction	8-11
Floating-Leaved Macrophytes	8-11
Emergent Macrophytes	8-12
<i>In Situ</i> Data and Aerial Photographic Comparison for Par Pond	8-13
Macrophyte Succession and Stabilization	8-13
Changes in Par Pond Wetland Macrophytes, 1975-1983	8-14
Seasonal and Annual Changes in Par Pond Macrophyte Beds, 1988-1990	8-14
Seasonal Changes	8-14
The Multiple Year Changes in Aquatic Macrophyte Distribution	8-14
Effects of Reduction in Cooling-Water Discharges	8-14
 Par Pond Drawdown	 8-17
 Pond B	 8-21
Site Description	8-21
Macrophytes	8-21
Introduction	8-21
Macrophyte Distribution and Standing Crop	8-22
Introduction	8-22
Species composition and structure	8-22
Floating-Leaved Macrophytes	8-23
<i>Nymphaea odorata</i>	8-23
<i>Brasenia schreberi</i>	8-23
<i>Nymphoides cordata</i>	8-24
<i>Nelumbo lutea</i> and <i>Potamogeton</i> sp	8-24
Non-Rooted Submerged Macrophytes	8-24
<i>Utricularia floridana</i>	8-24
<i>Utricularia inflata</i>	8-25
<i>Utricularia olivacea</i>	8-25
<i>Utricularia purpurea</i>	8-25
Rooted Submerged Macrophytes	8-25
<i>Cabomba caroliniana</i>	8-25
<i>Bacopa caroliniana</i>	8-26
<i>Myriophyllum heterophyllum</i>	8-26
Emergent Macrophytes	8-26
Comparison With Other Aquatic Systems	8-26
Comparison with Par Pond	8-26

References 8-29***Carolina Bays of SRS 9-1*****Introduction 9-3**

- General Characteristics of Carolina Bays 9-3**
- Previous Research on SRS Carolina Bays 9-3**
- Size and Distribution of Carolina Bays on SRS 9-3**

Hydrology 9-5**Water Chemistry 9-7**

- General Chemical Characteristics 9-7**
- Detailed Chemical Analyses of Bays of SRS 9-8**
- Variation in Oxygen and Temperature 9-8**

Soils 9-11**Vegetation 9-13**

- Introduction 9-13**
- Vegetation Pattern Control 9-13**
- Vegetation Zones 9-13**
- Community Types 9-13**
- Short-Term Succession 9-15**

Invertebrate Fauna 9-17

- Introduction 9-17**
- Macroinvertebrates 9-17**
- Zooplankton 9-18**

Vertebrate Fauna 9-19

- Introduction 9-19**
- Fishes 9-19**
- Migration in Carolina Bays 9-19**
- Abundance in Altered Bays 9-20**
- Vertebrate Species that use Carolina Bays 9-20**

Lost Lake Restoration 9-23

- Introduction 9-23**
- Restoration Plan 9-23**

Restoration Objectives	9-24
Strategy Considerations	9-26
Treatment Scheme	9-26
Soil Conditions	9-26
Hydrology	9-26
Monitoring	9-26
Wetland Area Treatments	9-26
Plantings	9-28
Initial Results	9-28
1991 Results	9-28
1992 Results	9-28

References	9-31
-------------------	-------------

Upper Three Runs 10-1

Drainage Description and Surface Hydrology	10-3
General Description	10-3
Effluent Contribution	10-3
Flow Measurements	10-4
Water Chemistry and Quality	10-7
Studies and Monitoring	10-7
Water-Quality Monitoring	10-7
Comprehensive Cooling Water Study	10-7
Priority Pollutants Survey	10-8
Chemical Assessment Studies	10-8
Field Data	10-8
Water Temperature	10-8
pH Measurements	10-9
Physical Characteristics and General Chemistry	10-10
Dissolved Oxygen	10-10
Conductivity	10-10
Suspended Solids and Turbidity	10-10
Major Anions and Cations	10-10
Alkalinity, Chloride, and Sulfate	10-10
Calcium, Magnesium, Sodium, and Potassium	10-10
Aluminum, Manganese, and Iron	10-11
Nutrients	10-14
Phosphorus	10-14
Nitrogen	10-14
Trace Elements	10-14
Organic Carbon	10-14
Priority Pollutants	10-14
Pesticides, Herbicides, and PCBs	10-17
Chemical Assessment Studies	10-17

M-Area Liquid Effluent Treatment Facility	10-17
Changes in M-Area Effluent	10-17
F/H Area Effluent Treatment Facility	10-21

Algae 10-27

Macrophytes 10-29

Introduction	10-29
Comprehensive Cooling Water Study	10-29

Zooplankton 10-31

Macroinvertebrates 10-33

Sampling Locations and Methods	10-33
Aquatic Insects Survey	10-33
Comprehensive Cooling Water Study	10-33
F/H Effluent Treatment Facility Monitoring Program	10-34
Tims Branch Monitoring Program	10-34
Results	10-34
Aquatic Insects Survey	10-34
Comprehensive Cooling Water Study	10-35
Introduction	10-35
Taxa Collected	10-35
Effluent Treatment Facility Monitoring Program	10-36
Taxa Collected	10-36
Dominant Taxa	10-36
Introduction	10-36
Chironomids	10-36
Trichoptera	10-36
Plecoptera	10-37
Ephemeroptera and Coleoptera	10-37
Mean Number of Taxa and Density of Organisms	10-37
Temporal Trends	10-38
Tims Branch Monitoring Program	10-39
1985-1986 Sampling Program	10-39
1988-1990 Sampling Program	10-40

Fish 10-55

Introduction	10-55
Sampling Conducted During the Comprehensive Cooling Water Study	10-55
Introduction	10-55
Ichthyoplankton Taxa Collected	10-56
Ichthyoplankton Densities	10-57
Studies to Assess Impacts from F- and H-Areas	10-57
Introduction	10-57
Comparison to Other SRS Streams	10-58
Differences Among Sample Stations	10-58
Differences Among Different Habitats	10-58

Effects of F- and H-Area Operations 10-60**References 10-61***Beaver Dam Creek 11-1***Drainage Description and Surface Hydrology 11-3**

General Description 11-3
Effluents Contribution 11-3
Flow Measurements 11-4

Water Quality 11-7

Studies and Monitoring 11-7
Water-Quality Monitoring 11-7
Comprehensive Cooling-Water Study 11-7
Priority Pollutants Survey 11-8
Chemical Assessment Studies 11-8

Field data 11-8

Water Temperature 11-8
pH Measurements 11-8

Physical Characteristics and General Chemistry 11-10

Dissolved Oxygen 11-10
Suspended Solids and Turbidity 11-10
Conductivity 11-10

Major Anions and Cations 11-11

Alkalinity, Chloride and Sulfate 11-11
Calcium, Magnesium, Sodium, and Potassium 11-11
Aluminum, Manganese, and Iron 11-11

Nutrients 11-12

Phosphorus 11-12
Nitrogen 11-12

Trace Elements 11-13**Organic Carbon 11-13****Priority Pollutants 11-14****Pesticides, Herbicides, and PCBs 11-14****Chemical Assessment Studies 11-14**

316(a) Demonstration 11-14

Algae 11-17**Macrophytes 11-19**

Introduction 11-19
Clean Water Act Compliance Study 11-19
Comprehensive Cooling Water Study 11-19

Effects of Reduced Power Plant Operation 11-19**Zooplankton 11-21****Comprehensive Cooling Water Study 11-21****Regulatory Compliance Study 11-21****Macroinvertebrates 11-23****Sampling Locations and Methods 11-23**

Comprehensive Cooling Water Study 11-23

Clean Water Act Compliance Study 11-23

Results 11-24

Introduction 11-24

Number of Taxa 11-24

Densities 11-25

Dominant Species 11-25

Differences Among Sampling Stations 11-25

Taxonomic Composition Changes Since 1984–1985 11-26

Fish 11-35**Introduction 11-35****Studies conducted during the D-Area 316(a) Demonstration 11-35**

Introduction 11-35

Adult Fish 11-35

Ichthyoplankton 11-46

Comprehensive Cooling Water Studies (1984-1986) 11-50

Adult and Juvenile fish 11-50

Ichthyoplankton 11-51

References 11-55*Fourmile Branch 12-1***Drainage Description and Surface Hydrology 12-3****General Description 12-3****Effluents Contributions 12-3****Delta 12-3****Flow Measurements 12-4****Water Chemistry and Quality 12-7****Studies and Monitoring 12-7**

Water-Quality Monitoring 12-7

Comprehensive Cooling Water Study 12-7

Priority Pollutant Study 12-8

Chemical Assessment Studies	12-8
Field Data	12-8
Water Temperature	12-8
pH Measurements	12-8
Physical Characteristics and General Chemistry	12-9
Dissolved Oxygen	12-9
Conductivity	12-9
Suspended Solids and Turbidity	12-10
Major Anions and Cations	12-10
Alkalinity, Chloride, and Sulfate	12-10
Calcium, Magnesium, Sodium, and Potassium	12-11
Aluminum, Manganese, and Iron	12-11
Nutrients	12-12
Phosphorus	12-12
Nitrogen	12-12
Trace Elements	12-13
Organic Carbon	12-14
Priority Pollutants	12-14
Pesticides, Herbicides, and PCBs	12-15
Chemical Assessment Studies	12-15
Seepline Sampling Study, 1987	12-15
Seepline Sampling Study, 1988 and 1989	12-15
Seepline Sampling Study, 1991 and 1992	12-15
Algae	12-17
Phytoplankton	12-17
Periphyton	12-17
Macrophytes	12-19
Introduction	12-19
Comprehensive Cooling Water Study	12-19
Expectations Since the Cessation of C Reactor Operation	12-19
Zooplankton	12-21
Macroinvertebrates	12-23
Sampling	12-23
Locations	12-23
Methods	12-23
Results	12-24
Introduction	12-24
Macroinvertebrate Community During Operation of C Reactor	12-24
Non-Thermal Areas	12-24
Delta	12-26
Creek Mouth	12-26
Recovery of Macroinvertebrate Community After Shutdown of C Reactor	12-27

Introduction	12-27
Recolonization	12-27
Taxa Collected	12-27

Fish 12-37

Introduction 12-37

Classifying Studies	12-37
Assessment of Thermal Impacts	12-37
Assessment of Potential Impacts from Contaminants	12-37

Studies Conducted During C Reactor Operations 12-38

Fish Movements in Relation to Reactor Operation 12-38

Introduction	12-38
Methods	12-38
Seasonal Variation	12-38
Reactor Shutdown	12-39
Movement	12-39
Upstream Migration	12-39
Species Collected	12-39
Effects of Reactor Restart	12-40

Fish Assemblages at Thermal Swamp Sites 12-40

Introduction	12-40
Faunal Groups	12-40
Dominant Species in Faunal Groups	12-40
Spatial Differentiation	12-42
Effects of Canopy Cover	12-43

Fish Assemblages at Thermal Stream Sites 12-43

Upstream of C Reactor	12-43
Downstream of C Reactor	12-43
Effects of Cool Water	12-44
Effects of Reactor Operation	12-44

Ichthyoplankton Distribution 12-45

Introduction	12-45
March-July 1984	12-45
Effects of Reactor Operation	12-45
Thermal Variation in Swamp	12-46
February-July 1985	12-46
Mouth of Fourmile Branch	12-49
Comparison of 1984 and 1985 Data	12-49

Effects of Temperature on Ichthyoplankton 12-49

Introduction	12-49
Effect of Reactor Operation	12-50
January 1985	12-50
Densities	12-50
Reproductive Phenology	12-50

Studies Conducted to Assess F- and H-Area Impacts 12-52

Introduction	12-52
Effects of Seepage Basin Constituents on Fish	12-52
Sampling Program	12-52
Changes in Fish Assemblage with Habitat Alterations	12-54
Fish Communities Comparison with Unimpacted Streams	12-54
Fish Analysis for RCRA Trace Metals	12-54
Summary of Studies	12-56

References 12-57

Pen Branch 13-1

Drainage Description and Surface Hydrology 13-3

General Description	13-3
Effluents Contribution	13-3
Delta	13-4
Flow Measurements	13-4

Water Chemistry and Quality 13-7

Studies and Monitoring	13-7
Water-Quality Monitoring	13-7
Comprehensive Cooling Water Study	13-7
Priority Pollutants Survey	13-8
Field Data (SREL 1986, Lower 1987)	13-8
Water Temperature	13-8
pH Measurements	13-8
Physical Characteristics and General Chemistry	13-8
Dissolved Oxygen	13-8
Suspended Solids and Turbidity	13-9
Conductivity	13-10
Major Anions and Cations	13-11
Alkalinity, Chloride, and Sulfate	13-11
Calcium, Magnesium, Sodium, and Potassium	13-12
Aluminum, Iron, and Manganese	13-13
Nutrients	13-13
Phosphorus	13-13
Nitrogen	13-13
Trace Elements	13-13
Organic Carbon	13-15
Priority Pollutants	13-15
Pesticides, Herbicides, and PCBs	13-17

Algae 13-19

Phytoplankton	13-19
Periphyton	13-19

Macrophytes 13-21

Introduction	13-21
Comprehensive Cooling Water Study	13-21
Introduction	13-21
Number of Taxa Collected	13-21
Expectations Since the Cessation of K-Reactor Operations	13-21

Zooplankton 13-23

Macroinvertebrates 13-25**Sampling 13-25**

- Comprehensive Cooling Water Study 13-25
- Pen Branch Recovery Study 13-25

Results 13-26

- Introduction 13-26
- Macroinvertebrate Community of Pen Branch During the Operation of K-Reactor 13-26
 - Introduction 13-26
 - Nonthermal Areas 13-26
 - Thermally Impacted Delta and Swamp 13-27
 - Number of Taxa Collected 13-27
 - Dominant Species 13-27
 - Densities 13-28
 - Biomass 13-28
- Recovery of Macroinvertebrate Community Subsequent to K-Reactor Shutdown 13-28
 - Introduction 13-28
 - Number of Taxa Collected 13-28
 - Taxa Richness 13-29
 - Dominant Species 13-29
 - Densities 13-30
 - Biomass 13-31

Fish 13-39**Introduction 13-39****Studies Conducted During K-Reactor Operations 13-39**

- Adult Fish 13-39
- Delta/Swamp Area 13-41
- Larval Fish 13-42
- Ichthyoplankton 13-42

Studies Conducted after the Shutdown of K-Reactor 13-42

- Recolonization of Pen Branch and Indian Grave Branch 13-42
- Effects of Artificial Flow Perturbations 13-44

References 13-45***L Lake and Steel Creek 14-1*****Drainage Description and Surface Hydrology 14-3****L Lake 14-3**

- General Description 14-3
- Effluent Contribution 14-3
- L Lake Dam 14-4
 - Description 14-4
 - Outlet Structure 14-4
- Level and Temperature Monitoring 14-5

Steel Creek 14-5

General Description	14-5
Effluents Contribution	14-5
Delta	14-6
Flow Measurements	14-6

Water Chemistry and Quality 14-9

L Lake 14-9

Water Quality Monitoring	14-9
Field Data	14-10
Temperature	14-10
pH Measurements	14-10
Physical Characteristics and General Chemistry	14-10
Dissolved Oxygen	14-10
Conductivity	14-10
Suspended Solids and Turbidity	14-10
Major Cations and Anions	14-11
Alkalinity, Chloride, and Sulfate	14-11
Calcium, Magnesium, Sodium, and Potassium	14-11
Aluminum, Manganese, and Iron	14-11
Nutrients	14-11
Phosphorus	14-11
Nitrogen	14-11
Trace Elements	14-13
Organic Carbon	14-13

Steel Creek 14-14

Studies and Monitoring	14-14
Water Quality Monitoring	14-14
Comprehensive Cooling Water Study	14-14
Priority Pollutants Survey	14-15
Chemical Assessment Studies	14-15
Field Data	14-15
Water Temperature	14-15
pH Measurements	14-15
Physical Characteristics and General Chemistry	14-15
Dissolved Oxygen	14-15
Conductivity	14-15
Suspended Solids and Turbidity	14-15
Major Anions and Cations	14-18
Alkalinity, Chloride, and Sulfate	14-18
Calcium, Magnesium, Sodium, and Potassium	14-18
Aluminum, Iron, and Manganese	14-18
Nutrients	14-18
Phosphorus	14-18
Nitrogen	14-18
Trace Elements	14-18
Organic Carbon	14-18
Priority Pollutants	14-23
Pesticides, Herbicides, and PCBs	14-23
Chemical Assessment Studies	14-23
L Lake/Steel Creek Biological Monitoring Program	14-23

Algae 14-27

L Lake 14-27

Phytoplankton	14-27
---------------	-------

Studies in L Lake	14-27	
Phytoplankton Establishment After the Construction of L Lake		14-27
Current Status of L Lake Phytoplankton	14-28	
Periphyton	14-28	
Studies in L Lake	14-28	
L Reactor Impacts	14-28	
Steel Creek	14-52	
Phytoplankton	14-52	
Periphyton	14-52	
Studies in Steel Creek	14-52	
Biomass Quantities	14-52	
Taxa Identified	14-53	
 Macrophytes	 14-69	
L Lake	14-69	
Steel Creek	14-69	
Comprehensive Cooling Water Study	14-69	
L-Lake/Steel Creek Biological Monitoring Program		14-73
 Zooplankton	 14-77	
L Lake	14-77	
Steel Creek	14-79	
Introduction	14-79	
Early Effects of L Lake on Steel Creek Zooplankton		14-79
Effect of L Lake Releases on Steel Creek Zooplankton		14-80
Zooplankton Taxa Found in Steel Creek		14-80
Species Densities	14-81	
Seasonal Variations	14-81	
 Macroinvertebrates	 14-85	
L Lake	14-85	
Sampling Locations and Methods		14-85
316(a) Demonstration	14-85	
Results	14-86	
Meroplankton	14-86	
Benthic Macroinvertebrates		14-86
Dominant Taxa and Taxa Richness		14-86
Densities	14-87	
Biomass	14-87	
Emergence Traps	14-88	
Steel Creek	14-88	
Sampling Locations and Methods		14-88
Comprehensive Cooling Water Study		14-88
316(a) Demonstration	14-89	
Results	14-89	
Introduction	14-89	
Taxa Richness	14-90	
Dominant Taxa	14-90	
Densities	14-91	
Standing Crop	14-91	
Drift	14-91	
Densities	14-91	

Dominant Species 14-92**Fish 14-97****L Lake 14-97**

Introduction 14-97

Discussion 14-97

Sampling Methods 14-97

Artificial Stocking Program 14-98

Physical and Chemical Conditions in L Lake 14-98

Species that Failed to Colonize L Lake 14-98

Successful early colonists of L Lake 14-99

Early Colonists 14-99*Species that Did Not Reproduce in L Lake* 14-100*Species that Reproduced but Did Not Persist in L Lake* 14-100*Species that Persisted in L Lake* 14-100

Decline of the early colonists 14-100

Fish Assemblages Upstream from Regions 4-8 14-103

Recent Status of the L Lake Fish Community 14-103

Steel Creek 14-104

Introduction 14-104

Studies Conducted Prior to the Restart of L-Reactor 14-105

Studies Conducted Following the Restart of L-Reactor 14-107

References 14-115***Lower Three Runs and Par Pond 15-1*****Drainage Description and Surface Hydrology 15-3****Par Pond 15-3**

General Description 15-3

Effluents Contribution 15-3

Recirculation of Water to P Area 15-4

Flow Patterns 15-4

Meteorological Factors 15-4

Drawdown of Par Pond 15-4

Lower Three Runs 15-5

General Description 15-5

Effluents Contribution 15-5

Flow Measurements 15-5

Water Chemistry and Quality 15-9**Par Pond 15-9**

Studies and Monitoring 15-9

Water Quality Monitoring 15-9

Comprehensive Cooling Water Study 15-9

Chemical Assessment Studies 15-10

Field Data 15-10

Water Temperature 15-10

pH Measurements	15-10	
Physical Characteristics and General Chemistry	15-10	
Dissolved Oxygen	15-10	
Conductivity	15-10	
Suspended Solids and Turbidity	15-11	
Major Anions and Cations	15-12	
Alkalinity, Chloride, and Sulfate	15-12	
Calcium, Magnesium, Sodium, and Potassium	15-13	
Aluminum, Iron, and Manganese	15-14	
Nutrients	15-16	
Phosphorus	15-16	
Nitrogen	15-17	
Trace Elements	15-17	
Organic Carbon	15-17	
Pesticides, Herbicides, and PCBs	15-17	
Lower Three Runs	15-17	
Studies and Monitoring	15-17	
Water-Quality Monitoring	15-17	
Comprehensive Cooling Water Study	15-18	
Priority Pollutant Study	15-19	
Monitoring Data	15-19	
Field Data	15-19	
Water Temperature	15-19	
pH Measurements	15-20	
Physical Characteristics and General Chemistry	15-20	
Dissolved Oxygen	15-20	
Conductivity	15-20	
Suspended Solids and Turbidity	15-20	
Major Anions and Cations	15-20	
Alkalinity, Chloride, and Sulfate	15-20	
Calcium, Magnesium, Sodium, and Potassium	15-21	
Aluminum, Iron, and Manganese	15-21	
Nutrients	15-21	
Phosphorus	15-21	
Nitrogen	15-21	
Trace Elements	15-22	
Organic Carbon	15-22	
Priority Pollutants	15-22	
Pesticides, Herbicides, and PCBs	15-22	
Algae	15-23	
Par Pond	15-23	
Phytoplankton	15-23	
Studies in the Par Pond System	15-23	
Taxonomic Groups Found In Par Pond	15-23	
Differences in Par Pond Locations	15-23	
Effect of Reactor Operation	15-23	
Changes in Community Structure, 1965-1985	15-24	
Community Comparison with Other Regional Lakes	15-24	
Periphyton	15-24	
Lower Three Runs	15-24	
Macrophytes	15-37	
Par Pond	15-37	

Lower Three Runs 15-37**Zooplankton 15-39****Par Pond 15-39**

Introduction	15-39
Study Methods	15-39
Analysis Partitions	15-39
Group Densities	15-39
Introduction	15-39
Protozoan	15-42
Rotifera	15-42
Cladoceran	15-42
Copepoda	15-43

Lower Three Runs 15-43**Macroinvertebrates 15-45****Par Pond 15-45**

Sampling Locations and Methods	15-45
Results	15-46
Number of Taxa Collected	15-46
1984-1985 Meroplankton	15-46
Benthic Macroinvertebrates	15-47
1984-1985 Sampling	15-47
1988-1989 Sampling	15-49

Lower Three Runs 15-51

Sampling Locations and Methods	15-51
Results	15-51
Community Composition	15-51
Biomass	15-52

Fish 15-63**Par Pond 15-63**

Introduction	15-63
Species Composition and Abundance	15-64
Largemouth Bass	15-65
Prey Fish	15-65
Adult and Juvenile Fish Surveys	15-66
Ichthyoplankton Surveys	15-68
Comparison of Par Pond and Pond B	15-69
Comparison of Par Pond and Other United States Reservoirs	15-70
Growth and Condition	15-70
Largemouth Bass	15-70
Bluegill and Black Crappie	15-72
Mosquito Fish	15-72
Diet	15-72
Critical Thermal Maxima	15-73
Movements and Body Temperatures	15-73
Reproduction	15-74
Bluegill	15-74
Largemouth Bass	15-75
Disease and Parasitism	15-75
Red-Sore Disease	15-75

Helminth Parasites	15-76
Metacercaria of the Trematode Clinostomum marginatum	15-77
Strigeid Trematodes	15-77
Summary of Results from Fish Studies	15-77
Lower Three Runs	15-79
Introduction	15-79
Sampling Conducted During the CCWS (1984-1985)	15-79
Sampling Methods	15-79
1984 Sampling Program	15-79
1985 Sampling Program	15-79
Comparison of 1984 and 1985 Sampling Programs	15-80
Sampling Conducted During the Stream Fisheries Characterization Study	15-80

References 15-83

Savannah River 16-1

Drainage Description and Surface Hydrology 16-3

General Description	16-3
Physiography	16-3
Mountain Province	16-3
Piedmont Region	16-4
Coastal Plain	16-4
Dredging Operations	16-4
Natural Levee	16-4
Effluents Contribution	16-4
Droughts	16-5
History	16-5
Flows	16-5
Flow Requirements	16-5
Flow Measurements	16-6

Water Chemistry and Quality 16-9

Studies and Monitoring	16-9
Water-Quality Monitoring	16-9
Monitoring Data	16-9
Comprehensive Cooling Water Study	16-10
Priority Pollutant Study	16-10
Monitoring Data	16-10
Field Data	16-10
Water Temperature	16-10
pH Measurements	16-10
Physical Characteristics and General Chemistry	16-11
Dissolved Oxygen	16-11
Conductivity	16-11
Suspended Solids and Turbidity	16-12

Major Anions and Cation	16-13
Alkalinity, Chloride, and Sulfate	16-13
Calcium, Magnesium, Sodium, and Potassium	16-14
Aluminum, Manganese, and Iron	16-15
Nutrients	16-15
Comparison to SRS Streams	16-15
Phosphorus	16-15
Nitrogen	16-15
Trace Elements	16-15
Organic Carbon	16-16
Priority Pollutants	16-16
Pesticides, Herbicides, and PCBs	16-16

Algae	16-19
Taxonomic Studies	16-19
Studies Assessing Dry Weight and Chlorophyll a	16-19

Macrophytes	16-21
--------------------	--------------

Zooplankton	16-23
--------------------	--------------

Macroinvertebrates	16-25
Sampling Locations and Methods	16-25
Results	16-25
Number of Taxa Collected	16-25
Dominant Taxa	16-25
Taxa Richness	16-25
Densities	16-26
Biomass	16-26

Fish	16-33
Introduction	16-33
Studies Emphasizing Striped Bass Reproductive Success	16-33
Studies Emphasizing SRS Impacts and General Ichthyoplankton Distribution	16-34

References	16-41
-------------------	--------------

Regional Lakes Study 17-1

Introduction	17-3
Purpose of the Regional Lakes Study	17-3
Reservoirs Studied in the Regional Lakes Study	17-3

Sampling Plan	17-7
Introduction	17-7
Water Quality Sampling Techniques	17-7
Phytoplankton, Zooplankton, and Macroinvertebrate Sampling Techniques	17-8
 Longitudinal Transect Sampling Results	 17-9
 Macronutrients, Phosphorus, and Nitrogen	 17-13
Alkalinity	17-13
Phosphorus	17-13
Nitrogen	17-13
Conclusions from Water-Quality Variables	17-13
 Indicators of Eutrophication	 17-17
 References	 17-21

Commercially and Recreationally Valuable Biota 18-1

Biota Found on SRS	18-3
 Biota Found in the Savannah River	 18-5
Commercial Fishing	18-6
Introduction	18-6
American Shad	18-6
Striped Bass	18-6
Sport Fishing	18-6
Introduction	18-6
Angler Preferences	18-7
Angler Harvests	18-7
Species Preference versus Catch	18-7
Catch Versus Availability	18-9
Bream	18-10
Crappie, Yellow Perch, and Largemouth Bass	18-10
Catfish	18-10
American Shad, Stripped Bass, and Hybrid Bass	18-10
Creel Surveys, 1988 and 1989	18-11
SRS Impact to Savannah River Fisheries	18-12
 References	 18-19

Laws Protecting Threatened and Endangered Species 19-1

Federal Endangered Species Act 19-3

State of South Carolina Acts and Programs 19-5

References 19-7

Threatened and Endangered Flora 20-1

Threatened and Endangered Flora Found in South Carolina 20-3

Programs for Identifying Species 20-3

Federally Listed Species Found in South Carolina 20-3

Threatened and Endangered Flora Found on SRS 20-5

References 20-9

Threatened and Endangered Fauna 21-1

Invertebrates 21-3

Introduction 21-3

Species Found on SRS 21-3

Brother Spike Mussel 21-3

American Sandburrowing Mayfly 21-3

Fishes 21-5

Introduction 21-5

Shortnose Sturgeon 21-5

Introduction 21-5

Habitat 21-6

Spawning 21-6

Time of Year 21-6

Temperature 21-6

Spawning Grounds 21-6

Eggs 21-6

Spawning Frequency 21-6

Stages of Development	21-7
Larval Development	21-7
Juvenile	21-7
Growth	21-7
Life Span	21-7
Feeding	21-7

Herpetofauna 21-9

Introduction 21-9

Amphibians 21-9

Reptiles 21-9

Introduction 21-9

Snakes 21-9

Alligator 21-9

Introduction 21-9

Protection History 21-10

General Life History 21-10

Aquatic Habitats on SRS 21-11

Introduction 21-11

Alligator Populations in the Par Pond System 21-11

Alligator Populations in Beaver Dam Creek 21-13

Alligator Populations in Steel Creek Below L Lake 21-16

Alligator Populations in Fourmile Branch 21-16

Alligator Populations in Pen Branch 21-16

Alligator Populations in Other SRS Areas 21-17

Avifauna 21-19

Introduction 21-19

Current and Past Residents 21-19

Visitors 21-19

Bald Eagle 21-19

Introduction 21-19

History in South Carolina 21-21

Inland Colonization 21-21

Bald Eagle Use of SRS 21-21

SRS Bald Eagle Study 21-21

Supplemental SRS Observations 21-23

Adult to Immature Ratio 21-25

Social Organization 21-25

Seasonal Use 21-25

Diet and Forage Behavior 21-25

Records of Marked/Tagged Birds 21-26

Reproductive Biology 21-27

Bald Eagle Nesting on SRS 21-27

Bald Eagle Management on SRS 21-28

Golden Eagle 21-28

History in South Carolina 21-28

Golden Eagle Use of SRS 21-29

Red-Cockaded Woodpecker 21-29

Introduction 21-29

Breeding 21-29

Habitat 21-30

Cavity Excavation	21-30
Foraging	21-30
Relationship Between Population Numbers and Suitable Habitat	21-31
Savannah River Forest Service Wildlife Management Program	21-31
Creating Nesting Habitats	21-31
Monitored Colonies at SRS	21-31
SRS Population Numbers	21-33
Wood Stork	21-33
Introduction	21-33
Birdsville Colony	21-34
Effect of Reactor Operations	21-34
Savannah River Swamp	21-34
Savannah River Ecology Laboratory Studies	21-35
Birdsville Colony Survey	21-35
Foraging Surveys 1983-1989	21-35
Introduction	21-35
Foraging Habitats	21-38
Vegetation Structure	21-38
Water Depth	21-39
Potential Prey Species	21-39
Major Diet Components	21-39
SRS Savannah River Swamp Surveys	21-39
Introduction	21-39
Surveying Techniques	21-40
Results of the Aerial Surveys	21-40
Introduction	21-40
Results of the 1983 Aerial Surveys	21-41
Results of the 1984 Aerial Surveys	21-42
Results of the 1985 Aerial Surveys	21-42
Results of the 1986 Aerial Surveys	21-42
Results of the 1987 Aerial Surveys	21-42
Results of the 1988 Aerial Surveys	21-43
Results of the 1989 Aerial Surveys	21-43
Results of the 1990 Aerial Surveys	21-43
Results of the 1991 Aerial Surveys	21-43
Results of the 1992 Aerial Surveys	21-43
Stream Flows and Numbers of Foraging Storks	21-43
Sources of Water Flow	21-43
Flow Effect on Number of Wood Storks	21-45
Fourmile Branch Delta	21-45
Pen Branch Delta	21-45
Steel Creek Delta	21-48
Beaver Dam Creek	21-48
Foraging Use	21-48
Par Pond	21-49
Wood Stork Use on Kathwood Lake	21-49
Introduction	21-49
Physical Attributes	21-50
Wood Stork Use	21-50

Mammals	21-53
Introduction	21-53
Bats	21-53
Carnivores	21-54

References 21-55

List of Figures

- Figure 1-1. Location of Pleistocene Marine Terraces on SRS (Langley and Marter 1973) 1-5
- Figure 1-2. Guide for Textural Classification 1-6
- Figure 1-3. SRS General Soils Map 1-9
- Figure 2-1. Locations of Carolina Bays on SRS (Schalles et al. 1989) 2-8
- Figure 2-2. Major Vegetation Types and Approximate Areas on SRS 2-9
- Figure 2-3. SRS Map Showing Names of USGS Quadrangle Maps and Page Numbers of the Landcover Map for that Quadrangle 2-10
- Figure 2-4. New Ellenton Quadrangle Land Cover Map 2-11
- Figure 2-5. Windsor Quadrangle Land Cover Map 2-12
- Figure 2-6. Jackson Quadrangle Land Cover Map 2-13
- Figure 2-7. New Ellenton southwest Quadrangle Land Cover Map 2-14
- Figure 2-8. New Ellenton southeast Quadrangle Land Cover Map 2-15
- Figure 2-9. Long Branch Quadrangle Land Cover Map 2-16
- Figure 2-10. Shell Bluff Quadrangle Land Cover Map 2-17
- Figure 2-11. Girard northwest Quadrangle Land Cover Map 2-18
- Figure 2-12. Girard northeast Quadrangle Land Cover Map 2-19
- Figure 2-13. Snelling Quadrangle Land Cover Map 2-20
- Figure 2-14. Girard Quadrangle Land Cover Map 2-21
- Figure 2-15. Millet Quadrangle Land Cover Map 2-22
- Figure 2-16. Martin Quadrangle Land Cover Map 2-23
- Figure 2-17. Locations of SRS Set-Asides 2-31
- Figure 3-1. Location of Drift Fences and Pitfall Traps in Steel Creek (1981–1982) and 1982 Turtle Trapping Areas (Source: Smith et al. 1982) 3-17

- Figure 3-2. Location of Reptile and Amphibian Sampling Transects in the Steel Creek Corridor and Delta, January 1986–December 1987 (Source: Giffin and Patterson 1988) 3-17
- Figure 3-3. Location of Reptile and Amphibian Sampling Transects on the L Lake Shoreline (Source: Patterson and Giffin 1988) 3-20
- Figure 3-4. Size Structure of Adult *Pseudemys scripta* from Different Habitats on SRS (Source: Gibbons 1970) 3-21
- Figure 3-5. Growth Rates of Juvenile *Pseudemys scripta* from Two Populations on SRS (Source: Gibbons 1970) 3-21
- Figure 3-6. Comparative Population Size Structure of Adult *Pseudemys* (*Chrysemys*) *scripta* from Different Habitats in South Carolina (Source: Gibbons 1970) 3-22
- Figure 3-7. Aquatic Habitats of SRS 3-33
- Figure 3-8. Location Map of the Par Pond System 3-34
- Figure 3-9. Total Number of Waterfowl and Associated Avian Species Observed in Regions 4–8 of L Lake (Source: Patterson and Giffin 1988) 3-36
- Figure 3-10. Cumulative Waterfowl and Associated Avian Species Taxa Richness in Regions 4–8 of L Lake (January 1986–December 1987) (Source: Patterson and Giffin 1988) 3-37
- Figure 4-1. SRS Map Showing Names of USGS Quadrangle Sheets 4-7
- Figure 2-2. Sitewide Wetlands Map 4-8
- Figure 4-3. New Ellenton Quadrant Wetlands Map 4-9
- Figure 4-4. Windsor Quadrant Wetlands Map 4-10
- Figure 4-5. Jackson Quadrant Wetlands Map 4-11
- Figure 4-6. New Ellenton SW Quadrant Wetlands Map 4-12
- Figure 4-7. New Ellenton SE Quadrant Wetlands Map 4-13
- Figure 4-8. Long Beach Quadrant Wetlands Map 4-14
- Figure 4-9. Shell Bluff Quadrant Wetlands Map 4-15
- Figure 4-10. Girard NW Quadrant Wetlands Map 4-16
- Figure 4-11. Girard NE Quadrant Wetlands Map 4-17

-
- Figure 4-12. Snelling Quadrant Wetlands Map 4-18
- Figure 4-13. Girard Quadrant Wetlands Map 4-19
- Figure 4-14. Millet Quadrant Wetlands Map 4-20
- Figure 4-15. Martin Quadrant Wetlands Map 4-21
- Figure 2-16. Sitewide Historical Wetlands Map 4-24
- Figure 4-17. New Ellenton Quadrant Historical Wetlands Map 4-25
- Figure 4-18. Windsor Quadrant Historical Wetlands Map 4-26
- Figure 4-19. Jackson Quadrant Historical Wetlands Map 4-27
- Figure 4-20. New Ellenton SW Quadrant Historical Wetlands Map 4-28
- Figure 4-21. New Ellenton SE Quadrant Historical Wetlands Map 4-29
- Figure 4-22. Long Branch Quadrant Historical Wetlands Map 4-30
- Figure 4-23. Shell Bluff Quadrant Historical Wetlands Map 4-31
- Figure 4-24. Girard NW Quadrant Historical Wetlands Map 4-32
- Figure 4-25. Girard NE Quadrant Historical Wetlands Map 4-33
- Figure 4-26. Snelling Quadrant Historical Wetlands Map 4-34
- Figure 4-27. Girard Quadrant Historical Wetlands Map 4-35
- Figure 4-28. Millet Quadrant Historical Wetlands Map 4-36
- Figure 4-29. Martin Quadrant Historical Wetlands Map 4-37
- Figure 5-1. Location of the SRS Savannah River Swamp 5-3
- Figure 5-2. Monthly Probabilities of the Savannah River Flooding 5-4
- Figure 5-3. Sediment Fans at the Fourmile Branch Delta Area (1986), the Pen Branch Delta Area (1981), and the Steel Creek Delta Area (1974) 5-5
- Figure 5-4. Timber Harvest in the Savannah River Swamp West of Beaver Dam Creek 5-8
- Figure 5-6. Timber Harvesting Activities in the SRS Savannah River Swamp (From 1943 Aerial Photography) 5-9
-

- Figure 5-5. Timber Harvesting Activities in the SRS Savannah River Swamp (From 1938 Aerial Photography) 5-9
- Figure 5-8. Estimate of Lumbered Areas within the SRS Savannah River Swamp (From 1938 Aerial Photography) 5-10
- Figure 5-7. Timber Harvesting Activities in the SRS Savannah River Swamp (From 1951 Aerial Photography) 5-10
- Figure 5-10. Estimate of Lumbered Areas within the SRS Savannah River Swamp (From 1951 Aerial Photography) 5-11
- Figure 5-9. Estimate of Lumbered Areas within the SRS Savannah River Swamp (From 1943 Aerial Photography) 5-11
- Figure 5-12. Two-Way Indicator Species Analysis of the SRS Savannah River Swamp Forest Data Indicated on Detrended Correspondence Analysis Ordination (Source: Gladden et al. 1985) 5-14
- Figure 5-11. Detrended Correspondence Analysis Ordination of Forested and Shrub-Dominated Sites in the SRS Savannah River Swamp (Source: Gladden et al. 1985) 5-14
- Figure 5-13. Areas of the SRS Savannah River Swamp Analyzed Using Multispectral Scanner Data, 1981–1985 5-22
- Figure 5-14. Location of Beaver Dam Creek on SRS 5-23
- Figure 5-15. Beaver Dam Creek Delta Growth (Source: Tinney et al. 1986) 5-24
- Figure 5-16. Vertical Aerial Photography of the Beaver Dam Creek Delta Area for Spring 1986, 1990, and 1992 5-26
- Figure 5-18. Fourmile Branch Corridor Changes (Source: Tinney et al. 1986) 5-30
- Figure 5-17. Fourmile Branch Delta Expansion Composite Image, 1961–1982 (Source: Gladden et al. 1985) 5-30
- Figure 5-19. Vertical Aerial Photography of the Fourmile Branch Delta Area During Thermal Operations of C Reactor 5-31
- Figure 5-20. Vertical Aerial Photography of the Fourmile Branch Delta Area After C-Reactor Shutdown 5-32
- Figure 5-22. Pen Branch Delta Expansion, 1955–1985 (Source: Tinney et al. 1986) 5-37

- Figure 5-21. Wetland Changes in the Pen Branch Corridor, 1955–1985 (Source: Tinney et al. 1986) 5-37
- Figure 5-23. Pen Branch Delta Expansion Composite Image, 1961–1982 (Source Christensen et al. 1984b) 5-38
- Figure 5-24. Thermal Patterns in the Pen Branch delta Under Non-Flood (Top) and Flood (Bottom) Conditions of the Savannah River (Source: Scott et al. 1986) 5-39
- Figure 5-25. Steel Creek Wetland Changes, 1955–1985 (Tinney et al. 1986) 5-46
- Figure 5-26. Steel Creek Growth and Revegetation Trends, 1951–1985 (Source: Tinney et al. 1986) 5-48
- Figure 5-1. Vertical Aerial Photography of the Steel Creek Delta Area Before (1985), During (1986, 1988), and After (1992) L-Reactor Shutdown 5-54
- Figure 6-1. Pen Branch Delta Area Evaluated for Wetlands Using SPOT HRV Data for 1987, 1988, and 1989, and the Location of Phenology Stations 6-5
- Figure 6-2. Savannah River Flow, Phenology Pattern in Pen Branch Delta, and Pen Branch Flow Data for 1987-1988 6-14
- Figure 6-3. Savannah River Flow, Phenology Pattern in Pen Branch Delta, and Pen Branch Flow Data for 1989-1990 6-15
- Figure 6-4. Savannah River Flow, Phenology Pattern in Pen Branch Delta, and Pen Branch Flow Data for 1991-1992 6-16
- Figure 6-5. Vertical Aerial Photography of the Pen Branch Delta in 1987, 1988, and 1990 6-17
- Figure 7-1. Location of L Lake on SRS 7-3
- Figure 8-1. Map of the Par Pond System 8-3
- Figure 8-2. General Distribution, by Depth, of Macrophytes Along the Par Pond Shoreline 8-6
- Figure 8-3. Depth at Outer Edge Along Macrophyte Beds in Par Pond as Measured in 1988 8-7
- Figure 8-4. Phenological Cycle of Cattails and Water-lilies in Par Pond (Source: Jensen et al. 1993) 8-7

-
- Figure 8-5. History of Par Pond Macrophyte Growth 8-13
- Figure 8-6. Change in Water-lily and Cattail Distribution in Par Pond Between April 17, 1988, and October 25, 1988 as Detected by SPOT Panchromatic Analysis (Source: Jensen et al. 1993) 8-15
- Figure 8-7. Par Pond Water-Level Change 8-17
- Figure 8-8. Vertical Aerial Photography Showing the Effects of the Drawdown of Par Pond 8-18
- Figure 8-9. Map of Pond B 8-21
- Figure 8-10. Standing Crop of Dominant Macrophyte Species at Four Sampling Depths and Three Sampling Periods During 1986 in Pond B. 8-22
- Figure 9-1. Location Map of Carolina Bays on SRS (adapted from Shields et al. 1982) 9-4
- Figure 9-2. Surface Water Levels of Three Carolina Bays on SRS—Thunder Bay, 83; Ellenton Bay, 176; and Rainbow Bay, 189 (Shalles et al. 1989) 9-5
- Figure 9-3. Water Level and Rainfall Data for Lost Lake Since August 1990 9-6
- Figure 9-4. Vertical Profiles of Dissolved Oxygen and Temperature at Four Sampling Stations in Three Carolina Bays in 1974-75 (Schalles 1979) 9-8
- Figure 9-5. Wetland Vegetation Community Types at Craig's Pond (Site 77) (Source: Hodge 1985) 9-14
- Figure 9-6. Wetland Vegetation Community Types at Ellenton Bay (Site 176) (Source: Hodge 1985) 9-14
- Figure 9-7. Changes in Zooplankton Species Composition from January to September 1984 at Rainbow Bay (Site 189) (Source: Shalles et al. 1989) 9-18
- Figure 9-8. Location of Lost Lake and the M-Area Settling Basin on SRS 9-23
- Figure 9-9. Lost Lake and the M-Area Basin Prior to Cleanup (Vertical and Oblique Photography) 9-24
- Figure 9-10. Lost Lake and the M-Area Basin During Cleanup (Vertical and Oblique Photography) 9-25
- Figure 9-12. Planting Scheme for Zone 1B at the Lost Lake/M-Area Basin Restora-
-

- tion Site. Zone 1B is Representative of the Eight Treatment Zones. 9-27
- Figure 9-11. Planting Plan at the Lost Lake/M-Area Basin Restoration Site 9-27
- Figure 9-13. Lost Lake and the M-Area Basin During Early Restoration Activities (Vertical and Oblique Photography) 9-29
- Figure 10-1. Location of Upper Three Runs on SRS 10-3
- Figure 10-1. Flow Measurement Sampling Stations for Upper Three Runs 10-4
- Figure 10-2. Maximum, Mean, and Minimum Flow Measurements for Upper Three Runs at Station 02197300 10-5
- Figure 10-3. Maximum, Mean, and Minimum Flow Measurements for Upper Three Runs at Station 02197310 10-5
- Figure 10-4. Maximum, Mean, and Minimum Flow Measurements for Upper Three Runs at Station 02197315 10-6
- Figure 10-5. Water Chemistry and Quality Sampling Stations for Upper Three Runs 10-7
- Figure 10-6. Macroinvertebrate Sampling Stations for Upper Three Runs 10-33
- Figure 10-7. Density of Macroinvertebrates in Upper Three Runs, 1985–1990 10-42
- Figure 10-8. Fish Sampling Stations for Upper Three Runs 10-55
- Figure 10-9 10-57
- Figure 11-1. Location of Beaver Dam Creek on SRS 11-3
- Figure 11-2. Flow Sampling Stations on Beaver Dam Creek 11-4
- Figure 11-3. Maximum, Mean, and Minimum Flow Measurements for Beaver Dam Creek at Station 02197326 11-5
- Figure 11-4. Water Chemistry and Quality Sampling Stations for Beaver Dam Creek 11-7
- Figure 11-5. Mean Density Total Zooplankton in Beaver Dam Creek, 1984–1985 11-21
- Figure 11-6. Mean Density Total Zooplankton in Beaver Dam Creek, 1988–1990 11-22

-
- Figure 11-7. Macroinvertebrate Sampling Stations for Beaver Dam Creek 11-23
- Figure 11-8. Fish Sampling Stations for Beaver Dam Creek 11-36
- Figure 11-9. Monthly Mean Hoopnetting Catch Per Unit Effort (No./Net Day) in Beaver Dam Creek, September 1988–February 1990 11-39
- Figure 12-1. Location of Fourmile Branch on SRS 12-3
- Figure 12-2. Flow Measurement Sampling Stations for Fourmile Branch 12-4
- Figure 12-3. Maximum, Mean, and Minimum Flow Measurements at Station XX 12-5
- Figure 12-4. Maximum, Mean, and Minimum Flow Measurements at Station XX 12-5
- Figure 12-5. Water-Quality Monitoring Sampling Stations on Fourmile Branch 12-7
- Figure 12-6. Mean Density of Total Zooplankton in Fourmile Branch 12-21
- Figure 12-7. Location of the Fourmile Branch Macroinvertebrates Sampling Station 12-23
- Figure 12-8. Macroinvertebrate Taxa richness in Fourmile Branch Following C-Reactor Shutdown 12-28
- Figure 12-9. Total Macroinvertebrate Mean Density (no./m²) in Fourmile Branch Following C-Reactor Shutdown 12-28
- Figure 12-10. Electrofishing, Fike Net, and Swamp Sampling Stations on Fourmile Branch 12-37
- Figure 12-11. Variability in the Daily Mean Number of Species and Individuals Entering Fourmile Branch on Different Reactor Cycles, 1983–1985 12-38
- Figure 12-12. Overall Percentage Composition of the Fish Assemblage Caught in the Fyke Nets in Fourmile Branch (Source: Aho et al. 1986) 12-39
- Figure 12-13. Average Linkage Cluster Analysis of the Fish Assemblage structure from Collections from 12 Sites during 3 Seasons in the Savannah River Swamp System (Source: Aho et al. 1986) 12-41
- Figure 12-14. Average Ichthyoplankton Density and Water Temperature at Four Sampling Stations along Fourmile Branch 12-47
- Figure 12-15. Monthly Mean Water Temperature and Ichthyoplankton Density at
-

- Each Sampling Site in Fourmile Branch (February–July 1985) 12-48
- Figure 12-16. Total Ichthyoplankton Densities at Fourmile Branch Locations During the 1984 and 1985 Sampling programs (Paller et al. 1986) 12-49
- Figure 12-17. Seasonal Changes of Total Ichthyoplankton Density at Each Station 12-51
- Figure 12-18. Mean Electrofishing Catch per Unit Effort at Sample Stations in Four-mile Branch 12-54
- Figure 13-1. Location of Pen Branch on SRS 13-3
- Figure 13-2. Flow Measurement Sampling Stations for Pen Branch 13-4
- Figure 13-4. Maximum, Mean, and Minimum Flow for Pen Branch at Station 02197348 13-5
- Figure 13-3. Maximum, Mean, and Minimum Flow for Pen Branch at Station 021973471 13-5
- Figure 13-5. Water Chemistry and Quality Sampling Stations for Pen Branch 13-7
- Figure 13-6. Mean Density of Total Zooplankton in Pen Branch 13-23
- Figure 13-7. Macroinvertebrate Sampling Stations for Pen Branch 13-25
- Figure 13-8. Fish Sampling Stations for Pen Branch 13-41
- Figure 14-1. Location of L Lake on SRS 14-3
- Figure 14-2. Location of Steel Creek on SRS 14-5
- Figure 14-4. Maximum, Mean, and Minimum Flow for Steel Creek 14-7
- Figure 14-3. Flow Measurement Sampling Stations for Steel Creek 14-7
- Figure 14-5. Water Quality Monitoring Stations for L Lake 14-9
- Figure 14-6. Water Quality Monitoring Stations for Steel Creek 14-14
- Figure 14-7. Algae Sampling Stations for L Lake 14-27
- Figure 14-9. Mean Phytoplankton Biovolume in the Pelagic Zone of Regions 4–8 in L Lake (January 1986–December 1987) (Source: Gladden et al. 1988) 14-29

- Figure 14-8. L-Lake Reactor and Monitoring History 14-29
- Figure 14-11. Mean Integrated Primary Productivity ($\pm$ SD) in L Lake 14-30
- Figure 14-10. Mean Algae Species Richness ($\pm$ SD) in L Lake 14-30
- Figure 14-13. Percent Abundance of Blue-Greens, Greens, and Diatoms in L Lake 14-31
- Figure 14-12. Mean Integrated Chlorophyll a ($\pm$ SD) in the Mixed Layer of L Lake 14-31
- Figure 14-14. Mean Total Periphyton Densities (organisms/mm²) on Periphytometer Slides from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-43
- Figure 14-15. Mean Periphyton Primary Productivity Per Hour (mg C/m²/h) from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-43
- Figure 14-17. Mean Periphyton Chlorophyll a (mg C/m²/h) in sediment Cores from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-44
- Figure 14-16. Mean Periphyton Primary Productivity Per Unit of Light (mg C/m²/E) from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-44
- Figure 14-18. Mean Periphyton Dry Mass (mg C/m²/E) on Periphytometer Slides from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-45
- Figure 14-19. Mean densities of Cyanophyta (organisms/mm²) on Periphytometer Slides from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-45
- Figure 14-20. Mean Biovolumes of Cyanophyta (μ m³ x 10³/mm²) from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989) 14-46
- Figure 14-21. Periphyton Sampling Stations for Steel Creek 14-52
- Figure 14-22. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Corridor Stations (January 1986–December 1989) 14-53
- Figure 14-23. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Marsh Stations (January 1986–December 1989) 14-54

- Figure 14-25. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Channel Stations (January 1986–December 1989) 14-55
- Figure 14-24. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Swamp Stations (January 1986–December 1989) 14-55
- Figure 14-26. Zooplankton in L Lake 14-77
- Figure 14-27. Zooplankton in L Lake 14-78
- Figure 14-28. Zooplankton in L Lake 14-78
- Figure 14-29. Zooplankton Sampling Stations in Steel Creek 14-80
- Figure 14-30. Zooplankton in Steel Creek 14-81
- Figure 14-31. Zooplankton in Steel Creek 14-82
- Figure 14-32. Zooplankton in Steel Creek 14-82
- Figure 14-33. Zooplankton in Steel Creek 14-83
- Figure 14-34. Zooplankton in Steel Creek 14-83
- Figure 14-35. Macroinvertebrate Sampling Stations for L Lake 14-85
- Figure 14-36. Macroinvertebrate Sampling Stations for Steel Creek 14-89
- Figure 14-37. Fish Sampling Stations for L Lake 14-97
- Figure 14-38. Mean Electrofishing Catch Rates (Logarithmically Transformed) of Five Species of Fish that Colonized L Lake, But Then Declined (January 1986–December 1988) 14-101
- Figure 14-39. Mean Fish Densities (no./1000 m³) in Regions 4–8 of L Lake During 1986 as Indicated by Plankton Net Tows 14-102
- Figure 14-40. Mean Electrofishing Catch Rates (Logarithmically Transformed) of Three Species of Fish that Persisted After Entering L Lake (January 1986–December 1988) 14-102
- Figure 14-41. Mean Annual Catch Per Unit Effort from Electrofishing Transects in L Lake 14-104
- Figure 15-1. Location of Par Pond on SRS 15-3
- Figure 15-2. Location of Lower Three Runs on SRS 15-5

Figure 15-3.	Flow Sampling Stations on Lower Three Runs	15-6
Figure 15-5.	Maximum, Mean, and Minimum Flows for Upper Three Runs at Station 02197400	15-7
Figure 15-4.	Maximum, Mean, and Minimum Flows for Upper Three Runs at Station 02197380	15-7
Figure 15-6.	Location Map of Par Pond	15-9
Figure 15-7.	Water Chemistry and Quality Sampling Stations for Lower Three Runs	15-19
Figure 15-8.	Location Map of Par Pond	15-40
Figure 15-9.	Mean Density of Protozoa in Par Pond	15-40
Figure 15-10.	Mean Density of Rotifera in Par Pond	15-41
Figure 15-11.	Mean Density of Cladocera in Par Pond	15-41
Figure 15-12.	Mean Density of Copepoda in Par Pond	15-42
Figure 15-13.	Macroinvertebrate Sampling Stations for Par Pond	15-45
Figure 15-14.	Macroinvertebrate Sampling Stations for Lower Three Runs	15-50
Figure 15-15.	Fish Sampling Stations for Par Pond	15-65
Figure 15-16.	Fish Sampling Stations for Lower Three Runs	15-80
Figure 16-1.	Map of the Savannah River	16-3
Figure 16-3.	Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197320	16-7
Figure 16-2.	Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197000	16-7
Figure 16-5.	Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197500	16-8
Figure 16-4.	Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197500	16-8
Figure 16-6.	Water Quality Sampling Stations for the Savannah River	16-9
Figure 16-7.	Algae Sampling Stations for the Savannah River	16-19

- Figure 16-8. A Comparison of ANSP Survey Results from 1985 through 1990 Showing No Change in the Overall Water Quality of the Savannah River Over the Period 16-20
- Figure 16-9 16-20
- Figure 17-1. Location of Lakes in the Regional Lakes Study 17-5
- Figure 17-2. Means and Standard Errors of Temperature in September 1988 and 1989 17-10
- Figure 17-3. Means and Standard Errors of pH in September 1988 and 1989 17-10
- Figure 17-4. Means and Standard Errors of Dissolved Oxygen (DO) in September 1988 and 1989 17-11
- Figure 17-5. Means and Standard Errors of Alkalinity in September 1988 and 1989 17-14
- Figure 17-6. Means and Standard Errors of Total Phosphorus in September 1988 and 1989 17-14
- Figure 17-7. Means and Standard Errors of Nitrate and Nitrite in September 1988 and 1989 17-15
- Figure 17-8. Means and Standard Errors of Ammonia in September 1988 and 1989 17-15
- Figure 17-9. Ranking of the Ten Reservoirs According to Three EPA Trophic Indicators During 1988 17-18
- Figure 17-10. Ranking of the Ten Reservoirs According to Three EPA Trophic Indicators During 1989 17-19
- Figure 17-11. Relationship Between Secchi Disk Depth and Chlorophyll a in the Ten Reservoirs During 1988 and 1989 17-20
- Figure 17-12. Relationship Between Log 10 of Chlorophyll a versus the Log 10 of Total Phosphorus in the Ten Reservoirs During 1988 and 1989 17-20
- Figure 18-1. Comparison of Freshwater Angler Relative Fishing Effort and Fish Harvest by Species (Source: Mackey et al. 1983) 18-8
- Figure 18-2. Comparison of Estuarine Angler Relative Fishing Effort and Fish Harvest by Species (Source: Mackey et al. 1983) 18-8
- Figure 18-3. Relative Abundance of Fish Taxa in Creel, Electrofishing, and Hoop-

	Net Collections	18-9
Figure 20-1.	Location of Rare and Threatened Plant Species on the Savannah River Site	20-6
Figure 21-1.	Shortnose Sturgeon (<i>Acipenser brevirostrum</i>)	21-5
Figure 21-2.	American Alligator (<i>Alligator mississippiensis</i>)	21-10
Figure 21-3.	Major Aquatic Habitats at SRS	21-11
Figure 21-4.	Par Pond System	21-12
Figure 21-5.	Size and Sex Structure of Alligators Captured in Par Pond, 1986-1988 (Source: Brandt 1989)	21-14
Figure 21-6.	Size Distribution of Alligators in Par Pond, 1974-1976 and 1986-1988 (Source: Brandt 1989)	21-14
Figure 21-7.	Alligator Population Growth in Par Pond 1972-1988 (Source: Brandt 1989)	21-15
Figure 21-8.	Size Structure of the Beaver Dam Creek Alligator Population as Assessed by Aerial Surveys in 1984 (Source: Seigel 1989)	21-16
Figure 21-9.	Bald Eagle (<i>Haliaeetus leucocephalus</i>)	21-20
Figure 21-10.	Ventral Appearance of Soaring Bald Eagles	21-20
Figure 21-11.	Number of Winter Observations of Bald Eagles During the SRS Christmas Bird Count Surveys on Par Pond and L Lake and the SREL Waterfowl Aerial Surveys	21-22
Figure 21-12.	Location of Bald Eagle Sightings on SRS (Source: Mayer et al. 1986)	21-24
Figure 21-13.	Percentage of Adult and Immature Bald Eagles Observed Seasonally on SRS Based on a Total of 197 Birds Observed Between 1959 and 1992	21-25
Figure 21-14.	Locations of the Two Bald Eagle Nests on SRS	21-26
Figure 21-15.	Golden Eagle (<i>Aquila chrysaetos</i>)	21-28
Figure 21-16.	Red-Cockaded Woodpecker (<i>Picoides borealis</i>)	21-30
Figure 21-17.	Location of Red-Cockaded Woodpecker Colonies on SRS (As of June 1993)	21-32

- Figure 21-18. Wood Stork (*Mycteria americana*) 21-33
- Figure 21-19. Location of Kathwood Lake and the Birdsville Wood Stork Colony 21-34
- Figure 21-20. Number of Wood Storks in the Birdsville Colony, 1984-1989 (Source: Coulter 1993) 21-36
- Figure 21-21. The Six Areas of the Savannah River Swamp that were Monitored for Foraging Wood Storks 21-41
- Figure 21-22. Percentage of Wood Storks Observed in the SRS Swamps from 1983-1988 Under Different Stream Flow Classes 21-45
- Figure 21-23. Number of Wood Storks Observed in the Fourmile Branch Delta and Sloughs with C Reactor Operating (Prior to June 28, 1985) and after C Reactor Shutdown (After June 28, 1985 through Summer 1986, and During Summer 1987 and 1988). 21-46
- Figure 21-24. Number of Wood Storks Observed in the Steel Creek Delta Prior to L-Reactor Restart (1983-1985) and After L-Reactor Restart (1986-1988) Versus Flow Classes 21-48
- Figure 21-25. Kathwood Lake and Hollow Creek 21-49
- Figure 21-26. Longitudinal Section Through Kathwood Lake Showing General Features of the Subimpoundments and Water Levels 21-50
- Figure 21-27. Maximum Number of Wood Storks Observed at Kathwood Lake During Ground Surveys, 1986-1992 21-51

List of Tables

Table 1-1.	Listing of Soil Mapping Units on SkS (Source: Rogers 1990)	1-8
Table 2-1.	Summary of SRFS Timber Management Plan, FY 78–FY 91 (Source: SRFS 1992)	2-27
Table 2-2.	Summary of Total Acres Planted and Seeded, FY 53–FY 91 (Source: SRFS 1992)	2-28
Table 2-3.	Planting Summary (Gross Seedlings Planted by Species, Thousands), FY 53–FY 91 (Source: SRFS 1992)	2-28
Table 2-4.	Summary of Standing Timber Value, FY 62–FY 91 (Source: SRFS 1992)	2-29
Table 2-5.	Summary of Type and Value of Timber Sold, FY 55–FY 91 (Source: SRFS 1992)	2-29
Table 2-6.	Summary of Type and Value of Timber Cut, FY 55–FY 91 (Source: SRFS 1992)	2-30
Table 3-1.	Amphibians and Reptiles of the SRS ^a (Source: Gibbons and Semlitsch 1991)	3-6
Table 3-2.	Reptiles and Amphibians Occurring on Sun Bay Study Area or Rainbow Bay Study Area	3-9
Table 3-3.	Direction of Movement of All Species of Amphibians and Reptiles Captured (original and recaptured) in Drift Fence and Pitfall Traps at Rainbow Bay and Sun Bay on SRS from April 1, 1981 - March 31, 1982 (Source: Vitt et al. 1982)	3-11
Table 3-4.	Direction of Movement of All Species of Amphibians and Reptiles Captured (original and recaptured) in Drift Fence and Pitfall Traps at Peripheral Areas Associated with Rainbow Bay on the Savannah River Site in South Carolina for One Year (April 1, 1981 - March 31, 1982) (Source: Vitt et al. 1982)	3-13
Table 3-5.	Number of Adult Amphibians Captured Entering the Refuge Ponds During Their Breeding Season from FY-1984 to FY-1988 (total for all four ponds) (Source: Scott et al. 1988)	3-14
Table 3-6.	Number of Amphibian Juveniles Produced at DWPF Refuge Ponds During FY-1985 to FY-1988 (Source: Scott et al. 1988)	3-15

Table 3-7.	Amphibians and Reptiles Found - in the Steel Creek Study Area Between September 1, 1981 and August 20, 1982 (Smith et al. 1982)	3-16
Table 3-8.	Total Number of Each Reptile and Amphibian Species Collected from Sampling Locations in Steel Creek (January 1986 - December 1987) (Patterson and Giffin 1988)	3-18
Table 3-9.	Total Number of Each Reptile and Amphibian Species Collected from Regions 4-8 of L Lake (January 1986 - December 1987). Animals identified to genus were not included in the total count if a species within that genus was identified. (Source: Patterson and Giffin 1988)	3-19
Table 3-10.	Reptiles and Amphibians of Par Pond (Source: Wilde 1985)	3-20
Table 3-11.	Birds of SRS	3-23
Table 3-12.	A Composite List of All Birds Observed in the Rainbow Bay Study Area from September 1, 1978 to March 31, 1980 (SREL 1980)	3-29
Table 3-13.	A Composite List of All Birds Observed in the Sun Bay Study Area from March 1, 1980 to March 31, 1980 (SREL 1980)	3-30
Table 3-14.	Bird Species Recorded in the Vicinity of Steel Creek (Source: Smith et al. 1981)	3-31
Table 3-15.	Locations on the SRS Where Waterfowl Have Been Observed Between 1952 and 1985 (Source: Mayer et al. 1986)	3-32
Table 3-16.	Number of Waterfowl and Water Birds Observed in Regions 4-8 of L Lake During migratory Season 1 (January - March 1986), Season 2 (October 1986-March 1987), and Season 3 (October-December 1987) (Source: Patterson and Giffin 1988)	3-35
Table 3-17.	Waterfowl and Associated Avian Species Observed on L Lake (January - December 1987) (Source: Patterson and Giffin 1988)	3-36
Table 3-18.	Mammals of the Savannah River Site Phylogenetic Listing ^a (Source: Cothran et al. 1991)	3-40
Table 3-19.	Mammal Species Found in the Five Major Habitats at SRS (Source: Cothran et al. 1991) ^a	3-42
Table 3-20.	Game, Edible, and Fur-Bearing Mammals of the SRS (Source: Cothran et al. 1991)	3-43

Table 3-21.	Mammals of Steel Creek Area (Source: Smith et al. 1981)	3-43
Table 3-22.	Species, Number of Individuals, and Rank of Small Mammals Caught in Drift Fences at the Rainbow Bay and Sun Bay Study Areas (Source: SREL 1980) ^a	3-44
Table 3-23.	Species and Number of Bats Collected at or Near the Rainbow Bay and Sun Bay Study Areas During Two Sampling Periods, June 26 - July 1, 1979 and August 20-24, 1979 (SREL 1980)	3-44
Table 3-24.	Large Mammal Species on the Rainbow Bay and Sun Bay Study Areas (Source: SREL 1980) ^a	3-45
Table 3-25.	Species, Number of Individuals, and Rank of Small Mammals Trapped Each Season for 10-day Periods at the Sun Bay Study Area (Source: SREL 1980) ^a	3-45
Table 3-26.	Species and Number of Individuals of Small Mammals Trapped in Four Habitats for 10-day Periods During Three Seasons at the Sun Bay Study Area (Source: SREL 1980) ^a	3-45
Table 3-27.	Summary of Numbers of Wild Turkeys Trapped and Removed by the SRS Wild Turkey Trapping Program (1977 to 1993) (Source: Caudell 1993)	3-47
Table 3-28.	Number of Furbearers Captured-Yearly During the Annual Furbearers Census (Source: Cothran et al. 1991)	3-48
Table 3-29.	Annual Number of Beavers Trapped on the SRS (Source: SRFS 1993)	3-49
Table 3-30.	Annual SRS White-tailed Deer Population Estimate and Harvest Data (Sources: Novak et al. 1991; WSRC 1992; Cothran et al. 1991)	3-50
Table 3-31.	Annual SRS Feral Swine Harvest Data (Source: Savereno and Findley 1989, and SRFS 1993)	3-51
Table 4-1.	Estimate of SRS Wetlands Derived from Landcover/Landuse Geographic Information System (GIS) Data Base	4-6
Table 4-2.	Estimates of Pre-SRS Wetlands Derived from 1943 and 1951 Black-and-White Aerial Photography of SRS (Christel-Rose 1993)	4-23
Table 5-1.	Areal Estimates of Pre-SRS Lumbering in the SRS Savannah River Swamp	5-8
Table 5-2.	Importance Values ^a of Dominant Woody Species in the SRS Savannah River Swamps (Gladden et al. 1985)	5-12

Table 5-3.	Area of Wetland Classes Found Within the SRS Savannah River Swamp, March 31, 1981 (Jensen et al. 1984a) ^a	5-16
Table 5-4.	Wetland Classification of the Steel Creek Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)	5-16
Table 5-5.	Wetland Classification of the Pen Branch Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)	5-17
Table 5-6.	Wetland Classification of the Fourmile Creek Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)	5-17
Table 5-7.	Wetland Classification of the Beaver Dam Creek Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)	5-17
Table 5-8.	Aerial Photography Used to Document Wetlands Change	5-20
Table 5-9.	Estimated Impacted Wetland Areas in SRS Thermal Creeks and Savannah River Swamp, 1985	5-21
Table 5-10.	Estimated Impacts and Discharge Conditions to Beaver Dam Creek from D-Area Discharges, 1952–1991	5-25
Table 5-11.	Wetlands Change in the Upper Beaver Dam Creek Area from 1981–1985 Based on Aircraft MSS Data	5-27
Table 5-12.	Wetlands Change in the Lower Beaver Dam Creek Area from 1981–1985 Based on Aircraft MSS Data	5-27
Table 5-13.	Estimated Impacts and Discharge Conditions to Fourmile Branch from Reactor Discharges, 1955–1991	5-29
Table 5-14.	Estimated Impacts and Discharge Conditions to Pen Branch from Reactor Discharges, 1954–1992	5-36
Table 5-15.	Wetland Classification Scheme for the Pen Branch “Tail” Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data	5-41
Table 5-16.	Pen Branch “Tail” Wetlands Change Detection Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data	5-41
Table 5-17.	Estimated Impacts and Discharge Conditions to Steel Creek from Reactor Discharges, 1954–1991	5-47
Table 5-18.	Steel Creek Delta Wetland Areas on March 31, 1981, and April 26, 1985, Based on Aircraft MSS Data	5-50

Table 5-19.	Steel Creek Delta Wetland Areas on April 26, 1985, Based on Aircraft MSS Data with Improved Discrimination of Scrub-Shrub and Deciduous Swamp Forest	5-51
Table 5-20.	Steel Creek Delta Wetlands Change Based on March 1981 and April 1985 Aircraft MSS Data	5-51
Table 5-21.	Changes in Area of Wetland Vegetation Classes in Steel Creek Corridor from L-Lake Dam to Steel Creek Delta. Estimates of Areas Covered (in hectares) by Wetland Vegetation Types in Steel Creek Corridor in 1985, 1986, and 1987	5-52
Table 5-22.	Changes in Area of Wetland Vegetation Classes in Steel Creek Delta in 1985, 1986, and 1987	5-53
Table 6-1.	Dates of SPOT HRV Data, Supplementary Vertical Aerial Photography, and Airborne Scanner Data Used for Classification of Pen Branch Delta Wetlands	6-6
Table 6-2.	Major Wetland Cover Types based on Classification of SPOT HRV Date for the Pen Branch Delta, Spring 1987 through 1992 (units in hectares) (Mackey 1993)	6-8
Table 6-3.	Pen Branch Delta Acreages 1987-1991 (Blohm 1993)	6-18
Table 6-4.	Pen Branch Corridor Acreages - Excluding Buffer - 1987-1991	6-18
Table 7-1.	Total Number of Plant Taxa Identified at Each Station, January 1986–December 1991 (Westbury 1992)	7-5
Table 7-2.	Species Planted at L Lake Between January and August 1987 (Kroeger 1990)	7-9
Table 8-1.	Plant Species Observed in Par Pond Wetlands in a July 1984 Survey	8-5
Table 8-2.	Par Pond Macrophyte Species	8-12
Table 8-3.	Vegetation Cover, Par Pond Lake Bed, August 1992a	8-19
Table 9-1.	Cation proportions for various southeastern coastal plain surface waters (softwater, lentic systems). (Sources: ¹ Tilly 1975, ² Daniel 1981, ³ Auble 1984, ⁴ Dierberg and Brezonik 1984, ⁵ Lichtler and Walker 1979)	9-7
Table 9-2.	Detailed chemical analysis, including anion/cation charge balance, for surface waters in six Carolina bays sampled as part of a regional survey in January 1988.a (Source: Schalles, et al., 1989)	9-9

Table 9-3.	Density of Certain Insect Orders, Oligochaetes, and Isopods (Number of Individuals/20 cm ²) Determined by Artificial Substrate Sampling at Rainbow Bay (Site 189) and Sun Bay (Site 45) (Source: Savannah River Ecology Laboratory 1980)	9-17
Table 9-4.	Use of Carolina Bay Habitats by Small Vertebrates ^a (Source: Gibbons and Semlitsch 1982).	9-21
Table 10-1.	Flow Summary for Upper Three Runs	10-4
Table 10-2.	Upper Three Runs Field Data	10-9
Table 10-3.	Upper Three Runs Physical Characteristics and General Chemistry	10-11
Table 10-4.	Upper Three Runs Major Anions	10-12
Table 10-5.	Upper Three Runs Major Cations (Total)	10-13
Table 10-6.	Upper Three Runs Nutrients	10-15
Table 10-7.	Upper Three Runs Trace Elements (Total)	10-16
Table 10-8.	Water Quality Parameters for Biological and Chemical Assessment of M-Area Discharge	10-18
Table 10-9.	Water Quality Parameters for Biological and Chemical Assessment of M-Area Discharge on Tims Branch (September 1988–September 1990)	10-22
Table 10-10.	Water Quality Parameters for Stream Assessments for F/H Area ETF Effluent Discharge (July 1987 - February 1990)	10-23
Table 10-11.	Summary Statistics for Macroinvertebrate Data from Hester Dendy Multiplate Samplers, Upper Three Runs, October 1984–September 1985	10-35
Table 10-12.	Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987–July 1991	10-36
Table 10-13.	Mean Number of Taxa Collected During Each Sampling Period from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987–July 1991	10-37
Table 10-14.	Mean Number of Taxa Collected Per Hester-Dendy Multiplate Sampler, Upper Three Runs, July 1987–July 1991	10-37

Table 10-15.	Mean Density of Macroinvertebrates (No./m ²) Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991	10-38
Table 10-16.	Mean Biomass (g/m ²) of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991	10-38
Table 10-17.	Shannon-Weaver Diversity of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991	10-38
Table 10-18.	Summary Statistics for Macroinvertebrate Data from Hester-Dendy Multiplate Samplers, Tim's Branch, 1985-1990	10-39
Table 10-19.	Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates, Tim's Branch, June 1985-December 1986	10-40
Table 10-20.	Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates, Tim's Branch, September 1988-March 1990	10-41
Table 10-21.	Macroinvertebrate Taxa Collected from Hester Dendy Multiplate Samplers and by Qualitative Sampling, Upper Three Runs, July 1987-July 1991	10-43
Table 10-22.	Macroinvertebrate Taxa Collected from Hester-Dendy Multiplate Samplers and by Qualitative Sampling, Tim's Branch, 1985-1986	10-50
Table 10-23.	Number and Percent Composition of Ichthyoplankton Collected from Upper Three Runs, March 14-June 3, 1984	10-56
Table 10-24.	Number and Percent Composition of Ichthyoplankton Collected from Upper Three Runs, February-July 1985.	10-56
Table 10-25.	Fishes Collected by Electrofishing from Sample Stations in Upper Three Runs, Hollow Creek, and Several Tributaries.	10-59
Table 11-1.	Flow Summary for Beaver Dam Creek	11-5
Table 11-2.	Water Quality Measurements in Beaver Dam Creek (1987-1991)	11-9
Table 11-3.	Beaver Dam Creek Field Data	11-9
Table 11-4.	Beaver Dam Creek Physical Characteristics and General Chemistry	11-10

Table 11-5.	Beaver Dam Creek Major Anions	11-11
Table 11-6.	Beaver Dam Creek Major Cations (Total)	11-12
Table 11-7.	Beaver Dam Creek Nutrients	11-13
Table 11-8.	Beaver Dam Creek Trace Elements (Total)	11-14
Table 11-9.	Mean Values for Water Chemistry Parameters at Stations Sampled in Beaver Dam Creek (Source: Specht et al. 1990)	11-16
Table 11-10.	The Annual Mean, Number of Reaches Mapped During Year (M) and Standard Deviation (s) October 1984–September 1985 (Source: Firth et al. 1986)	11-20
Table 11-11.	Total Number of Macroinvertebrate Taxa Collected on Multiplate Samplers in Beaver Dam Creek (October 1984–September 1985, September 1988–February 1990 (Source: Specht et al. 1990)	11-24
Table 11-12.	Mean Density and Biomass of Macroinvertebrates Collected on Multiplate Samples in Beaver Dam Creek (October 1984–September 1985, September 1988–February 1990) (Source: Specht et al. 1990)	11-25
Table 11-13.	Mean Relative Abundance (Percent Composition) of Higher Order Taxonomic Groups of Macroinvertebrates from Quantitative Sampling in Beaver Dam Creek. September 1988–February 1990 (Source: Specht et al. 1990)	11-27
Table 11-14.	Descriptive Statistics for Total Macroinvertebrate Densities (Organisms/m ²) and Mean Number of Taxa from Quantitative (Multiplate) Sampling in Beaver Dam Creek. September 1988–February 1990 (Source: Specht et al. 1990)	11-27
Table 11-15.	Mean Relative Abundance (Percent Composition) of Higher Order Taxonomic Groups of Macroinvertebrates Collected on Hester Dendy Multiplate Samplers. October 1984–September 1985 (Source: Specht et al. 1990)	11-28
Table 11-16.	Macroinvertebrate Taxa Found in Beaver Dam Creek, All Sampling Methods Combined. “X” Denotes Quantitative (Multiplate) Sampling and “*” Denotes Qualitative Sampling (Dip Nets and Drift) Only (September 1988–February 1990) (Source: Specht et al. 1990)	11-29
Table 11-17.	Total Number of Fish and Species Collected by Electrofishing in Beaver Dam Creek. September 1988–February 1990	11-37

- Table 11-18. Electrofishing CPUE (no./100 m) at Stations 1 - 6 in Beaver Dam Creek. September 1988–February 1990 11-38
- Table 11-19. Relative Abundance (Percent Composition) of Species Collected by Electrofishing at Stations 1–6 in Beaver Dam Creek. September 1988–February 1990 11-40
- Table 11-20. Total Number of Fish and Species Collected by Hoopnetting in Beaver Dam Creek. No Hoopnets Were Set During March and April, 1989. September 1988–February 1990 11-41
- Table 11-21. Hoopnetting CPUE (no./net day) at Stations 1-6 in Beaver Dam Creek September 1988–February 1990^a 11-42
- Table 11-22. Relative Abundance (Percent Composition) of Species Collected by Hoopnetting at Stations 1–6 in Beaver Dam Creek. September 1988–February 1990^a 11-43
- Table 11-23. Species Number and Relative Abundance (% Composition) of Fishes in Nine Southeastern Streams. Relative Abundances are Based on the Number of Individual Fish in Each Family 11-44
- Table 11-24. Total Number of Ichthyoplankton Collected from Stations 1-6 in Beaver Dam Creek February–July 1989 11-47
- Table 11-25. Monthly Ichthyoplankton Collections from Beaver Dam Creek. February–July 1989 11-47
- Table 11-26. Average Densities (Organisms/1000m³) of Ichthyoplankton Collected from stations 1–6 in Beaver Dam Creek. February–July 1989 11-48
- Table 11-27. Number and Percent Composition of Ichthyoplankton Collected from Steel Creek, Upper Three Runs, and Lower Three Runs, 1984–1985 (Source: Specht 1987) 11-48
- Table 4-28. Dominant Species^a Collected from Beaver Dam Creek by Electrofishing at Stations 2,5, and 6 During the CCWS (1983), Overwintering Study (1984–1985), and at Each station During the Specht et al. (1990) Study 11-50
- Table 11-29. Dominant Species Collected from Hoopnets at Station 6 During the CCWS Overwintering Study (1984–1985) and the Specht et al. (1990) Study 11-52

- Table 11-30. Number and Percent Composition of Ichthyoplankton Collected from Beaver Dam Creek 1984.
(Source: Specht et al. 1987) 11-53
- Table 11-31. Number and Percent Composition of Ichthyoplankton Collected from Beaver Dam Creek 1985. (Source: Specht et al. 1987) 11-54
- Table 10-1 Flow Summary for Fourmile Branch 12-5
- Table 12-2. Field Data Identified in Fourmile Branch Studies (Source: SREL 1986, SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991) 12-9
- Table 12-3. Physical Characteristics and General Chemistry Identified in Fourmile Branch Studies (Sources: SREL 1986, SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991) 12-10
- Table 12-4. Major Anions Identified in Fourmile Branch Studies (Source: SREL 1986, SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991) 12-11
- Table 12-5. Major Cations (Total) Identified in Fourmile Branch Studies (Source: (SREL 1986), SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991) 12-12
- Table 12-6. Nutrients Identified in Fourmile Branch Studies (Source: (SREL 1986), SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991) 12-13
- Table 12-7. Trace Elements (Total) Identified in Fourmile Branch Studies (Source: (SREL 1986), SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991) 12-14
- Table 12-8. Results from Seep Line Sampling Study of Fourmile Branch (Source: Haselow et al. 1990) 12-16
- Table 12-9. Periphyton Biomass (g dry wet/m²) at Two Stations in Fourmile Branch During Winter and Spring Sampling 1983–1984^a (Source: Specht 1987) 12-17
- Table 12-10. Organic Standing Crop (g AFDW/m²) at Each 1983–1984 Station (Winter and Spring 1984)^a (Source: Specht 1987) 12-17
- Table 12-11. Periphyton Biomass (g/m²) Mean, n, Standard Error, Coefficient of Variation (CV) and Minimum and Maximum Values for Each 1984–1985 Station (October 1984–September 1985) (Source: Specht 1987) 12-18

- Table 12-12. Annual Mean, N, and Standard Deviation are Presented for the Following Vegetation Parameters on a per m^2 Basis at Each Mapped 1984–1985 Station: Aquatic Vascular Plant (AVP) Area (m^2/m^2); AVP Volume (m^3/m^2); AVP Biomass (g/m^2) and AVP Percent Cover (October 1984–September 1985) (Source: Firth et al. 1986) 12-19
- Table 12-13. Locations of Macroinvertebrate Sampling Stations and Sampling Methods in Fourmile Branch. 1982-1987 12-24
- Table 12-14. Mean Number of Taxa, Density, and Biomass for Macroinvertebrates Collected on Hester Dandy Multiplate Samplers in Fourmile Branch (October 1984 – September 1985) (Source: Firth et al. 1986, O’Hop et al. 1986) 12-25
- Table 12-15. Percent Composition of Macroinvertebrate Taxa Collected on Hester Dandy Multiplate Samplers in Fourmile Branch (October 1984 – September 1985) (Source: Firth et al. 1986, O’Hop et al. 1986) 12-25
- Table 12-16. Relative Abundance (%) of Macroinvertebrate Functional Groups in Fourmile Branch (October 1984–September 1985) (Source: Firth et al. 1986, O’Hop et al. 1986) 12-26
- Table 12-17. Mean Invertebrate Density/m at Each Station in Fourmile Branch for Each Taxon Collected on Hester-Dendy Multiplate Samplers (October 1984–September 1985) 12-29
- Table 12-18. Macroinvertebrate taxa found on artificial substrates in Fourmile Branch. (June 1985–September 1987) 12-33
- Table 12-19. Fish Species Present in 4 Fourmile Branch Study Sites Within the Savannah River Swamp System (taken from Aho et al. 1986) 12-41
- Table 12-20. Two Way Table Comparing Faunal Groups and Fish Species Associations Contributing at least 5% to the Abundance of a Specific Group Within the Savannah River Swamp System. (Source: Aho et al. 1986) 12-42
- Table 12-21. Summary of the Site Characteristics for the Twelve Locations Within the Savannah River Swamp System (Source: Aho et al. 1986) 12-43
- Table 12-22. Number of Fish Collected on Six Dates During Electrofishing Collections by ECS at Fourmile Branch Near Road A-7 12-44
- Table 12-23. Fish Collected from Fourmile Branch near Road A and Road A-13.2 12-45

Table 12-24.	Fish Collected from the Fourmile Branch Delta	12-45
Table 12-25.	Number and Percent Composition of Ichthyoplankton Collected from Fourmile Branch (March 14–July 31, 1984) (Source: Paller 1985)	12-46
Table 12-26.	Number and Percent Composition of Ichthyoplankton Collected from Fourmile Branch (February–July 1985) (Source: Paller et al. 1986a)	12-48
Table 12-27.	Relative abundance (i.e., percent composition) of fish collected at six sample stations in Fourmile Branch and one sample station in the headwaters of Pen Branch. June 1990.	12-53
Table 12-28.	Mean (standard error) electrofishing catch per unit effort (CPUE expressed as number fish per 100 m) at six sample stations in Fourmile Branch and one sample station in the headwaters of Pen Branch. June 1990.	12-55
Table 13-1	Flow Summary for Pen Branch	13-5
Table 13-2.	Pen Branch Field Data	13-9
Table 13-3.	Pen Branch Physical Characteristics and General Chemistry	13-10
Table 13-4.	Pen Branch Major Anions	13-11
Table 13-5.	Pen Branch Major Cations (Total)	13-12
Table 13-6.	Pen Branch Nutrients	13-14
Table 13-7.	Pen Branch Trace Elements (Total)	13-15
Table 13-8.	Pen Branch Major Anions	13-16
Table 13-9.	Mean Number of Taxa, Density, and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in Pen Branch (October 1984–September 1985)	13-26
Table 13-10.	Percent Abundance of Major Groups of Macroinvertebrate Taxa Collected on Hester-Dendy Multiplate Samplers in Pen Branch During Reactor Operation (October 1984–September 1985)	13-27
Table 13-11.	Mean Number of Taxa, Density, and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in Pen Branch and Indian Grave Branch During Ambient Thermal Conditions (December 1988–May 1989) (Source: Enwright 1989a, 1989b, 1989c)	13-29

Table 13-12.	Percent Abundance of Major Groups of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers in Pen Branch and Indian Grave Branch During Ambient Thermal Conditions (December 1988–May 1989) (Source: Enwright 1989a, 1989b, 1989c)	13-30
Table 13-13.	Mean Invertebrate Density/number/m ² at Each Station on Pen Branch for Each Taxon Collected on Hester-Dendy Multiplate Samplers (October 1984–September 1985) (Source: Firth et al. 1986)	13-31
Table 13-14.	Mean Density (number/m ²) of Macroinvertebrates on Hester-Dendy Multiplate Samplers in Pen Branch and Indian Grave Branch During Ambient Thermal Conditions (December 1988–May 1989)	13-35
Table 13-15.	Distribution and Percent Composition of the Fish Assemblages Collected from Streams on the Savannah River Plant	13-40
Table 13-16.	Percent composition of Electrofishing Collections from Pen Branch During the recent extended outage of K-Reactor. Samples were collected monthly from November 1988–March 1989.	13-43
Table 14-1.	Flow Summary for Steel Creek	14-6
Table 14-2.	Water Quality Data (range of values) for L Lake (November 1985–December 1991)	14-12
Table 14-3.	Steel Creek - Field Data	14-16
Table 14-4.	Steel Creek - Physical Characteristics and General Chemistry	14-17
Table 14-5.	Steel Creek - Major Anions	14-19
Table 14-6.	Steel Creek - Major Cations (Total)	14-20
Table 14-7.	Steel Creek - Nutrients	14-21
Table 14-8.	Steel Creek - Trace Elements (Total)	14-22
Table 14-9.	Water Quality Measurements in Steel Creek (1987–1991)	14-25
Table 14-10.	Water Quality Data (range of values) for Steel Creek (November 1985–December 1991)	14-25
Table 14-11.	Phytoplankton Taxa Collected from L-Lake Pelagic Zone Sampling Stations. January 1986–December 1989.	14-32
Table 14-12.	Phytoplankton collected from Regions 5 and 7 in L Lake and in Par Pond, January–December 1990 and 1991.	14-38

- Table 14-13. Numerically Important Periphyton Taxa in Sediment Cores from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989. 14-46
- Table 14-14. Volumetrically Important Periphyton Taxa in Sediment Cores from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989. 14-48
- Table 14-15. Numerically Important Periphyton Taxa on Periphytometer Slides from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989. 14-49
- Table 14-16. Volumetrically Important Periphyton Taxa on Periphytometer Slides from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989. 14-50
- Table 14-17. Annual Means for Periphyton Chlorophyll *a* Content (mg/m^2) Accumulated on Glass Slides Incubated in Steel Creek and Meyer's Branch. Minimum and Maximum Values are Presented in Appendix Table 1. January 1986–December 1991. 14-56
- Table 14-18. Annual Means for Periphyton Ash-free Dry Mass (g/m^2) Accumulated on Glass Slides Incubated in Steel Creek and Meyer's Branch. Minimum and Maximum Values are Presented in Appendix Table 2. January 1986–December 1991. 14-57
- Table 14-19. Periphyton Community Composition on Glass Slides Incubated in Steel Creek and Meyer's Branch. Relative Abundance of Major Algal Divisions. January 1986–December 1991. 14-57
- Table 14-20. Seasonal Common Taxa (> 5% Abundance Listed in Order of Importance) of Periphytic Algae Growing on Glass Slides. January 1986–December 1989. 14-59
- Table 14-21. Number of Macrophyte Taxa at 4 Steel Creek and 2 Meyers Branch Sampling Stations (November 1983–May 1984) (Source: Gladden et al. 1985) 14-69
- Table 14-22. Macrophyte Standing Crop ($\text{g AFDW}/\text{m}^2$)* at Steel Creek Swamp 1983-1984 Stations During Winter, Spring, and Summer 1984. Mean, Standard Deviations (s), Coefficient of Variation (CV), and Number of Samples (n) are Given for Samples Collected January–September 1984. (Source: Kondratieff and Kondratieff 1985a, 1985b) 14-70

- Table 4-23. Biomass (g/m^2) and Percent of Total Biomass Contributed by Macrophyte Genera Collected at Steel Creek Stations 33 and 35 During Winter, Spring, and Summer Sampling (November 1983–May 1984) (Source: Kondratieff and Kondratieff 1985a) 14-70
- Table 14-24. Annual Mean N, and Standard Deviation (s) are Presented for the Following Vegetation Parameters on a per m^2 Basis at Each Mapped 1984–1985 Station: Aquatic Vascular Plant (AVP) Area (m^2/m^2); AVP Volume (m^3/m^2); AVP Biomass (g/m^2) and AVP Percent Cover (October 1984–September 1985) (Source: Firth et al. 1986) 14-71
- Table 14-25. The Annual Mean, Number of Reaches Mapped During Year (N) and Standard Deviation (s) are Given for the Following Plant Taxa Parameters: Area (m^2/m^2); Volume (m^3/m^2); Biomass (g/m^2); Percent Cover (percent of mapped area covered by species in question) (October 1984–September 1985) (Source: Firth et al. 1986) 14-71
- Table 14-26. Mean Total Vegetation (%) Cover at Selected Steel Creek Stations During Summer Quarter. Summary Statistics for 1991 are in Appendix Table 12. July–September 1985–1991. 14-73
- Table 14-27. Summary Statistics for Total Vegetation Percent Cover at Selected Steel Creek Stations in Summer 1991. 14-73
- Table 14-28. Mean Percent Cover (%) of Common Aquatic Macrophyte Taxa ($\geq 1.0\%$ cover) at Selected Steel Creek Stations. Summary Statistics for 1991 are in Appendix Table 13. July–September 1985–1991. 14-74
- Table 14-29. Summary statistics for percent cover (%) of aquatic macrophyte taxa which have been common at selected Steel Creek stations in summer 1991. 14-75
- Table 14-30. Meroplankton Densities (Number/1000 m^3) in L Lake, 1986–1991 14-86
- Table 14-31. Meroplankton Biomass ($\text{g}/1000 \text{ m}^3$) in L Lake, 1986–1991 14-86
- Table 14-32. Monthly Mean Number of Macroinvertebrate Taxa Collected from Ponar Dredge Samples in L Lake, 1986–1991 14-87
- Table 14-33. Benthic Macroinvertebrate Density (No./ m^2) in L Lake, 1986–1991 14-87
- Table 14-34. Benthic Macroinvertebrate Biomass (g/m^2) in L Lake, 1986–1991 14-88

- Table 14-35. Mean Number of Macroinvertebrate Taxa/Station Collected from Hester-Dendy Multiplate Samplers in Steel Creek and Meyer's Branch, 1986–1991 14-92
- Table 14-36. Relative Abundance of Macroinvertebrate Groups in Steel Creek, 1986–1991 14-92
- Table 14-37. Mean Annual Macroinvertebrate Densities (No./m²) on Hester-Dendy Multiplate Samplers in Steel Creek and Meyer's Branch, 1986–1991 14-95
- Table 14-38. Mean Annual Macroinvertebrate Biomass (g/m²) on Hester-Dendy Multiplate Samplers in Steel Creek and Meyer's Branch, 1986–1991 14-96
- Table 14-39. Mean Annual Density (No./1000 m³) of Macroinvertebrate Drift in Steel Creek and Meyer's Branch, 1986–1991 14-96
- Table 14-40. Electrofishing Catch Rates Over Time in L Lake. Only Dominant Taxa and Catch Rates > 0.1 Fish/Minute are Shown. 14-99
- Table 41. Table 1. Relative Abundance of Ichthyoplankton in Steel Creek, 1983–1985 (Paller et al. 1985). 14-109
- Table 42. Table 2. Fish Collected During the Night in Open Channel, Channel/Weed Bed Interface and Weed Bed Habitats. February–July 1985. 14-110
- Table 43. Table 4.4 Distribution and Percent Composition of the Fish Assemblages Collected from Streams on the Savannah River Plant 14-111
- Table 44. Table 4. Mean Electrofishing Catch Per Unit Effort (CPUE; No./100 m) and Relative Abundance (% Composition) of Common Species in an Open-Canopy Marsh Habitat in the Steel Creek Swamp. Samples were collected from between the islands before and after the impoundment of L Lake and restart of L-Reactor. 1983–1988. 14-112
- Table 45. Table 5. Mean Electrofishing Catch Per Unit Effort (CPUE; No./100 m) and Relative Abundance (% Composition) of Common Species in a Closed-Canopy Swamp Habitat in the Steel Creek Swamp before and after the impoundment of L Lake and restart of L-Reactor. 1983–1988. 14-113
- Table 46. Table 7. Mean Electrofishing Catch Per Unit Effort (CPUE; No./100 m) at a Sample Station in the Mouth of Steel Creek Before (1983, 1984, and 1985) and after (1986, 1987, and 1988) the Impoundment of L Lake and Restart of L-Reactor. 1983–1988. 14-114
- Table 15-1. Flow Summary for Lower Three Runs 15-6

Table 15-2.	Lower Three Runs/Par Pond Field Data	15-11
Table 15-3.	Lake/Steel Creek Biological Monitoring Program (November 1985–December 1991) (Source: Kretchmer and Chimney 1992)	15-12
Table 15-4.	Lower Three Runs/Par Pond - Physical Characteristics and General Chemistry	15-13
Table 15-5.	Lower Three Runs/Par Pond - Major Anions	15-14
Table 15-6.	Lower Three Runs/Par Pond - Major Cations (Total)	15-15
Table 15-7.	Lower Three Runs/Par Pond - Nutrients	15-16
Table 15-8.	Lower Three Runs/Par Pond - Trace Elements (Total)	15-18
Table 15-9.	Phytoplankton Taxa Collected from Par Pond During Monthly Sampling in 1984-1985 and Quarterly Sampling in 1978	15-25
Table 15-10.	Principal Periphyton Species ^a Collected from Par Pond ^b (Wilde 1985)	15-33
Table 15-11.	The Annual Mean, Number of Reaches Mapped During Year (M) and Standard Deviation (s), October 1984–September 1985 (Source: Firth et al. 1986)	15-37
Table 15-12.	Percent Composition (relative abundance) of Major Macroinvertebrate Meroplankton Taxa Collected in Par Pond and Pond B. January 1984–June 1985.	15-46
Table 15-13.	Mean Species Richness (no. of taxa) and Mean Density of Organisms in Par Pond and Pond B Macroinvertebrate Meroplankton Samples. January 1984–June 1985.	15-47
Table 15-14.	Mean Species Richness, Mean Density and Mean Species Diversity for Benthic Macroinvertebrates from Par Pond and Pond B. February 1984–May 1985.	15-48
Table 15-15.	Percent Composition (relative abundance) of Major Benthic Macroinvertebrate Taxa Collected in Par Pond and Pond B. H = Hot Arm, N = North Arm, D = Cold Dam and I = Intake Arm. February 1984–May 1985.	15-48
Table 15-16.	Composition of Benthic Macroinvertebrate Community Presented as Mean Densities (organisms/m ²) from Par Pond and Pond B. H = Hot Arm, N = North Arm, D = Cold Dam and I = Intake Arm. February 1984–May 1985.	15-49

Table 15-17.	Percent Composition (Relative Abundance) of Major Groups of Macroinvertebrates in Ponar Dredge Samples Collected from Par Pond, September 1988 and 1989	15-50
Table 15-18.	Average Macroinvertebrate Density, Biomass, Taxa Per Sampler and Total Taxa Collected from Hester-Dendy Multiplate Samplers in Lower Three Runs, October 1984–September 1985	15-51
Table 15-19.	Macroinvertebrate Taxa Collected from Par Pond and Pond B, 1984–1985	15-53
Table 15-20.	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.	15-58
Table 15-21.	Principal Reports Describing Fish Studies in the Par Pond System	15-63
Table 15-22.	Species of Fish in Par Pond, Pond B, and Pond C ^a	15-64
Table 15-23.	Species Relative Abundance (percent composition and percent total weight) of Adult Fishes Collected From Par Pond and Pond B. ^a January 1984–June 1985.	15-67
Table 15-24.	Species Relative Abundance as Percent Composition (and number) of Adult Fishes Collected From Sample Areas in Par Pond. January 1984–June 1985.	15-68
Table 15-25.	Critical Thermal Maximum Estimates for Bluegill from Two Locations at Different Acclimation Temperatures	15-74
Table 15-26.	Seasonal Distribution of A. Hydrophila-Like Bacteria at Selected Stations in Par Pond (Source: Fliermans et al. 1977)	15-76
Table 16-1.	Flow Summary for the Savannah River	16-6
Table 16-2.	Savannah River Field Data	16-11
Table 16-3.	Savannah River Physical Characteristics and General Chemistry	16-12
Table 16-4.	Savannah River Major Anions	16-13
Table 16-5.	Savannah River Major Cations (Total)	16-14
Table 16-6.	Savannah River Nutrients	16-17
Table 16-7.	Savannah River Trace Elements (Total)	16-18

- Table 16-8. Relative Abundance (Percent) of Major Taxonomic Groups of Macroinvertebrates on Hester-Dendy Multiplate Samplers in the Savannah River, 1984–1985 16-26
- Table 16-9. Mean Number of Taxa Per Sampler, Density and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in the Savannah River, 1983–1984. 16-27
- Table 16-10. Macroinvertebrate Drift Density (No/1000 m³) in the Savannah River, October 1983–July 1985 16-28
- Table 16-11. Macroinvertebrate Taxa Collected from Hester-Dendy Multiplate Samplers and Drift in the Savannah River, 1983–1985 16-29
- Table 16-12. Number and Percent Composition of Fish Larvae and Eggs Collected in the Savannah River and Tributary Creeks, February–July 1983. 16-36
- Table 16-13. Ichthyoplankton Taxa Collected from the Savannah River, Tributaries, Oxbows, and the Savannah River Plant Intake Canals, February–July 1984.^a 16-37
- Table 16-14. Ichthyoplankton Taxa Collected from the Savannah River, Tributaries, Oxbows, and the Savannah River Intake Canals, February–July 1985. (The study area was between RM 89.3 and 187.1 and included 22 river transects, 2 intake canals, the mouths of 14 tributary creeks, and 5 oxbows.) 16-38
- Table 17-1. Physical Characteristics of Regional Reservoirs Used in Comparative Study (Source: Bowers 1992) 17-4
- Table 17-2. Land Use in Drainage Areas of Offsite Reservoirs 17-4
- Table 18-1. Commercial Landing Data for Fish Taken From Savannah River, 1970–1979 (Source: Adapted from Du Pont 1983) 18-5
- Table 18-2. Commercial Landing Data for Shellfish Taken from Coastal Regions of Savannah River, 1972–1979 (Source: DOE 1984, Adapted from Du Pont 1982) 18-5
- Table 18-3. Fish Species Preferred and Caught by Savannah River Sport Fishermen (Source: DOE 1988, adapted from Schmitt and Hornsby 1985) 18-7
- Table 18-4. Combined annual estimates of angler pressure, harvest, and catch rate for the freshwater and estuarine sections of the Savannah River between December 29, 1979 and December 24, 1982 and January 10, 1988 and December 24, 1988 (Source: Schmitt 1990) 18-11

- Table 18-5. Creel Harvest Estimates for the Combined Freshwater Portions of the Savannah River Creel Surveys of 1979–1982 and 1988 (Source: Schmitt 1989) 18-12
- Table 18-6. “Other” Species Harvested in the 1979–1982 and 1988 Savannah River Creel Surveys (Source: Schmitt 1989) 18-13
- Table 18-7. Estuarine Harvest Estimates of 1979–1982 and 1988 Savannah River Roving Creel Surveys (Source: Schmitt 1989) 18-14
- Table 18-8. Estimated Fished-for Effort (hours) in the Estuarine and Freshwater Sections of the Savannah River Creel in the 1979–1982 and 1988 Surveys (Source: Schmitt 1989) 18-15
- Table 18-9. Savannah River Roving Creel Survey Harvest Estimates for the Period from October 8, 1989 to March 10, 1990 (Source: Schmitt 1989) 18-16
- Table 18-10. Savannah River Roving Creel Survey Estimates for the Period from October 8, 1989 to March 10, 1990 (Source: Schmitt 1989) 18-16
- Table 18-11. Savannah River Roving Creel Fished-for Estimates for the Period from October 8, 1989 through March 10, 1990 (Source: Schmitt 1990) 18-17
- Table 20-1. Plant Species Listed by the Federal Government, State of South Carolina, or the South Carolina Heritage Trust as Endangered, Threatened, or of Special Concern Known to Currently Occur on the Savannah River Site (Sources: 50 CFR 17.11 and 17.12 (August 1992); Federal Register 54:554-579. South Carolina Code of Laws of 1976, 1988 Cumulative Supplement, R. 123-150. South Carolina Wildlife and Marine Resources Department, Heritage Trust Database 1989) 20-6
- Table 20-2. Names and Status of Plant Species of Concern Found on SRS 20-7
- Table 20-3. Names and Status of Plant Species of Concern that May Occur on SRS 20-8
- Table 21-1. Estimated Population Size and Sex Ratios for Alligators Inhabiting Par Pond in 1972-1974 and 1986-1988 (Source: Brandt 1989) 21-13
- Table 21-2. Distribution of alligators in the Par Pond reservoir in 1987 and during/after the lowering of the reservoir’s water level by 6 m from June to September 1991. (Source: Brisbin et al. 1992) 21-15
- Table 21-3. Bald Eagle Sightings on SRS from September 1984 to August 1985 (Source: Mayer et al. 1985) 21-23

Table 21-4.	Bald Eagle Sightings on SRS from September 1985 to January 1986 (Source: Mayer et al. 1986)	21-24
Table 21-5.	Number of Nestlings Produced Annually by the Bald Eagle Nesting Pairs on SRS	21-27
Table 21-6.	Listing of the Golden Eagle Sightings on SRS	21-29
Table 21-7.	Acres Altered by the Savannah River Forestry Service to Create Nesting Habitats for the Red-Cockaded Woodpecker	21-31
Table 21-8.	Numbers of Documented Red-Cockaded Woodpeckers on SRS	21-31
Table 21-9.	Number of Red-Cockaded Woodpeckers on SRS as of June 15, 1993	21-32
Table 21-10.	Number of Active Nests in the Birdsville Colony	21-36
Table 21-11.	Reproductive Success of Wood Storks at the Birdsville Colony	21-37
Table 21-12.	Mean Distances of Wood Stork Foraging Sites from the Birdsville Col- ony in 1983 Through 1989	21-37
Table 21-13.	Habitat Types of Wood Stork Foraging Sites in East-Central Georgia in 1983 Through 1989 (Source: Coulter 1986c, 1987, 1988, 1989, 1990)	21-38
Table 21-14.	Water Depth (cm) at Locations Where Wood Storks Landed at Foraging Sites, 1983 Through 1989 (Source: Coulter 1986c, 1987, 1988, 1989, 1990)	21-39
Table 21-15.	Number of Aerial Surveys Used to Monitor the Number of Wood Storks on the SRS Savannah River Swamp 1983 Through 1992 (Source: Mey- ers 1984; Coulter 1986c, 1987, 1988, 1989, 1990, 1993; Bryan 1992a, 1992b)	21-40
Table 21-16.	Number of Wood Storks Observed in the SRS Savannah River Swamp During the Summer, 1983 Through 1992	21-41
Table 21-17.	Number of Observations of Wood Storks in the SRS Savannah River Swamp, June Through September, 1983-1988	21-44
Table 21-18.	Total Numbers of Wood Storks Observed in the SRS Savannah River Swamp, June Through September, 1983-1988	21-44

-
- Table 21-19. Cumulative Percentage of Flow Classes in Fourmile Branch Delta Area for 1983 Through Late June 1985, Late June 1985 Through 1986, and 1987 Through 1988 21-46
- Table 21-20. Cumulative Percentage of Flow Classes in Pen Branch Delta Area for 1983 Through 1987 and Following Shutdown in 1988 21-47
- Table 21-21. Cumulative Percentage of Flow Classes in Steel Creek Delta Area Prior to L-Reactor Restart (1983 Through 1985) and After L-Reactor Restart (1986 through 1988) 21-47
- Table 21-22. Cumulative Percentage of Flow Classes in Beaver Dam Creek Delta Area, June through September, 1983 Through 1988 21-47
- Table 21-23. Endangered and Threatened Mammals of South Carolina. 21-53

Introduction

The purpose of SRS Ecology: Environmental Information Document is to provide a source of ecological information based on the existing knowledge gained from research conducted at the Savannah River Site. This document provides a summary and synthesis of ecological research in the three main ecosystem types found at SRS and information on the threatened and endangered species residing there.

The Savannah River Site is composed of an area of 80,267 hectares (310 square miles) in portions of Aiken, Allendale, and Barnwell counties of South Carolina, and is located along the Savannah River. This area has a wide range of habitats, from well-drained upland forests to swamps, wetlands, and river systems. The entire site has been designated as a National Environmental Research Park by the Department of Energy. Part I—Terrestrial Resources describes the soils, terrestrial vegetation cover types, and wildlife forms that are commonly found on SRS and evaluates the importance and sensitivity of the systems to site activities. Much of the upland area of the Savannah River Site is managed for commercial timber production, game management includes annual deer and hog hunts and wild turkey habitat enhancement

Over 20% of the Savannah River Site is covered by wetlands including bottomland hardwoods, cypress-tupelo swamp forests, two large cooling water reservoirs (Par Pond and L Lake), scrub-shrub areas primarily along former thermal creeks and swamps, and approximately 200 isolated upland wetland depressions or Carolina bays. Most of the wetlands are in similar condition to pre-Savannah River Site conditions, except in those areas related to Savannah River Site thermal releases primarily from past reactor operations. Once-through, secondary cooling water was released directly to small tributary streams or to cooling lakes from the early-to-middle 1950s until the middle-to-late 1980s at temperatures in excess of 35° to 40° centigrade and frequently as high as 65° to 70° centigrade. These thermal releases degraded the wetlands along the creek corridors and adjacent portions of the SRS Savannah River swamp. Following cessation of cooling water releases to creek and swamp wetlands, successional revegetation by scrub-shrub vegetation and a variety of persistent and non-persistent wetland vegetation occurred and continues today. The shorelines of the cooling lakes have or have had (Par Pond was lowered in 1991) extensive aquatic macrophyte communities. Therefore, wetlands continue to present a mosaic of valuable habitats on the Savannah River Site. Part II—Wetlands Resources describes these areas of the Savannah River Site.

The Southeastern United States has abundant freshwater resources, which provide diverse habitats. There are five main drainage basins located on the Savannah River Site. The five streams that originate on, or pass through the SRS before flowing into the Savannah River are: Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Steel Creek, and Lower Three Runs. A sixth stream, Pen Branch, does not flow directly into the Savannah River but joins Steel Creek in the Savannah River floodplain swamp. The upper reaches of Lower Three Runs were impounded in 1958 to form Par Pond. L Lake was formed in 1985 by damming Steel Creek above the Meyers Branch confluence. Part III—Aquatic Resources describes and defines the physical and biological characteristics of these systems and provide a source and synopsis of information from the many aquatic studies conducted through the years at the Savannah River Site. In the past, aquatic systems have been a major focus of ecological research at the Savannah River Site because of the impacts from site operations. Chapters in Part III deal with each of the five drainage systems and the Savannah

River, encompassing their hydrological description, water chemistry characteristics, habitat formers and lower food chain, macroinvertebrate populations, and fish communities. The regional lakes study, abstracted in the final chapter, was a large study that collected data from lakes around the State of South Carolina and compared those lakes with the two large reservoirs at the Savannah River Site.

The protection and restoration of biota to a point where their existence is not jeopardized is a principal goal of federal and state environmental programs. Numerous private organizations and other groups have formed at local and national levels to complement governmental protection of those plants and animals collectively referred to as "species of concern". Part IV—Threatened and Endangered Species discusses the status of species of concern at the Savannah River Site, emphasizing the biota that: (1) are listed or proposed as endangered or threatened by the U.S Department of the Interior, U. S. Department of Commerce, or the State of South Carolina; (2) currently exist onsite either as a permanent or temporary resident; and (3) have habitat preferences or affinities for ecosystems present on the Savannah River Site. Species that are not currently classified as endangered or threatened by federal or state agencies or whose status is under review are not addressed. The bald eagle and red-cockaded woodpecker are residents of the Savannah River Site. The wood stork is known to forage in areas on the site. Other species, like the american alligator listed as threatened by similarity of appearance, and the shortnose sturgeon that spawns in the Savannah River, along with other species of concern found here that are proposed for listing, like the american sand burrowing mayfly, are discussed within Part IV.

Part I

T e r r e s t r i a l R e s o u r c e s

The Savannah River Site is composed of an area of 80,267 hectares (310 square miles) in portions of Aiken, Allendale, and Barnwell counties of South Carolina, and is located along the Savannah River. This area has a wide range of habitats, ranging from well-drained upland forests to swamps, wetlands, and river systems. The entire site has been designated as a National Environmental Research Park by the Department of Energy. The purpose of Part I—Terrestrial Resources is to describe the soils, terrestrial vegetation cover types, and wildlife forms that are commonly found on SRS and to evaluate the importance and sensitivity of the systems to site activities.

Chapter 1

Soils

Chapter Contents

Introduction (page 1-3)

SRS Soils (page 1-5)

SRS Soil Survey (page 1-7)

Soil Groups (page 1-9)

References (page 1-13)

Introduction

Soils are a basic terrestrial resource because they exert influences on nearly all other environmental aspects of the flora and fauna and can affect the decisions made in many disciplines. Foresters and agronomists use soils information as a guide to production potential; while planners, engineers, research scientists, and waste management and environmental compliance personnel have to consider the limitations of soils characteristics. Soil is the natural, three-dimensional body of the earth's surface, which contains mineral and organic matter and air. The integrated effect of climate and living matter acting on soil and conditioning over time affect its properties. The Soil Survey of Savannah River Plant Area (Rogers 1990) is the best source for information on soils on SRS.

SRS Soils

Geological Origin

Soils on SRS have formed in deep beds of marine sediments. The Aiken Plateau ranges from 10 to 50 million years old. Most geologists agree that the area generally has surface deposits of varying thickness and commonly called Pinehurst Upland Unit, Tobacco Road, and Dry Branch that overlay the Barnwell Formation, McBeam, and Congaree Formation at descending depths below the soil surface. The Congaree Formation is near sea level and is just above the Ellenton Formation. Erosion has cut into the surface deposits over the entire site and some areas have exposed lower formations, such as the McBeam.

The Pleistocene marine terraces have been identified by Cooke (1936) on SRS. This group of terraces represents successive recessions of the ocean during the glacial epoch about 10 thousand to 1 million years ago (Figure 1-1). The Brandywine Terrace is the highest and oldest. It lies adjacent to the Aiken Plateau and parallels the Savannah River at elevations between 150 and 250 feet above sea level. The Sunderland Terrace lies between 90 and 150

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

feet and is the second oldest. The Wicomico Terrace, the youngest, is along the floodplain between the river and about 90 feet above sea level (Cooke 1936, Langley and Marter 1973). Because the soils have been worked by water, they are naturally low in nutrients and have low cation-exchange capacity.

Soil Texture

Particle size, referred to as soil texture, is a very important descriptor of soil characteristics. Soil texture is the relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are sand, loamy sand, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, and clay (Figure 1-2). The most common surface textures on SRS are sand and loamy sand while the subsoil textures are usually sandy loam or sandy clay loam. Soil texture can have a significant impact on the physical and chemical characteristics of a soil series.

Figure 1-2. Guide for Textural Classification

SRS Soil Survey

General Characteristics of SRS Soils

There are many different soils on SRS, and in some areas they change within short distances. Soils on SRS range from seasonally wet, hydric soils to well drained. Composition ranges from mostly sand-size particle with high hydraulic conductivity rates to high clay content with moderately low to low hydraulic conductivity rates. These differences, where the areas are large enough, are shown as a soil series within a mapping unit. A mapping unit is an area dominated by one major kind of soil with other similar soils included. There are 4 orders and 28 soil series recognized on SRS. The classification of a soil series is descriptive of the soils history, evolution, and current characteristics. On SRS there are sizable areas where the upper two meters of soil has been altered to the extent that the soil profile cannot be identified. These areas are placed in the taxonomic system at a higher level and, therefore, less specific characteristics are given (Rogers 1990).

Soil Maps

An extremely valuable part of the SRS soil survey is the detailed soil map units: these are shown at the back of the survey on aerial photos at a scale of 1:15840 (4 in./mi). Map units are drawn on the photo and consist of the soil for which the unit was named along with other similar associated soils and, usually, inclusions of small areas of dissimilar soils. Because of the possibility of small areas of dissimilar soils, a field investigation to identify such inclusions should always precede any commitment to manage or build on the soil area. The map unit is generally shown with the major soil series as the name of the unit. There are 50 soil mapping units recognized on SRS that are large enough to be shown on the photos at the publication scale used in the SRS soil report (see Table 1-1 on page 1-8). Other small but important soils are shown with special spot symbols on the maps, such as one to three acre wet areas (Rogers 1990).

Tabular Data

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

Table 1-1. Listing of Soil Mapping Units on SRS (Source: Rogers 1990)

Soil Unit Name and Slope	Total Acres
Ailey sand, 2 to 6% slopes	2450
Albany sand, 0 to 6% slopes	940
Blanton sand, 0 to 6% slopes	38,767
Blanton sand, 6 to 10% slopes	3200
Chastain clay, frequently flooded, nearly level	7860
Dorovan muck, frequently flooded, nearly level	2045
Dothan sand, 0 to 2% slopes	1625
Dothan sand, 2 to 6% slopes	14,010
Enula fine sandy loam, 0 to 2% slopes	310
Fluvaquents, frequently flooded, nearly level	4550
Fuquay sand, 0 to 2% slopes	1190
Fuquay sand, 2 to 6% slopes	20,674
Fuquay sand, 6 to 10% slopes	750
Hornsville sandy loam, 0 to 2% slopes	2640
Kinston loam, frequently flooded, nearly level	600
Lakeland sand, 0 to 6% slopes	8150
Lakeland sand, 6 to 10% slopes	320
Lucy sand, 0 to 2% slopes	400
Lucy sand, 2 to 6% slopes	1590
Lucy sand, 6 to 10% slopes	440
Neeses loamy sand, 2 to 6% slopes	360
Norfolk loamy sand, 0 to 2% slopes	880
Norfolk loamy sand, 2 to 6% slopes	2220
Ochlockonee loamy sand, occasionally flooded, nearly level	330
Ocilla loamy sand, 0 to 2% slopes	1470
Ogeechee sandy loam, nearly level	1780
Orangeburg loamy sand, 0 to 2% slopes	1150
Orangeburg loamy sand, 2 to 6% slopes	5110
Orangeburg loamy sand, 6 to 10% slopes	330
Pickney sand, frequently flooded, nearly level	10,290
Rembert sandy loam, nearly level	6530
Shellbluff loam, frequently flooded, nearly level	2000
Smithboro loam, nearly level	990
Tawcaw silty clay, frequently flooded, nearly level	2750
Toccoa loam, frequently flooded, nearly level	310
Troup sand, 0 to 6% slopes	14,560
Troup sand, 6 to 10% slopes	1920
Troup sand, 10 to 15% slopes	1140
Troup and Lucy sand, 15 to 25% slopes	2100
Troup and Lucy sand, 25 to 40% slope	650
Udorthents, firm, variable slopes	540
Udorthents, friable, variable slopes	5940
Udorthents-Urban land, gently sloping	680
Urban land, gently sloping	510
Vaocluse sandy loam, 2 to 6% slopes	1180
Vaocluse-Ailey complex, 6 to 10% slopes	6580
Vaocluse-Ailey complex, 10 to 15% slopes	5670
Wagram sand, 0 to 2% slopes	1290
Wagram sand, 2 to 6% slopes	4350
Williman sand, nearly level	1977
Water	133

Soil Groups

Introduction

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

Chastain-Tawcaw-Shellbluff Association

The Chastain-Tawcaw-Shellbluff association consists of nearly level soils on the flood-plains along the major streams, mainly along the Savannah River. This association makes

Figure 1-3. SRS General Soils Map

up about 6% of the survey area. The association is about 60% Chastain soils, 20% Tawcaw soils, 15% Shellbluff soils, and 5% soils of minor extent.

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

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

Rembert-Hornsville Association

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

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

Blanton-Lakeland Association

The Blanton-Lakeland association consists of nearly level to sloping soils on uplands. Stands of longleaf and loblolly pine with an oak understory are on the broad, sandy ridges. This association makes up about 18% of the survey area. It is about 40% Blanton soils, 20% Lakeland soils, and 40% soils of minor extent.

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

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

Fuquay-Blanton-Dothan Association

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

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

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

Orangeburg Association

The Orangeburg association consists mainly of soils on broad upland ridges and in nearly level to sloping areas northwest of Upper Three Runs. Slopes generally are smooth. Planted loblolly pine is currently the dominant vegetation on this soil type. This association makes up about 2% of the survey area. It is about 70% Orangeburg soils and 30% soils of minor extent.

The Orangeburg soils have a friable, red, loamy subsoil.

The soils of this association are well suited for woodlands, sanitary facilities, building site development, wildlife habitat, and other uses.

Vaocluse-Ailey Association

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

Vaocluse soils have a loamy surface layer and subsurface layer that have a combined thickness of less than 20 inches. Ailey soils have moderately thick, sandy surface and subsurface layers. Both soils have a loamy subsoil that has a brittle layer.

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

Troup-Pickney-Lucy Association

The Troup-Pickney-Lucy association consists of moderately steep and steep soils on uplands and nearly level soils on the floodplains along streams. The steeper areas are on the southeast bank of Upper Three Runs and along both sides of Tinker Creek. Areas of this association are long and narrow. This association has the most sloping soils in SRS. The soils on the floodplains have a higher content of organic matter than the other soils. The vegetation is mostly hardwoods mixed with loblolly pine. This association makes up about

10% of the survey area. It is about 45% Troup soils, 40% Pickney soils, 10% Lucy soils, and 5% soils of minor extent.

Troup soils are well drained. They have a thick, sandy surface and subsurface layers and a loamy subsoil at a depth of 40 to 80 in. Pickney soils are very poorly drained. They have a thick, black surface soil and are sandy throughout. Lucy soils are well drained. They have moderately thick, sandy surface and subsurface layers and a loamy subsoil at a depth of 20 to 40 in.

The soils are fairly well suited for woodlands. These soils are poorly suited for sanitary facilities and building site development because of the slope and the flooding. Some areas of less sloping soils are available for use as sites for sanitary facilities or buildings. The soils on floodplains are not suited to building site development.

References

- Cooke, C. W. Geology of the Coastal Plain of South Carolina. Geological Survey Bull. Number 868, U.S. Department of the Interior, Washington, DC, 196 p. (1936).
- Langley, T. M. and W. L. Marter. The SRP Plant Site. Publication DP-1323. Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC. 175 p. (1973).
- Rogers, V. A. Soil Survey of Savannah River Plant Area, Parts of Aiken, Barnwell, and Allendale Counties, South Carolina. U.S. Department of Agriculture, Soil Conservation Service, 127 pp., 46 maps (1990).

Chapter 2

Vegetation

Chapter Contents

Introduction (page 2-3)

Terrestrial Land Cover Types (page 2-5)

Successional Patterns (page 2-25)

Commercially and Recreationally Valuable Biota (page 2-27)

Set-Aside Areas (page 2-31)

References (page 2-33)

Introduction

The current land cover of SRS reflects the past disturbances and manipulations that have occurred since the site was purchased in 1950. At that time the site was approximately 40% old field and crop land and the remainder was forested. Management by the U.S. Forest Service has largely been directed toward timber management and watershed protection and has changed the site to one that is predominately forested in nature. Early changes due to development of SRS have been detailed by Dukes (1984).

Terrestrial Land Cover Types

Introduction

The listed vegetation on SRS consists of 1322 species representing 151 separate taxonomic families (Batson et al. 1985). These species occur over a large number of cover types, ranging from upland, well-drained forests to swamp forests and Carolina bays. More detailed descriptions of the land cover types and vegetation within these cover types can be found in Workman and McLeod (1990); Ezra et al. (1986); Gladden et al. (1985); Jones et al. (1981); and Whipple et al. (1981). Species nomenclature is according to Radford et al. (1968).

Non-Forested Cover Types

Industrial/Transportation Related Land Cover Types

This land cover type includes administrative or production facilities and immediately contiguous surrounding areas (e.g., fly ash basins, borrow pits, and cleared areas). Roads, right-of-ways, and railroad facilities are included in the transportation class. Utility corridors and electric substations are included in the industrial land cover type; however, cleared utility corridors are included based on the land cover actually present (e.g., grassland/scrub-shrub) and electrical substations were mapped as industrial. Borrow pits are considered as active or reclaimed covered with grasses/scrub-shrub vegetation (Ezra et al. 1986).

Grassland/Forb/Scrub-Shrub

Non-woody plants dominate this land cover type, with grasses and forbs comprising more than 50% of the vegetation cover. This land cover type occurs primarily on power line right-of-ways and in a few forest openings. This cover type also includes timber land from which trees have recently been cleared with less than 10% canopy or crown closure. These areas are primarily areas where there has been recent clear-cutting and block-planting of pines—primarily loblolly or longleaf pine. Scrub-shrub land includes predominantly bare soil, scrub-shrub canopy of less than 25% closure, and young pine seedlings and saplings less than five years old and less than 6 m tall. The SRS wildlife food plots are included in the grassland/forb cover type.

Open Water

This cover type consists of areas of continuous cover by water, either natural or man-made. There are approximately 2000 hectares on SRS that fall in this category. This cover type is covered in detail in Part III—Aquatic Resources of this document.

Forested Cover Types

Evergreen Forests

The coniferous forest land cover type includes areas with trees that are at least 6 m tall and are predominantly coniferous species. The evergreen forested areas are dominated by pines, primarily longleaf and loblolly pine (*Pinus palustris* and *P. taeda*, respectively). Slash pine

(*P. elliotii*) and shortleaf pine (*P. echinata*) are also common on SRS. Much of this cover type has been established by the pine plantation management plan of the U.S. Forest Service, although some examples of natural coniferous stands still exist. Other broad-leaved species, such as those oaks that are tardily deciduous and maintain some of their leaves throughout the season, are not included. This cover type is generally located on dry upland sites and includes former agricultural fields. Understory species include black cherry (*Prunus serotina*), various oaks (*Quercus* spp.), persimmon (*Diospyros virginiana*), and other species. The understory is generally sparse under densely stocked pine stands. In areas that are more open, blackberry (*Rubus* spp.), dog-fennel (*Eupatorium compositifolium*), and broomsedge (*Andropogon* spp.) are common.

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

Deciduous Forests

Upland hardwood cover types include areas with trees that are at least 6 m tall and are predominated by deciduous species. Guidelines classify an area as deciduous forest when deciduous trees composed at least 70% of the canopy layer. The deciduous forest class includes the upland hardwood forest and the mesic hardwood forest types described by Whipple et al. (1981). On drier sites and sandy ridges, turkey, bluejack, and black-jack oaks (*Quercus laevis*, *Q. incana*, and *Q. marilandica*) dominate the canopy with longleaf pine present in various densities. In less xeric areas, other oaks and hickories (*Carya* spp.) are also present. Understory species in the drier sites include vacciniums, hollies, lespedezas, and various lichens. On mid- and lower slopes, the deciduous forest includes laurel oak (*Q. laurifolia*), yellow poplar (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), as well as hickories and holly. Understory on the more mesic sites include vacciniums, hollies, various ferns, grapes, sassafras, dogwood, and greenbriers. Although stands comprised of predominantly deciduous species are not abundant on SRS, there are areas located on former homestead sites (windbreaks and hedgerows) that are important for wildlife habitat.

In addition to coniferous and deciduous forest stands, there are areas with both types of trees. Where more than 30% intermixture occurs of these two types, they are generally classified as mixed forests.

Bottomland Hardwood Forests

Bottomland hardwood forest cover types are found along SRS streams and on the "islands" or "ridges" of the Savannah River swamp and major drainages. Elevations of these ridges are high enough to normally prevent prolonged flooding of the forest communities established there. Typical canopy species include water oak (*Quercus nigra*), laurel oak (*Quercus laurifolia*), sweetgum (*Liquidambar styraciflua*), elms (*Ulmus alata* and *U. americana*), red maple (*Acer rubrum*), and yellow poplar (*Liriodendron tulipifera*) (Good and Whipple 1982; Whipple et al. 1981; Jensen et al. 1984a, 1984b). Holly (*Ilex opaca*), redbay (*Persea borbonia*), sweet bay (*Magnolia virginiana*), hackberry (*Celtis laevigata*), and ironwood (*Carpinus caroliniana*) are common in the subcanopy and understory. Greenbriers, grapes,

and other vines are common in the shrub and ground layers. Herbaceous plants are less common due to the more dense shading.

Swamp Forests

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

Sections of the swamp forest that have been historically impacted by reactor effluents through increased siltation and thermal damage are in the process of going through a successional revegetation of the damaged area. These areas are covered in detail in Part II—Wetlands Resources of this document.

Carolina Bays

The Carolina bay cover type is present throughout SRS. Currently, 194 confirmed or suspected Carolina bays have been identified (see Figure 2-1 on page 2-8). These shallow depressions contain hydric or mesic plant communities and range from lakes to marshes, bogs, or swamp forests (Schalles et al. 1989). The plant communities present in the bays are highly variable and are often controlled by the magnitude of flooding and recent history. These bays only occur in upland, interstream areas of the coastal plain of the Southeastern U.S. They are characterized by their elliptical or ovoid shape with a northwest/southeast orientation of their long axis. Often they will have a sandy rim around the margin. Most bays are continually or seasonally flooded and are generally partially filled with inorganic clays and silts and/or organic peats. This cover type is presented in more detail in Chapter 9—Carolina Bays of this document.

Landcover Maps

Figure 2-1 on page 2-8 provides a general overview of the major vegetation types and approximate areas on SRS. Analysis of aerial photography using multispectral sensors produced a more detailed assessment of cover type, which was mapped according to the boundaries of the USGS quadrangle maps. These maps are generally produced at a scale of 1:24,000 (the maps are not produced to that scale in this document) and represent an area of approximately 14,750 hectares (57 square miles). Figure 2-1 shows the appropriate quadrant map names for each section of SRS and Figure 2-1 through Figure 2-16 show the cover type within the SRS boundaries for each of these quadrants. The landcover types in these figures were delineated using photogrammetric techniques from color aerial photographs taken in March 1989. The more dominant land cover types are described in detail in “Non-Forested Cover Types” and “Forested Cover Types” on page 2-5. Areas dominated by water (streams, ponds, and lakes) are covered in Part III—Aquatic Resources and are not detailed here. Swamp forests and wetlands are covered in detail in Part II—Wetlands Resources and are described in the following sections by general composition only.

Figure 2-1. Locations of Carolina Bays on SRS (Schalles et al. 1989)

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

Figure 2-3. SRS Map Showing Names of USGS Quadrangle Maps and Page Numbers of the Landcover Map for that Quadrangle

OF

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Fays/Emergent Wetland
- Site Boundary

Figure 2-4. New Ellenton Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-5. Windsor Quadrangle Land Cover Map

Figure 2-6. Jackson Quadrangle Land Cover Map

- Industrial/Transportation
- ▨ Deciduous Forest
- ▧ Evergreen Forest
- ▩ Grassland/Scrub-Shrub/Barren
- Open Water
- ▤ Swamp Forest
- ▦ Bottomland Hardwood
- ▧ Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-7. New Ellenton southwest Quadrangle Land Cover Map

- Industrial/Transportation
- ▨ Deciduous Forest
- ▩ Evergreen Forest
- ▤ Grassland/Scrub-Shrub/Barren
- Open Water
- ▧ Swamp Forest
- ◊ Bottomland Hardwood
- ▦ Carolina Bays/Emergent Wetland
- - - Site Boundary

Figure 2-8. New Ellenton southeast Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-9. Long Branch Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-10. Shell Bluff Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-11. Girard northwest Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-12. Girard northeast Quadrangle Land Cover Map

- Industrial/Transportation
- ▨ Deciduous Forest
- ▩ Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- ▨ Swamp Forest
- ▩ Bottomland Hardwood
- ▩ Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-13. Snelling Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-14. Girard Quadrangle Land Cover Map

Figure 2-15. Millet Quadrangle Land Cover Map

- Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Grassland/Scrub-Shrub/Barren
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 2-16. Martin Quadrangle Land Cover Map

Successional Patterns

Descriptions of some land cover types have been detailed in the general references more extensively than others. The successional relationship of some of the communities has received limited research attention. Van Lear and Jones (1987) suggested the use of land type and vegetation as an indicator for site classification and potential successional direction for hardwood sites. The extensive forest management practices on SRS often preclude the natural succession patterns of the sites. Jones et al. (1981) suggested successional pathways for many of the major SRS forest communities. Specialized research areas, such as thermally impacted swamp areas and Carolina bays, have also received some attention regarding natural succession. Many of these studies are discussed in more detail in this document in Part II—Wetland Resources. Further studies describing the relationship of community structure and environmental factors on the succession are clearly needed for many of the cover types, especially the hardwood and non-swamp communities.

Commercially and Recreationally Valuable Biota

Timber Acreage

The SRS timber crop is of prime commercial value. This resource is actively managed by the Savannah River Forest Station (SRFS) under an established timber management plan. This plan specifies management requirements for nearly 182,000 acres of commercial forest and over 12,000 acres of nonforest land. The commercial operation's primary product is pine pulpwood, but it also provides pine sawtimber, hardwood sawtimber, and pulpwood (Table 2-1). This resource has been developed since 1953 through the planting or replanting of nearly 123,000 acres with approximately 129 million seedlings of various tree species (Table 2-2 and Table 2-3) (SRFS 1992).

Timber Commercial Value

The commercial value of SRS standing timber in 1991, based on bids from previous years, was over \$170 million (Table 2-4). The cumulative value of timber sold on SRS from 1955 through 1991 was over \$34 million (timber sold may include uncut trees), and the cumulative value of timber cut for the same period was over \$32 million (Table 2-5 and Table 2-6) (SRFS 1992).

Table 2-1. Summary of SRFS Timber Management Plan, FY 78–FY 91 (Source: SRFS 1992)

Timber Management Plan Data		
Management plan period FY 78 through FY 91 completed and submitted:		
Commercial forest land	181,605 acres	
Nonforest land	12,445 acres	
Water	4294 acres	
Total	198,344 acres	
Net Marketable Volume as of 9/30/91		
	Sawtimber	Pulpwood
	MBF ^a Scribner	Cords (Thousands)
Pine	482.5	2453.6
Hardwood	413.8	957.1
Total	896.3	3410.7
Predicted Annual Net Growth - Including InGrowth		
Pine	6.0%	11.0%
Hardwood	0.4%	0.5%

^aMBF - millions of board feet

Table 2-2. Summary of Total Acres Planted and Seeded, FY 53–FY 91 (Source: SRFS 1992)

Fiscal Year	Planted Loblolly	Planted Slash	Planted Longleaf	Planted Hardwood	Direct Seeded Longleaf	Cumulative Total
1953-73	11,671	38,527	14,858	-	21,948	87,004
1974	1051	-	101	-	-	88,156
1975	702	-	350	64	-	89,272
1976	620	-	468	12	-	90,372
1977	831	-	266	-	-	91,469
1978	1033	-	310	-	-	92,812
1979	1985	-	-	-	-	94,797
1980	1994	-	160	-	-	96,951
1981	2312	-	314	-	-	99,577
1982	2537	-	-	-	41	102,155
1983	1450	-	402	-	41	104,048
1984	1913	-	239	-	31	106,231
1985	2042	-	205	-	20	108,498
1986	2026	-	221	-	-	110,745
1987	1649	-	559	-	-	112,953
1988	2148	-	540	-	-	115,641
1989	1709	-	976	-	-	118,326
1990	1995	-	821	-	-	121,142
1991	504	-	1329	-	-	122,975

Table 2-3. Planting Summary (Gross Seedlings Planted by Species, Thousands), FY 53–FY 91 (Source: SRFS 1992)

Fiscal Year	Loblolly	Slash	Longleaf	Hardwood	Cumulative Total (Thousands)
1953-73 ^a	12,228 ^b	40,298	50,029	-	102,555
1974	546	-	50	-	103,151
1975	391	-	210	16	103,768
1976	337	-	255	6	104,366
1977	500	-	225	-	105,091
1978	550	-	225	-	105,866
1979	1300	-	-	-	107,166
1980	1530	-	160	-	108,856
1981	1574	-	311	-	110,741
1982 ^a	1578	-	41	-	112,360
1983 ^a	1465	-	350	-	114,175
1984 ^a	1550	-	279	-	116,004
1985 ^a	1500	-	146	-	117,650
1986	1500	-	200	-	119,350
1987	1200	-	570	-	121,120
1988	1517	-	477	-	123,114
1989	1275	-	750	-	125,139
1990	1400	-	750	-	127,289
1991	599	-	1000	-	128,888

^a1000 longleaf seedlings tabulated for each acre seeded.

^bIncludes 5000 cypress planted in FY 72.

Table 2-4. Summary of Standing Timber Value, FY 62–FY 91 (Source: SRFS 1992)

Fiscal Year	Dollar Value	Fiscal Year	Dollar Value
1962	\$15,976,230	1977	\$36,700,000
1963	17,857,517	1978	53,310,113
1964	19,822,323	1979	63,849,134
1965	22,841,055	1980	70,234,047
1966	25,169,794	1981	83,930,420
1967	25,308,675	1982	92,108,240
1968	26,333,842	1983a	91,976,122
1969	27,372,000	1984	103,084,852
1970	28,370,995	1985b	94,812,504
1971	29,200,617	1986	117,481,333
1972	30,258,114	1987	118,898,339
1973	32,456,000	1988	134,872,708
1974	33,156,000	1989	151,465,057
1975	33,962,000	1990	169,909,264
1976	35,822,000	1991	170,248,875

^aValue decreased due to change in unit value used. Value of products are determined by weighted average of preceding 12 months high bid.

^bDecrease due to decrease in value of products.

Table 2-5. Summary of Type and Value of Timber Sold, FY 55–FY 91 (Source: SRFS 1992)

Timber Sales Sold						
Fiscal Year	KBF ^a Pine S/T ^b	MBF Hdwd S/T ^b	Cords Pine	Cords Hdwd	Total Value	Cumulative Value
1955-72	18,802	22,314	319,020	14,525	\$3,960,501	\$3,960,501
1973	1587	0	60,075	0	614,548	4,575,049
1974	546	0	45,792	0	686,144	5,261,193
1975	2829	164	52,320	529	1,004,087	6,265,280
1976	542	41	62,139	773	931,870	7,197,150
1977	576	0	47,994	0	827,993	8,025,143
1978	3901	230	34,360	738	1,096,620	9,121,763
1979	3711	149	31,936	540	982,567	10,104,330
1980	8338	1362	27,641	1565	1,369,259	11,473,589
1981	9621	1125	20,951	3074	2,198,522	13,672,111
1982	8361	958	21,432	2976	1,701,463	15,373,574
1983	6247	910	14,938	1423	1,211,092	16,584,666
1984	10,756	1532	20,789	4661	2,380,124	18,964,790
1985	8785	294	25,628	1051	1,752,573	20,717,363
1986	5519	181	15,257	1203	1,139,573	21,856,936
1987	10,250	0	20,411	7667	1,601,137	23,458,073
1988	9121	397	19,584	1299	2,115,273	25,573,346
1989	13,364	218	27,349	475	3,266,680	28,840,026
1990	6705	209	26,010	3114	2,129,758	30,969,784
1991	9832	0	23,087	1869	3,138,369	34,108,153

^aKBF = thousands of board feet

^bS/T = sawtimber

Table 2-6. Summary of Type and Value of Timber Cut, FY 55–FY 91 (Source: SRFS 1992)

Timber Sales Cut							
Fisc. Year	KBF ^a Pine S/T ^c	KBF Hdwd S/T ^c	Cords P/W ^d Pine	Cords P/W ^d Hdwd	Total Value	Cumulative Value	
1955-73 ^b	37,584	-	340,316	-	4,245,160	4,245,160	
1974	2510	-	49,599	-	704,134	4,949,294	
1975	830	-	33,762	-	538,578	5,488,272	
1976	1239	-	46,963	-	772,572	6,260,844	
1977	1598	-	60,719	-	881,805	7,142,649	
1978	1159	-	53,763	-	969,466	8,112,115	
1979	3846	-	51,255	-	1,373,737	9,485,852	
1980	7601	-	43,879	-	1,548,117	11,033,969	
1981	6355	-	23,188	-	1,468,699	12,502,668	
1982	7066	-	18,865	-	56,058	13,758,726	
1983	6867	630	18,223	4036	1,295,222	15,053,948	
1984	12,929	2216	15,720	4247	2,000,451	17,054,399	
1985	5388	1237	15,625	1750	1,216,167	18,270,566	
1986	10,279	383	25,358	4102	2,072,245	20,342,811	
1987	11,143	181	27,147	3513	2,261,324	22,604,135	
1988	9428	282	23,650	2643	1,982,695	24,586,830	
1989	10,353	115	19,651	35	2,399,602	26,986,432	
1990	1542	209	22,093	2699	1,481,852	28,468,284	
1991	15,358	1969	29,084	769	4,378,618	32,846,902	

^aKBF = thousands of board feet.

^bPine and hardwood for both sawtimber and pulpwood were consolidated for statistical purposes prior to FY 83.

^cS/T = sawtimber

^dP/W = pulpwood

Set-Aside Areas

A series of set-aside areas have been designated by the Department of Energy on SRS. These areas are selected and managed by the Savannah River Ecology Laboratory (SREL) as representative of major or unique vegetational communities on site. The set-aside task group contains representatives from many organizations at SRS, including DOE, WSRC, SREL, U. S. Forest Service, and Soil Conservation Service. This group serves as an advisory group and provides input to SREL for consideration.

The project was initiated in 1967 to promote ecological research (Hillestad and Bennett 1982). The project began with 10 set-aside areas and now includes 30 designated areas (Figure 2-17). The set-aside program spans a variety of habitat types and includes examples of pine stands, hardwood forest, riparian areas, and swamp forest. Many of these areas include Carolina bays within their boundaries and are the habitat for many of the threatened and endangered species of flora on SRS (see Chapter 20—Threatened and Endangered Flora). Because the set-asides are located within the SRS boundaries, they provide locations for long-term projects that are protected from routine public access. Because they are subject to

Figure 2-17. Locations of SRS Set-Asides

very few of the disturbances associated with other areas of SRS, they also provide control areas to study and provide data for ecological change studies.

At the time of publication, a new document is being drafted that will update the set-aside program and include all areas added since the initial report of Hillestad and Bennett (1982). New areas for inclusion into the set-aside program are also under review as is the possible elimination of one of the original areas because it no longer fits the set-aside criteria.

References

- Batson, W. T., J. S. Angerman, and J. T. Jones. Flora of the Savannah River Plant. SRO-
NERP-15, Savannah River Ecology Laboratory, Aiken, SC, 63 pp. (1985).
- Dukes, E. K. The Savannah River Plant: Environment. DP-1642, E. I. du Pont de Nemours
and Company, Savannah River Laboratory, Aiken, SC (1984).
- Ezra, C. E., L. R. Tinney, and H. E. Mackey, Jr. Pen Branch and Four Mile Creek Land
Cover Database, Savannah River Plant, Aiken, SC, DOE(ONS-SRL)-8605, EG&G
Energy Measurements, Inc., Las Vegas, NV, 54 pp. (1986).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive
Cooling Water Study - Annual Report. DP-1697, Vol. 1-11, E. I. du Pont de Nemours
and Company, Savannah River Laboratory, Aiken, SC (1985).
- Good, B. J. and S. A. Whipple. "Tree Spatial Patterns: South Carolina Bottomland and
Swamp Forests", *Bull. Torrey Bot Club.* 109(4):529-536 (1982).
- Hillestad, H. O. and S. H. Bennett, Jr. Set-Aside Areas, National Environmental Research
Park Savannah River Plant, Aiken SC. SRO-819-11, Savannah River Ecology Labora-
tory, Aiken, SC, 28 pp. (1982).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. SRP Swamp Vegetation Map. DPST-84-
372, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC
(1984a).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. "Nontidal Wetland Mapping in South
Carolina Using Airborne Multispectral Scanner Data". *Remote Sensing of Environ-
ment.* 16:1-12 (1984b).
- Jones, S. M., D. H. Van Lear, and S. K. Cox. Major Forest Community Types of the Savan-
nah River Plant: A Field Guide, SRO-NERP-9, Savannah River Ecology Laboratory,
Aiken, SC, 65 pp. (1981).
- Radford, A. E., H. E. Ahles, and C. R. Bell. *Manual of the Vascular Flora of the Carolinas.*
U. North Carolina Press, Chapel Hill, 1183 pp. (1968).
- Savannah River Forest Station. Fact Sheet U.S. Forest Service Natural Resource Manage-
ment Program, Savannah River Site (1992).
- Schalles, J. F., R. R. Sharitz, J. W. Gibbons, and J. N. Knox. Carolina Bays of the Savannah
River Plant. SRO-NERP-18, Savannah River Ecology Laboratory, Aiken, SC, 70 pp.
(1989).
- Van Lear, D. H. and S. M. Jones. An Example of Site Classification in the Southwestern
Coastal Plain based on Vegetation and Land Type. *So. J. Applied For.* 11:23-28. (1982).
- Whipple, S. A., L. H. Wellman, and B. J. Good. A Classification of Hardwood and Swamp
Forests of the Savannah River Plant, South Carolina, SRO-NERP-9, Savannah River
Ecology Laboratory, Aiken, SC, 65 pp. (1981).
- Workman, S. W. and K. W. McLeod. Vegetation of the Savannah River Site: Major Commu-
nity Types. SRO-NERP-19, Savannah River Ecology Laboratory, Aiken, SC, 137 pp.
(1990).

Chapter 3

Wildlife

Chapter Contents

Introduction (page 3-3)

Herpetofauna (page 3-5)

Avifauna (page 3-23)

Mammals (page 3-39)

Commercially and Recreationally Valuable Biota (page 3-47)

References (page 3-53)

Introduction

SRS is comprised of varied and diverse habitats. This mixture provides habitat for a wide variety of terrestrial and semi-aquatic wildlife. At the time of government acquisition, approximately 67% of SRS was forested, the remainder was cropland and pasture. After closure to the public, former home and farm sites went through vegetational succession, being invaded primarily by pines. This succession to pine forest was aided by an extensive planting program implemented by the U.S. Forest Service. Currently, 94% of SRS is forested (Workman and McLeod 1990).

Herpetofauna

Introduction

SRS supports an abundant herpetofauna because of its temperate climate and diverse habitats. The herpetofauna of SRS includes 17 salamanders, 26 frogs and toads, one crocodilian (see Chapter 21—Threatened and Endangered Fauna for the current status of the American alligator on SRS), 12 turtles, 9 lizards, and 36 snakes. Table 3-1 on page 3-6 contains a taxonomic listing of the species found on SRS. Gibbons and Semlitsch (1991) provide an overview, description, and identification keys to the herpetofauna of SRS.

Carolina Bays

Studies of the reptiles and amphibians of Carolina bays have produced a knowledge base of what species use the bays and peripheral areas (Table 3-2 on page 3-9), their movements (Table 3-3 on page 3-11 and Table 3-4 on page 3-13), and the success of refuge ponds for mitigation purposes (Table 3-5 on page 3-14 and Table 3-6 on page 3-15).

Steel Creek and L Lake

Steel Creek was sampled for herpetofauna before (Smith et al. 1981, 1982) and after the 1985 construction of L Lake (Gladden et al. 1988). Table 3-7 on page 3-16 lists the species and number of animals captured in the Steel Creek study area (Figure 3-1 on page 3-17) during 1981 and 1982. Similar data from sampling stations (Figure 3-2 on page 3-17) in 1986 and 1987 are presented in Table 3-8 on page 3-18. Reptiles and amphibians have been collected in the lower regions of L Lake since 1986 (Figure 3-3 on page 3-20). The qualitative data (Table 3-9 on page 3-19) do seem to indicate that the populations of amphibians and turtles using L Lake may be declining while snakes and lizards appear to be stable (Patterson and Giffin 1988).

Par Pond

The reptiles and amphibians known to inhabit Par Pond are listed in Table 3-10 on page 3-20. Turtles and snakes in the Par Pond system and surrounding areas were studied from 1967 to 1985 (Gladden et al. 1985). Recent research is limited to ongoing projects by the Savannah River Ecology Laboratory. The turtle population of Par Pond shows some interesting effects of thermal loading on growth rates, adult size, feeding regime, and reproduction (Gibbons 1970). Par Pond turtles have a larger body size than turtles in other SRS habitats (Figure 3-4 on page 3-21). This larger body size and higher growth rate (Figure 3-5 on page 3-21) are correlated with diet and feeding habits and augmented year-round activity and feeding, which is probably a result of thermal effluents from P Reactor.

Male turtles in Par Pond achieve sexual maturity faster than those in other bodies of water at SRS, while females reach a larger size at sexual maturity (Figure 3-6 on page 3-22). Larger body size in female turtles allows for larger egg or clutch size (Gladden et al. 1985). It is not

known whether these higher growth rates have been maintained since the cessation of thermal inputs in 1988.

Pen Branch

There have been few studies of the herpetofauna of the Pen Branch area (other than the American alligator, see Chapter 21—Threatened and Endangered Species). During the operation of K Reactor, no reptiles or amphibians would be expected to inhabit areas of thermal discharge (Gladden et al. 1985). No studies of the Pen Branch herpetofauna have been instituted since the K-Reactor outage.

Table 3-1. Amphibians and Reptiles of the SRS^a (Source: Gibbons and Semlitsch 1991)

Class	Order	Family	Genus Species	Common Name
Amphibia	Caudata— salamanders	Proteidae	<i>Necturus punctatus</i>	dwarf waterdog
		Amphiumidae	<i>Amphiuma means</i>	two-toed amphiuma
		Sirenidae	<i>Siren lacertina</i>	greater siren
			<i>S. intermedia</i>	lesser siren
		Ambystomatidae	<i>Ambystoma talpoideum</i>	mole salamander
			<i>A. opacum</i>	marbled salamander
			<i>A. maculatum</i>	spotted salamander
			<i>A. tigrinum</i>	tiger salamander
		Salamandridae	<i>Notophthalmus viridescens</i>	eastern (red-spotted) newt
		Plethodontidae	<i>Desmognathus fucosa</i>	dusky salamander
			<i>D. auriculatus</i>	southern dusky salamander
			<i>Plethodon glutinosus</i>	slimy salamander
			<i>Pseudotriton montanus</i>	mud salamander
			<i>P. ruber</i>	red salamander
			<i>Eurycea cirrigera</i>	two-lined salamander
			<i>E. longicauda</i>	long-tailed (three-lined) salamander
			<i>E. quadridigitata</i>	dwarf salamander
	Anura—frogs and toads	Pelobatidae	<i>Scaphiopus holbrooki</i>	eastern spadefoot toad
		Bufonidae	<i>Bufo terrestris</i>	southern toad
			<i>B. quercicus</i>	oak toad
			<i>B. woodhousei</i> ^a	Woodhouse toad
		Hylidae	<i>Acris gryllus</i>	southern cricket frog
			<i>A. crepitans</i>	northern cricket frog
			<i>Hyla cinerea</i>	green treefrog
			<i>H. gratiosa</i>	barking treefrog
			<i>H. femoralis</i>	pine woods treefrog
			<i>H. squirella</i>	squirrel treefrog
			<i>H. chrysoscelis</i>	Cope's gray treefrog
			<i>H. avivoca</i>	bird-voiced treefrog
			<i>Pseudacris triseriata</i> ^a	striped chorus frog
			<i>P. nigrita</i>	southern chorus frog
			<i>P. ornata</i>	ornate chorus frog

Table 3-1. (cont)

Class	Order	Family	Genus Species	Common Name
Reptilia	Crocodilia—Crocodilians	Microhylidae Ranidae	<i>P. crucifer</i>	spring peepers
			<i>P. brimleyi</i> ^a	Brimley's chorus frog
			<i>P. ocularis</i>	little grass frog
			<i>Gastrophryne carolinensis</i>	eastern narrow-mouthed toad
			<i>Rana catesbeiana</i>	bullfrog
			<i>R. virgatipes</i>	carpenter frog
			<i>R. clamitans</i>	bronze frog or green frog
			<i>R. palustris</i>	pickerel frog
			<i>R. areolata</i>	Carolina gopher frog or crawfish frog
			<i>R. grylio</i>	pig frog
			<i>R. sphenoccephala</i>	southern leopard frog
			<i>Alligator mississippiensis</i>	American alligator
	Chelonia—turtles	Chelydridae Kinosternidae	<i>Chelydra serpentina</i>	common snapping turtle
			<i>Sternotherus odoratus</i>	stinkpot
			<i>Kinosternon inosternon subrubrum</i>	eastern mud turtle
		Emydidae	<i>K. bauri</i>	striped mud turtle
			<i>Chrysemys picta</i>	painted turtle
			<i>Clemmys guttata</i>	spotted turtle
			<i>Terrapene carolina</i>	eastern box turtle
			<i>Pseudemys concinna</i>	river cooter
			<i>P. floridana</i>	Florida cooter
			<i>Deirochelys reticularia</i>	chicken turtle
			<i>Trachemys scripta</i>	slider turtle
		Trionychidae	<i>Trionyx spiniferus</i>	spiny softshell turtle
	Squamata—snakes and lizards			
	Iguanidae	<i>Anolis carolinensis</i>	green anole	
		<i>Sceloporus undulatus</i>	eastern fence lizard	
		Teiidae	<i>Cnemidophorus sexlineatus</i>	six-lined racerunner
			Scincidae	
		Scincidae	<i>Scincella lateralis</i>	ground skink
			<i>Eumeces fasciatus</i>	five-lined skink
			<i>E. laticeps</i>	broad-headed skink
			<i>E. inexpectatus</i>	southeastern five-lined skink
			Anguidae	<i>Ophisaurus ventralis</i>
		<i>O. attenuatus</i>		slender glass lizard
		Colubridae	<i>Nerodia cyclopion</i>	green water snake
			<i>N. taxispilota</i>	brown water snake
	<i>N. erythrogaster</i>		red-bellied water snake	
	<i>N. fasciata</i>		bounded water snake	
	<i>N. sipedon</i> ^a		northern water snake	
<i>N. taxispilota</i>	brown water snake			
<i>Carphophis amoenus</i>	worm snake			
<i>Cemophora coccinea</i>	scarlet snake			
<i>Lampropeltis getulus</i>	common kingsnake			
<i>L. triangulum</i>	scarlet kingsnake			
<i>Pituophis melanoleucus</i>	pine snake			
<i>Regina rigida</i>	glossy crayfish snake			
<i>R. septemvittata</i>	queen snake			
<i>Rhadinaea flavilata</i>	pine woods snake			

Table 3-1. (cont)

Class	Order	Family	Genus Species	Common Name
			<i>Tantilla coronata</i>	southeastern crowned snake
			<i>Seminatrix pygaea</i>	black swamp snake
			<i>Storeria dekayi</i>	brown snake
			<i>S. occipitamaculata</i>	red-bellied snake
			<i>Thamnophis sirtalis</i>	common garter snake
			<i>T. sauritus</i>	eastern ribbon snake
			<i>Virginia valeriae</i>	smooth earth snake
			<i>V. striatula</i>	rough earth snake
			<i>Heterodon platyrhinos</i>	eastern hognose snake
			<i>H. simus</i>	southern hognose snake
			<i>Diadophis punctatus</i>	ringneck snake
			<i>Farancia abacura</i>	mud snake
			<i>F. erythrogramma</i>	rainbow snake
			<i>Coluber constrictor</i>	black racer
			<i>Masticophis flagellum</i>	coachwhip
			<i>Opheodrys aestivus</i>	rough green snake
			<i>Elaphe guttata</i>	corn snake
			<i>E. obsoleta</i>	rat snake
		Elapidae	<i>Micrurus fulvius</i>	eastern coral snake
		Viperidae (= Crotalidae)	<i>Agkistrodon contortrix</i>	copperhead
			<i>A. piscivorus</i>	cottonmouth
			<i>Sistrurus miliarius</i>	pygmy rattlesnake
			<i>Crotalus horridus</i>	timber or canebrake rattlesnake

^aSpecies whose presence on the SRS has been reported but not recently confirmed, or species with which taxonomic problems are associated

Table 3-2. Reptiles and Amphibians Occurring on Sun Bay Study Area or Rainbow Bay Study Area

Genus Species	Common Name
Amphibians	
<i>Necturus punctatus</i> ^a	dwarf waterdog
<i>Amphiuma means</i>	two-toed amphiuma
<i>Siren intermedia</i>	lesser siren
<i>Ambystoma talpoideum</i>	mole salamander
<i>A. opacum</i>	marbled salamander
<i>A. maculatum</i> ^a	spotted salamander
<i>A. t. tigrinum</i>	eastern tiger salamander
<i>Notophthalmus v. viridescens</i>	red-spotted newt
<i>Desmognathus fucus</i>	southern dusky salamander
<i>Plethodon g. glutinosus</i>	slimy salamander
<i>Pseudotriton m. montanus</i>	eastern mud salamander
<i>P. ruber vioscai</i>	southern red salamander
<i>Eurycea cirrigera</i>	southern two-lined salamander
<i>E. longicauda guttolineata</i>	three-lined salamander
<i>E. quadridigitata</i>	dwarf salamander
Frogs and Toads	
<i>Scaphiopus h. holbrooki</i>	eastern spadefoot toad
<i>Bufo terrestris</i>	southern toad
<i>B. quercicus</i>	oak toad
<i>B. woodhousei fowleri</i> ^a	Fowler's toad
<i>Acris g. gryllus</i>	southern cricket frog
<i>Hyla cinerea</i>	green treefrog
<i>H. gr. iosa</i>	barking treefrog
<i>H. femoralis</i>	pine woods treefrog
<i>H. squirella</i>	squirrel treefrog
<i>H. chrysoscelis</i>	gray treefrog
<i>Pseudacris n. nigrita</i>	southern chorus frog
<i>P. ornata</i>	ornate chorus frog
<i>P. c. crucifer</i>	northern spring peeper
<i>P. ocularis</i> ^a	little grass frog
<i>Gastrophryne carolinensis</i>	eastern narrow-mouthed toad
<i>Rana catesbeiana</i>	bullfrog
<i>R. virgatipes</i> ^a	carpenter frog
<i>R. c. clamitans</i>	bronze frog
<i>R. sphenoccephala</i>	southern leopard frog
<i>R. palustris</i> ^a	pickerel frog
<i>R. areolata capito</i>	Carolina gopher frog
Crocodylians	
<i>Alligator mississippiensis</i> ^a	American alligator
Turtles	
<i>Chelydra s. serpentina</i>	common snapping turtle
<i>Sternotherus odoratus</i>	stinkpot
<i>Kinosternon s. subrubrum</i>	eastern mud turtle
<i>K. bauri palmarum</i> ^a	striped mud turtle
<i>Clemmys guttata</i> ^a	spotted turtle
<i>Terrapene c. carolina</i>	eastern box turtle
<i>Trachemys scripta</i>	yellow-bellied turtle
<i>Pseudemys f. floridana</i> ^a	Florida cooter
<i>Deirochelys r. reticularia</i>	eastern chicken turtle

Table 3-2. (cont)

Genus Species	Common Name
Lizards	
<i>Anolis c. carolinensis</i>	green anole
<i>Sceloporus u. undulatus</i>	southern fence lizard
<i>Cnemidophorus s. sexlineatus</i>	six-lined racerunner
<i>Scincella lateralis</i>	ground skink
<i>Eumeces fasciatus</i>	five-lined skink
<i>E. laticeps</i>	broad-headed skink
<i>E. inexpectatus</i>	southeastern five-lined skink
<i>Ophissaurus ventralis</i>	eastern glass lizard
<i>O. attenuatus longicaudus</i>	slender glass lizard
Snakes	
<i>Nerodia cyclopion floridana</i> ^a	Florida green water snake
<i>N. taxispilota</i>	brown water snake
<i>N. e. erythrogaster</i>	red-bellied water snake
<i>N. f. fasciata</i>	banded water snake
<i>Regina r. rigida</i>	eastern glossy water snake
<i>Storeria d. dekayi</i>	northern brown snake
<i>S. o. occipitomaculata</i>	red-bellied snake
<i>Thamnophis s. sirtalis</i>	eastern garter snake
<i>T. s. sauritus</i>	eastern ribbon snake
<i>Heterodon platyrhinos</i>	eastern hognose snake
<i>H. simus</i>	southern hognose snake
<i>Diadophis p. punctatus</i>	southern ringneck snake
<i>Farancia a. abacura</i>	eastern mud snake
<i>F. e. erytrogramma</i>	rainbow snake
<i>Coluber constrictor priapus</i>	southern black racer
<i>Masticophis f. flagellum</i>	eastern coachwhip
<i>Ophedrys aestivus</i>	rough green snake
<i>Elaphe g. guttata</i>	corn snake
<i>E. o. obsoleta</i>	black rat snake
<i>Pituophis m. melanoleucus</i>	northern pine snake
<i>Lampropeltis g. getulus</i>	eastern kingsnake
<i>L. triangulum elapoides</i>	scarlet kingsnake
<i>Cemphora coccinea copei</i>	northern scarlet snake
<i>Tantilla coronata</i>	southeastern crowned snake
<i>Virginia striatula</i> ^a	rough earth snake
<i>V. v. valeriae</i>	eastern earth snake
<i>Micrurus f. fulvius</i> ^a	eastern coral snake
<i>Agkistrodon c. contortrix</i> ^a	southern copperhead
<i>A. p. piscivorus</i>	eastern cottonmouth
<i>Sistrurus m. miliarius</i> ^a	Carolina pygmy rattlesnake
<i>Crotalus horridus atricaudatus</i>	canebrake rattlesnake

Table 3-3. Direction of Movement of All Species of Amphibians and Reptiles Captured (original and recaptured) in Drift Fence and Pitfall Traps at Rainbow Bay and Sun Bay on SRS from April 1, 1981 - March 31, 1982 (Source: Vitt et al. 1982)

Species	Rainbow Bay				Sun Bay			
	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile
Class Amphibia								
Order Caudata								
<i>Ambystoma talpoideum</i>	929	1	527	3	1970	0	697	1
<i>Ambystoma opacum</i>	26	2	22	12	15	3	18	30
<i>Ambystoma t. tigrinum</i>	123	0	97	1	26	0	14	0
<i>Notophthalmus v. viridescens</i>	1548	0	727	0	517	0	507	0
<i>Plethodon g. glutinosus</i>	2	0	3	0	2	0	1	1
<i>Pseudotriton ruber vioscai</i>	2	0	0	0	8	0	2	0
<i>Pseudotriton m. montanus</i>	0	0	0	0	0	0	0	0
<i>Eurycea quadridigitata</i>	166	2	30	23	1	0	1	0
Total	2896	5	1406	39	2539	3	1240	32
Order Anura								
<i>Scaphiopus h. holbrooki</i>	56	2	50	0	26	1	20	0
<i>Bufo terrestris</i>	314	0	313	0	138	0	95	0
<i>Bufo quercicus</i>	13	0	11	0	10	0	9	0
<i>Acris g. gryllus</i>	1	0	0	0	2	0	0	0
<i>Hyla cinerea</i>	1	0	0	0	0	0	0	0
<i>Hyla c. crucifer</i>	72	124	34	784	56	10	21	75
<i>Hyla gratiosa</i>	0	0	1	0	0	0	0	0
<i>Hyla femoralis</i>	3	0	0	0	2	0	1	0
<i>Hyla chrysoscelis</i>	1	0	0	0	2	1	2	0
<i>Pseudacris n. nigrita</i>	109	0	72	3	3	0	1	0
<i>Pseudacris ornata</i>	580	57	303	3107	207	2	128	55
<i>Gastrophryne carolinensis</i>	2299	0	1477	0	316	0	327	0
<i>Rana catesbeiana</i>	0	0	1	0	1	1	0	0
<i>Rana clamitans</i>	2	1	2	1	40	43	28	38
<i>Rana ulricularia</i>	120	0	36	4	8	0	2	0
Total	3571	184	2300	3899	811	58	634	168
Class Reptilia								
Order Chelonia								
<i>Chelydra s. serpentina</i>	0	0	0	0	4	0	2	3
<i>Sternotherus odoratus</i>	0	0	0	0	32	2	16	7
<i>Kinosternon s. subrubrum</i>	20	2	11	1	0	0	0	0
<i>Terrapene c. carolina</i>	1	0	1	0	1	0	1	0
<i>Pseudemys s. scripta</i>	1	0	0	0	0	0	0	0
<i>Deirochelys r. reticularia</i>	3	0	1	0	1	0	1	0
Total	25	2	13	1	38	2	20	10
Order Squamata								
Suborder Lacertilia								
<i>Anolis c. carolinensis</i>	31	5	28	14	15	1	14	1
<i>Sceloporus u. undulatus</i>	2	3	0	0	3	10	6	4
<i>Cnemidophorus s. sexlineatus</i>	3	1	2	0	22	6	32	1
<i>Scincella laterale</i>	2	3	4	0	1	0	1	0
<i>Eumeces laticeps</i>	0	1	0	0	0	1	0	0
Total	38	13	34	14	41	18	53	6

Table 3-3. (cont)

Species	Rainbow Bay				Sun Bay			
	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile
Class Amphibia								
Suborder Serpentes								
<i>Nerodia e. erythrogaster</i>	0	0	1	0	1	0	0	0
<i>Nerodia f. fasciata</i>	3	0	1	0	0	0	0	1
<i>Storeria d. dekayi</i>	1	3	6	0	1	0	0	0
<i>Storeria o. occipitomaculata</i>	24	1	11	0	5	0	3	0
<i>Thamnophis s. sirtalis</i>	0	3	0	3	0	0	0	0
<i>Diadophis p. punctatus</i>	3	1	8	0	5	0	3	0
<i>Farancia a. abacura</i>	3	11	0	4	-	-	-	-
<i>Lampropeltis g. getulus</i>	1	1	1	0	0	0	0	0
<i>Heterodon platyrhinos</i>	0	0	0	0	3	2	1	0
<i>Heterodon simus</i>	0	0	0	0	6	0	2	0
<i>Lampropeltis triangulum elapsoides</i>	0	0	0	0	0	0	1	0
<i>Coluber constrictor</i>	5	3	0	2	3	1	3	1
<i>Cemophora coccinea copei</i>	2	0	2	0	5	0	6	0
<i>Tantilla coronata</i>	28	0	25	0	59	0	42	0
<i>Virginia v. valeriae</i>	8	0	7	0	2	0	3	0
<i>Agkistrodon p. piscivorus</i>	0	0	0	0	1	0	0	0
Total	78	23	62	9	91	3	64	2
Grand total	6608	227	3815	3962	3520	84	2011	218

Table 3-4. Direction of Movement of All Species of Amphibians and Reptiles Captured (original and recaptured) in Drift Fence and Pitfall Traps at Peripheral Areas Associated with Rainbow Bay on the Savannah River Site in South Carolina for One Year (April 1, 1981 - March 31, 1982) (Source: Vitt et al. 1982)

Species	Linda's Pond				Pickerel Pond			
	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile
Class Amphibia								
Order Caudata								
<i>Ambystoma talpoideum</i>	236	0	187	0	226	0	140	0
<i>Ambystoma opacum</i>	21	0	26	0	3	0	2	2
<i>Notophthalmus v. viridescens</i>	9	0	0	0	32	0	23	1
<i>Plethodon g. glutinosus</i>	4	0	3	0	12	8	28	1
<i>Pseudotriton ruber vioscai</i>	0	0	1	0	7	0	29	0
<i>Eurycea quadridigitata</i>	0	0	0	0	7	0	3	0
Total	270	0	217	0	287	8	225	4
Order Anura								
<i>Scaphiopus h. holbrooki</i>	5	0	18	0	8	0	36	0
<i>Bufo terrestris</i>	12	0	26	0	20	0	44	0
<i>Bufo quercicus</i>	0	0	1	0	0	0	0	0
<i>Hyla c. crucifer</i>	0	0	1	0	1	0	17	7
<i>Hyla femoralis</i>	0	0	1	0	0	0	1	0
<i>Pseudacris n. nigrita</i>	0	0	1	0	0	0	1	0
<i>Pseudacris ornata</i>	6	0	5	0	5	1	5	6
<i>Gastrophryne carolinensis</i>	89	3	456	0	19	0	103	0
<i>Rana catesbeiana</i>	2	0	2	5	0	0	0	0
<i>Rana clamitans</i>	2	0	0	0	6	1	2	1
<i>Rana ulricularia</i>	0	0	0	0	6	0	9	0
Total	116	3	511	5	65	2	218	14
Order Chelonia								
<i>Sternotherus odoratus</i>	0	0	0	0	1	0	0	0
<i>Kinosternon s. subrubrum</i>	3	1	1	0	0	0	0	0
<i>Terrapene c. carolina</i>	0	0	2	0	4	0	1	0
<i>Pseudemys s. scripta</i>	0	0	0	0	0	0	0	0
Order Squamata								
Suborder Lacertilia								
<i>Anolis c. carolinensis</i>	0	0	1	0	4	1	5	1
<i>Sceloporus u. undulatus</i>	1	0	6	0	0	0	2	0
<i>Cnemidophorus s. sexlineatus</i>	0	0	0	0	0	0	1	0
<i>Scincella laterale</i>	1	0	0	0	1	0	1	0

Table 3-4. (cont)

Species	Linda's Pond				Pickereel Pond			
	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile	Entering Adult	Entering Juvenile	Exiting Adult	Exiting Juvenile
<i>Eumeces laticeps</i>	0	0	0	0	0	0	1	0
Total	2	0	7	0	5	1	10	1
Suborder Serpentes								
<i>Storeria d. dekayi</i>	0	0	0	0	1	0	0	0
<i>Storeria o. occipitamaculata</i>	0	0	2	0	1	0	7	0
<i>Thamnophis s. sirtalis</i>	0	0	0	0	0	0	0	2
<i>Diadophis p. punctatus</i>	1	0	1	0	3	0	5	0
<i>Farancia a. abacura</i>	0	1	0	3	0	0	0	0
<i>Heterodon platyrhinos</i>	0	0	0	0	0	0	1	0
<i>Heterodon simus</i>	1	0	0	0	0	0	0	0
<i>Lampropeltis triangulum elapsoides</i>	0	0	1	0	0	0	1	0
Class Reptilia								
Order Chelonia								
<i>Coluber constrictor</i>	0	0	0	0	0	0	0	1
<i>Cemophora coccinea copei</i>	1	0	3	0	0	0	2	0
<i>Tantilla coronata</i>	8	0	20	1	3	0	8	0
<i>Virginia v. valeriae</i>	3	0	1	0	0	0	1	0
Total	14	1	28	4	8	0	25	3
Grand total	405	5	766	9	370	11	479	22

Table 3-5. Number of Adult Amphibians Captured Entering the Refuge Ponds During Their Breeding Season from FY-1984 to FY-1988 (total for all four ponds) (Source: Scott et al. 1988)

Species	1984	1985	1986	1987	1988
Salamanders					
<i>Ambystoma talpoideum</i>	9	4	62	59	33
<i>Ambystoma tigrinum</i>	0	0	1	1	0
<i>Notophthalmus viridescens</i>	3	0	9	8	5
<i>Eurycea quadridigitata</i>	1	1	0	0	0
Total	13	5	72	68	38
Frogs and Toads					
<i>Scaphiopus holbrooki</i>	18	11	7	12	5
<i>Bufo terrestris</i>	34	156	161	53	62
<i>Bufo quercicus</i>	4	0	0	0	0
<i>Hyla crucifer</i>	17	27	121	5	28
<i>Hyla femoralis</i>	1	1	0	0	0
<i>Hyla crysoscelis/versicolor</i>	3	2	1	3	0
<i>Pseudacris nigrita</i>	0	2	2	0	0
<i>Pseudacris ornata</i>	4	4	6	0	10
<i>Gastrophryne carolinensis</i>	68	69	36	34	29
<i>Rana catesbeiana</i>	1	0	1	0	0
<i>Rana clamitans</i>	13	5	7	0	0
<i>Rana utricularia</i>	24	14	98	20	21
Total	187	291	440	127	155
Grand total	200	296	512	195	193

Table 3-6. Number of Amphibian Juveniles Produced at DWPF Refuge Ponds During FY-1985 to FY-1988 (Source: Scott et al. 1988)

Species	Pond A				Pond B				Pond D				Total			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988	1985	1986	1987	1988
<i>Ambystoma talpoideum</i>	0	6	1	0	0	32	29	60	0	5	202	142	0	43	232	202
<i>Notophthalmus viridescens</i>	0	11	41	85	0	0	2	0	0	8	1	57	0	19	44	142
<i>Total salamanders</i>	0	17	42	85	0	32	31	60	0	13	203	199	0	62	276	344
<i>Bufo terrestris</i>	50	1	0	3	16	1	0	0	0	14	0	298	66	16	0	301
<i>Acris gryllus</i>	-	-	5	0	-	-	0	0	-	-	13	27	0	0	18	27
<i>Hyla crucifer</i>	306	0	0	97	85	3	0	147	640	1	1	8	1031	4	1	252
<i>Hyla gratiosa</i>	24	10	31	2	100	15	17	16	41	98	5	65	165	123	53	83
<i>Rana catesbeiana</i>	-	-	0	-	-	9	1	-	-	0	0	-	-	-	9	1
<i>Pseudacris ornata</i>	0	0	0	1	0	0	0	6	0	-	0	0	0	-	0	7
<i>Hyla chryso: celis/versicolor</i>	59	0	2	0	77	0	2	0	6	1	0	1	142	1	4	1
<i>Rana utricularia</i>	19	1	21	287	646	6	0	72	0	7	0	0	665	14	21	359
<i>Total frogs and toads</i>	458	12	59	390	924	24	20	241	687	121	19	399	2069	158	106	1031

Table 3-7. Amphibians and Reptiles Found - in the Steel Creek Study Area Between September 1, 1981 and August 20, 1982 (Smith et al. 1982)

Order	Genus Species	Common Name	Captures
Salamanders			122
	<i>Siren iniermedia</i>	greater siren	1
	<i>Siren lacertina</i>	lesser siren	3
	<i>Ambystoma talpoideum</i>	mole salamander	17
	<i>A. opacum</i>	marbled salamander	37
	<i>A. maculatum</i>	spotted salamander	6
	<i>Notophthalmus viridescens</i>	red-spotted newt	6
	<i>Plethodon glutinosus</i>	slimy salamander	30
	<i>Pseudotriton montanus</i>	eastern mud salamander	1
	<i>Eurycea bislineata</i>	southern two-lined salamander	2
	<i>E. longicauda</i>	three-lined salamander	3
	<i>E. quadridigitata</i>	dwarf salamander	16
Frogs and Toads			100
	<i>Scaphiopus holbrooki</i>	eastern spadefoot toad	5
	<i>Bufo terrestris</i>	southern toad	-30
	<i>Acris gryllus</i>	southern cricket frog	-30
	<i>Pseudacris ornata</i>	ornate chorus frog	11
	<i>Hyla crucifer</i>	northern spring peeper	3
	<i>H. cinerea</i>	green treefrog	-40
	<i>H. gratiosa</i>	barking treefrog	2
	<i>Gastrophryne carolinensis</i>	eastern narrow-mouthed toad	1
	<i>Rana catesbeiana</i>	bullfrog	4
	<i>R. clamitans</i>	bronze frog	8
	<i>R. utricularia</i>	southern leopard frog	+100
	<i>R. grylio</i>	pig frog	3
	<i>R. virgatipes</i>	carpenter frog	3
Turtles			108
	<i>Chelydra serpentina</i>	common snapping turtle	3
	<i>Sternotherus odoratus</i>	stinkpot	5
	<i>Kinosternon</i> spp.	mud turtle	7
	<i>Terrapene carolina</i>	eastern box turtle	1
	<i>Pseudemys scripta</i>	pond slider	73
	<i>P. floridana</i>	Florida cooter	11
	<i>P. concinna</i>	river cooter	3
	<i>Deirochelys reticularia</i>	chicken turtle	5
Lizards			33
	<i>Anolis carolinensis</i>	green anole	11
	<i>Sceloporus undulatus</i>	southern fence lizard	2
	<i>Cnemidophorus sexlineatus</i>	six-lined race runner	8
	<i>Eumeces fasciatus</i>	five-lined skink	5
	<i>E. laticeps</i>	broad-headed skink	6
	<i>E. inexpectatus</i>	southeastern five-lined skink	1
Snakes			14
	<i>Nerodia</i> spp.	water snakes	5
	<i>Storeria occipitomaculata</i>	red-bellied snake	3
	<i>S. dekayi</i>	brown snake	1
	<i>Diadophis punctatus</i>	southern ringneck snake	1
	<i>Seminatrix pygaea</i>	swamp snake	1
	<i>Coluber constrictor</i>	black racer	1
	<i>Crotalus horridus</i>	canebrake rattlesnake	2

Figure 3-1. Location of Drift Fences and Pitfall Traps in Steel Creek (1981–1982) and 1982 Turtle Trapping Areas (Source: Smith et al. 1982)

Figure 3-2. Location of Reptile and Amphibian Sampling Transects in the Steel Creek Corridor and Delta, January 1986–December 1987 (Source: Giffin and Patterson 1988)

Table 3-8. Total Number of Each Reptile and Amphibian Species Collected from Sampling Locations in Steel Creek (January 1986 - December 1987) (Patterson and Giffin 1988)

Taxon	1986	1987
marbled salamander	-	1
mole salamander	-	1
two-lined salamander	-	8
slimy salamander	2	12
lesser siren	7	14
greater siren	1	2
cricket frog	1	-
green treefrog	6	5
spring peeper	-	1
gray treefrog	2	1
bullfrog	7	1
bronze frog	25	2
leopard frog	6	24
southern toad	8	-
narrow-mouthed toad	2	-
spadefoot toad	-	1
alligator	7	13
snapping turtle	9	5
river cooter	-	1
chicken turtle	4	-
striped mud turtle	-	1
mud turtle	8	11
Florida cooter	7	10
yellow-bellied slider	82	93
stinkpot	8	9
spiny softshell	3	2
box turtle	1	-
green anole	28	7
six-lined racerunner	2	2
broad-headed skink	1	-
five-lined skink	3	1
ground skink	7	2
eastern glass lizard	-	1
cottonmouth	10	24
black racer	2	1
corn snake	0	1
rainbow snake	1	2
chain king snake	-	1
red-bellied watersnake	1	2
banded watersnake	3	1
brown watersnake	7	15
brown snake	2	1
southeastern crowned snake	0	1
ribbon snake	1	1

Note: Only individuals identified to species are included in this table.

Table 3-9. Total Number of Each Reptile and Amphibian Species Collected from Regions 4-8 of L Lake (January 1986 - December 1987). Animals identified to genus were not included in the total count if a species within that genus was identified. (Source: Patterson and Giffin 1988)

Taxon	1986	1987
amphibians		
marbled salamander	3	-
mole salamander	5	-
red-spotted newt	1	-
slimy salamander	13	1
red salamander	1	-
lesser siren	1	-
narrow-mouthed toad	10	7
green treefrog	1	-
bullfrog	4	-
bronze frog	1	-
leopard frog	5	2
spadefoot frog	3	5
southern toad	11a	7
total	59	22
reptiles		
alligator	1	3
mud turtle	3	1
Florida cooter	2	-
yellow-bellied slider	47	23
box turtle	2	3
spiny softshell	2	1
green anole	43	29
six-lined racerunner	11	16
five-lined skink	6	5
southeastern five-lined skink	3	-
broad-headed skink	6	4
ground skink	17	10
fence lizard	38	27
cottonmouth	3	3
black racer	1	3
canebrake rattlesnake	1	-
corn snake	1	-
rainbow snake	1	-
eastern hognose snake	5	1
southern hognose snake	-	1
coach whip	-	1
red-bellied watersnake	-	1
brown watersnake	7	6
green snake	-	1
red-bellied snake	1	-
southeastern crowned snake	2	6
garter snake	-	1
smooth earth snake	1	-
total	204	146
annual total	263	168

^aDoes not include recently metamorphosed juvenile captured in drift fences in July 1986

Figure 3-3. Location of Reptile and Amphibian Sampling Transects on the L Lake Shoreline (Source: Patterson and Giffin 1988)

Table 3-10. Reptiles and Amphibians of Par Pond (Source: Wilde 1985)

Frogs	
<i>Rana utricularia</i>	leopard frog
<i>Rana catesbeiana</i>	bullfrog
<i>Rana clamitans</i>	green frog
<i>Acris gryllus</i>	cricket frog
<i>Hyla cinerea</i>	green tree frog
<i>Hyla crucifer</i>	spring peeper
<i>Bufo terrestris</i>	southern toad
<i>Bufo quercicus</i>	oak toad
<i>Gastrophryne carolinensis</i>	narrow mouthed toad
Aquatic Salamanders	
<i>Siren intermedia</i>	lesser siren
<i>Amphiuma means</i>	amphiuma
Snakes	
<i>Nerodia fasciata</i>	banded water snake
<i>Nerodia cyclopion</i>	green water snake
<i>Nerodia taxipilots</i>	brown water snake
<i>Agkistrodon piscivorus</i>	cottonmouth
Turtles	
<i>Pseudemys scripta</i>	slider turtle
<i>Pseudemys floridana</i>	Florida cooter
<i>Sternotherus odoratus</i>	musk turtle
<i>Kinosternum subrubrum</i>	mud turtle
<i>Chelydra serpentina</i>	snapper
<i>Deirochelys reticularia</i>	chicken turtle
Crocodylians	
<i>Alligator mississippiensis</i>	American alligator

Figure 3-4. Size Structure of Adult *Pseudemys scripta* from Different Habitats on SRS (Source: Gibbons 1970)

Figure 3-5. Growth Rates of Juvenile *Pseudemys scripta* from Two Populations on SRS (Source: Gibbons 1970)

Figure 3-6. Comparative Population Size Structure of Adult *Pseudemys (Chrysemys) scripta* from Different Habitats in South Carolina (Source: Gibbons 1970)

Avifauna

Birds Found on SRS

The SRS environment supports a diverse and mobile avifauna that includes migrant, seasonal, and permanent residents. Norris (1963) identified 213 species of birds on SRS (Table 3-11). Information on avifauna other than waterfowl on SRS is limited to early research (Norris 1957, 1963), Christmas bird counts (Angerman 1979, 1980), and ecological inventories (Smith et al. 1981; SREL 1979, 1980).

Composite lists of birds observed at Rainbow Bay (Table 3-12 on page 3-29) and Sun Bay (Table 3-13 on page 3-30) are indicative of the wide variety of birds found on SRS. In 1978 the numbers of birds observed at Rainbow Bay doubled in November compared to inventories in September and October, indicating increased usage of the area for overwintering (SREL 1979). A list of birds found in the vicinity of Steel Creek appears in Table 3-14 on page 3-31. This information was compiled from various studies conducted prior to 1981 (Smith et al. 1981).

Table 3-11. Birds of SRS

Scientific Name	Common Name	Residency Status ^a	Location of Sighting ^b	Abundance ^c
<i>Gavia immer</i>	common loon	T. V.	river swamp, Par Pond	2
<i>Podiceps auritus</i>	horned grebe	W. V.	ponds	3
<i>Podilymbus podiceps</i>	pieb-billed grebe	P. R.	ponds	common
<i>Phalacrocorax auritus</i>	double-crested cormorant	W. V.	near ponds	7
<i>Anhinga anhinga</i>	anhinga	S. V.	ponds, creeks	3
<i>Ardea herodias</i>	great blue heron	P. R.	ponds, Carolina bays, creeks	common
<i>Butorides virescens</i>	green heron	S. R.	creeks	uncommon
<i>Florida caerulea</i>	little blue heron	S. V.	ponds	common
<i>Casmerodius albus</i>	great egret	P. R.	Carolina bays, ponds	common
<i>Leucophoxy thula</i>	snowy egret	S. V.	river swamp, ponds	uncommon
<i>Nycticorax nycticorax</i>	black-crowned night heron	T. V.	ponds	2
<i>Nyctanassa violacea</i>	yellow-crowned night heron	S. V.	river swamp, Carolina bays	2
<i>Ixobrychus exilis</i>	least bittern	S. R.	Carolina bays	common
<i>Botaurus lentiginosus</i>	American bittern	W. V.	Carolina bays	uncommon
<i>Mycteria americana</i>	wood stork	S. V.	near creeks	uncommon
<i>Guara alba</i>	white ibis	S. V.	river and Carolina bays	15
<i>Branta canadensis</i>	Canada goose	W. V.	ponds	1
<i>Chen hyperborea</i>	blue/snow goose	T. V. / W. V.	Carolina bays	6
<i>Anas platyrhynchos</i>	mallard	W. V. / S. R.	Carolina bays	common
<i>Anas rubripes</i>	black duck	W. V.	Carolina bays	17
<i>Anas acuta</i>	pintail	W. V.	Carolina bays	1
<i>Anas carolinensis</i>	green-winged teal	W. V.	Par Pond	common
<i>Anas discors</i>	blue-winged teal	T. V.	ponds, Carolina bays	common
<i>Mareca americana</i>	American widgeon	W. F.	ponds	uncommon

Table 3-11. (cont)

Scientific Name	Common Name	Residency Status ^a	Location of Sighting ^b	Abundance ^c
<i>Spatula clypeata</i>	northern shoveler	T. V. / W. V.	Carolina bays	3
<i>Aix sponsa</i>	wood duck	P. R.	river swamp	common
<i>Aythya collaris</i>	ring-necked duck	W. V.	ponds, Carolina bays	common
<i>Aythya valisneria</i>	canvasback	W. V.	ponds	1
<i>Aythya affinis</i>	lesser scaup	T. V.	ponds	uncommon
<i>Glaucionetta albeola</i>	bufflehead	T. V.	ponds	5
<i>Changula hyemalis</i>	oldsquaw	W. V.	Par Pond	1
<i>Erismatura jamaicensis</i>	ruddy duck	T. V.	ponds	uncommon
<i>Lophodytes cucullatus</i>	hooded merganser	W. V.	ponds, streams	uncommon to common
<i>Cathartes aura</i>	turkey vulture	P. R.	ubiquitous	common
<i>Coragyps atratus</i>	black vulture	P. R.	ubiquitous	very common
<i>Ictinia mississippiensis</i>	Mississippi kite	S. R.	lower terraces	uncommon
<i>Accipiter striatus</i>	sharp-shinned hawk	W. V.	ubiquitous	infrequent
<i>Accipiter cooperii</i>	Coopers hawk	P. R.	ubiquitous	common
<i>Buteo jamaicensis</i>	red-tailed hawk	P. R.	piners, powerline poles	common
<i>Buteo lineatus</i>	red-shouldered hawk	P. R.	river swamp, lower terraces	common
<i>Buteo platypterus</i>	broad-winged hawk	S. R.	deciduous woods	rare
<i>Haliaeetus leucocephalus</i>	bald eagle	T. V.	near Par Pond	3
<i>Circus cyaneus</i>	marsh hawk	W. V.	old fields	common
<i>Pandion haliaetus</i>	osprey	T. V.	ponds	16
<i>Falco peregrinus</i>	peregrine falcon	W. V.	near Par Pond	rare
<i>Falco columbarius</i>	pigeon hawk	T. V.	lower terrace	rare
<i>Falco sparverius</i>	American kestrel	P. R.	old field	common
<i>Colinus virginianus</i>	northern bobwhite	P. R.	ubiquitous in ground cover	common
<i>Meleagris gallopavo</i>	wild turkey	P. R.	near streams and swamps	rare
<i>Rallus elegans</i>	king rail	S. R.	Carolina bays	common
<i>Rallus limicola</i>	virginia rail	T. V.	-	rare
<i>Porzana carolina</i>	sora	T. V.	-	uncommon
<i>Porphyryula martinica</i>	purple gallinule	S. R.	Carolina bays	uncommon
<i>Gallinula chloropus</i>	common gallinule	T. V.	Carolina bays, ponds	uncommon
<i>Fulica americana</i>	American coot	W. R.	ponds, Carolina bays	common
<i>Charadrius vociferus</i>	killdeer	P. R.	edges of ponds, bays	uncommon
<i>Philohela minor</i>	American woodcock	P. R.	-	rare
<i>Capella gallinago</i>	common snipe	W. R.	marshes	common
<i>Actitis macularia</i>	spotted sandpiper	T. V.	edges of ponds, streams	common
<i>Tringa solitaria</i>	solitary sandpiper	T. V.	ponds	uncommon
<i>Totanus melanoleucuss</i>	greater yellowlegs	T. V.	ponds	uncommon
<i>Totanus flavipes</i>	lesser yellowlegs	T. V.	-	uncommon
<i>Erolia minutilla</i>	least sandpiper	T. V.	-	uncommon
<i>Crocethia alba</i>	sanderling	T. V.	-	3
<i>Lobipes lobatus</i>	northern phalarope	T. V.	bays	2
<i>Larus delawarensis</i>	ring-billed gull	W. R.	river, ponds	5
<i>Larus philadelphia</i>	Bonaparte's gull	T. V.	ponds	rare
<i>Chlidonias nigra</i>	black tern	T. V.	bays	scarce
<i>Zenaidura macroura</i>	mourning dove	P. R.	fields, oak forests	common
<i>Columbigallina passerina</i>	ground dove	-	Par Pond, streams	5
<i>Coccyzus americanus</i>	yellow-billed cuckoo	S. R.	floodplain, forests	common
<i>Coccyzus erythrophthalmus</i>	black-billed cuckoo	T. V.	-	1
<i>Tyto alba</i>	barn owl	P. R.	terrace forests	2
<i>Otus asio</i>	screech owl	P. R.	trees	few

Table 3-11. (cont)

Scientific Name	Common Name	Residency Status ^a	Location of Sighting ^b	Abundance ^c
<i>Bubo virginianus</i>	great horned owl	P. R.	pine trees	uncommon
<i>Strix varia</i>	barred owl	P. R.	floodplain timber	common
<i>Asio flammeus</i>	short-eared owl	W. V.	fields	common
<i>Caprimulgus carolinensis</i>	Chuck-will's widow	S. R.	forested areas	common
<i>Chordeiles minor</i>	common nighthawk	S. R.	open pineland	common
<i>Chaetura pelagica</i>	chimney swift	S. R.	river swamp	common
<i>Archilochus colubris</i>	ruby-throated hummingbird	S. R.	broadleaf forests	common
<i>Megaceryle alcyon</i>	belted kingfisher	P. R.	ponds, streams	uncommon
<i>Colaptes auratus</i>	yellow-shafted flicker	P. R.	swamp forests	common
<i>Hylatomus pileatus</i>	pileated woodpecker	P. R.	river swamps, floodplain, forests	common
<i>Centurus carolinus</i>	red-bellied woodpecker	P. R.	river swamps, floodplain, forests	common
<i>Melanerpes erythrocephalus</i>	red-headed woodpecker	P. R.	power poles	common
<i>Sphyrapicus varius</i>	yellow-bellied sapsucker	W. V.	mixed forests, swamps	common
<i>Dendrocopos villosus</i>	hairy woodpecker	P. R.	dead timber	uncommon
<i>Dendrocopos pubescens</i>	downy woodpecker	P. R.	broadleaf and mixed forests	common
<i>Dendrocopos borealis</i>	red-cockaded woodpecker	P. R.	pine trees	rare
<i>Tyrannus tyrannus</i>	eastern kingbird	S. R.	open country	abundant
<i>Tyrannus dominicensis</i>	gray kingbird	-	-	1
<i>Tyrannus verticalis</i>	western kingbird	-	-	1
<i>Myiarchus crinitus</i>	great crested flycatcher	S. R.	broadleaf and mixed forests	common
<i>Sayornis phoebe</i>	eastern phoebe	W. V.	near water	common
<i>Empidonax virescens</i>	acadian flycatcher	S. R.	river swamp	abundant
<i>Empidonax trailli</i>	traill's flycatcher	T. V.	-	1
<i>Empidonax minimus</i>	least flycatcher	T. V.	-	1
<i>Contopus virens</i>	eastern wood pewee	S. R.	open mixed woods	common
<i>Eremophila alpestris</i>	horned lark	W. V.	open fields	uncommon
<i>Iridoprocne bicolor</i>	tree swallow	T. V.	-	2
<i>Riparia riparia</i>	bank swallow	T. V.	stream	1
<i>Stelgidopteryx ruficollis</i>	rough-winged swallow	S. R.	clay banks	common
<i>Hirundo rustica</i>	barn swallow	T. V.	-	uncommon
<i>Progne subis</i>	purple martin	S. R.	old house sites	common
<i>Cyanocitta cristata</i>	blue jay	P. R.	woods	common
<i>Corvus brachyrhynchos</i>	common crow	P. R.	pinces and mixed forests	abundant
<i>Cirvyss ossufragus</i>	fish crow	S. R.	floodplain forests, bays	common
<i>Parus carolinensis</i>	Carolina chickadee	P. R.	open wooded areas	common
<i>Parus bicolor</i>	tufted titmouse	P. R.	open wooded areas	common
<i>Sitta carolinensis</i>	white-breasted nuthatch	P. R.	river swamp	uncommon
<i>Sitta pusilla</i>	brown-headed nuthatch	P. R.	open pine forests	common
<i>Certhia familiaris</i>	brown creeper	W. V.	-	rare
<i>Troglodytes aedon</i>	house wren	W. V.	scrubby growth	uncommon
<i>Troglodytes troglodytes</i>	winter wren	W. V.	forest floor	common
<i>Thryomanes bewickii</i>	Bewick's wren	W. V.	brush, wood piles	common
<i>Thryothorus ludovicianus</i>	Carolina wren	P. R.	swamps, floodplain, forests	common
<i>Telmatodytes palustris</i>	long-billed marsh wren	W. V.	Carolina bays	uncommon
<i>Minus polyglottos</i>	mockingbird	P. R.	trees, shrubs	abundant
<i>Dumetella carolinensis</i>	catbird	W. V.	swamp border	common
<i>Toxostoma rufum</i>	brown thrasher	P. R.	thickets	common

Table 3-11. (cont)

Scientific Name	Common Name	Residency Status ^a	Location of Sighting ^b	Abundance ^c
<i>Turdus migratorius</i>	American Robin	W. V.	ubiquitous	common
<i>Hylocichla mustelina</i>	wood thrush	S. R.	floodplain forests	common
<i>Hylocichla guttata</i>	hermit thrush	W. V.	broadleaf and mixed forests	common
<i>Hylocichla ustulata</i>	Swainson's thrush	T. V.	-	uncommon
<i>Hylocichla minima</i>	gray-checked thrush	T. V.	-	rare
<i>Hylocichla fuscescens</i>	veery	T. V.	river swamp	common
<i>Sialia sialis</i>	eastern bluebird	P. R.	open woodlands	abundant
<i>Poliophtila caerulea</i>	blue-gray gnatcatcher	S. R.	ubiquitous	abundant
<i>Regulus satrapa</i>	golden-crowned kinglet	W. R.	broadleaf and mixed forests	common
<i>Regulus calendula</i>	ruby-crowned kinglet	W. R.	forest edges, shrubs	abundant
<i>Anthus spinoletta</i>	water pipit	W. V.	old fields	common
<i>Anthus spragueii</i>	Sprague's pipit	W. V.	fields	rare
<i>Bombycilla cedrorum</i>	cedar waxwing	W. V.	fruit-seeking	common
<i>Lanius ludovicianus</i>	loggerhead shrike	P. R.	open country	common
<i>Sturnus vulgaris</i>	starling	P. R.	-	uncommon
<i>Vireo griseus</i>	white-eyed vireo	S. R.	broadleaf forests	common
<i>Vireo flavifrons</i>	yellow-throated vireo	S. R.	broadleaf and mixed forests	common
<i>Vireo solitarius</i>	solitary vireo	W. V.	river swamp	rare
<i>Vireo olivaceus</i>	red-eyed vireo	S. R.	broadleaf forests, swamp	abundant
<i>Mniotilta varia</i>	black-and-white warbler	T. V.	-	uncommon
<i>Protonotaria citrea</i>	prothonotary warbler	S. R.	swamp, streams	common
<i>Limnothlypis swainsonii</i>	Swainson's warbler	S. R.	swamp, streams	common
<i>Helmitheros vermivorus</i>	worm-eating warbler	T. V.	-	uncommon
<i>Vermivora chrysoptera</i>	golden-winged warbler	T. V.	-	uncommon
<i>Vermivora pinus</i>	blue-winged warbler	T. V.	broadleaf forests	7
<i>Vermivora peregrina</i>	Tennessee warbler	T. V.	-	uncommon
<i>Vermivora celata</i>	orange-crowned warbler	W. V.	-	rare
<i>Vermivora ruficapilla</i>	Nashville warbler	T. V.	-	rare
<i>Parula americana</i>	parula warbler	S. R.	broadleaf forests	abundant
<i>Dendroica petechia</i>	yellow warbler	T. V.	willow borders	uncommon
<i>Dendroica magnolia</i>	magnolia warbler	T. V.	-	uncommon
<i>Dendroica tigrina</i>	Cape May warbler	T. V.	-	uncommon
<i>Dendroica caerulescens</i>	black-throated warbler	T. V.	-	abundant
<i>Dendroica coronata</i>	Myrtle warbler	W. V.	waxmyrtle	common
<i>Dendroica virens</i>	black-throated green warbler	T. V.	-	uncommon
<i>Dendroica cerulea</i>	cerulean warbler	T. V.	-	rare
<i>Dendroica fusca</i>	blackburnian warbler	T. V.	-	uncommon
<i>Dendroica dominica</i>	yellow-throated warbler	S. R.	river swamp, streams	uncommon
<i>Dendroica pennsylvanica</i>	chestnut-sided warbler	T. V.	-	uncommon
<i>Dendroica castanea</i>	bay-breasted warbler	T. V.	-	uncommon
<i>Dendroica striata</i>	blackpoll warbler	T. V.	-	uncommon
<i>Dendroica pinus</i>	pine warbler	P. R.	pinelands	common
<i>Dendroica kirtlandii</i>	Kirtland's warbler	T. V.	-	rare
<i>Dendroica discolor</i>	prairie warbler	S. R.	open pine and scrub oaks	common
<i>Dendroica palmarum</i>	palm warbler	W. R.	open country	common
<i>Seiurus aurocapillus</i>	ovenbird	T. V.	broadleaf forest	abundant
<i>Seiurus noveboracensis</i>	northern waterthrush	T. V.	ponds	common
<i>Seiurus motacilla</i>	Louisiana waterthrush	S. R.	streams	common
<i>Oporornis formosus</i>	Kentucky warbler	S. R.	pond margins, broadleaf forests	common

Table 3-11. (cont)

Scientific Name	Common Name	Residency Status ^a	Location of Sighting	Abundance ^c
<i>Oporornis agilis</i>	Connecticut warbler	T. V.	-	rare
<i>Geothlypis trichas</i>	yellowthroat	P. R.	fields, streams, bays	common
<i>Icteria virens</i>	yellow-breasted chat	S. R.	scrubby areas, lower terraces	common
<i>Wilsonia citrina</i>	hooded warbler	S. R.	river swamp	common
<i>Wilsonia pusilla</i>	Wilson's warbler	T. V.	-	rare
<i>Wilsonia canadensis</i>	Canada warbler	T. V.	-	rare
<i>Setophaga ruticilia</i>	American redstart	T. V.	broadleaf forests	common
<i>Passer domesticus</i>	house sparrow	P. R.	industrial areas	common
<i>Dolichonyx oryzivorus</i>	bobolink	T. V.	fields	common
<i>Sturnella magna</i>	eastern meadowlark	P. R.	fields	common
<i>Sturnella neglecta</i>	western meadowlark	W. V.	-	rare
<i>Agelaius phoeniceus</i>	red-winged blackbird	P. R.	Carolina bays	common
<i>Icterus spurius</i>	orchard oriole	S. R.	old farm sites	common
<i>Icterus galbula</i>	northern oriole	T. V. / W. V.	-	rare
<i>Euphæus carolinus</i>	rusty blackbird	W. V.	river swamp	uncommon
<i>Quiscalus quiscula</i>	common grackle	P. R.	near bays	common
<i>Molothrus ater</i>	brown-headed cowbird	W. V.	fields	uncommon
<i>Piranga olivacea</i>	scarlet tanager	T. V.	broadleaf forest	common
<i>Piranga rubra</i>	summer tanager	S. R.	mixed forest	common
<i>Richmondena cardinalis</i>	cardinal	P. R.	edge growth, hammocks	abundant
<i>Pheucticus ludovicianus</i>	rose-breasted grosbeak	T. V.	-	uncommon
<i>Guiraca caerulea</i>	blue grosbeak	S. R.	grassy fields	common
<i>Passerina cyanea</i>	indigo bunting	S. R.	ubiquitous	common
<i>Passerina ciris</i>	painted bunting	S. R.	lower terraces	common
<i>Carpodacus purpureus</i>	purple finch	W. V.	upland areas	common
<i>Spinus pinus</i>	pine siskin	W. V.	-	rare
<i>Spinus tristis</i>	American goldfinch	P. R.	lower terraces	uncommon to common
<i>Pipilo erythrophthalmus</i>	rufous-sided towhee	P. R.	shrub, pine-oak forests	common
<i>Passerculus sandwichensis</i>	Savannah sparrow	W. R.	old fields	very abundant
<i>Ammodramus savannarum</i>	grasshopper sparrow	W. V.	-	uncommon
<i>Passerherbulus caudatus</i>	LeConte's sparrow	W. V.	-	rare
<i>Passerherbulus henslowii</i>	Henslow's sparrow	T. V.	-	rare
<i>Pooecetes gramineus</i>	vesper sparrow	W. V.	open areas	common
<i>Aimophila aestivalis</i>	Bachman's sparrow	P. R.	pine woods	common
<i>Junco hyemalis</i>	slate-colored junco	W. V.	upland pine-oak	common
<i>Spizella passerina</i>	chipping sparrow	P. R.	pine	common
<i>Spizella pusilla</i>	field sparrow	P. R.	lower terraces	common
<i>Zonotrichia albicollis</i>	white-throated sparrow	W. V.	moist areas	abundant
<i>Passerella iliaca</i>	fox sparrow	P. R.	lower terraces	common
<i>Melospiza lincolni</i>	Lincoln's sparrow	T. V.	-	rare
<i>Melospiza georgiana</i>	swamp sparrow	W. V.	bays, marshy areas	common
<i>Melospiza melodia</i>	song sparrow	W. V.	open, brushy areas	abundant

^a P. R. - Permanent resident

S. R. - Summer resident

S. V. - Summer visitant - nonbreeding

W. V. - Winter visitant - usually regular, fall to spring

Table 3-11. (cont)

T. V. - Transient visitant - spring and/or fall

^b Area where the birds were most commonly observed. Location of sighting is not given for one of the following reasons:

- (1) birds were seen only in migration,
- (2) birds were seen in areas not typical or expected of the species,
- (3) birds were seen only in nearby areas offsite,
- (4) birds were observed only as a result of road kills or kills from collision with a television tower, or
- (5) record was not made of location of bird sighting.

^c Abundance is qualitative where available.

Source: Norris (1963); scientific and common names revised as necessary

Table 3-12. A Composite List of All Birds Observed in the Rainbow Bay Study Area from September 1, 1978 to March 31, 1980 (SREL 1980)

Species	Status	Species	Status	Species	Status
great blue heron	permanent	eastern kingbird	summer	ruby-crowned kinglet	winter
green heron	summer	great-crowned flycatcher	summer	cedar waxwing	winter
little blue heron	summer	eastern phoebe	winter	loggerhead shrike	permanent
cattle egret	migrant	acadian flycatcher	summer	white-eyed vireo	summer
yellow-crowned night heron	summer	least flycatcher	migrant	yellow-throated vireo	summer
white ibis	migrant	eastern wood pewee	summer	solitary vireo	winter
mallard	winter	rough-winged swallow	summer	red-eyed vireo	summer
wood duck	permanent	purple martin	summer	black-and-white warbler	summer
turkey vulture	permanent	blue jay	permanent	prothonotary warbler	summer
black vulture	permanent	orchard oriole	summer	orange-crowned warbler	winter
sharp-shinned hawk	permanent	Brewer's blackbird	winter	Nashville warbler	migrant
Cooper's hawk	permanent	common grackle	permanent	parula warbler	summer
red-tailed hawk	permanent	brown-headed cowbird	permanent	yellow-rumped warbler	winter
red-shouldered hawk	permanent	scarlet tanager	migrant	yellow-throated warbler	summer
broad-winged hawk	summer	summer tanager	summer	pine warbler	permanent
marsh hawk	summer	cardinal	permanent	prairie warbler	winter
American kestrel	permanent	blue gosbeak	summer	palm warbler	winter
northern bobwhite	permanent	indigo bunting	summer	northern waterthrush	migrant
killdeer	permanent	pine siskin	winter	Louisiana waterthrush	
lesser yellowlegs	migrant	American goldfinch	winter	Kentucky warbler	summer
morning dove	permanent	common crow	permanent	Nashville warbler	migrant
yellow-billed cuckoo	summer	fish crow	permanent	yellowthroat	permanent
screech owl	permanent	black-capped chickadee	permanent	yellow-breasted chat	summer
great horned owl	permanent	Carolina chickadee	permanent	hooded warbler	summer
barred owl	permanent	tufted titmouse	permanent	American redstart	migrant
chuck-will's widow	summer	brown-headed nuthatch	permanent	eastern meadowlark	permanent
common nighthawk	summer	brown creeper	winter	red-winged blackbird	permanent
chimney swift	summer	house wren	migrant	rufous-sided towhee	
ruby-throated hummingbird	summer	Carolina wren	permanent	Savannah sparrow	winter
belted kingfisher	permanent	mockingbird	permanent	Bachman's sparrow	permanent
yellow-shafted flicker	permanent	catbird	permanent	slate-colored junco	winter
pileated woodpecker	permanent	brown thrasher	permanent	chipping sparrow	permanent
red-bellied woodpecker	permanent	American robin	permanent	field sparrow	permanent
red-headed woodpecker	permanent	wood thrush	summer	white-crowned sparrow	migrant
yellow-bellied sapsucker	winter	hermit thrush	winter	white-throated sparrow	winter
hairy woodpecker	permanent	Swainson's thrush	migrant	fox sparrow	winter
downy woodpecker	permanent	eastern bluebird	permanent	swamp sparrow	winter
		blue-gray gnatcatcher	summer	song sparrow	winter
		golden-crowned kinglet	winter		

Table 3-13. A Composite List of All Birds Observed in the Sun Bay Study Area from March 1, 1980 to March 31, 1980 (SREL 1980)

Species	Status	Species	Status
cattle egret	migrant	American robin	permanent
great egret	summer	wood thrush	summer
turkey vulture	permanent	hermit thrush	winter
black vulture	permanent	eastern bluebird	permanent
sharp-shinned hawk	permanent	blue-gray gnatcatcher	summer
Cooper's hawk	permanent	golden-crowned kinglet	winter
red-tailed hawk	permanent	ruby-crowned kinglet	winter
red-shouldered hawk	permanent	cedar waxwing	winter
broad-winged hawk	summer	loggerhead shrike	permanent
American kestrel	permanent	white-eyed vireo	summer
northern bobwhite	permanent	yellow-throated vireo	summer
solitary sandpiper	migrant	solitary vireo	winter
white-rumped sandpiper	migrant	red-eyed vireo	summer
mourning dove	permanent	black-and-white warbler	summer
yellow-billed cuckoo	summer	prothonotary warbler	summer
screech owl	permanent	parula warbler	summer
common nighthawk	summer	yellow-rumped warbler	winter
belted kingfisher	permanent	pine warbler	permanent
chimney swift	summer	prairie warbler	summer
yellow-shafted flicker	permanent	palm warbler	winter
pileated woodpecker	permanent	Kentucky warbler	summer
red-bellied woodpecker	permanent	yellowthroat	permanent
red-headed woodpecker	permanent	yellow-breasted chat	summer
yellow-bellied	winter	hooded warbler	summer
sapsucker		American redstart	migrant
hairy woodpecker	permanent	red-winged blackbird	permanent
downy woodpecker	permanent	orchard oriole	summer
eastern kingbird	summer	northern oriole	summer
great-crested flycatcher	summer	rusty blackbird	winter
eastern phoebe	winter	common grackle	permanent
acadian flycatcher	summer	brown-headed cowbird	permanent
barn swallow	summer	scarlet tanager	migrant
blue jay	permanent	summer tanager	summer
common crow	permanent	cardinal	permanent
fish crow	permanent	blue gosbeak	summer
Carolina chickadee	permanent	indigo bunting	summer
tufted titmouse	permanent	American goldfinch	winter
brown-headed nuthatch	permanent	rufous-sided towhee	permanent
brown creeper	winter	Bachman's sparrow	permanent
house wren	migrant	chipping sparrow	permanent
Carolina wren	permanent	field sparrow	permanent
mockingbird	permanent	white-throated sparrow	winter
catbird	permanent	swamp sparrow	winter
brown thrasher	permanent	song sparrow	winter

Table 3-14. Bird Species Recorded in the Vicinity of Steel Creek (Source: Smith et al. 1981)

pied-billed grebe	anhinga	great blue heron
green heron	little blue heron	great egret
white ibis	wood duck	turkey vulture
black vulture	sharp-shinned hawk	red-tailed hawk
red-shouldered hawk	broad-winged hawk	northern bobwhite
wild turkey	purple gallinule	northern phalarope
black tern	mourning dove	yellow-billed cuckoo
screech owl	great horned owl	barred owl
chuck-will's widow	common nighthawk	chimney swift
ruby-throated hummingbird	belted kingfisher	yellow-shafted flicker
pileated woodpecker	red-bellied woodpecker	red-headed woodpecker
yellow-bellied sapsucker	hairy woodpecker	downy woodpecker
red-cockaded woodpecker	eastern kingbird	great crested flycatcher
eastern phoebe	acadian flycatcher	eastern wood pewee
bank swallow	barn swallow	blue jay
common crow	fish crow	Carolina chickadee
tufted titmouse	white-breasted nuthatch	brown-headed nuthatch
house wren	Carolina wren	long-billed marsh wren
mockingbird	catbird	brown thrasher
American robin	wood thrush	hermit thrush
eastern blackbird	blue-gray gnatcatcher	water pipit
white-eyed vireo	yellow-throated vireo	red-eyed vireo
black-and-white warbler	prothonotary warbler	northern parula
yellow-rumped warbler	yellow-throated warbler	pine warbler
prairie warbler	ovenbird	northern waterthrush
Kentucky warbler	yellowthroat	yellow-breasted chat
hooded warbler	American redstart	eastern meadowlark
red-winged blackbird	orchard oriole	common grackle
brown-headed cowbird	summer tanager	cardinal
blue-grosbeak	indigo bunting	painted bunting
rufous-sided towhee	LeConte's sparrow	Bachman's sparrow
chipping sparrow	field sparrow	white-throated sparrow

Waterfowl

Introduction

Waterfowl use most of the suitable habitat available on SRS (Table 3-15) and have been studied more than the upland birds. Mayer et al. (1986) presents extensive information pertaining to waterfowl use of SRS. Large numbers of waterfowl have occurred on SRS since public access to the site was terminated in the early 1950s. Studies have documented 31 species of waterfowl as occurring on SRS. The Savannah River Ecology Laboratory (SREL) has been conducting waterfowl research and surveys onsite for the past 15 years. This research has included work on waterfowl use of SRS, wood duck reproductive biology, and waterfowl wintering ecology (Mayer et al. 1986).

Table 3-15. Locations on the SRS Where Waterfowl Have Been Observed Between 1952 and 1985 (Source: Mayer et al. 1986)

Species - Common Name ^a	Par Pond	Pond C	Pond B	Beaver Dam Creek	Fourmile Branch	Pen Branch	Steel Creek	Upper Three Runs	Carolina Bays	Basins
tundra swan	yes	no	no	no	no	no	no	no	no	no
Canada goose	yes	yes	no	no	no	no	no	no	no	yes
blue/snow goose	no	no	no	no	no	no	no	no	yes	yes
mallard	yes	no	yes	yes	yes	yes	yes	no	yes	yes
American black duck	yes	no	yes	yes	yes	no	yes	no	yes	no
gadwall	yes	yes	yes	yes	yes	no	yes	no	no	no
pintail	yes	no	no	no	no	no	yes	no	yes	no
green-winged teal	yes	no	no	no	no	no	yes	no	no	no
blue-winged teal	yes	no	no	yes	yes	no	yes	no	yes	yes
American wigeon	yes	no	no	yes	yes	no	yes	no	yes	no
northern shoveler	yes	no	yes	no	no	no	yes	no	yes	no
wood duck	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
redhead	yes	no	no	no	no	no	no	no	no	no
ring-necked duck	yes	yes	yes	yes	no	no	yes	no	yes	yes
canvasback	yes	no	no	no	no	no	no	no	no	no
greater scaup	yes	no	no	no	no	no	no	no	no	no
lesser scaup	yes	yes	yes	no	no	no	no	no	no	yes
common goldeneye	yes	no	no	no	no	no	no	no	no	no
bufflehead	yes	yes	yes	no	no	no	yes	no	no	yes
oldsquaw	yes	no	no	no	no	no	no	no	no	no
white-winged scoter	yes	no	no	no	no	no	no	no	no	no
ruddy duck	yes	yes	no	no	no	no	no	no	yes	no
hooded merganser	yes	yes	yes	yes	yes	no	yes	yes	no	yes
red-breasted merganser	yes	no	no	no	no	no	no	no	no	no
common loon	yes	no	no	no	no	no	no	no	no	no
horned grebe	yes	no	no	no	no	no	no	no	yes	no
pied-billed grebe	yes	yes	yes	no	no	no	yes	no	yes	yes
king rail	no	no	no	no	no	yes	no	no	yes	no
common gallinule	yes	no	no	no	no	no	no	no	yes	no
purple gallinule	yes	no	no	no	no	no	no	no	yes	no
American coot	yes	yes	yes	no	no	no	yes	no	yes	yes

^aSee Table 3-11 on page 3-23 for a listing of common names and scientific names of waterfowl species in this volume

Effects of Wetlands Drainage

With the continued drainage of wetlands in the plains region of western Canada and the United States, continental waterfowl numbers are likely to continue to decrease because of reduced productivity and recruitment each year. Waterfowl numbers on SRS will probably reflect these declines, but not to the extent that will probably be observed in other wintering areas in the southeast because of the low human disturbance of wintering waterfowl on SRS. Reduced disturbance allows the wetland areas of SRS to serve as a refuge for these birds (Mayer et al. 1986).

Studies of Waterfowl Populations on SRS

Introduction

Waterfowl use of SRS has been assessed through aerial surveys of the Par Pond system and the Savannah River swamp and through roost counts in the Steel Creek drainage (Figure 3-7). Aerial surveys are the most successful method of estimating waterfowl numbers each winter. The most abundant waterfowl species in the Savannah River swamp (determined by numbers counted) were consistently mallards and wood ducks. Numbers of these species on SRS increased onsite over the four-year period (1981-1985) of the surveys; however, mid-

Figure 3-7. Aquatic Habitats of SRS

winter mallard numbers in both the Atlantic Flyway and in South Carolina decreased during the same time period. More mallards occurred in the SRS Savannah River swamp, the Steel Creek delta and the sloughs between the Fourmile Branch and Pen Branch deltas than in the Beaver Dam Creek or Pen Branch deltas. No differences were found between wood duck counts on the Fourmile Branch delta sloughs, the Steel Creek delta, or the Beaver Dam Creek delta. The Savannah River swamp was used extensively for foraging by both mallards and wood ducks (Mayer et al. 1986).

Par Pond System

Aerial surveys over the Par Pond system were conducted during the winter and early spring from 1981 to 1985. These surveys identified 20 species. Lesser scaup were the most numerous species observed, followed by ring-necked ducks, ruddy ducks, and buffleheads. Over this four-year period, waterfowl numbers on the Par Pond system increased, while midwinter numbers declined in the Atlantic Flyway and South Carolina. Lesser scaup, buffleheads, and ruddy ducks were found in fewer numbers in the North Arm of Par Pond than in all four other areas of Par Pond (Figure 3-8). Ruddy ducks were more frequently observed in the Hot Arm of Par Pond than in the Intake Arm. The other three species were significantly more abundant in the West Arm (Mayer et al. 1986).

Lesser scaup and ring-necked duck counts fluctuated within reactor cycles on Par Pond, although no discernible trends could be attributed to thermal influence (Mayer et al. 1986). Only the ruddy ducks showed differences between the warm and ambient areas of Par Pond during the reactor cycles. Pond C has limited use by waterfowl during the wintering season. The majority of this use is during periods when the reactor is not operating. The abundance of waterfowl species is different on Pond B than on Par Pond, with buffleheads being most frequently sighted, followed by ruddy ducks, lesser scaup, and ring-necked ducks

Figure 3-8. Location Map of the Par Pond System

L Lake

The completion of L Lake in 1985 provided additional habitat for wintering waterfowl on SRS. Waterfowl and other water birds began using L Lake after its completion; data for two partial and one complete migratory season is shown in Table 3-16. As littoral zone plant communities and invertebrate populations increase in this system, waterfowl use will likely increase and become more diversified. There was no decrease in the use of the Par Pond system since waterfowl began using L Lake. If this trend continues, the waterfowl use of SRS will increase as a result of the increase in wintering habitat (Mayer et al. 1986).

Waterfowl and water-associated bird use of L Lake has been monitored from 1986 until present. Species observed from January 1986 through December 1987 are presented in Table 3-17 on page 3-36. Comparison of abundance by lake region and season appear in Figure 3-9 on page 3-36. Increased use by waterfowl species and increasing cumulative taxa richness (Figure 3-10 on page 3-37) suggests that L Lake is becoming similar to Par Pond as habitat for waterfowl use (Patterson and Giffin 1988).

Table 3-16. Number of Waterfowl and Water Birds Observed in Regions 4-8 of L Lake During migratory Season 1 (January - March 1986), Season 2 (October 1986-March 1987), and Season 3 (October-December 1987) (Source: Patterson and Giffin 1988)

Species	Region 4			Region 5			Region 6			Region 7			Region 8		
	Season			Season			Season			Season			Season		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
common loon	-	9	1	-	10	-	-	1	1	-	6	-	-	7	-
pied-billed grebe	-	57	24	3	48	20	-	22	24	-	84	60	-	268	164
horned grebe	-	4	7	-	5	-	-	3	1	-	17	3	-	29	4
double-crested cormorant	58	251	220	-	37	4	30	66	4	3	13	121	15	53	41
anhinga	-	10	-	-	-	-	-	6	8	-	1	2	-	-	-
great blue heron	-	9	21	-	17	25	1	30	11	1	30	60	-	10	24
great egret	1	15	14	-	4	21	1	8	15	1	-	31	1	-	14
cattle egret	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-
green-backed heron	-	-	-	-	3	-	-	2	-	-	-	-	-	-	-
white ibis	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Canada goose	-	-	-	-	-	-	-	-	-	6	-	8	1	-	-
wood duck	-	4	10	-	15	-	6	14	20	1	-	22	-	1	-
mallard	-	-	1	-	-	64	-	-	-	-	-	-	-	-	-
blue-winged teal	-	3	-	-	-	-	2	1	1	10	19	9	4	19	1
lesser scaup	-	-	-	-	11	-	-	-	-	88	1	-	5	-	1
bufflehead	72	-	-	12	-	-	10	7	-	64	16	1	19	22	-
hooded merganser	-	1	-	2	2	-	-	14	-	-	-	-	-	2	-
common merganser	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
red-breasted merganser	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
ruddy duck	-	9	-	-	-	-	-	-	-	-	5	-	-	14	-
unknown waterfowl	4	-	86	1	-	-	-	-	-	19	87	34	-	154	24
American coot	342	411	8	75	275	49	2	185	239	4	135	37	5	230	25
number of species	4	13	10	4	11	6	7	14	10	9	11	11	7	11	8

Table 3-17. Waterfowl and Associated Avian Species Observed on L Lake (January - December 1987) (Source: Patterson and Giffin 1988)

Scientific Name	Common Name
<i>Branta canadensis</i>	Canada goose
<i>Anas platyrhynchos</i>	Mallard
<i>Anas discors</i>	Blue-winged teal
<i>Aix sponsa</i>	Wood duck
<i>Aythya affinis</i>	Lesser scaup
<i>Bucephala albeola</i>	Bufflehead
<i>Lophodytes cucullatus</i>	Hooded merganser
<i>Mergus serrator</i>	Red breasted merganser
<i>Casmerodius albus</i>	Great egret
<i>Bubulcus ibis</i>	Cattle egret
<i>Ardea herodias</i>	Great blue heron
<i>Fulica americana</i>	American coot
<i>Podilymbus podiceps</i>	Pied-billed grebe
<i>Podiceps auritus</i>	Horned grebe
<i>Phalacrocorax auritus</i>	Double-crested cormorant
<i>Anhinga anhinga</i>	Anhinga
<i>Gavia immer</i>	Common loon

Figure 3-9. Total Number of Waterfowl and Associated Avian Species Observed in Regions 4-8 of L Lake (Source: Patterson and Giffin 1988)

Figure 3-10. Cumulative Waterfowl and Associated Avian Species Taxa Richness in Regions 4–8 of L Lake (January 1986–December 1987) (Source: Patterson and Giffin 1988)

Nest Box Surveys

Wood ducks are the only waterfowl species to breed commonly on SRS. Nest box surveys were conducted on SRS between 1973 and 1985 (Mayer et al. 1986). In the 1985 nesting season, nest initiations and duckling production were down from 1984 because of lower water levels at the nest sites. Dump nesting was found to be a common behavior among wood duck hens on SRS. Use of nest boxes by other species, such as the redheaded woodpecker, has only slightly reduced nest box availability for wood ducks. Mark-recapture studies of wood ducks in the Steel Creek delta were used to estimate a population size of 29 to 63 breeding females and recruitment at 10 to 37 females per year.

Upland Game Birds

Information regarding upland game birds can be found in “Commercially and Recreationally Valuable Biota” on page 3-47

Threatened and Endangered Birds

Information regarding birds found on SRS that are listed as threatened or endangered (bald eagle, red-cockaded woodpecker, wood stork) can be found in Chapter 21—Threatened and Endangered Species.

Mammals

Introduction

Table 3-18 on page 3-40 lists 54 of the 57 species of mammals found in South Carolina (Golley 1966) that may occur on SRS (Cothran et al. 1991). The variety of available habitat contributes to the diversity of mammal species. The distribution of species by habitat type for the five major habitats on SRS is shown in Table 3-19 on page 3-42. There are eight species that potentially could occur on SRS whose presence has not been confirmed. They include the cougar, white-footed mouse, swamp rabbit, big brown bat, hoary bat, Brazilian free-tailed bat, little brown bat, and the southeastern bat. Several introduced mammal species are present on SRS, including the feral dog, feral cat, feral swine, house mouse, Norway rat, and black rat. The feral swine is the only one of these species that occurs in large numbers; it is hunted for population control. Further information on the feral swine can be found on page 3-49.

Commercially or recreationally valuable mammals include game, edible, and fur-bearing species. These are listed in Table 3-20 on page 3-43 and are covered in greater detail in "Commercially and Recreationally Valuable Biota" on page 3-47.

Studies Of Mammal Populations on SRS

Biological inventories of mammals have been conducted in two areas of SRS—the Defense Waste Processing Facility site (SREL 1980) and the designated Away From Reactor site (SREL 1979). In addition, data from collections and sightings of mammals in the Steel Creek area during the summer of 1981 were summarized in Smith et al. (1981). Table 3-21 on page 3-43 lists the mammals of the Steel Creek area taken from drift fences, pitfall traps, and board transects; species collected or observed; and species expected to inhabit the area.

The mammals found in the Sun Bay and Rainbow Bay study areas are shown in Table 3-22 on page 3-44, Table 3-23 on page 3-44, and Table 3-24 on page 3-45. Table 3-22 summarizes capture data and rank of species of small mammals caught in drift fences in the areas of the two Carolina bays studied during the biological inventory of the DWPF site (Smith et al. 1981). Table 3-23 shows data on bats collected in areas near Sun Bay and Rainbow Bay. The larger mammals actually trapped, observed, or whose tracks were observed are shown in Table 3-24. Data for small mammal numbers and rank by season and habitat type are shown in Table 3-25 and Table 3-26 on page 3-45, respectively.

Table 3-18. Mammals of the Savannah River Site Phylogenetic Listing^a (Source: Cothran et al. 1991)

Order	Family	Genus Species	Common Name
Marsupialia	Didelphidae	<i>Didelphis virginiana virginiana</i>	opossum
Insectivora	Soricidae	<i>Blarina carolinensis carolinensis</i>	short-tailed shrew
		<i>Cryptotis parva parva</i>	least shrew
		<i>Sorex longirostris longirostris</i>	southeastern shrew
	Talpidae	<i>Condylura cristata parva</i>	star-nosed mole
		<i>Scalopus aquaticus howelli</i>	eastern mole
Chiroptera	Vespertilionidae	<i>Eptesicus fuscus fuscus</i>	big brown bat
		<i>Lasionycteris noctivagans</i>	silver-haired bat
		<i>Lasiurus borealis borealis</i>	red bat
		<i>Lasiurus cinereus cinereus</i>	hoary bat
		<i>Lasiurus intermedius floridana</i>	northern yellow bat
		<i>Lasiurus seminolus</i>	seminole bat
		<i>Myotis austroriparius</i>	southeastern bat
		<i>Myotis lucifugus lucifugus</i>	little brown bat
		<i>Nycticeius humeralis humeralis</i>	evening bat
		<i>Pipistrellus subflavus subflavus</i>	eastern pipistrelle
		<i>Plecotus rafinesquii macrotis</i>	big-eared bat
Xenarthra	Dasypodidae	<i>Dasypus novemcinctus mexicanus</i>	nine-banded armadillo
Lagomorpha	Leporidae	<i>Sylvilagus aquaticus aquaticus</i>	swamp rabbit
		<i>Sylvilagus floridanus mallurus</i>	eastern cottontail
		<i>Sylvilagus palustris palustris</i>	marsh rabbit
Rodentia	Cricetidae	<i>Neotoma floridana floridana</i>	eastern wood rat
		<i>Ochrotomys nuttallii nuttallii</i>	golden mouse
		<i>Oryzomys palustris palustris</i>	rice rat or marsh rice rat
		<i>Peromyscus gossypinus gossypinus</i>	cotton mouse
		<i>Peromyscus leucopus leucopus</i>	wood mouse or white-footed mouse
		<i>Peromyscus polionotus lucubrans</i>	old field mouse
		<i>Reithrodontomys humulis humulis</i>	eastern harvest mouse
		<i>Sigmodon hispidus komareki</i>	hispid cotton rat
		<i>Microtus pinetorum pinetorum</i>	pine vole
		<i>Ondatra zibethicus zibethicus</i>	muskrat
	Muridae	<i>Mus musculus brevirostris</i>	house mouse
		<i>Rattus norvegicus norvegicus</i>	norway rat or brown rat
		<i>Rattus rattus rattus</i>	roof rat or black rat
	Castoridae	<i>Castor canadensis carolinensis</i>	beaver
	Sciuridae	<i>Glaucomys volans saturatus</i>	southern flying squirrel
		<i>Sciurus carolinensis carolinensis</i>	eastern gray squirrel
		<i>Sciurus niger niger</i>	eastern fox squirrel
Carnivora	Canidae	<i>Canis latrans frustror</i>	coyote
		<i>Canis familiaris</i>	feral dog
		<i>Urocyon cinereoargenteus cinereoargenteus</i> and <i>U. c. floridanus</i>	gray fox
		<i>Vulpes vulpes fulva</i>	red fox
	Felidae	<i>Felis catus</i>	feral cat
		<i>Felis concolor coryi</i>	mountain lion (puma, cougar, panther)
		<i>Felis rufus floridanus</i>	bobcat
	Mustelidae	<i>Lutra canadensis lataxina</i>	river otter
		<i>Mephitis mephitis elongata</i>	striped skunk
		<i>Mustela frenata olivacea</i>	long-tailed weasel
		<i>Mustela vison mink</i>	mink

Order	Family	Genus Species	Common Name
Artiodactyla		<i>Spilogale putorius putorius</i>	eastern spotted skunk
	Procyonidae	<i>Procyon lotor solutus</i>	raccoon
	Ursidae	<i>Ursus americanus americanus</i>	black bear
	Cervidae	<i>Odocoileus virginianus virginianus</i>	white-tailed deer
	Suidae	<i>Sus scrofa</i>	feral swine

*Modified from Simpson (1945)

Table 3-19. Mammal Species Found in the Five Major Habitats at SRS (Source: Cothran et al. 1991)^a

Mammal Species	Old Fields and Clearcuts	Pine Plantations	Scrub Oak Longleaf Pine	Upland and Lowland Hardwoods	Aquatic and Semi-Aquatic
<i>Blarina carolinensis</i>	X	X	X		
<i>Castor canadensis</i>					X
<i>Condylura cristata</i>	X				X
<i>Cryptotis parva</i>	X	X		X	
<i>Didelphis virginiana</i>	X	X	X	X	
<i>Felis rufus</i>	X		X	X	
<i>Glaucomys volans</i>				X	
<i>Lasionycteris noctivagans</i>				X	
<i>Lasiurus borealis</i>	X	X		X	
<i>Lasiurus intermedius</i>				X	
<i>Lasiurus seminolus</i>		X		X	
<i>Lutra canadensis</i>					X
<i>Mephitis mephitis</i>	X	X		X	
<i>Microtus pinetorum</i>	X			X	
<i>Mustela frenata</i>	X			X	
<i>Mustela vison</i>				X	X
<i>Neotoma floridana</i>	X			X	
<i>Nycticeius humeralis</i>		X		X	
<i>Ochrotomys nuttalli</i>	X	X	X	X	
<i>Odocoileus virginianus</i>	X	X	X	X	
<i>Ondatra zibethicus</i>					X
<i>Oryzomys palustris</i>	X			X	X
<i>Peromyscus gossypinus</i>	X	X		X	
<i>Peromyscus polionotus</i>	X	X	X		
<i>Pipistrellus subflavus</i>		X		X	
<i>Plecotus ratinesquii</i>				X	
<i>Procyon lotor</i>	X	X	X	X	X
<i>Reithrodontomys humilis</i>	X	X			
<i>Scalopus aquaticus</i>	X		X	X	
<i>Sciurus carolinensis</i>		X	X	X	
<i>Sciurus niger</i>		X	X		
<i>Sigmodon hispidus</i>	X				
<i>Sorex longirostris</i>	X	X			
<i>Spilogale putorius</i>	X	X		X	
<i>Sus scrofa</i>	X	X		X	
<i>Sylvilagus floridanus</i>	X	X	X	X	
<i>Sylvilagus palustris</i>				X	X
<i>Urocyon cinereoargenteus</i>	X		X	X	
<i>Ursus americanus</i>				X	
<i>Vulpes vulpes</i>	X				

^aX indicates that a species is likely to be found in the habitat.

Table 3-20. Game, Edible, and Fur-Bearing Mammals of the SRS (Source: Cothran et al. 1991)

Genus Species	Common Name
<i>Odocoileus virginianus</i>	white-tailed deer
<i>Sylvilagus floridanus</i>	eastern cottontail
<i>Sciurus carolinensis</i>	gray squirrel
<i>Sciurus niger</i>	fox squirrel
<i>Urocyon cinereoargenteus</i>	gray fox
<i>Vulpes vulpes</i>	red fox
<i>Felis rufus</i>	bobcat
<i>Procyon lotor</i>	raccoon
<i>Didelphis virginiana</i>	opossum
<i>Ursus americana</i>	black bear
<i>Sus scrofa</i>	feral swine
<i>Mustela vison</i>	mink
<i>Lutra canadensis</i>	otter
<i>Castor canadensis</i>	beaver
<i>Ondatra zibethicus</i>	muskrat

Table 3-21. Mammals of Steel Creek Area (Source: Smith et al. 1981)

Genus Species	Common Name
<i>Blarina carolinensis</i>	short-tailed shrew
<i>Oryzomys palustris</i>	rice rat
<i>Cryptotis parva</i>	least shrew
<i>Sorex longirostris</i>	southeastern shrew
<i>Condylura cristata</i>	star-nosed mole
<i>Microtus pinetorum</i>	pine vole
<i>Ochrotomys nuttalli</i>	golden mouse
<i>Peromyscus</i> spp.	white-footed/deer mouse
<i>Scalopus aquaticus</i>	eastern mole
<i>Neotoma floridana</i>	eastern wood rat
<i>Sigmodon hispidus</i>	hispid cotton rat
<i>Sciurus carolinensis</i>	gray squirrel
<i>Sciurus niger</i>	fox squirrel
<i>Glaucomys volans</i>	flying squirrel
<i>Odocoileus virginianus</i>	white-tailed deer
<i>Sus scrofa</i>	feral swine
<i>Ursus americana</i>	black bear
<i>Procyon lotor</i>	raccoon
<i>Didelphis virginiana</i>	opossum
<i>Urocyon cinereoargenteus</i>	gray fox
<i>Castor canadensis</i>	beaver
<i>Lutra canadensis</i>	otter
<i>Mustela frenata</i>	weasel
<i>Mustela vison</i>	mink
<i>Mephitis mephitis</i>	striped skunk
<i>Sylvilagus palustris</i>	marsh rabbit
<i>Ondatra zibethicus</i>	muskrat
<i>Felis rufus</i>	bobcat
Vespertilionidae	bat species

Table 3-22. Species, Number of Individuals, and Rank of Small Mammals Caught in Drift Fences at the Rainbow Bay and Sun Bay Study Areas (Source: SREL 1980)^a

Species	Rainbow Bay No. of Captures	Rank	Sun Bay No. of Captures	Rank
Shrews				
<i>Sorex l. longirostris</i> , southeastern shrew	5	4	0	
<i>Blarina carolinensis</i> , short-tailed shrew	32	2	2	2
<i>Cryptotis p. parva</i> , least shrew	3	5	0	
Unid. shrew	89	-	29	
Moles				
<i>Scalopus aquaticus</i> , eastern mole	2	6	0	
<i>Condylura cristata parva</i> , star-nosed mole	1	7	0	
Cricetids				
<i>Reithrodontomys h. humulis</i> , eastern harvest mouse	157	1	1	3
<i>Ochrotomys nuttali aureolus</i> , golden mouse	2	6	0	
<i>Peromyscus polionotus</i> , old-field mouse	1	7	0	
<i>Peromyscus g. gossypinus</i> , cotton mouse	0	-	1	3
<i>Neotoma floridana</i> , eastern wood rat	0	-	1	3
<i>Sigmodon hispidus</i> , hispid cotton rat	14	3	4	
<i>Microtus p. pinetorum</i> , pine vole	5	4	4	
Unid. mouse	21	-	26	
Total	332	-	68	

^a Each species is ranked according to its relative abundance in samples; species of equal abundance are ranked the same.

Table 3-23. Species and Number of Bats Collected at o. Near the Rainbow Bay and Sun Bay Study Areas During Two Sampling Periods, June 26 - July 1, 1979 and August 20-24, 1979 (SREL 1980)

Species	Rainbow Bay	Dick's Pond	Sun Bay	Beaver Pond
<i>Pipistrellus subflavus subflavus</i> , eastern pipistrelle	0	4	0	4
<i>Lasiurus seminolus</i> , Seminole bat	1	5	1	2
<i>Lasiurus b. borealis</i> , red bat	1	0	0	0
<i>Lasiurus</i> spp., Unknown <i>Lasiurus</i>	1	1	1	1
<i>Nycticeius h. humeralis</i> , evening bat	0	1	0	1
Total	3	11	2	8

Table 3-24. Large Mammal Species on the Rainbow Bay and Sun Bay Study Areas (Source: SREL 1980)^a

Species	Rainbow Bay			Sun Bay		
	Trapped	Visual Obser.	Track Obser.	Trapped	Visual Obser.	Track Obser.
<i>Procyon lotor</i> - raccoon	x	x	x	x		x
<i>Sylvilagus</i> spp. - rabbit		x	x		x	x
<i>Sylvilagus floridanus</i> - eastern cottontail	x	x		x		
<i>Sciurus niger</i> - fox squirrel					x	
<i>Sciurus carolinensis</i> - gray squirrel	x	x		x		
<i>Vulpes vulpes</i> - red fox	x		x			x
<i>Urocyon cinereoargenteus</i> - gray fox	x	x	x			x
<i>Odocoileus virginianus</i> - whitetail deer		x	x		x	x
<i>Spilogale putorius</i> - spotted skunk		x				
<i>Mephitis mephitis</i> - striped skunk	x	x				
<i>Castor canadensis</i> - beaver			x			
<i>Felis rufus</i> - bobcat	x	x	x			
<i>Didelphis virginiana</i> - opossum				x		
<i>Mustela vison</i> - mink						x

^a X indicates that at least one individual was trapped, sighted, or that its tracks were observed.

Table 3-25. Species, Number of Individuals, and Rank of Small Mammals Trapped Each Season for 10-day Periods at the Sun Bay Study Area (Source: SREL 1980)^a

Species	Winter		Spring		Summer	
	No. of Captures	Rank	No. of Captures	Rank	No. of Captures	Rank
<i>Blarina carolinensis</i> - short-tailed shrew	1	4	1	2	6	3
<i>Oryzomys palustris palustris</i> - rice rat	1	4	0	-	0	-
<i>Peromyscus polionotus</i> - old-field mouse	5	2	1	2	0	-
<i>Peromyscus gossypinus gossypinus</i> - cotton mouse	15	1	9	1	16	1
<i>Ochrotomys nuttali aureolus</i> - golden mouse	2	3	1	2	7	2
<i>Sigmodon hispidus</i> - hispid cotton rat	1	4	0	-	0	-
Total	25		12		29	

^a Each species is ranked according to its relative abundance in samples; species of equal abundance are ranked the same.

Table 3-26. Species and Number of Individuals of Small Mammals Trapped in Four Habitats for 10-day Periods During Three Seasons at the Sun Bay Study Area (Source: SREL 1980)^a

Species	Habitat Clearcut	Lowland Hardwoods	Upland Hardwoods	Pine Plantation
<i>Blarina carolinensis</i> - short-tailed shrew	1	3	3	1
<i>Oryzomys palustris palustris</i> - rice rat	0	1	0	0
<i>Peromyscus polionotus</i> - old field mouse	5	0	0	
<i>Peromyscus gossypinus gossypinus</i> - cotton mouse	2	26	8	4
<i>Ochrotomys nuttali aureolus</i> - golden mouse	1	8	1	0
<i>Sigmodon hispidus</i> - hispid cotton rat	1	0	0	0
Total	10	38	12	6
Habitat rank	3	1	2	4

^a Each habitat is ranked according to the abundance of species in samples; habitats of equal abundance are ranked the same.

Commercially and Recreationally Valuable Biota

Unexploitable Resources

Introduction

Many potentially valuable commercial and recreational wildlife resources on SRS are not exploited due to restricted access. Animals that could be commercially trapped or recreationally hunted include bobcat, beaver, fox, mink, muskrat, opossum, otter, rabbit, raccoon, skunk, squirrel, migratory waterfowl, bobwhite, dove, wild turkey, snipe, and woodcock.

Wild Turkeys

In 1972 the South Carolina Wildlife and Marine Resources Department (SCWMRD) began a wild turkey propagation program on SRS to provide birds for relocation into other areas of the state. The SCWMRD released 36 turkeys on SRS during the winters of 1972-1974 and planted food crops in openings to supplement natural forage and facilitate trapping. Approximately 50 openings were provided by 1986 when the plantings were discontinued. Turkey trapping began in 1977 and continued annually until 1986 when demand for stock turkeys dropped. No trapping occurred in 1987 and 1988. Trapping resumed in 1989 due to an increase in demand. In 1991 and 1992, some of the wild turkeys trapped on SRS were given to the State of North Carolina at the request of the North Carolina Wildlife Resource Commission for stocking new areas of that state. Since 1977, a total of 470 turkeys have been trapped on SRS, and 440 have been removed. A summary of turkey trapping and removal is shown in Table 3-27 (Caudell 1993).

Table 3-27. Summary of Numbers of Wild Turkeys Trapped and Removed by the SRS Wild Turkey Trapping Program (1977 to 1993) (Source: Caudell 1993)

Year	Turkeys Trapped			Turkeys Removed		
	Male	Female	Total	Male	Female	Total
1977	12	8	20	12	4	16
1978	12	-	12	12	-	12
1979	10	6	16	6	6	12
1980	7	4	11	7	4	11
1981	6	-	6	6	-	6
1982	0	1	1	0	0	0
1983	44	19	63	44	19	63
1984	27	38	65	26	38	64
1985	12	13	25	11	11	22
1986	4	8	12	4	8	12
1987	-	-	-	-	-	-
1988	-	-	-	-	-	-
1989	9	22	31	9	21	30
1990	8	-	8	8	-	8
1991	32	25	57	32	9	41
1992	38	66	104	38	66	104
1993	11	28	39	11	28	39
Total	232	238	470	226	214	440

Mammals

Commercially or recreationally valuable mammals include game, edible, and fur-bearing species; these are listed in Table 3-20 on page 3-43. The fur-bearing mammals of SRS, although not an exploitable resource, have been extensively studied through a census program that began in 1954 and continued until 1982. Annual numbers of the six most commonly captured species appear in Table 3-28. There have been wide fluctuations in both numbers of individuals and species composition over the years of the survey and may be a function of the change in habitat type since the closure of the site to the public (Cothran et al. 1991).

As a result of damage and nuisance problems, SRFS began a control trapping program in 1983 for beavers on SRS. Since initiation of this program, 817 beavers have been trapped onsite (Table 3-29 on page 3-49).

Table 3-28. Number of Furbearers Captured-Yearly During the Annual Furbearers Census (Source: Cothran et al. 1991)

Year	Total Number	Gray Fox	Bobcat	Raccoon	Opossum	Striped Skunk	Red Fox
1954	123	73	14	20	4	2	10
1955	48	24	5	13	1	5	0
1956	71	35	12	15	2	0	7
1957	47	32	2	7	1	2	3
1958	36	20	~	9	3		
1959	38	21	3	10	1	2	
1960	56	22	8	16	3	3	4
1961	45	19	7	12	0	0	7
1962	58	35	6	9	3	2	3
1963	35	26	3	4	0		
1964	56	36	2	14	2	2	0
1965	70	41	3	18	6	0	2
1966	46	8	10	19	8	0	
1967	39	18	10	5	6	0	0
1968	72	22	5	28	15	2	0
1969	49	18	7	10	4	9	
1970	47	24	5	7	7	4	0
1971	18	6	2	1	8	1	0
1972	48	1	1	10	28	8	0
1973	29	5	3	6	15	0	0
1974	42	8	2	10	19	3	0
1975	40	16	0	8	16	0	0
1976	33	15	3	3	10	1	0
1977	47	5	0	11	30		
1978	42	9	2	9	22	0	0
1979	77	18	4	12	41	2	0
1980	138	45	5	38	47	3	0
1981	50	9	8	8	25	0	0
1982	65	2	1	5	56	1	0
Total	1565	613	135	337	383	55	42

Table 3-29. Annual Number of Beavers Trapped on the SRS (Source: SRFS 1993)

Year	Number of Beavers Trapped Per Year
1983	196
1984	44
1985	192
1986	148
1987	84
1988	0
1989	0
1990	0
1991	0
1992	153
Total	817

Exploitable Resources

Introduction

Organized fall hunts for white-tailed deer and feral swine are the only allowable recreational hunting use of SRS by the public. The purpose of these hunts is to control the site's deer and swine populations, reduce animal-vehicle accidents, and reduce depredations to SRFS pine regeneration areas by the feral swine.

White-Tailed Deer

The SRS deer herd, estimated to be as low as 25 animals in 1951, increased rapidly after the site was closed to the public. Annual estimates of the deer herd from 1965 through 1992 appear in Table 3-30 on page 3-50. By the early 1960s, deer-vehicle collisions were a frequent occurrence. This and the potential for habitat degradation prompted the institution of controlled public hunts in 1965 (Langley and Marter 1973). The public hunts were managed by SRFS from 1965 to 1980, E. I. du Pont de Nemours from 1981 to 1988, and WSRC after 1989. From 1965 to 1992, a total of 29,702 white-tailed deer were killed during the public hunts (Table 3-30); the average annual kill was 1100.

Feral Swine

The SRS feral swine population originated from free-ranging domestic swine that were abandoned after the resident farmers were relocated in 1952. These animals have reproduced and expanded their distribution throughout the southwestern portion of SRS along the Savannah River. In the late 1970s, a second, small population of feral swine was discovered along the Upper Three Runs drainage corridor in the northern part of the site. Based on morphological criteria, this second population was determined to not be derived from the original feral population along the Savannah River. This second population has subsequently expanded throughout the northern half of SRS and finally merged with the distribution of the original population in the late 1980s. The resulting combined SRS feral swine population currently inhabits approximately 70 percent of the site's total area (Mayer and Brisbin 1991). From 1965 to 1992, 2083 feral swine were killed during the public hunts (Table 3-31 on page 3-51), the average annual kill was 77 swine.

As a result of an increase in both the size of the population and the damage being caused by the feral swine on the SRS, SRFS implemented a subcontract in 1985 to control the numbers of these animals onsite. Between 1985 and 1991, only corral traps baited with corn were used in this effort. In 1992, the subcontractor was also allowed to use trained hunting dogs to catch feral swine for removal. Between 1985 and 1992, 2059 feral swine were removed from SRS, with an average of 294 swine being taken annually (Table 3-31).

Table 3-30. Annual SRS White-tailed Deer Population Estimate and Harvest Data (Sources: Novak et al. 1991; WSRC 1992; Cothran et al. 1991)

Year	Estimated Population	Deer/ Vehicle Accidents	Public Hunt Harvest Data			
			Number of Bucks	Number of Does	Total Annual Harvest	Mean Age of Deer (in years)
1965	2591	19	80	118	198	2.00
1966	3074	16	244	297	541	1.85
1967	3081	30	481	551	1032	1.70
1968	2903	51	332	366	699 ^a	1.63
1969	4070	63	443	445	888	1.54
1970	4248	58	417	447	864	1.67
1971	4475	48	418	446	864	1.68
1972	4677	50	403	405	808	1.70
1973	5250	62	511	570	1081	1.64
1974	5302	44	728	823	1551	1.80
1975	4701	48	519	519	1038	1.75
1976	4657	23	665	592	1257	1.81
1977	4089	35	620	651	1271	1.83
1978	3846	34	625	659	1284	1.75
1979	4163	25	550	528	1078	1.70
1980	4793	28	481	480	961	1.65
1981	5368	58	832	959	1791	1.64
1982	5157	49	987	1076	2063	1.68
1983	4247	41	732	865	1597	1.69
1984	3661	41	499	541	1040	1.75
1985	3770	38	487	532	1019	1.64
1986	3553	34	474	464	938	1.65
1987	3492	38	308	294	602	1.70
1988	3962	51	453	398	851	1.71
1989	4364	64	405	307	712	1.80
1990	4885	93	549	514	1063	1.89
1991	5375	104	576	516	1092	1.91
1992	5909	111	790	729	1519	1.70
Selected Totals		1356	14609	15092	29702	

^aOne deer was not sexed.

Table 3-31. Annual SRS Feral Swine Harvest Data (Source: Savereno and Findley 1989, and SRFS 1993)

Year	Public Hunt Harvest	SRFS Subcontract Trapper Harvest	Total Combined Annual Harvest
1965-1969	36	-	36
1970	34	-	34
1971	10	-	10
1972	17	-	17
1973	12	-	12
1974	38	-	38
1975	45	-	45
1976	176	-	176
1977	57	-	57
1978	28	-	28
1979	61	-	61
1980	32	-	32
1981	33	-	33
1982	189	-	189
1983	133	-	133
1984	104	-	104
1985	79	160	239
1986	123	238	361
1987	123	170	293
1988	146	326	472
1989	179	177	356
1990	134	302	436
1991	126	183	309
1992	168	503	671
Total	2083	2059	4142

References

- Angerman, J. American Birds, Savannah River Plant, Aiken, South Carolina, Vol. 33, pp. 465-466 (1979).
- Angerman, J. American Birds, Savannah River Plant, Aiken, South Carolina, Vol. 34, pp. 465-466 (1980).
- Caudell, M. Personal Communication with J. J. Mayer. South Carolina Marine and Wildlife Resources Department, SRS Office. (1993).
- Cothran, E. G., M. H. Smith, J. O. Wolff, and J. B. Gentry. Mammals of the Savannah River Site. SRO-NERP-21, Savannah River Ecology Laboratory, Aiken, SC, 191 pp. (1991).
- Gibbons, J. W. "Reproductive Dynamics of a Turtle (*Pseudemys scripta*) Population in a Reservoir Receiving Heated Effluent from a Nuclear Reactor." Can. J. Zool. 48:881-885 (1970).
- Gibbons, J. W. and R. D. Semlitsch. Guide to the Reptiles and Amphibians of the Savannah River Site. US Department of Energy, Savannah River Environmental Research Park, Univ of Georgia Press (1991).
- Giffin, M. A. and K. K. Patterson. Steel Creek Wildlife: L-Lake/Steel Creek Biological Monitoring Program, January 1986 - December 1987. DPST-88-657, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988).
- Gladden, J. B., W. L. Specht, J. A. Bowers, N. V. Halverson, H. E. Mackey, and E. W. Wilde. Compliance of the Savannah River Plant L-Reactor Cooling System with Environmental Regulations - Demonstration in Accordance with Section 316(a) of the Clean Water Act, November 1985 - December 1987. DP-1766, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988).
- Gladden, J. B., M. W. Lowe, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study - Annual Report. DP-1697, Vol. 1-11, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Golley, F. B. South Carolina Mammals. Contributions from the Charleston Museum, XV, E. Milby Burton, Ed., Charleston, SC, 181 pp. (1966).
- Langley, T. M. and W. L. Marter. The Savannah River Plant Site. DP-1323, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1973).
- Mayer, J. J. and I. L. Brisbin, Jr. Wild Pigs in the United States: Their History, Current Morphology and Current Status. Univ. of Georgia Press, Athens, Ga. (1991).
- Mayer, J. J., R. A. Kennamer, and R. T. Hoppe. Waterfowl of the Savannah River Plant, Comprehensive Cooling Water Study, Final Report. SREL-22, Savannah River Ecology Laboratory, Aiken, SC. 188 pp (1986).
- Norris, R. A. "Breeding Bird Census: Two South Carolina Censuses." Audubon Field Notes, 11:1-4 (1957).
- Norris, R. A. "Birds of the AEC Savannah River Plant Area." Contributions from the Charleston Museum, The Charleston Museum, Charleston, SC (1963).
- Novak, J. M., K. T. Schribner, W. D. Dupont, and M. H. Smith. Catch-effort Estimation of White-tailed Deer Population Size. J. Wildlife Management 55:31-38. (1991).
- Patterson, K. K. and M. A. Giffin. L-Lake Wildlife: L-Lake/Steel Creek Biological Monitoring Program, January 1986 - December 1987. DPST-88-650, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988).
- Savereno, A. J. and T. T. Fendley. Feral Hogs on the Savannah River Site: a Review of Herd History and Characteristics with Recommendations for Management. A Report submitted to the Stress and Wildlife Division of the Savannah River Ecology Laboratory. 127 p. (1989).
- Scott, D. E., H. K. Pechman, J. N. Knox, R. A. Estes, and J. H. McGregor. Ecological Studies Related to Construction of the Defense Waste Processing Facility on the Savannah

- River Plant, 1987-88 Annual Report. SREL-32, Savannah River Ecology Laboratory, Aiken, SC (1988).
- Simpson, G. G. "The Principles of Classification and a Classification of Mammals." *Bull. Am. Mus. Nat. Hist.* 85 (1945).
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. An Evaluation of the Steel Creek Ecosystem in Relation to then Proposed Restart of the L Reactor. SREL-9, Savannah River Ecology Laboratory, Aiken, SC (1981).
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. An Evaluation of the Steel Creek Ecosystem in Relation to then Proposed Restart of the L Reactor. SREL-12, Savannah River Ecology Laboratory, Aiken, SC (1982).
- SREL Ecological Inventory for the Proposed AFR Site, Final Report. Savannah River Ecology Laboratory, Aiken, SC (1979).
- SREL Ecological Inventory for the Proposed Site of the Defense Waste Processing Facility on the Savannah River Plant in Aiken, South Carolina. SREL-7, Savannah River Ecology Laboratory, Aiken, SC (1980).
- SRFS. Savannah River Site Wildlife, Fisheries and Botany Status Report - FY 1992. USDA Forest Service, Savannah River Forest Station. (1993).
- Vitt, L. J., R. D. Semlitsch, and M. L. Cothran. Ecological Inventory for the Proposed Site of the Defense Waste Processing Facility on the Savannah River Plant in Aiken, South Carolina, Annual Report. SREL-13, Savannah River Ecology Laboratory, Aiken, SC (1982).
- Wilde, E. W. Compliance of the Savannah River Plant P-Reactor Cooling System with Environmental Regulations: Demonstrations in Accordance with Sections 316(a) and (b) of the Federal Water Pollution Control Act of 1972. DP-1708, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- WSRC. Savannah River Site Deer Hunts (U). WSRC-IM-90-51, 35 p. (1992).
- Workman, S. W. and K. W. McLeod. Vegetation of the Savannah River Site: Major Community Types. SRO-NERP-19, Savannah River Ecology Laboratory, Aiken, SC, 137 pp. (1990).

Part II

W e t l a n d s R e s o u r c e s

Over 20% of the Savannah River Site is covered by wetlands including bottomland hardwoods, cypress-tupelo swamp forests, two large cooling water reservoirs (Par Pond and L Lake), scrub-shrub areas primarily along former thermal creeks and swamps, and approximately 200 isolated upland wetland depressions or Carolina bays. Most of the wetlands are in similar condition to pre-SRS conditions, except in those areas related to SRS thermal releases primarily from past reactor operations. Once-through, secondary cooling water was released directly to small tributary streams or to cooling lakes from the early-to-middle 1950s until the middle-to-late 1980s at temperatures in excess of 35° to 40° centigrade and frequently as high as 65° to 70° centigrade. These thermal releases degraded the wetlands along the creek corridors and adjacent portions of the SRS Savannah River swamp. Following cessation of cooling water releases to creek and swamp wetlands, successional revegetation by scrub-shrub vegetation and a variety of persistent and non-persistent wetland vegetation occurred and continues today. The shorelines of the cooling lakes have or have had (Par Pond was lowered in 1991) extensive aquatic macrophyte communities. Therefore, wetlands continue to present a mosaic of valuable habitats on SRS.

Chapter 4

Sitewide Wetland Resources

Chapter Contents

Introduction (page 4-3)

Recent Site-Wide Wetland Distribution (page 4-5)

Pre-SRS Wetland Distribution (page 4-23)

References (page 4-39)

Introduction

SRS is bordered on the southwest for 16 km by the SRS Savannah River swamp. Six streams drain SRS and are bordered primarily by bottomland hardwood forests. The remainder of SRS wetlands consists of Carolina bays; former cooling-water canals, ponds, and lakes; a few former farm ponds; and freshwater marshes. The main streams on SRS are Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs. All of these streams (except Upper Three Runs) have been influenced by SRS cooling water discharges. These discharges, once 10 to 20 times the natural stream flows, caused the streams to overflow their original banks along much of their length, reducing or modifying the original bottomland hardwood forests along much of Fourmile Branch, Pen Branch, and Steel Creek. Wetland areas of SRS include a mosaic of vegetation forms and species. Species that are characteristically dominant for a given wetland type may differ depending on whether the wetland is undisturbed, had received thermal effluents, or is undergoing successional revegetation following cessation of cooling-water releases. Also, in wetlands undergoing successional revegetation, species may differ depending on the stage of succession.

Recent Site-Wide Wetland Distribution

Several inventories of SRS wetlands have been developed from aerial photography (Mackey et al. 1985; Shields et al. 1982). Shields et al. (1982) reported that approximately 194 Carolina bays exist on SRS and Mackey et al. (1985) indicated that wetlands cover over 21% of SRS. The primary wetland cover types summarized in Mackey et al. (1985) were bottomland hardwood forest, cypress-tupelo swamp forest, scrub-shrub areas, emergent marsh, and open water. The cypress-tupelo swamp forest is located predominantly within the Savannah River swamp. Scrub-shrub and emergent marsh areas are found in post-thermal areas of the SRS Savannah River swamp streams (Fourmile Branch, Pen Branch, and Steel Creek), along the shoreline of the former cooling lakes, and within Carolina bays.

Table 4-1 on page 4-6 presents a summary of the estimated areas of wetlands on SRS as derived from a landcover/landuse geographic information system (GIS) database developed from multi-date aerial photography taken in the late 1980s (Guber 1993). Most of the pond/lakes class in Table 4-1 is from the Par Pond system and L Lake. Figure 4-1 shows a map of the wetlands as derived from the landcover/landuse GIS database, and Figures 4-2a through 4-2m show more detail for each of 13 USGS 7.5" quadrant sheets for SRS. As with all photographic surveys, these aerial estimates and maps provide guidance to locations and types of wetlands on SRS; however, field verification would be needed for detailed mapping and wetland delineation.

Table 4-1. Estimate of SRS Wetlands Derived from Landcover/Landuse Geographic Information System (GIS) Data Base

Wetland * Class	Hectares by SRS 7.5" USGS Quad Sheets													Totals
	New Ellenton	Windsor	Jackson	New Ellenton SW	New Ellenton SE	Long Branch	Shell Bluff Landing	Girard NW	Girard NE	Snelling	Girard	Millet	Martin	
bottomland hardwood	9.4	464.8	739.1	2316.6	1978.6	133.3	1787.3	2352.9	1582.7	952.2	458.6	425.3	622.9	13823.7
swamp forest	-	-	0.9	-	-	-	283.1	845.3	-	-	971.1	211.7	19.6	2331.7
bottomland scrub- shrub	-	-	39.9	128.4	84.5	7.1	95.8	247.6	168.3	3.7	53.0	7.0	7.8	843.1
emergent wetland	-	1.0	-	39.9	29.0	5.6	76.3	255.6	40.1	4.0	58.4	9.5	-	519.4
aquatic beds	-	-	-	-	69.9	4.8	-	1.3	9.1	0.8	-	-	-	85.9
intermittent flooded	-	-	-	8.1	7.0	-	-	32.8	3.3	-	-	-	-	51.2
non- vegetated wetland	-	-	-	-	-	21.9	-	2.9	-	-	-	-	-	24.8
Carolina bay	-	-	-	1.3	0.2	-	-	13.5	-	-	-	-	-	15.0
open water	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pond/lakes	-	-	-	12.3	645.1	11.8	12.5	363.7	478.9	0.6	-	1.5	2.5	1528.9
Savannah River	-	-	-	-	-	-	208.0	34.7	-	-	92.7	46.5	-	381.9
streams	-	-	-	-	-	-	1.1	134.0	-	-	-	3.3	-	138.4
canals	-	-	-	-	34.8	-	-	0.6	10.1	-	-	-	-	45.5
other	-	-	-	-	-	-	12.3	17.4	-	-	-	-	-	29.7
waterways	-	-	-	-	-	-	-	-	-	-	-	-	-	-
totals	9.4	465.8	779.9	2506.6	2849.1	184.5	2476.4	4302.3	2292.5	961.3	1633.8	704.8	652.8	19819.2

*Landcover/Landuse derived wetland classes are those as described in Ezra and Tinney 1985, Ezra 1985, Ezra et. al. 1986, Guber 1993.

Figure 4-1 SRS Map Showing Names of USGS Quadrangle Sheets

Figure 2-2. Sitewide Wetlands Map

Figure 4-3. New Ellenton Quadrant Wetlands Map

- Industrial
- Transportation
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 4-4. Windsor Quadrant Wetlands Map

Figure 4-5. Jackson Quadrant Wetlands Map

Figure 4-6. New Ellenton SW Quadrant Wetlands Map

Figure 4-7. New Ellenton SE Quadrant Wetlands Map

Figure 4-8. Long Beach Quadrant Wetlands Map

Figure 4-9. Shell Bluff Quadrant Wetlands Map

- Industrial
- Transportation
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 4-10. Girard NW Quadrant Wetlands Map

- Industrial
- Transportation
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 4-11. Girard NE Quadrant Wetlands Map

- Industrial
- Transportation
- Open Water
- Swamp Forest
- Bottomland Hardwood
- Carolina Bays/Emergent Wetland
- Site Boundary

Figure 4-12. Snelling Quadrant Wetlands Map

Figure 4-13. Girard Quadrant Wetlands Map

Figure 4-14. Millet Quadrant Wetlands Map

Figure 4-15. Martin Quadrant Wetlands Map

Pre-SRS Wetland Distribution

To evaluate long-term changes or trends in wetlands on SRS, Christel-Rose (1993) evaluated vertical, aerial photography of SRS, principally from January and May 1951 with supplemental photography from March, April, and May 1943. Six wetland classes were identified from the photography—bottomland hardwood forest, swamp forest, open water area, bottomland scrub-shrub, emergent wetland, and drained wetland (wetland that appeared to have been ditched for conversion to agricultural uses). These data are summarized in Table 4-3 and shown in Figures 4-3 and 4-4a through 4-4m. When pre-SRS data are compared with the landcover/landuse geographic information system derived wetland classes for 1989, the principle trends are an apparent decline in bottomland hardwood forest and an increase in large bodies of open water. This change in landscape at SRS is the result of the discharge of cooling water effluent to SRS steams (principally Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek) and the result of the construction of two large cooling-water systems on SRS—the Par Pond system on Lower Three Runs in 1958 and L Lake on Steel Creek in 1985. Differences between the pre-SRS wetlands estimates (Table 4-2) and the 1989 estimates (Table 4-1 on page 4-6) may vary based on the quality and types of photographic material available for the two time periods; because of this, acres are only indicators of general trends and potential changes.

Table 4-2 Estimates of Pre-SRS Wetlands Derived from 1943 and 1951 Black-and-White Aerial Photography of SRS (Christel-Rose 1993)

Wetland * Class	Hectares by SRS 7.5" USGS Quad Sheets													Totals
	New Ellenton	Windsor	Jackson	New Ellenton SW	New Ellenton SE	Long Branch	Shell Bluff Landing	Girard NW	Girard NE	Snelling	Girard	Millet	Martin	
bottomland hardwood	5.3	198.4	376.2	2215.0	2136.0	94.5	2036.9	3552.5	1868.7	894.1	563.8	496.4	639.3	15077.1
swamp forest	-	-	-	-	-	-	267.9	889.5	-	-	961.2	207.2	14.9	2340.7
open water	-	4.6	-	16.3	27.5	7.9	215.8	47.8	11.5	-	93.2	13.6	-	438.2
bottomland scrub- shrub	-	17.4	257.0	324.6	149.0	16.4	47.3	577.7	39.4	52.7	26.2	8.9	31.5	1548.1
emergent wetland	-	0.5	52.3	38.4	68.4	28.1	10.9	152.0	38.1	8.9	-	10.1	-	407.7
drained wetlands	-	-	72.4	42.0	42.8	21.7	0.7	49.6	90.3	-	-	-	-	319.5
totals	5.3	220.9	757.9	2636.3	2423.7	168.6	2579.5	5269.1	2048.0	955.7	1644.4	736.2	685.7	20131.3

Figure 2-16. Sitewide Historical Wetlands Map

Figure 4-17. New Ellenton Quadrant Historical Wetlands Map

Figure 4-18. Windsor Quadrant Historical Wetlands Map

Figure 4-19. Jackson Quadrant Historical Wetlands Map

Figure 4-20. New Ellenton SW Quadrant Historical Wetlands Map

Figure 4-21. New Ellenton SE Quadrant Historical Wetlands Map

Figure 4-22. Long Branch Quadrant Historical Wetlands Map

Figure 4-23. Shell Bluff Quadrant Historical Wetlands Map

- Transportation
- ▨ Bottomland Hardwood
- ▧ Bottomland Scrub-Shrub
- ░ Swamp Forest
- ░ Emergent Wetland
- ▦ Drained Wetland/Ditched
- Open Water
- - - Site Boundary

Figure 4-24. Girard NW Quadrant Historical Wetlands Map

Figure 4-25. Girard NE Quadrant Historical Wetlands Map

Figure 4-26. Snelling Quadrant Historical Wetlands Map

Figure 4-27. Girard Quadrant Historical Wetlands Map

Figure 4-28. Millet Quadrant Historical Wetlands Map

Figure 4-29. Martin Quadrant Historical Wetlands Map

References

- Christel-Rose, L. M. "Historical Wetlands Mapping and GIS Processing for the Savannah River Site Database." EGG-11265-1018, EG&G Energy Measurements, Inc., P.O. Box 1912, Las Vegas, NV 89125. (1993)
- Guber, A. L. "Land Cover Mapping and GIS Processing for the Savannah River Site Database". In preparation, as EGG-11265-1016, EG&G Energy Measurements, Inc., PO Box 1912, Las Vegas, NV 89125. 1993.
- Mackey, H. E., Jr., J. R. Jensen, M. E. Hodgson, and E. J. Christensen. *Savannah River Plant Wetlands Map Update*. DPST-85-661, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1985).
- Shields, J. D., N. D. Woody, A. S. Dicks, G. J. Hollod, J. Schalles, and G. J. Leversee. 1982. *Locations and Areas of Ponds and Carolina Bays at the Savannah River Plant*. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, USA.

Chapter 5

SRS Savannah River Swamp

Chapter Contents

Introduction (page 5-3)

General Wetland Patterns of the SRS Savannah River Swamp (page 5-7)

Long-Term Trends and Effects of Cooling-Water Releases on SRS Streams and the SRS Savannah River Swamp (page 5-19)

References (page 5-55)

Introduction

About 3800 ha of the Savannah River swamp lie within SRS between Upper Three Runs Creek and Steel Creek; this area is referred to as the SRS Savannah River swamp. The SRS Savannah River swamp borders the Savannah River for approximately 16 km and has an average width of about 2.2 km (Figure 5-1). An embankment or natural levee occurs along the north side of the Savannah River. Breaches in the levee allow water from Beaver Dam Creek, Fourmile Branch, and Steel Creek to flow to the river. The combined discharges of Steel Creek and Pen Branch enter the river near the southeast portion of the SRS Savannah River Swamp.

On the landward side of the levee, the Savannah River swamp contains stands of cypress and tupelo trees, bottomland hardwoods, scrub-shrub, and open marsh areas. During periods of flooding, river water overflows the levee and floods the swamp, leaving only isolated islands. The river overflows into the swamp when river elevations are between 27 and 28 m above mean sea level (MSL) or at flows of about 15,300 cfs. During flooding, the water from SRS streams flows through the swamp parallel to the river and enters the river offsite.

The wetlands community structure of the SRS Savannah River swamp has been influenced by a variety of environmental perturbations. Like most riverine swamps of the southeastern United States, this forest has been selectively logged. Virtually all of the swamp was dominated by second-growth timber in the early 1950s. When SRS initiated operations, the swamp was characterized primarily by a closed-canopy forest of bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) in the deep water sites and poorly drained

Figure 5-1. Location of the SRS Savannah River Swamp

sloughs, and by hardwoods on the island ridges (Sharitz et al. 1974a; Mackey 1987; Tinney et al. 1986).

The SRS Savannah River swamp currently receives thermal effluent from the D-Area power plant and formerly received thermal effluent from C Reactor until late June 1985, K Reactor until summer 1988, and L Reactor via L Lake until summer 1988. The discharge of cooling-water effluents from the SRS reactors and the coal-fired power plant modified the SRS Savannah River swamp in several ways. Deposition of sediment from erosion associated with increased flows to creeks formed sedimentation deltas in the swamp (Figure 5-3) (Ruby et al. 1981). Water temperatures in those portions of the swamp near where thermal effluents entered the swamp exceeded the thermal tolerances of most vascular plant species and resulted in extensive forest mortality (Sharitz et al. 1974b; Tinney et al. 1986; Mackey 1987). Finally, the input of increased volumes of cooling water from the creeks into the SRS Savannah River swamp modified the hydrologic regime of the system. This change in hydrologic regime was further influenced by flood-control activities on the Savannah River (Figure 5-2). Examination of long-term discharge fluctuations in the Savannah River revealed that following construction of Clarks Hill Dam in the early 1950s, water levels in the river have been neither as high nor as low as they were prior to dam construction. SRS effluent discharges maintained relatively higher water levels in the SRS Savannah River swamp throughout the year near the deltas. Dry periods necessary for extensive regeneration of the dominant woody swamp-forest species seldom occurred under this modified hydrologic regime (Sharitz et al. 1986).

Figure 5-2. Monthly Probabilities of the Savannah River Flooding

Approximate Locations of Photographs

Fourmile Branch Delta (1986)

Pen Branch Delta (1981)

Steel Creek Delta (1974)

Figure 5-3. Sediment Fans at the Fourmile Branch Delta Area (1986), the Pen Branch Delta Area (1981), and the Steel Creek Delta Area (1974)

General Wetland Patterns of the SRS Savannah River Swamp

Pre-SRS Logging of the Swamp

To understand the status of the SRS Savannah River swamp prior to SRS operations, an historical review of pre-SRS photography of the swamp was conducted. To identify the extent of logging activities in the swamp, black-and-white, vertical, aerial photography of three years (1938, 1943, 1951) was interpreted to locate the prominent logging railroads, roads, haul lines, timber staging areas, and clear cuts in the SRS portion of the Savannah River swamp.

Lumbering was an important industry in early America and the exploitation of the abundant swamp and bottomland-forest resources for export rendered barrel staves and heads from the oaks; shingles from the durable cypress wood; building lumber, turpentine, pitch, and tar from loblolly pine; and naval stores (ship building supplies) from a combination of the timbers (Herndon 1979). Timber companies were early supporters of the railroads, as the lines were extended toward regions of vast virgin timber (Scott 1979). Where swampy terrain inhibited conventional methods of moving timber, the lumber companies located mills along railroads and constructed their own railways into the swamps to facilitate movement of timber (Fetters 1990). Usually, they used cypress trees to construct elevated trestles into otherwise inaccessible areas. This apparently was the case in the area of SRS (Fetters 1990).

The swamp forests at SRS remained intact until the early part of this century due to the restrictive nature of the swamp topography. The Leigh Banana Case Company was the primary lumbering company in the SRS Savannah River swamp. Located at Leigh, SC, south of the present day junction of Highway 125 and Fourmile Branch, the company produced veneer or vegetable crates. To provide access to the best timber of the SRS Savannah River swamp, 14 miles of track, (two-thirds on trestles), were constructed (Fetters 1990). Along these railroads, outriders on mules hauled "snakes" into the woods. These were attached to logs that were hauled back by the "snaker" and loaded onto railroad cars. Dikes were constructed at breaks in the levee along the Savannah River to facilitate drainage of the swamp and roads were also constructed along and outward from the railroad. Staging areas were established to snake logs to a central point for hauling to the railroads. These activities allowed greater access to the bottomland hardwoods and created distinctive patterns in the swamp that are distinguishable on the historical aerial photography.

Logging operations started in earnest in the upper SRS Savannah River swamp after the turn of the century. Standard 1:20,000 scale, black-and-white, vertical aerial photography of the SRS swamp in 1938 shows extensive lumbering in the swamp. The extent of later logging was evident in aerial photography from 1943 and 1951. With the purchase of SRS in 1951 by DOE, these lumbering operations came to a close. Some logging did take place in the swamp between Beaver Dam Creek and the Savannah River in the early 1970s (Figure 5-4), but these data are not included in this report.

The lumbering features in the swamp were classified for 1938, 1943, and 1951 as railroad, logging roads, drag points (the staging areas where logs were hauled), haul lines, and an areal boundary of harvested land (Figure 5-5 on page 5-9 through Figure 5-7 on page 5-10). Buffers were generated around the roads, drag points, and haul lines to approximate the area

of disturbance for each year (Figure 5-8 on page 5-10 through Figure 5-10 on page 5-11). Estimates of land disturbed by lumbering in the swamp were thus estimated for each year to provide an estimate of lumbering impact prior to SRS. These totals are presented in Table 5-1.

The areas derived from the aerial photography data indicate that much of the 3800 ha SRS Savannah River swamp had been disturbed by lumbering activities prior to purchase by DOE. The 1973 aerial photography shows that additional areas were lumbered after SRS was established. This lumbering information can be combined with photographic and image-change detection data, delta sedimentation data, and data on effects of previous thermal effluents to provide a more complete picture of the current SRS swamp environment.

Table 5-1. Areal Estimates of Pre-SRS Lumbering in the SRS Savannah River Swamp

Year	"Buffered" Lumbered Zones (Hectares)	Harvested Areas (Hectares)	Total (Hectares)
1938	1100	1116	1488
1943	856	17	871
1951	229	32	241
		Total	2600

Approximate Area of Coverage

Beaver Dam Creek Area

3642-45

Figure 5-4. Timber Harvest in the Savannah River Swamp West of Beaver Dam Creek

Figure 5-5. Timber Harvesting Activities in the SRS Savannah River Swamp (From 1938 Aerial Photography)

Figure 5-6. Timber Harvesting Activities in the SRS Savannah River Swamp (From 1943 Aerial Photography)

Figure 5-7. Timber Harvesting Activities in the SRS Savannah River Swamp (From 1951 Aerial Photography)

Figure 5-8. Estimate of Lumbered Areas within the SRS Savannah River Swamp (From 1938 Aerial Photography)

Figure 5-9. Estimate of Lumbered Areas within the SRS Savannah River Swamp (From 1943 Aerial Photography)

Figure 5-10. Estimate of Lumbered Areas within the SRS Savannah River Swamp (From 1951 Aerial Photography)

Wetland Communities of the SRS Savannah River Swamp

The composition of the SRS Savannah River swamp forest has been extensively examined. Summaries of the wetland community structure of the swamp were provided by Repaske (1981), Whipple et al. (1981); and Smith et al. (1981, 1982). Additional areas of the swamp were studied in 1983 and 1984 (Gladden et al. 1985). These data provided information on density, size class (relative basal area), and importance values of woody species distributed throughout disturbed and relatively undisturbed portions of the SRS Savannah River swamp (Table 5-2). In addition, since 1981 numerous remote sensing surveys have been conducted of the swamp which provide evaluations of changes in specific areas of the swamp largely influenced by cooling water effluents from SRS operations (Brewster and Tinney 1984; Christensen et al. 1984a, 1984b, 1986, 1987, 1988; Ezra et al. 1986; Jensen et al. 1983, 1984a, 1984b, 1986a, 1986b, 1987; Tinney et al. 1986; Mackey 1990, 1993; Blohm 1993).

In the late 1970s and early 1980s, data for the woody species surveys of the swamp were analyzed using standard plant community analysis procedures (Mueller-Dombois and Ellenberg 1974). Importance values were calculated using relative density and relative dominance (basal area). Detrended correspondence analysis ordination was employed to array the data along axes calculated using the importance values of the plant species (Hill, 1979a; Smith et al. 1981, 1982). This technique grouped the wetland communities along gradients that can be interpreted to reflect plant community responses to environmental perturbations (Hill & Gauch 1980). A two-way indicator species analysis was then used to separate the data into major plant community types, based upon importance of dominant wood species (Hill 1979b). Comparisons of species arrays or groupings and community types with environmental characteristics provided an indication of the major environmental variables responsible for woody species distribution in the SRS swamp (Gladden et al. 1985).

Table 5-2. Importance Values^a of Dominant Woody Species in the SRS Savannah River Swamps (Gladden et al. 1985)

Species	Deciduous Natural (N=34) ^b	Swamp Forest Thermal (N=20)	Swamp Forest Post- Thermal (N=21)	Scrub-Shrub Revegetated (N=49)	Deciduous Bottomland Forest (N=24)
<i>Nyssa aquatica</i>	103	126	75	<1	7
<i>Taxodium distichum</i>	68	54	64	11	11
<i>Fraxinus</i> spp.	10	12	44	12	7
<i>Itea virginica</i>	3	3	-	5	<1
<i>Planera aquatica</i>	2	2	5	9	4
<i>Cephalanthus occidentalis</i>	<1	1	9	76	1
<i>Liquidambar styraciflua</i>	<1	-	-	-	25
<i>Quercus laurifolia</i>	<1	-	1	-	16
<i>Salix</i> spp.	-	<1	-	82	<1
<i>Carpinus caroliniana</i>	-	-	-	-	28
<i>Quercus nigra</i>	-	-	-	-	17

^aImportance value (Curtis & McIntosh 1950) = relative density + relative dominance (as percentage)

^bN = number of plots sampled

Each site was assigned a relative value of 1 to 3 based on a hydrologic scale (1 = deeply and continuously flooded, 2 = shallowly and continuously flooded, 3 = occasionally flooded) and on a perturbation scale (1 = tree mortality characteristic of natural swamp, 2 = low perturbation with slight tree mortality, 3 = high perturbation and high tree mortality). These scalars showed that the swamp forest communities are distributed along two major environmental axes: a water depth or hydrologic regime gradient and a perturbation or disturbance gradient. Thus in Figure 5-11 on page 5-14, quadrants symbolized by squares or triangles show no perturbation or low levels of perturbation. Those symbolized by circles are highly disturbed and contain no or almost no species representative of the original swamp forest. Open symbols represent sites occurring in areas of only occasional flooding. Partially darkened or completely darkened symbols represent quadrants at shallow or deeply flooded sites (Gladden et al. 1985).

The two-way indicator species analysis (Hill 1979b) separated the swamp forest into the major wetlands community types (Figure 5-12 on page 5-14). Deciduous bottomland hardwood forests occur in areas that are slightly elevated and better drained and that are flooded only occasionally during the year. These communities are dominated by a mixture of oak species (*Quercus nigra*, *Q. laurifolia*, *Q. michauxii*, *Q. lyrata*), as well as red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), ash (*Fraxinus caroliniana* and *F. americana*), and other hardwood species. The species composition of the understory appears to be controlled by the wetness of the substrate. Sweet bay (*Magholia virginiana*), tulip poplar (*Liriodendron tulipifera*), and hollies (*Ilex* spp.) are found in drier localities, while red bay (*Persea borbonia*) and ironwood (*Carpinus caroliniana*) occur in stands with longer periods of soil saturation. *Smilax* spp. and woody vines are common (Gladden et al. 1985).

The deciduous swamp forest, which occurs in deeper water and on continuously flooded sites, is characterized by two canopy dominants: bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). The understory is typically sparse and is composed of ash, bald cypress, occasional black gum, water tupelo, red maple, and water elm (*Planera aquatica*). Most saplings are restricted to stumps, logs, or accumulated sediments and debris at the bases of the trees. St. John's wort (*Hypericum* spp.), Virginia willow (*Itea virginica*), false nettle (*Boehmeria cylindrica*), and woody vines such as poison ivy (*Rhus radicans*) and pepper-vine (*Ampelopsis arborea*) occur in the understory on stumps and fallen logs. The ground cover is limited in the swamp forest by continuous flooding and low light penetration through the canopy. In areas of slow current, duckweed (*Lemna* spp. and *Spirodela* spp.), waterweed (*Egeria densa*), and coontail (*Ceratophyllum demersum*) are found (Gladden et al. 1985).

Woody plant community types occurring in the most highly disturbed areas are dominated by successional scrub-shrub species, such as willow (*Salix* spp.) and buttonbush (*Cephalanthus occidentalis*). These scrub-shrub communities occur where the original swamp forest has been eliminated, but where water temperatures are not too high to preclude the growth of woody species. Willow-dominated scrub-shrub communities tend to occur on sand bars or on occasionally flooded sites; whereas, buttonbush-dominated scrub-shrub communities occur on sites with deeper water and represent the early successional invasion of deeper water sites (Gladden et al. 1985). The understory of the buttonbush community contains nonpersistent emergent wetland species such as hydrolea (*Hydrolea quadrivalvis*), aneilema (*Aneilema keisak*), waterpepper (*Polygonum hydropiperoides*), water purslane (*Ludwigia palustris*), and wapato (*Sagittaria latifolia*). Climbing hemp (*Mikania scandens*) and pepper-vine also occur (Gladden et al. 1985). Herbaceous vegetation in the willow community

Figure 5-11. Detrended Correspondence Analysis Ordination of Forested and Shrub-Dominated Sites in the SRS Savannah River Swamp (Source: Gladden et al. 1985)

Figure 5-12. Two-Way Indicator Species Analysis of the SRS Savannah River Swamp Forest Data Indicated on Detrended Correspondence Analysis Ordination (Source: Gladden et al. 1985)

is often sparse due to the dense canopy. Small patches of herbs include redtop panicgrass (*Panicum agrostoides*), waterpepper, false nettle, St. John's wort, sensitive fern (*Onoclea sensibilis*), climbing hemp, and pepper-vine (Gladden et al. 1985).

In addition to wetlands surveys of individual sites in the SRS Savannah River swamp, remote sensing overflights were conducted in 1981 to provide a wetlands map of the SRS Savannah River swamp (Jensen et al. 1984a, 1984b). Individual maps of each delta area were also prepared to quantify wetland areas and to establish a data base to evaluate future changes in the swamp (Christensen et al. 1986). High altitude imagery was used to map the entire SRS Savannah River swamp and the low altitude imagery was used to map individual delta areas (Jensen et al. 1984a, 1984b).

Wetlands Classification Scheme

The Savannah River swamp contains areas of diverse cover types, such as woody vegetation, mud flats, and open water. A classification scheme was developed for use with the remotely sensed data which was comparable with ground survey data collected from the swamp. The classification scheme selected was adopted with minor modifications from the wetlands classification system developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) and used for the National Wetland Maps (Stewart et al. 1980). Six of the wetland classes commonly identified in the SRS Savannah River swamp are given in the following (Jensen et al. 1984b):

- Persistent Emergent (PE) Wetland dominated chiefly by perennial herbaceous species, including cattail (*Typha latifolia*), bulrush (*Scirpus cyperinus*), cutgrass (*Leersia* spp.) and false nettle (*Boehmeria cylindrica*). *Aneilema keisak*, an annual, is also locally abundant.
- Nonpersistent Emergent (NPE) Wetland contains several species of smartweed (*Polygonum* spp.), as well as hydrolea (*Hydrolea quadrivalvis*) in the deeper water areas. The NPE vegetation type is characterized by water primrose (*Ludwigia* spp.) on shallow sandbars and mud flats.
- Scrub-Shrub (SS) Wetland dominated by willow (*Salix nigra* and *S. caroliniana*) on the sandbars, and buttonbush (*Cephalanthus occidentalis*) in deeper water. Typically, SS represents a transition from emergent marsh to swamp forest.
- The Deciduous Swamp Forest (DSF) dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*).
- Deciduous Bottomland Forest (DBF) characterized by oaks (*Quercus* spp.), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), and hickory (*Carya* spp.). DBF vegetation is less water tolerant than species in the DSF vegetation.
- An algal bed (AB) cover class was found in the thermal delta areas, such as the Fourmile Branch delta, and the class was dominated by thermally-tolerant blue-green algae.

Analysis of the 1981 MSS remote sensing data for the SRS Savannah River swamp estimated that the swamp is covered primarily by cypress-tupelo forest (47%) and drier bottomland-hardwood islands (40%) (Table 5-3 on page 5-16). The islands contain some pine trees (2.2%). The remainder of the SRS swamp is composed of scrub-shrub and marsh wetland communities which are located near the points of entry of SRS thermal and post-thermal streams. In these formerly thermal delta areas, cypress-tupelo and bottomland hardwood forests were replaced by a mixture of scrub-shrub vegetation and persistent and nonpersis-

tent marsh vegetation. Because these delta areas have more wetland heterogeneity, higher spatial resolution MSS data were used to map the wetland communities in the deltas (Jensen et al. 1984b).

Estimates of the wetland vegetation areas for the Steel Creek, Pen Branch, Fourmile Branch, and Beaver Dam Creek deltas are listed in Table 5-4 on page 5-16 through Table 5-7 on page 5-17. Discussions of classification methods, accuracy assessment, and phenology problems are presented in Jensen et al. (1984b, 1986a) and Christensen et al. (1986). Additional data, estimating changes since 1981 for the deltas, are presented in the sections that follow.

Table 5-3. Area of Wetland Classes Found Within the SRS Savannah River Swamp, March 31, 1981 (Jensen et al. 1984a)^a

Wetland Cover Class	Hectares	Percentage of Swamp
Open Water in Swamp (W) ^b	27	0.7
Nonpersistent Emergent Marsh (NPE)	152	4.0
Persistent Emergent Marsh (PE)	55	1.4
Scrub-Shrub (SS)	155	4.1
Deciduous Swamp Forest (DSF)	1793	47.2
Deciduous Bottomland Forest (DBF)	1528	40.2
Pine Forest (NEF)	83	2.2
Unclassified (U)	8	0.2
Total	3801	100.0

^aObtained by analyzing multispectral scanner data (2440 meters AGL) collected by the Energy Measurements Group of EG&G, Las Vegas, Nevada

^bDoes not include 221 ha of Savannah River water adjacent to the SRS Savannah River swamp; probably includes some area of algal beds

Table 5-4. Wetland Classification of the Steel Creek Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)

Wetland Cover Class	Hectares	Percentage
Open Water in Swamp (W)	6.34	3
Nonpersistent Emergent Marsh (NPE)	17.93	9
Persistent Emergent Marsh (PE)	20.32	10
Scrub-Shrub (SS)	34.37	18
Deciduous Swamp Forest (DSF)	64.68	34
Deciduous Bottomland Forest (DBF)	16.95	9
Unclassified (U)	0.06	1
Masked ^a	32.03	16
Total	192.68	100

^aUpland (nonswamp) area

Table 5-5. Wetland Classification of the Pen Branch Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)

Wetland Cover Class	Hectares	Percentage
Open Water (W)	2.40	1
Aquatic Bed (AB)	11.91	3
Nonpersistent Emergent (NPE)	43.44	11
Persistent Emergent (PE)	4.07	1
Shrub-Shrub (SS)	37.36	10
Deciduous Swamp Forest (DSF)	166.83	43
Deciduous Swamp Forest (DBF)	51.23	13
Unclassified (U)	0.07	0
Masked ^a	68.04	18
Total	385.35	100

^aUpland (nonswamp) area

Table 5-6. Wetland Classification of the Fourmile Creek Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)

Wetland Cover Class	Hectares	Percentage
Open Water (W)	9.44	5
Aquatic Bed (AB)	19.54	10
Nonpersistent Emergent (NPE)	19.20	10
Persistent Emergent (PE)	3.65	2
Shrub-Shrub (SS)	12.62	7
Deciduous Swamp Forest (DSF)	68.16	35
Deciduous Swamp Forest (DBF)	50.96	26
Unclassified (U)	1.20	1
Masked ^a	7.90	4
Total	192.67	100

^aUpland (nonswamp) area

Table 5-7. Wetland Classification of the Beaver Dam Creek Delta and Vicinity Based on March 31, 1981, MSS Data (Mackey 1987)

Wetland Cover Class	Hectares	Percentage
Open Water (W)	50.05	8.7
Nonpersistent Emergent (NPE)	15.61	2.6
Persistent Emergent (PE)	42.35	7.4
Shrub-Shrub (SS)	59.82	10.4
Deciduous Swamp Forest (DSF)	141.79	24.7
Deciduous Swamp Forest (DBF)	264.55	46.2
Total	574.17	100.0

Long-Term Trends and Effects of Cooling-Water Releases on SRS Streams and the SRS Savannah River Swamp

Introduction

From 1953 until the late 1980s, cooling water discharges from SRS reactors and D-Area powerhouse altered wetland vegetation in the SRS stream floodplains and the Savannah River swamp. High effluent flows eroded stream banks and deposited sediments, forming a delta at the junction of each of the four streams and the swamp. To assess the status and predict future changes of the SRS swamp deltas, aerial photographs from 1951-1985 were analyzed (Tinney et al. 1986) using photointerpretation and computer techniques to provide the following information:

- past and current expansion rates
- location and changes of impacted areas
- estimates of total areas affected

Multispectral remote sensing data from 1981 to 1993 are also available for the SRS swamp areas. These multispectral scanner (MSS) data allow estimation of changes by wetland community types for the delta areas for given time periods. For example, Christensen et al. (1986) evaluated changes in the swamp delta areas for 1981-1985 with MSS data and updated the Steel Creek delta through 1987; and Blohm (1993) conducted a detailed evaluation of the Pen Branch delta for 1987-1991.

The wetlands changes in the Steel Creek area are particularly interesting because thermal discharge temperatures and flows varied markedly. Both L and P Reactors discharged effluents into the stream from 1954 to 1963. L Reactor continued to discharge thermal effluent to Steel Creek from 1963 to 1968. When P Reactor stopped releasing thermal effluents to Steel Creek in 1963, the upper Steel Creek corridor began to revegetate. In 1968, thermal discharges into Steel Creek ceased and the lower Steel Creek floodplain and delta region began undergoing post-thermal succession or revegetation (Smith et al. 1981, 1982; Christensen et al. 1986).

Pen Branch and Fourmile Branch began receiving reactor effluents in 1954 and 1955, respectively. In contrast to Steel Creek, neither stream received effluents from more than one reactor. Additionally, both reactors operated with only minor changes in operating conditions after the initial startup. C Reactor was shutdown in late June 1985 and the Fourmile Branch corridor and delta have been undergoing successional revegetation. K Reactor was shut down in the spring of 1988 and Pen Branch delta has been undergoing successional revegetation (Mackey 1990, 1993; Blohm 1993). A fourth source of thermal effluent to the SRS Savannah River swamp is from D Area, which contained a heavy water production facility (placed on standby in 1982) and a coal-fired power plant (currently operating). Effluents from D Area were consistently lower in both volume and temperature than effluents from the reactor areas.

Photographic Surveys

Introduction

Aerial photographs of the SRS thermal creeks and Savannah River swamp were evaluated for years between 1951 and 1985 (Tinney et al. 1986). These photographs provide a visual record of the history of the deltas and creeks and allowed assessment of wetlands vegetation changes. The photographs were interpreted using standard photogrammetric techniques (Wolf 1974; Burnside 1979; Christensen et al. 1984a; Tinney et al. 1986). Impact area boundaries from each year were registered to a common scale in a geographic information system (GIS) (Howland 1980, Borrell 1982). The GIS was queried using Boolean logic to document the condition of the creek and delta wetland forests at each date and the change between dates (Townshend 1981). The dates and types of photography used are summarized in Table 5-8. Most of the aerial photography was panchromatic (0.4-0.7 μm), acquired at scales larger than or equal to 1:20,000. The aerial photography had a standard 60% endlap and 30% sidelap, which facilitated stereoscopic analysis (Tinney et al. 1986).

Quantitative estimates of wetland losses were based on identification of areas in the creek floodplains and the SRS Savannah River swamp where indigenous bottomland hardwood and cypress-tupelo swamp forest had been damaged from exposure to thermal effluents and sediment deposition. Forest areas were classified as the following:

- no damage
- partial damage (5-95% canopy loss)
- complete damage (95-100% canopy loss)

This classification scheme was useful for identifying areas where damage had occurred or was under way, or where natural succession or vegetation had taken place (Christensen et al. 1984a, 1984b, 1986; Tinney et al. 1986).

Table 5-8. Aerial Photography Used to Document Wetlands Change

Date	Spectral Sensitivity	Format	Steel Creek	Pen Branch	Fourmile Branch	Beaver Dam Creek
04-04-51	Panchromatic	B&W positive	X	o	o	X
05-01-55	Panchromatic	B&W positive	X	X	X	X
03-21-56	Panchromatic	B&W positive	X	X	X	X
03-15-61	Panchromatic	B&W positive	X	X	X	X
05-05-66	Near infrared	B&W positive	X	X	X	X
03-18-73	Panchromatic	B&W positive	X	X	o	o
02-13-74	Panchromatic	B&W positive	X	o	X	X
10-27-78	Panchromatic	B&W positive	o	o	o	X
02-20-82	Color	Positive	X	X	X ^a	X
04-06-84	Near infrared	Color positive	X	X	X	X
04-25-85	Color infrared	Color print	X	X	X	X

o Photography was not available

^a Photography was not used for area estimates because of poor quality

Summary of Photographic Surveys, 1951–1985

Thermal loading, flooding, and siltation resulting from SRS operational discharges visibly altered about 1020 ha of SRS creeks and the Savannah River swamp (Table 5-9). Most of the affected areas include former bottomland hardwood and cypress-tupelo forest. Cypress-tupelo losses in the swamp are being partially offset by revegetation primarily with bottomland hardwood and scrub-shrub species in the Beaver Dam and Steel Creek delta areas. Revegetation and initial invasion of scrub-shrub species began in the Fourmile Branch corridor and delta areas after C-Reactor shutdown in late June 1985 and in the Pen Branch corridor and delta area after K-Reactor shutdown in the spring of 1988.

Multispectral Scanner Surveys of the SRS Swamp Delta Areas

One of the most powerful uses of digital remote sensing data is for evaluating land-use/land cover changes through time. Remote sensing change detection combines multiple-date data and image analyses to identify both temporal and spatial changes. Multispectral scanner (MSS) data analysis can quantitatively be used to discriminate among a variety of vegetation types (Jensen 1986). Baseline vegetation maps of the Savannah River swamp and the four delta swamp areas (Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek) were prepared using aircraft MSS data (Jensen et al. 1984a, 1984b; Gladden et al. 1985) (Figure 5-13 on page 5-22). Satellite MSS data (Landsat, Thematic Mapper, and SPOT) are commonly used to detect and monitor change. For the most part, satellite data are useful for large-scale change detection, because the ground resolution currently available with Thematic Mapper is 30 x 30 meters, with SPOT HRV is 20 x 20 meters, and with SPOT panchromatic is 10 x 10 meters. Aircraft-based sensors fly lower and have ground resolutions of a few meters. At this scale, much more detailed discrimination of vegetation types and area estimates can be made. However, change detection using high-resolution, aircraft MSS data is seldom conducted. Classification consistency and registration difficulties are probably the two major reasons that aircraft MSS data are infrequently used for change detection studies. Research on the Savannah River swamp deltas addressed both of these considerations (Christensen et al. 1986; Jensen et al. 1987; Blohm 1993).

Portions of the Pen Branch, Fourmile Branch, Steel Creek, and Beaver Dam Creek deltas in the Savannah River swamp were evaluated for wetlands vegetation change using aircraft multispectral scanner (MSS) data acquired at 1220 m and 2440 m altitude from 1981 to 1985. The MSS data for each delta were registered and classified, and wetlands vegetation change detection categories were determined (Christensen et al. 1986; Jensen et al. 1983; Jensen et al. 1984b; Jensen et al. 1986a; Jensen et al. 1986b; Jensen et al. 1987.)

Table 5-9. Estimated Impacted Wetland Areas in SRS Thermal Creeks and Savannah River Swamp, 1985

	Area (hectares)		Total
	Stream Corridors	Swamp Deltas	
Steel Creek	82.9	81.9	164.8
Pen Branch	92.6	151.8	244.4
Fourmile Branch	93.0	357.3	450.3
Beaver Dam Creek	-	159.9	159.9
Total	268.5	750.9	1019.4

Figure 5-13. Areas of the SRS Savannah River Swamp Analyzed Using Multispectral Scanner Data, 1981–1985

Comparison of the Photographic and MSS Surveys, 1981-1985

In general, even though the data were analyzed with different approaches and criteria for wetland change detection, the wetland community trends in the delta areas of the SRS Savannah River swamp observed with the MSS surveys from 1981 to 1985 agreed with the changes noted in the photographic surveys. For example, in the thermally influenced deltas of Fourmile Branch (until 1985) and Pen Branch, expansion of these deltas into the deciduous swamp forest (DSF) was still occurring. Using photographic techniques, about 30 ha of cypress-tupelo forest were estimated to have been converted to open water marsh and/or scrub-shrub wetlands in the Fourmile Branch delta area from 1981 to 1984. Using MSS data to analyze about one-half of the same Fourmile Branch delta area, approximately 14.1 ha of swamp forest were estimated to have been converted to either marsh and/or scrub-shrub wetland communities. When evaluated with photographic methods, the thermally influenced Pen Branch delta showed a decline in cypress-tupelo forest of about 37 ha from 1981 to 1985 with most of the decline occurring in the Pen Branch “tail” area. MSS data analyses of the “tail” region showed a decline of swamp forest of 28.7 ha from 1981 to 1985.

Evaluation of both the photographic and MSS data demonstrated stabilization or successional revegetation in the Beaver Dam Creek and Steel Creek deltas from 1981 through 1985. Most of the revegetation took place as open water and marsh wetland communities shifted to scrub-shrub or young bottomland hardwood communities.

Beaver Dam Creek

Beaver Dam Creek Watershed Characteristics

Beaver Dam Creek is a small stream that carries thermal effluents from the D-Area coal-fired power plant. Until 1982 it carried effluent from the heavy water production facility. Prior to SRS operations, Beaver Dam Creek was probably an intermittent stream. The creek is located 1–3-km west of Fourmile Branch (Figure 5-14). A narrow band of bottomland hardwoods and scrub-shrub forest borders the stream from the D-Area process-water outfall to the river swamp. Beaver Dam Creek received from 2.1 to 3.5 m³/sec of heated process water discharges from the heavy water production plant and the steam plant when both were operating. As heavy water operations were reduced, discharges decreased.

Beaver Dam Creek Delta Characteristics

Two different effluent sources from D Area have affected the Beaver Dam Creek delta area (Evans and Giesy 1978; Gladden et al. 1985). Cooling water discharges from the D-Area powerhouse and heavy-water facilities were primarily responsible for vegetation damage in the middle and lower parts of the delta. The upper portion was also affected by ash-basin overflow (Evans and Giesy 1978). Since the early 1970s, cooling-water temperature and flows along with sediment basin discharges have decreased. Portions of the delta have begun to revegetate, especially in the upper part, which no longer receives discharges.

Of the four deltas, the most change was found on the Beaver Dam Creek delta, even though the change period has been the shortest. Almost the entire upper portion of the delta has experienced extensive revegetation. Due to a discharge reduction, the upper delta remains dry most of the year (except during flooding of the Savannah River). As a result, less water-tolerant scrub-shrub (willow and buttonbush) and deciduous bottomland forest species

Figure 5-14. Location of Beaver Dam Creek on SRS

(sycamore, ash, poplar, and oak) have colonized the former marsh (persistent emergent and non-persistent emergent).

Beaver Dam Creek Delta Trends

In 1952 operations in D Area began discharging heated effluents via a canal to the Beaver Dam Creek area of the SRS Savannah River swamp (Figure 5-14 on page 5-23). Both the D-Area heavy water facility and the coal-fired powerhouse used Savannah River water for cooling. Additionally, water was pumped for the extraction of heavy water (Gladden et al. 1985). Table 5-10 on page 5-25 and Figure 5-15 summarize the history of discharges to and changes in the Beaver Dam Creek delta area. Canopy decline was observed in 1956 aerial photography. The affected area totaled 19.0 ha and received an average flow of about 120 cfs. During the next 11 years, the Beaver Dam Creek delta area expanded at variable rates with a maximum rate of about 10 ha/yr during 1961–1966. The effluent temperature began to decrease in 1973 and continued to decline until 1978; a concurrent net decline of delta expansion occurred. By 1985 a total of about 14 ha had revegetated in the Beaver Dam Creek area. The annual average effluent temperature declined from 38°C to 27–28°C Table 5-10 on page 5-25). The affected Savannah River swamp delta area of Beaver Dam Creek in 1985 totaled about 160 ha and is revegetating at a rate of about 4.2 ha/yr. Relatively little change has been noted in the Beaver Dam Creek delta area from 1986 to 1992 (Figure 5-15). In addition to thermal discharges, the Beaver Dam Creek delta area also received coal fly ash basin effluent discharge (Evans and Giesy 1978). Coal fly ash deposition affected at least 8 to 10 ha of swamp (Gladden et al. 1985).

MSS Surveys of the Beaver Dam Creek Delta, 1981–1985

Multispectral scanner (MSS) data of the Beaver Dam Creek delta were acquired at 2440 m above ground level (AGL) on March 31, 1981, and at 1220 m on April 26, 1985.

Figure 5-15. Beaver Dam Creek Delta Growth (Source: Tinney et al. 1986)

Table 5-10. Estimated Impacts and Discharge Conditions to Beaver Dam Creek from D-Area Discharges, 1952–1991

Year	Total Impacted area (ha)	Average Expansion Rate (ha/yr)	Average Annual Discharge (cfs) or Flow at USGS Station ^a	Average Annual Temperature (°C) ^b
1952	-	-	-	-
1953	-	-	-	-
1954	-	-	-	-
1955	-	-	-	-
1956	19.0	-	121	-
1957	-	-	123	-
1958	-	-	108	-
1959	-	-	104	-
1960	-	-	91	-
1961	54.0	7.0	88	-
1962	-	-	89	-
1963	-	-	-	-
1964	-	-	88	-
1965	-	-	-	-
1966	103.7	9.9	-	-
1967	-	-	-	-
1968	-	-	-	-
1969	-	-	-	-
1970	-	-	-	-
1971	-	-	-	-
1972	-	-	-	38
1973	-	-	-	38
1974	167.0	7.9	-	36
1975	-	-	92	34
1976	-	-	78	32
1977	-	-	78	28
1978	164.8	0.6 ^c	74	27
1979	-	-	79	28
1980	-	-	82	27
1981	-	-	113	27
1982	157.0	2.0 ^c	90	27
1983	-	-	89	27
1984	164.1	3.6 ^c	84	-
1985	159.9	4.2 ^c	89	-
1986	-	-	89	-
1987	-	-	88	-
1988	-	-	71	-
1989	-	-	67	-
1990	-	-	73	-
1991	-	-	95	-

^aFor the years 1956–1964, the data are for the 681-5G pumphouse, which supplies river water to D Area. For the years 1975–1982, the data are flow measurements at the Health Protection Monitoring Station on Beaver Dam Creek before the flow discharges into the Savannah River swamp on SRS. 35.32 cfs = 1 cms. For the years 1983–1991, the data are from the USGS recording station.

^bFor the years 1972–1983, the temperature data are annual average data at the Health Protection Monitoring Station on Beaver Dam Creek before the flow enters the Savannah River swamp on SRS.

^cRevegetation rate

Figure 5-16. Vertical Aerial Photography of the Beaver Dam Creek Delta Area for Spring 1986, 1990, and 1992

The change in landcover from March 31, 1981, to April 26, 1985, is listed in Table 5-11 and Table 5-12. For the upper Beaver Dam Creek delta, the most noticeable decreases in land-cover type were nonpersistent emergent marsh (-60.0%), persistent emergent marsh (-52.2%), and deciduous swamp forest (-12.6%). Conversely, the area experienced increases in deciduous bottomland forest (35.7%), scrub-shrub (10.0%), and water (13.5%). Thus, the upper Beaver Dam Creek area returned to a more wooded condition.

In the lower Beaver Dam Creek delta, the nonpersistent emergent marsh decreased tremendously (99.9% reduction). This wetlands type probably changed into persistent emergent marsh, which showed a substantial increase of 24.4%. Deciduous swamp forest, scrub-shrub, and water all decreased in area (-7.4%, -3.5%, and -1.1%, respectively). The deciduous bottomland forest increased (5.52). These statistics suggest that while change took place in the lower Beaver Dam Creek delta, it was not as marked as the revegetation in the upper Beaver Dam Creek delta.

Fourmile Branch

Fourmile Branch Watershed Characteristics

Fourmile Branch flows southwest for 24 km before emptying into the Savannah River, and together with Beaver Dam Creek drains over 59 km². In the swamp, part of the flow from Fourmile Branch combines with Beaver Dam Creek. Most of the Fourmile Branch flow discharges into the Savannah River through an opening in the levee between the swamp and

Table 5-11. Wetlands Change in the Upper Beaver Dam Creek Area from 1981–1985 Based on Aircraft MSS Data

Wetlands Type	Number of Hectares		Difference	Percentage Change
	1981	1985		
Water	14.8	16.8	+2.0	+13.5
Nonpersistent Emergent Marsh	8.5	3.4	-5.1	-60.0
Persistent Emergent Marsh	32.9	15.7	-17.2	-52.2
Scrub-Shrub	35.7	39.3	+3.6	+10.0
Deciduous Swamp Forest	65.8	57.5	-8.3	-12.6
Deciduous Bottomland Forest	70.3	95.4	+25.1	+35.7

Table 5-12. Wetlands Change in the Lower Beaver Dam Creek Area from 1981–1985 Based on Aircraft MSS Data

Wetlands Type	Number of Hectares		Difference	Percentage Change
	1981	1985		
Water	35.2	34.8	-0.4	-1.1
Nonpersistent Emergent Marsh	7.1	0.0	-7.1	-99.9
Persistent Emergent Marsh	9.4	11.7	+2.3	+24.4
Scrub-Shrub	8.5	8.8	-0.3	-3.5
Deciduous Swamp Forest	76.0	70.4	-5.6	-7.4
Deciduous Bottomland Forest	194.2	204.8	+10.6	+5.5

river, while another portion of the flow traverses the swamp and mixes with water from Steel Creek and Pen Branch. During river flooding, however, the flow from Fourmile Branch travels through the swamp toward Steel Creek and enters the river near or downstream from the Steel Creek area. Fourmile Branch receives effluents from F and H Areas and until 1985 received thermal discharges from C Reactor (about 11.3 m³/sec).

Fourmile Branch Corridor and Delta

Photographic data of the Fourmile Branch corridor and delta were evaluated (Table 5-13, Figure 5-17 on page 5-30, Figure 5-18, and Figure 5-14 on page 5-23). As of 1985, the Fourmile Branch impact area covered 450.3 ha (Table 5-13). Impacted Savannah River swamp canopy totaled 357.3 ha and the area in the Fourmile Branch corridor totaled 93 ha. Figure 5-19 on page 5-31 shows typical photography of the Fourmile Branch delta area during thermal periods of operation of C Reactor. Since late June 1985, C Reactor has been shutdown and natural successional revegetation is occurring in the Fourmile corridor and delta areas. Flows to Fourmile Branch have remained low since June 1985 (Table 5-13). Figure 5-20 on page 5-32 shows the Fourmile Branch delta area from 1986–1992 with invasion of scrub-shrub into the lower corridor and delta sediment fan.

The shape and expansion history of the Fourmile Branch delta impact area are different from other areas of the swamp receiving reactor effluents. Even though Fourmile Branch had a flow and temperature history similar to that of Pen Branch, the Fourmile Branch impact area (357 ha) is more than twice as large as the Pen Branch delta impact area (152 ha).

One explanation for the size difference is that the geomorphology of the Fourmile Branch delta area and swamp area are not like the other two deltas (Stevenson 1982). Hardwood islands and former river channels are common in the region of the Savannah River swamp where the Fourmile Branch thermal effluent dispersed. In contrast, Steel Creek and Pen Branch deltas have fewer hardwood islands and former river channels in the immediate vicinity. As a result of the local geomorphology, Fourmile Branch discharges to the swamp have spread not only in the traditional deltaic form (similar to Pen Branch and Steel Creek deltas), but also between elevated hardwood ridges in the Savannah River swamp (Figure 5-17 on page 5-30).

Fourmile Branch Delta—MSS Surveys 1981–1984

Using airborne multispectral scanner data, a 190-ha area of the Fourmile Branch delta for 1981 and 1984 was evaluated for wetlands change (Figure 5-13 on page 5-22). The April 1984 image was registered to the March 1981 image. Similar to the Pen Branch delta, the major change was swamp forest (cypress-tupelo) to nonpersistent emergent (NPE) wetland (9.3 hectares). Most of the change occurred along the northern and western delta fringes, where a thinned cypress community had existed in 1981. Two areas of persistent emergent (PE) wetland (1.6 ha) replaced swamp forest toward the southern edge of the delta. Swamp forest loss totals were similar to those in the Pen Branch delta, and loss rates from 1981 to 1984 are similar to previous rates determined from aerial photographic techniques (Gladden et al. 1985; Tinney et al. 1986).

Table 5-13. Estimated Impacts and Discharge Conditions to Fourmile Branch from Reactor Discharges, 1955–1991

Year	Fourmile Branch Savannah River Swamp		Fourmile Branch Corridor		Annual Average Reactor Discharge or Fourmile Branch Flows	
	Total Affected Area ^a (ha)	Expansion Rate (ha/yr)	Total Affected Area ^a (ha)	Expansion Rate of Forest Canopy Mortality (ha/yr)	Flow (cfs) ^b	Temperature (°C)
1955	-	-	-	-	100 ^c	47
1956	0.0	-	-	-	156	60
1957	0.0	-	-	-	220	66
1958	-	-	-	-	200	71
1959	-	-	-	-	273	71
1960	-	-	-	-	327	71
1961	15.8	-	105.8	17.5	389	66
1962	-	-	-	-	389	67
1963	-	-	-	-	385	68
1964	-	-	-	-	390	66
1965	-	-	-	-	385	30
1966	97.9	16.4	106.7	0.2	390	67
1967	-	-	-	-	391	71
1968	-	-	-	-	395	71
1969	-	-	-	-	390	70
1970	-	-	-	-	387	64
1971	-	-	-	-	388	65
1972	-	-	-	-	387	67
1973	-	-	-	-	387	58
1974	246.8	18.6	-	-	316	62
1975	-	-	-	-	352	59
1976	-	-	-	-	376	62
1977	-	-	-	-	376	62
1978	-	-	-	-	376	62
1979	-	-	-	-	376	61
1980	-	-	-	-	377	63
1981	-	-	-	-	376	63
1982	-	-	-	-	376	64
1983	-	-	-	-	375	68
1984	350.8	10.4	-	-	375	-
1985	357.3	6.5	93.0	0.7 ^d	220	-
1986	-	-	-	-	47	-
1987	-	-	-	-	32	-
1988	-	-	-	-	20	-
1989	-	-	-	-	24	-
1990	-	-	-	-	33	-
1991	-	-	-	-	64	-

^a Greater than 5% canopy loss

^b 35.32 cfs = 1 cms. For years 1955–1984, the data are from Tinney et al. 1986. For years 1985–1991, the data are from the USGS recording station.

^c Approximate

^d Revegetation rate

Figure 5-17. Fourmile Branch Delta Expansion Composite Image, 1961–1982 (Source: Gladden et al 1985)

Figure 5-18 Fourmile Branch Corridor Changes (Source: Tinney et al. 1986)

Figure 5-19. Vertical Aerial Photography of the Fourmile Branch Delta Area During Thermal Operations of C Reactor

5262-25

Approximate Location of Photographs

April 1986

6795-099

April 1990

7234-110

May 1992

Figure 5-20. Vertical Aerial Photography of the Fourmile Branch Delta Area After C-Reactor Shutdown

Fourmile Branch Ground Surveys 1982, 1987, 1989, 1990

Fourmile Branch received cooling water discharge from C-Reactor from 1955 when the reactor began operation until June 1985, when the reactor was shut down (Table 5-13 on page 5-29). The delta was criss-crossed by numerous small channels interspersed with islands (Figure 5-19 on page 5-31). With the shutdown of C Reactor in 1985, all but two of the main channels disappeared and the delta became much drier (Figure 5-20 on page 5-32). In mid-August 1987, a lightning-caused fire burned a large portion of the delta. Another lightning fire started on the delta in June 1988.

Field surveys in 1982, as well as photography and MSS analyses of 1981 data, resulted in identification of six communities that seemed to reflect water temperature and depth of eroded material deposited. These were: (1) thermal delta; (2) post-thermal delta; (3) scrub-shrub wetland; (4) reduced-canopy cypress-tupelo forest; (5) bottomland hardwood ridges; and (6) closed-canopy cypress-tupelo forest. Communities 1-4 are in decreasing order of disturbance, whereas 5 and 6 represent undisturbed communities.

The Fourmile Branch delta vegetation was resampled during summer of 1987 and 1989 by the University of Georgia, Savannah River Ecology Laboratory. Sampling was conducted in the mid and lower corridor, the delta, and in nearby cypress-tupelo and hardwood island stands. Community analyses were grouped to correspond to the six communities identified in the 1982 surveys. An additional category was added to the dry delta. The closed-canopy cypress-tupelo swamp was not sampled. The reduced canopy cypress-tupelo community remained largely unchanged with false nettle (*Boehmeria cylindrica*) still a dominant herb. Marsh St. Johnswort (*Hypericum walteri*) replaced bugleweed (*Lycopus* spp.) as another dominant. Pepper-vine (*Ampelopsis arborea*), buttonbush (*Cephalanthus occidentalis*) and Virginia willow (*Itea virginica*) were common shrubs in this community.

The bottomland hardwood island showed little change in woody flora with a continued high diversity of trees. Due to C-Reactor shutdown, the island no longer received woody detritus from the disturbed delta and the ground layer shifted from greenbrier (*Smilax* spp.), poison ivy (*Rhus radicans*) and grape (*Vitis rotundifolia*) to two grasses (*Panicum* spp. and *Arundinaria gigantea*) and palmetto (*Sabal minor*).

The scrub-shrub transition zone was no longer continuously flooded, but buttonbush, pepper-vine, and false nettle remained dominant. The major component of the woody vegetation of the post-thermal area (the southeast side of the delta) was pine (*Pinus taeda*) although some sweetgum (*Liquidambar styraciflua*) saplings were present. The herbaceous layer of this side of the delta was similar to that of the southeast side. Bulrush (*Scirpus cyperinus*) and fireweed (*Erechtites hieracifolia*) were common. Neither the dry delta, nor the areas along the stream, had many species which had been present in the thermal delta. Water primroses (*Ludwigia leptocarpa*, *L. alternifolia* and *L. decurrens*) were still present, but not common. *Ammania coccinea* and *Rotala ramosior* were no longer present. Almost 50% of the herbaceous cover of the delta had burned immediately prior to sampling in 1987.

As would be expected in an early successional stage, the most dominant species were herbaceous. *Erechtites hieracifolia* and *Boehmeria cylindrica* were found in over 50% of the plots surveyed in 1987. Species having a mean cover greater than 25% included *E. hieracifolia*, *Scirpus cyperinus*, *Sacciolepis striata*, and *Erianthus giganteus*. Shrubs were less

frequent, with young *Salix* spp., the most abundant, occurring in 20.7% of the plots. Trees were even less abundant (approx. 1900/ha), especially those greater than 10 cm dbh (approx. 300/ha). *Salix* spp. and *Fraxinus* spp. had the greatest densities (greater than 500/ha) and were primarily less than 10 cm dbh.

In 1989, the two species most frequently found in 1987 were joined by three additional species (*Polygonum hydropiperoides*, *Scirpus cyperinus*, and *Paspalum urvillei*) with combined frequencies greater than 50%. No species had a mean percent cover greater than 25%. Seventeen herbaceous species were found in 1989, in contrast to the 12 found in 1987. New species included *Andropogon virginicus*, *Rhus radicans*, and *Rubus* spp. *Juncus effusus* doubled its frequency from 1987 to 1989, while *Carex alata* was absent by 1989. The most frequently occurring shrub in 1989 was *Rubus* sp., which replaced the young *Salix* found in 1987. The abundance of trees did not change greatly between 1987 and 1989. *Salix* density declined by a third, while *Fraxinus* density increased slightly. Two additional species, *Liquidambar styraciflua* and *Quercus falcata*, were found. *Liquidambar* is an aggressive species, capable of dominating sites. *Quercus falcata* is more characteristic of a mixed-species bottomland forest.

In the summer of 1990, an additional survey was conducted of the lower corridor and upper delta area of Fourmile Branch (Dames and Moore 1991); 68 species were found within the sampling area. Summaries of the major strata are in the following subsections.

Overstory Stratum

No overstory vegetation was found in the sampling area within the braided stream area of the Fourmile Branch floodplain. Overstory vegetation was lost from the area due to the upstream thermal effluent release from C Reactor. Dead snags, mainly bald cypress (*Taxodium distichum*), remained in the delta region of Fourmile Branch.

Understory Stratum

The understory stratum had a total of seven species within the sampling area. Tag alder (*Alnus serrulata*) and black willow (*Salix nigra*) were the dominant species. Both the tag alder and black willow had a relative frequency of 23.08%. Tag alder had the greatest relative dominance (41.14%) and the greatest relative density (45.3%).

Shrub Stratum

Ten species were measured within the shrub stratum of Fourmile Branch. The dominant species were black willow, tag alder, and bay berry (*Myrica heterophylla*). Black willow had the highest relative frequency (25.8%) and the highest relative dominance (52.7%).

Ground Cover Stratum

Seventy-two species were recorded. Cutgrass (*Leersia oryzoides*) had the greatest dominance followed by climbing hempweed (*Mikania scandens*), false nettle (*Boehmeria cylindrica*), and tear-thumb (*Polygonum sagittatum*). The species with the greatest frequency were climbing hempweed (7.99%), false nettle (7.35%), knotweed (*Polygonum punctatum*) (6.39%), and tear-thumb (*Polygonum sagittatum*) (5.43%).

Pen Branch

Pen Branch Watershed Characteristics

Until Pen Branch enters the Savannah River swamp, it follows a path parallel to Steel Creek and Fourmile Branch. Pen Branch flow enters the swamp about 5 km from the river and flows southeast toward the Steel Creek delta area. The only significant tributary is Indian Grave Branch, which flows into Pen Branch about 8 km upstream from the Savannah River swamp. Pen Branch and Indian Grave Branch drain about 55 km² above the swamp. Indian Grave Branch received effluent cooling water from K Reactor. Above the K-Area discharge, Indian Grave Branch flow averages about 0.03 m³/sec. Above the confluence of Indian Grave Branch, Pen Branch is also a small stream, with a flow averaging 0.14 to 0.28 m³/sec (Newman et al. 1986).

The headwaters of Pen Branch consist of a largely unperturbed blackwater stream. Downstream from K Area, thermal effluent from K Reactor joined Pen Branch via Indian Grave Branch. When K Reactor operated, discharged cooling water from K Area accounted for over 98% of the stream volume. Where Pen Branch discharged into the swamp, it formed a delta. The flow from Pen Branch usually spread over the delta and continued through the swamp as shallow sheet flow until it entered the lower reaches of Steel Creek and discharged into the Savannah River. However, when the Savannah River would inundate the floodplain swamp, the flow from Pen Branch would be forced against the northern border of the swamp, across the Steel Creek delta, and be discharged into the Savannah River downstream from the mouth of Steel Creek (Shines and Tinney 1983).

Some hardwoods exist on the outer perimeter of the thermally affected areas, but most occur in non-thermal tributaries or upstream of the K-Area discharge (Ezra et al. 1986). Emergent marsh and open water are common on the delta (Mackey 1990, 1993).

Pen Branch Corridor and Delta Trends

In 1951, the Savannah River swamp and Pen Branch corridor had a closed canopy forest. In 1954, K Reactor began discharging thermal effluent to Pen Branch. The discharge volume (approximately 100 cfs) and temperature were low (Table 5-14 on page 5-36). However, canopy change in the corridor was visible as early as 1955 and 1956 in the aerial photographs (Figure 5-21 on page 5-37). About 11 hectares of bottomland hardwood forest along the corridor were partially defoliated by May 1955. Since discharge temperatures were relatively low, flooding from reactor effluents was probably the major cause of damage.

Reactor discharge temperatures began a steady rise during 1955 and 1956, and by the end of March 1956, 54 ha along the corridor had been affected. By 1961, canopy defoliation was apparent throughout the corridor (113 ha) and had reached the Savannah River swamp (4.5 ha) (Table 5-14, Figure 5-21 and Figure 5-22 on page 5-37). Most of the trees were affected, probably due to the increasing temperatures ($\bar{x}$ = 65°C) and flows ($\bar{x}$ = 338 cfs). During the next five years, the Pen Branch corridor impact area stabilized (116 ha). At the same time, a delta formed in the swamp at a rate of 9 ha/yr, reaching 51 ha by 1966 (Table 5-14 and Figure 5-22). Average flow (395 cfs) and temperature (64°C) remained relatively high (Christensen et al. 1984b, Tinney et al. 1986).

With lower K-Reactor power levels, discharge temperatures were reduced to 53°C by 1966 (Table 5-14). The delta expansion rate also decreased to 1.6 ha/yr. Reduced power opera-

Table 5-14. Estimated Impacts and Discharge Conditions to Pen Branch from Reactor Discharges, 1954–1992

Year	Pen Branch Savannah River Swamp		Pen Branch Corridor		Annual Average Reactor Discharge or Pen Branch Flows	
	Total Affected Area ^a (ha)	Expansion and Revegetation Rate (ha/yr)	Total Affected Area ^a (ha)	Expansion Rate of Forest Canopy Mortality (ha/yr)	Flow (cfs) ^b	Temperature (°C)
1954	-	-	-	-	100 ^c	26
1955	0	-	11.0	-	100 ^c	42
1956	0	-	53.8	42.8	131	63
1957	-	-	-	-	183	64
1958	-	-	-	-	214	66
1959	-	-	-	-	277	70
1960	-	-	-	-	334	66
1961	4.5	9.4	112.9	11.8	398	63
1962	-	-	-	-	399	63
1963	-	-	-	-	394	66
1964	-	-	-	-	394	67
1965	-	-	-	-	392	62
1966	51.4	-	115.7	0.6	389	53
1967	-	-	-	-	389	58
1968	-	-	-	-	389	63
1969	-	-	-	-	389	57
1970	-	-	-	-	386	46
1971	-	-	-	-	388	57
1972	-	-	-	-	390	55
1973	63.1	1.7	-	-	388	59
1974	-	-	-	-	324	61
1975	-	-	-	-	373	58
1976	-	-	-	-	376	57
1977	-	-	-	-	375	57
1978	-	-	-	-	378	57
1979	102.4	6.6	-	-	379	61
1980	-	-	-	-	380	64
1981	-	-	-	-	380	64
1982	121.0	6.2	-	-	381	67
1983	-	-	-	-	380	-
1984	147.4	13.2	-	-	370	59
1985	151.8	4.4	92.6	-1.2	367	-
1986	-	-	-	-	270	-
1987	-	-	-	-	329	-
1988	-	-	-	-	140	-
1989	-	-	-	-	78	-
1990	-	-	-	-	57	-
1991	-	-	-	-	200	-
1992	-	-	-	-	160	-

^aIncludes greater than 5% canopy loss

^b35.82 cfs = 1 cms. For years 1954–1984, the data are from Tinney et al. 1986. For years 1985–1991, the data are from the USGS recording station as SRS Road A13.2. For 1992 the data are from Mackey 1993.

^cApproximate

Figure 5-21. Wetland Changes in the Pen Branch Corridor, 1955–1985 (Source: Tinney et al. 1986)

Figure 5-22. Pen Branch Delta Expansion, 1955–1985 (Source: Tinney et al. 1986)

tions and discharge temperatures continued through 1974 when SRS began an energy conservation program in all reactor areas. Since less cooling water was used, K-Reactor discharges dropped an average of 20 cfs (Table 5-14). However, delta growth accelerated to 6.6 ha/yr after 1973 despite the reduced flows and temperatures. After 1979, reactor power levels began to return to higher levels. Effluent temperatures increased ($\bar{x} = 65^{\circ}\text{C}$) and the Pen Branch delta growth continued. In 1985, the impact zone was about 152 ha and was expanding at a rate of about 4 ha/yr (Table 5-14) (Christensen et al. 1984b; Tinney et al. 1986).

As of 1985, a total of approximately 245 ha of forested wetlands were impacted by thermal discharges from K Reactor. Defoliated canopy was visible in both the stream floodplain (93 ha) and SRS swamp (152 ha). Although the Pen Branch delta was expanding at a rate of 4 to 5 ha/yr in 1985, no additional wetlands losses were expected in the stream corridor (Tinney et al. 1986).

Much of the swamp canopy loss in the early to mid-1980s near Pen Branch delta occurred in the southeasterly direction from the main Pen Branch delta, adjacent to the upland terrace along the Savannah River swamp (Figure 5-23) (Sharitz et al. 1986; Christensen et al. 1986; Jensen et al. 1987). EG&G thermal infrared surveys showed that during river flooding, thermal effluents from both Fourmile Branch and Pen Branch were channeled along the northeast bank of the swamp away from the river (Figure 5-24) (Shines and Tinney 1983). River flooding seems to correlate with the southeastern progression of the Pen Branch delta. From 1966 to March 1973, the southeastern "tail" changed little (Figure 5-23). Spring flooding frequency and duration were low during this period. After 1973, the "tail" began to increase in size along with an increase in springtime flooding frequency. The channeling of thermal effluents during the spring and summer growing season, when the cypress-tupelo forest is most sensitive, may have resulted in increased mortality (Sharitz et al. 1986). The post-1973 increase in river flooding intensity may have caused the increase in the delta expansion rate

Figure 5-23. Pen Branch Delta Expansion Composite Image, 1961–1982
(Source Christensen et al. 1984b)

from 1.7 to 6.6 ha/yr, when reactor discharge temperatures and flows remained relatively constant (Christensen et al. 1984b).

Wetland Characteristics of the Pen Branch Delta Area, Early 1980s

Pen Branch received thermal effluent from K Reactor. Temperatures of the reactor effluents at the point of release into Pen Branch commonly exceeded 65°C. Water temperatures throughout the length of the then thermal portion of Pen Branch typically exceeded 40°C in the summer months. The original flora of the stream and associated floodplains was destroyed and the area underwent successional revegetation. Sharitz et al. (1974a) found only 34 species of vascular plants in the stream corridor of Pen Branch at a site immediately above the delta where the stream enters the Savannah River swamp. All of the plants were growing above the water on sandbars or small islands formed by fallen logs and tree stumps. Of the floodplain area sampled, only 56% supported vascular plant life. The Pen Branch floodplain flora was characterized by herbaceous plants. The dominant species was *Ludwigia leptocarpa*, which was shown to have a relatively high tolerance to the elevated thermal conditions of the SRS swamp (Christy and Sharitz 1980). The other species were mostly perennial herbaceous plants characteristic of disturbed areas. Perennial herbs constituted 60% of the Pen Branch flora and annual herbs another 20%. In another early survey, Irwin (1975) sampled the vegetation of stump communities at three sites in the thermal portion of Pen Branch. Fifteen stumps from each of three areas corresponding to mean annual water temperatures of approximately 50°C, 45°C, and 40°C were evaluated. The vegetation of the stump communities in Pen Branch included old-field species, roadside weeds and

Figure 5-24. Thermal Patterns in the Pen Branch delta Under Non-Flood (Top) and Flood (Bottom) Conditions of the Savannah River (Source: Scott et al. 1986)

aquatic herbs. Twenty-six of the species were herbaceous, and of the nine woody species, three were tree seedlings. There was no clearly distinguishable relationship between stream water temperature and stump community composition, although the upstream sites (water temperature approximately 50°C) were dominated by several old-field species, including *Eupatorium* spp. and *Andropogon virginicus*. Downstream sites (water temperatures approximately 40–45°C) had a greater dominance of aquatic species, such as *Ludwigia leptocarpa* and *Ammannia coccinea*. Woody plants are relatively intolerant of the elevated temperature and substrate conditions. Other information on the in-stream habitat formers of the thermal and non-thermal streams of SRS are summarized in the Comprehensive Cooling Water Study and other studies at SRS from 1983 to 1985 (Firth et al. 1986).

MSS Surveys—Pen Branch Delta

Central Portion MSS Surveys, 1981–1984

The April 1984 MSS data were registered to March 1981 data for a 190-ha area centered on the Pen Branch delta (Figure 5-13 on page 5-22). The most obvious difference between 1981 and 1984 is the emergent marsh expansion into thinned cypress-tupelo areas. About 12 ha of cypress-tupelo were replaced by nonpersistent emergent and persistent emergent wetlands. The majority of the area of cypress-tupelo lost was adjacent to the existing thermal delta or southeast along the Savannah River swamp terrace edge.

Tail Portion MSS Surveys, 1981–1985

Expansion of the Pen Branch delta occurred southeast of the main portion of the delta along the SRS Savannah River swamp terrace edge. The Pen Branch “tail” extended southeast for approximately 3 km along an upland terrace adjacent to the Savannah River swamp. This area was influenced by thermal effluents, especially during flood events (Figure 5-24 on page 5-39). A separate evaluation of this area was conducted using aircraft MSS data from March 31, 1981, and April 29, 1985. Two 375-ha subsets from the 1981 and 1985 MSS data were evaluated (Figure 5-13 on page 5-22).

The MSS data were classified into the following wetland vegetation classes once the 1981 and 1985 imagery were registered to one another (Table 5-15):

- W - Open Water
- EM - Emergent Marsh (persistent and nonpersistent)
- DSF - Deciduous Swamp Forest
- DBF - Deciduous Bottomland Forest

One additional class of deciduous swamp forest, referred to as transition deciduous swamp forest (T-DSF), was found in both the 1981 and 1985 imagery. T-DSF consists of cypress-tupelo swamp forest with a sparse, stressed canopy which allowed radiant flux from the emergent marsh below to be integrated within a typical pixel. The stressed cypress-tupelo was documented *in situ* in the Pen Branch tail by Scott et al. (1986) and radiometrically by Jensen et al. (1986b). The statistics associated with the changes in the Pen Branch delta from 1981 to 1985 are summarized in Table 5-16 on page 5-41.

Table 5-15. Wetland Classification Scheme for the Pen Branch "Tail" Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data

Wetlands Class	Representative Species	
	Common Name	Scientific Name
W - Open Water		
EM - Emergent Marsh	Bulrush	<i>Scirpus cyperinus</i>
	Cutgrass	<i>Leersia</i> spp.
	False Nettle	<i>Boehmeria cylindrica</i>
	Water Primrose	<i>Ludwigia</i> spp.
	Hydrolea	<i>Hydrolea quadrivalvis</i>
DSF - Deciduous Swamp Forest	Cypress	<i>Taxodium distichum</i>
	Tupelo	<i>Nyssa aquatica</i>
DBF - Deciduous Bottomland Forest	Oak	<i>Quercus</i> spp.
	Sweetgum	<i>Liquidambar styraciflua</i>
	Red Maple	<i>Acer rubrum</i>
	Hickory	<i>Carya</i> spp.

Table 5-16. Pen Branch "Tail" Wetlands Change Detection Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data

From	To	Hectares
Deciduous Swamp Forest (DSF)	Emergent Marsh (EM)	3.64
Deciduous Swamp Forest (DSF)	Transition-DSF (T-DSF)	12.14
Deciduous Swamp Forest (DSF)	Open Water (W)	9.30
Transition-DSF (T-DSF)	Emergent Marsh (EM)	2.42
Transition-DSF (T-DSF)	Open Water	1.21
Transition-DSF (T-DSF) No Change		5.66

Pen Branch Ground Surveys 1990

In the summer of 1990, a series of vegetation surveys was conducted along the Pen Branch drainage from the K-Reactor discharge canal to the Pen Branch "Tail" area (Dames and Moore 1991). In the following paragraphs these surveys are summarized by survey area along the creek and for each vegetation stratum.

Indian Grave Branch Section

Introduction

Indian Grave Branch, a 2.5-mile-long tributary to Pen Branch, has steep, incised banks with a flow approximately 15 feet to 20 feet wide. Sampling plots were located along Indian Grave Branch beginning approximately 1000 feet north of Road B and extending south to the confluence of Pen Branch. Ninety-nine species were found.

Overstory Stratum

Thirteen species were found in the overstory. The average height of the overstory canopy was 62 feet. The most dominant species occurring within the sample plots were yellow poplar (*Liriodendron tulipifera*) and black gum (*Nyssa sylvatica*). Red maple (*Acer rubrum*)

had the highest density within the sampling plots. Following red maple in relative density were black gum, yellow poplar, sweet gum (*Liquidambar styraciflua*), and sycamore (*Platanus occidentalis*).

Understory Stratum

Fourteen species were found in the understory. American holly (*Ilex opaca*) had the highest importance value of the 14 species. Following American holly were sweet gum, redbay (*Persea borbonia*), and tag alder (*Alnus serrulata*). American holly also had the greatest relative density.

Shrub Stratum

Twenty-seven species were found in the shrub stratum. American holly had the greatest relative dominance, followed by tag alder. Red bay had the greatest relative density, followed by American holly and sweet bay (*Magnolia virginiana*).

Ground Cover Stratum

One hundred five species were found in the ground stratum. Soft rush (*Juncus effusus*) had the highest importance value. Following soft rush were netted chainfern (*Woodwardia areolata*), dogfennel (*Eupatorium capillifolium*), and cutgrass (*Leersia* sp.).

Mid-Corridor Section

Introduction

This section began approximately 100 feet north of Road 125 and extended south for approximately three miles. This sampling area ranges in elevation from 135 feet to 115 feet msl. For approximately one mile, the sampling area has steep banks leading down to the floodplain of the creek. From this point, the topography surrounding Pen Branch flattens. Due to the flat terrain, the surface runoff contributing to Pen Branch flows as wide sheets of water rather than being confined to small intermittent tributaries. Eighty-eight species were found in this section of Pen Branch.

Overstory Stratum

The average canopy height of the overstory vegetation was 70 feet. Red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), yellow poplar (*Liriodendron tulipifera*), and ash (*Fraxinus* sp.) were the most common species in this stratum.

Understory Stratum

Fifteen species were measured within the understory of this section. Wax myrtle (*Myrica cerifera*) was the dominant species. Wax myrtle had the highest importance value for the area, followed by black willow (*Salix nigra*), tag alder (*Alnus serrulata*), and sweet gum (*Liquidambar styraciflua*).

Shrub Stratum

Nine species were found in the shrub-layer of this section. Black willow had the highest importance value followed by wax myrtle, tag alder, red maple, and sweet gum.

Ground Cover Stratum

One hundred one species were found in the ground cover layer. False nettle (*Boehmeria cylindrica*) had the highest importance value, followed by woolgrass (*Scirpus cylindrica*), jewel weed (*Impatiens capensis*), climbing hempweed (*Mikania scandens*), and marsh dew-flower (*Murdannia keiskei*), all with about equal importance values.

Lower Pen Branch Corridor

Introduction

The lower Pen Branch corridor begins south of Road A-13.2 (Risher Pond Road) and extends south for approximately 0.75 mile. This stretch of Pen Branch drops only 10 feet in elevation through the sampling area, beginning at 100 feet msl in elevation and dropping to 90 feet msl at the southernmost plot. This area was dominated by scrub-shrub growth and had a series of braided streams which ran parallel. Within the braided streams were many islands on which thick masses of ground cover vegetation (persistent emergent) were thriving. Nonpersistent emergent vegetation was also well represented in the area. Seventy-six species were found.

Overstory Stratum

The overstory vegetation in this area was represented by seven species. The average canopy height was 64 feet. Sweet gum (*Liquidambar styraciflua*) and black gum (*Nyssa sylvatica*) were the dominant species followed by red maple (*Acer rubrum*).

Understory Stratum

Nine species were found in the understory. The dominant species was black willow (*Salix nigra*). Following black willow were black gum, tag alder (*Alnus serrulata*), buttonbush (*Cephalanthus occidentalis*), and American holly (*Ilex opaca*).

Shrub Stratum

Thirteen species were found in this stratum. Black willow had the highest importance value. Black willow was the most common, followed by tag alder, buttonbush, and sweet bay (*Magnolia virginiana*).

Ground Cover Stratum

Seventy-eight species were found within this layer. False nettle (*Boehmeria cylindrica*) was the dominant species, followed by fireweed (*Erechtites hieracifolia*) and woolgrass (*Scirpus cylindrica*).

Upper Delta Area

Introduction

The upper delta was similar to the lower corridor area in that it had braided streams and islands occurring within the broad, flat floodplain. Elevation ranged from 85 feet msl to 80 feet msl. Dead trees occupied this lower section, and woody debris from a previously forested area was scattered throughout. The loss of the overstory resulted in a thick growth of scrub-shrub and persistent emergent vegetation. Sixty-one species were found in this section.

Overstory Stratum

No overstory vegetation was measured. All sampling plots were located in the wide floodplain of the lower section of Pen Branch. The area once was well forested; however, in 1990 it contained many dead snags of black gum (*Nyssa* sp.) and bald cypress (*Taxodium distichum*).

Understory Stratum

Only five species were found in the understory stratum. Black willow (*Salix nigra*) was the dominant species followed by buttonbush (*Cephalanthus occidentalis*).

Shrub Stratum

The shrub stratum had a total of 12 species. Black willow dominated followed by buttonbush.

Ground Cover Stratum

The ground cover stratum was dominated by false nettle (*Boehmeria cylindrica*) followed by fireweed (*Erechtites hieracifolia*) and dog-fennel (*Eupatorium capillifolium*). The presence of dog-fennel demonstrates the drying nature of the Pen Branch delta since K-Reactor shutdown in 1988 (Mackey 1993).

Mid-Delta Area

Introduction

This area is located within the delta region of the confluence of Pen Branch and the Savannah River floodplain. The area was dominated by persistent and non-persistent vegetation and has a soft substrate that is inundated with water. The elevation of the sampling area is approximately 80 feet msl. Located to the east of this area is the Pen Branch boardwalk. Little shrub and understory vegetation was observed in the area and no overstory stratum was sampled. Thirty-one plant species were found within the mid-delta region.

Overstory Stratum

There was no overstory vegetation within this area.

Understory Stratum

Only one individual wax myrtle (*Myrica cerifera*) met the criterion for understory stratum vegetation.

Shrub Stratum

The shrub layer contained three species, black willow (*Salix nigra*), buttonbush (*Cephalanthus occidentalis*), and wax myrtle.

Ground Cover Stratum

Thirty-four species were measured in this stratum. Broad-leaf arrowhead (*Sagittaria latifolia*) had the greatest importance value, followed by river seedbox (*Ludwigia leptocarpa*), cattail (*Typha latifolia*), and beggar tick (*Bidens frondosa*).

Pen Branch "Tail" Area

Introduction

The Pen Branch tail area begins east of the Pen Branch boardwalk and extends east for approximately 1.25 miles. The area was dominated by persistent and nonpersistent emergent vegetation. To the east, there was an increase in mature bald cypress trees (*Taxodium distichum*) and the density of seedlings and saplings greatly increased. Seventy-seven species were found in the area.

Overstory Stratum

Bald cypress, water tupelo (*Nyssa aquatica*), and black gum (*Nyssa sylvatica*) were the three species occupying this area. The average height of the sparse canopy was 78 feet. The overstory vegetation became progressively more dense as distance from the mouth of Pen Branch increased.

Understory Stratum

Four species were measured in the understory stratum of this area. Wax myrtle (*Myrica cerifera*) was the most common with black willow (*Salix nigra*) second.

Shrub Stratum

The shrub stratum, like the overstory and understory strata, was represented by only a few species, in this case five. Wax myrtle was the dominant species, followed by buttonbush (*Cephalanthus occidentalis*).

Wax myrtle appeared to be better established than the other species in this area. This area lies within the floodplain of the Savannah River. The plot was located just below the wetland/upland boundary of the Savannah River floodplain and remained inundated with water for a great portion of the growing season. The area sampled was undergoing succession from persistent/nonpersistent vegetation to a palustrine forest.

Ground Cover Stratum

Sixty-eight species were found in the ground cover stratum of this area. Marsh dewflower (*Murdannia keisak*), a highly successful introduced plant, was the most common plant. Broad-leaf arrowhead (*Sagittaria latifolia*), cattail (*Typha latifolia*), and false nettle (*Boerhaavia cylindrica*) were also common.

Summary of 1990 Pen Branch Ground Survey

Because of past disturbances which removed the overstory in areas of Pen Branch affected by reactor effluent, growing conditions were excellent for typical pioneer plant species. Except in areas of deep water, the vegetation over much of the corridor and delta responded vigorously to the reactor outage, producing dense herbaceous and woody growth. Cover in these sites generally approached 100%. The exact species composition depends on substrate and hydrology and chance colonization events (Mackey 1990, 1993; Blohm 1993).

Steel Creek

Steel Creek Watershed Characteristics

Steel Creek is located in the eastern half of SRS. Steel Creek and its major tributary, Meyers Branch, drain approximately 91 km² of upland before entering the swamp and flowing to the Savannah River. The drainage basin for Meyers Branch constitutes over half of the overall watershed area (50.85 km²). The stream slope changes from 4.6 m/km at the head to 0.8 m/km as it enters the Savannah River (Newman 1986).

Steel Creek Corridor and Delta Trends

In 1951, a closed canopy forest extended throughout much of the Savannah River swamp and Steel Creek corridor. Although portions of the forest had been previously logged

Figure 5-25. Steel Creek Wetland Changes, 1955–1985 (Tinney et al. 1986)

Table 5-17. Estimated Impacts and Discharge Conditions to Steel Creek from Reactor Discharges, 1954–1991

Year	Steel Creek Delta Savannah River Swamp		Steel Creek Corridor		Annual Average Reactor Discharge or Creek Flow	
	Total Affected Area ^a (ha)	Expansion and Revegetation Rate (ha/yr)	Total Affected Area ^a (ha)	Expansion Rate of Forest Canopy Mortality (ha/yr)	Flow (cfs) ^d	Temperature (°C)
1954	0	-	-	-	200	32
1955	0	-	48.1	48.1	200	44
1956	72.8	72.8	132.2	84.1	257	64
1957	-	-	-	-	270	71
1958	-	-	-	-	386	69
1959	-	-	-	-	557	72
1960	-	-	-	-	649	72
1961	122.6	10.1	143.4	2.2	758	67
1962	-	-	-	-	763	68
1963	-	-	-	-	372	66
1964	-	-	-	-	376	67
1965	-	-	-	-	371	69
1966	124.2	0.4	146.0	0.5	370	70
1967 ^b	-	-	-	-	368	69
1968 ^b	-	-	-	-	370	67
1974	120.6	0.4	147.0	0.1	-	-
1981	-	-	-	-	32	-
1982	113.3	0.9 ^c	-	-	56	-
1983	-	-	-	-	72	-
1984	90.1	7.8 ^c	-	-	79	-
1985	81.9	8.1 ^c	76.1	5.9 ^c	83	-
1986	-	-	-	-	250	-
1987	-	-	-	-	260	-
1988	-	-	-	-	240	-
1989	-	-	-	-	130	-
1990	-	-	-	-	130	-
1991	-	-	-	-	180	-

^aGreater than 5% canopy loss

^bL Reactor discharged for two months before shutdown

^cRevegetation rate

^d35.32 cfs = 1 cms. For years 1954–1968, the data are from Tinney et al. 1986. For years 1981–1991, the data are from the USGS recording station.

Figure 5-26. Steel Creek Growth and Revegetation Trends, 1951–1985 (Source: Tinney et al. 1986)

(Jensen et al. 1993), a second-growth forest of bald cypress, water tupelo, and bottomland hardwoods was present. In 1954, both L and P Reactors began releasing thermal effluents to Steel Creek. The discharge volume (approximately 200 cfs total) and temperature (30 to 40°C) were relatively low (Table 5-17). Approximately one year after startup, 48 ha of bottomland forest were partially defoliated in the Steel Creek corridor below both L and P Reactors (Table 5-17 and Figure 5-25). Canopy loss continued into 1956 with 132 ha of corridor floodplain forest damaged (Table 5-17 and Figure 5-25). At the same time, the first signs of canopy loss also appeared in the swamp (Figure 5-26 on page 5-48). In a one-year period, 73 ha of cypress-tupelo canopy were partially defoliated in the swamp. Canopy loss in the swamp continued at an overall rate of 10 ha/yr while in the Steel Creek floodplain defoliation slowed to 2.2 ha/yr from 1956 to 1961 (Table 5-17). During this period reactor discharge temperatures averaged approximately 70°C (Table 5-17).

Maximum flow in Steel Creek occurred between 1960 and 1963 (Table 5-17). However, from 1961 to 1966, the floodplain and the swamp impact zones grew at a rate of about 0.5 ha/yr (Figures 11 and 12). The lower growth rate probably occurred because P-Reactor thermal effluents were diverted to Par Pond in 1963. From 1961 to early 1963, reactor discharges to Steel Creek averaged 760 cfs, but dropped to about 370 cfs from 1963 to 1968 (Table 5-17). Water temperatures remained relatively constant. In 1966, the total impact area was near maximum size at 124 ha in the swamp and 146 ha in the Steel Creek corridor (Table 5-17).

In 1963, P-Reactor thermal effluents were diverted to Par Pond, allowing the natural successional revegetation of bottomland forest to begin in the upper portion of the Steel Creek corridor. When L Reactor discontinued operations in 1968, the swamp and remainder of the floodplain forest also began to revegetate. Between 1968 and 1982, new forest canopy cover established in the swamp at a rate of less than one ha/yr (Figure 5-26). After 1982, the canopy recovery rate accelerated to about 8 ha/yr as young hardwoods matured. However, most new regrowth of woody species was of *Salix* spp. (willow) and not the original cypress-tupelo swamp forest (Repaske 1981, Smith et al. 1981). Some cypress-tupelo

regeneration occurred in fringe areas of the swamp impact zone where thermal exposure had been less extreme (Tinney et al. 1986).

Some cypress-tupelo regeneration occurred offsite in the Creek Plantation Swamp (south-east of SRS). Thermal effluent from Steel Creek entered the area after 1956, particularly when the swamp was flooded in late winter and early spring. By 1961, about 5 ha of swamp canopy offsite had been altered. After 1963, the canopy began to recover and by 1966 the impact area visible on aerial photographs had been reduced to 4 ha. Currently, a closed canopy exists in the previously impacted offsite area (Christensen et al. 1984a; Tinney et al. 1986).

Wetland Characteristics of the Steel Creek Drainage Area, Early 1980s

The wetlands of the Steel Creek drainage have been studied extensively since 1981. Smith et al. (1981, 1982) summarized the results of many of the early studies. These initial studies were expanded during the Comprehensive Cooling Water Study that continued into 1985, immediately prior to the restart of L Reactor in 1985 (Mackey 1987). Generally, these studies documented that the Steel Creek ecosystem has been in a state of successional revegetation since the 1968 L-Reactor shutdown.

With long-term reactor shutdown, plant succession on the Steel Creek delta proceeded rapidly. The initial flora of the emergent sandbars was dominated by fimbriatylis (*Fimbristylis autumnalis*), water primrose (*Ludwigia leptocarpa* and *L. decurrens*), sedges (*Cyperus* spp.), and echinochloa (*Echinochloa walteri*) (McCaffrey 1982). Smartweed (*Polygonum punctatum*), wapato (*Sagittaria latifolia*), and cut grass (*Leersia oryzoides*) became dominant plants four to eight years after reactor shutdown. Seven years after shutdown, aneilema (*Aneilema keisak*) became an additional dominant; cut grass increased and smartweed decreased in dominance.

Begger ticks (*Bidens* spp.), marsh St. John's-wort (*Hypericum walteri*), false nettle (*Boehmeria cylindrica*), and bulrush (*Scirpus cyperinus*) had an intermediate ranking in importance four to eight years after reactor shutdown. Redtop panicgrass (*Panicum agrostoides*) also had an intermediate ranking at the later date. Buttonbush (*Cephalanthus occidentalis*) and willow (*Salix* spp.) appeared during this time while seedlings of other woody species were ephemeral. According to Martin et al. (1977), the Steel Creek delta was covered with water and resembled a freshwater marsh in 1975. The vegetation was characterized by a low, dense herbaceous cover with numerous clumps of large graminoids and widely spaced shrubs. In 1981, there were three major stages of succession in the persistent emergent wetland. There were areas of abundant knot grass that generally fit the description by Martin et al. (1977); areas in which numerous small buttonbush and willow plants were nearly as tall as the knot grass (approximately 1.5 m); and other areas that were dominated by a mixture of willow and buttonbush shrubs which were taller than the knot grass.

In 1981-1982, following 14 years of revegetation, cut grass remained dominant in habitats similar to those described by Martin et al. (1977) with knot grass of increased importance and redtop panicgrass commonly occurring. Aneilema (*Aneilema keisak*) and waterpepper (*Polygonum hydropiperoides*) were still abundant, especially in the more deeply flooded areas.

The major difference in vegetative cover after 15 years of successional revegetation was the increase in woody vegetation. The dominant species was willow (*Salix* spp.). Seedlings of

bald cypress (*Taxodium distichum*), water ash (*Fraxinus* spp.), water elm (*Planera aquatica*), and red maple (*Acer rubrum*) also occurred, especially toward the delta periphery. The survival and growth of these plants are largely dependent upon the duration and timing of flooding (Broadfoot and Williston 1973; Whitlow and Harris 1979; Sharitz et al. 1986; McLeod et al. 1986; Scott et al. 1985).

Because of a raised substrate on which hardwood species may become established, it is likely that the deltaic fan will eventually become more like deciduous bottomland hardwood forest (*Quercus lyrata*--*Carya aquatica*--*Nyssa aquatica*) than the original deciduous swamp forest.

Succession in the areas of deeper water is dependent upon water depth and flow. Here submerged aquatic plants (*Ceratophyllum demersum* and *Myriophyllum brasiliense*) colonized submerged logs. These species are joined by numerous emergent aquatic species, including smartweed (*Polygonum lapathifolium*) and aneilema (*Aneilema keisak*) in deeper water with low flow. Hydrolea (*Hydrolea quadrivalvis*) dominates the periphery of the deltaic fan and occurs over a wide range of water depths, along with parrot-feather (*Myriophyllum brasiliense*) and *Ludwigia* spp. The shallower areas allow the presence of wapato with abundant rhynchospora (*Rhynchospora corniculata*). Waterpepper occurs in similar habitats. Both wapato and waterpepper are transitional species occurring in both nonpersistent emergent wetlands and in persistent emergent wetlands.

Steel Creek Delta MSS Surveys, 1981–1985

The Steel Creek delta was formed between 1954 and 1968 by cooling water discharges from L and P Reactors. The visibly impacted zone covered about 140 ha and was shaped in the traditional deltaic form, with an extended tail stretching parallel to the adjacent upland terrace and Savannah River (Tinney et al. 1986). Steel Creek delta revegetation has been well documented (Sharitz et al. 1974b; Smith et al. 1981; Mackey 1982; Jensen et al. 1984b; Christensen et al. 1984b, 1986; Gladden et al. 1985; Mackey et al. 1987). Early Steel Creek delta wetland maps based on ground surveys and vertical aerial photographic interpretation showed fairly distinct communities, distributed according to sedimentation patterns and water levels (Smith et al. 1981). After 1981, successional vegetation changes continued to proceed on the Steel Creek delta. The most obvious change observed with the MSS data was the extensive replacement of persistent emergent communities with scrub-shrub communities in the center portion of the delta. Sediment accumulations from past reactor discharges raised this part of the delta, keeping water depths lower and favoring

Table 5-18. Steel Creek Delta Wetland Areas on March 31, 1981, and April 26, 1985, Based on Aircraft MSS Data

Wetland Classes	March 31, 1981		April 26, 1985	
	Hectares	Percentage	Hectares	Percentage
Water	0.00	0.00	4.26	1.79
NPE	29.75	12.53	16.33	6.84
PE	27.07	11.40	11.32	4.74
SS	28.17	11.87	56.82	23.81
DSF	82.04	34.56	80.57	33.75
DBF	14.40	6.07	13.47	5.64

scrub-shrub invasion and establishment. Scrub-shrub has expanded in the water marsh areas, replacing nonpersistent emergent; and persistent emergent has colonized former non-persistent emergent areas. Most of the thinned cypress-tupelo canopy was consolidated along the margins of the Steel Creek delta area (Christensen et al. 1986).

MSS data for Steel Creek delta were collected on April 26, 1985, and compared to the March 31, 1981, data. MSS data for 1981 and 1985 for an area of 240 ha centered on the Steel Creek delta was registered (Figure 5-13). The 1981 and 1985 data were classified into the following wetland vegetation classes:

- W - Water
- EM - Emergent Marsh (Persistent and Nonpersistent)
- DSF - Deciduous Swamp Forest
- DBF - Deciduous Bottomland Forest

Descriptions of wetlands classification techniques used with these data are described in Christensen et al. (1986). The wetland acreage statistics for the 1981 and 1985 classification maps are shown in Table 5-18 and Table 5-19, respectively.

The classification maps were compared to document the change from 1981 to 1985; the results are summarized in Table 5-20. It is important to remember that with the restart of L Reactor, additional water was present in Steel Creek delta in 1985. Also, the delta wetlands vegetation changed rapidly from 1981 to 1985. Approximately 1.9 ha of persistent emergent (PE) marsh changed to nonpersistent emergent (NPE) marsh. About 14 ha of PE changed

Table 5-19. Steel Creek Delta Wetland Areas on April 26, 1985, Based on Aircraft MSS Data with Improved Discrimination of Scrub-Shrub and Deciduous Swamp Forest

Wetland Classes	Hectares	Percentage
Water	4.26	1.79
Nonpersistent Emergent Marsh (NPE)	16.33	6.84
Persistent Emergent Marsh (PE)	11.32	4.74
Scrub-Shrub (SS-Buttonbush)	38.63	16.18
Scrub-Shrub (SS-Willow)	18.20	7.62
Deciduous Swamp Forest (DSF-Tupelo)	36.26	15.19
Deciduous Swamp Forest (DSF-Cypress)	44.31	18.56
Deciduous Bottomland Hardwood (DBF)	13.47	1.79

Table 5-20. Steel Creek Delta Wetlands Change Based on March 1981 and April 1985 Aircraft MSS Data

From	To	Hectares
Nonpersistent Emergent Marsh (NPE)	Water	1.10
Nonpersistent Emergent Marsh (NPE)	Persistent Emergent Marsh (PE)	3.26
Nonpersistent Emergent Marsh (NPE)	Scrub-Shrub (SS)	8.62
Persistent Emergent Marsh (PE)	Nonpersistent Emergent Marsh (NPE)	1.87
Persistent Emergent Marsh (PE)	Scrub-Shrub (SS)	13.79
Scrub-Shrub (SS)	Persistent Emergent Marsh (PE)	3.26
Scrub-Shrub (SS)	Nonpersistent Emergent Marsh (NPE)	1.40

into scrub-shrub (SS). Approximately 1.1 ha of NPE changed into persistent emergent (PE) marsh. Also, 8.6 ha of NPE changed into SS. Some NPE changed into water (3.3 ha). Some SS (3.3 ha) changed into PE and some (1.4 ha) changed to NPE in certain regions of the delta.

MSS Surveys Below L Lake, 1985–1987

The Steel Creek corridor and delta areas were surveyed in spring 1985, 1986, and 1987 using airborne multispectral scanner (MSS) techniques. Data obtained during the remote sensing overflights were processed to obtain estimates of the aerial coverage of major wetland vegetation classes for each year so that estimates of wetland change following the restart of L Reactor in 1985 could be made.

Bottomland hardwood and scrub-shrub vegetation dominated the Steel Creek corridor area between L-Lake Dam and the Savannah River swamp (Table 5-21 on page 5-52). The only trend evident across the three years was a shift from bottomland hardwood to emergent wetland vegetation types. This change indicated that portions of the hardwood forest canopy became more open along the Steel Creek corridor, and herbaceous vegetation invaded areas where light penetrated the canopy. Although changes in coverage have occurred in both the scrub-shrub and open-water classes, consistent trends did not appear during the survey years.

Vegetation cover changes in the delta were small after the restart of L Reactor in 1985 (Table 5-22). Neither deciduous bottomland forest, nor deciduous swamp forest vegetation classes exhibited changes that would indicate substantial community alteration from 1985 to 1987. Scrub-shrub, nonpersistent emergent marsh, persistent emergent marsh, parrots feather, and open-water cover classes appeared to have undergone changes related to increased flooding resulting from L-Reactor operations. Specifically, cover of scrub-shrub and persistent emergent marsh vegetation appeared to decline while non-persistent emergent marsh, parrots feather, and open-water cover classes increased in aerial extent from 1985 to 1987. Between 1987 and 1993, flows to Steel Creek remained low to moderate (Table 5-14 on page 5-36) and little change was noted in the vegetation patterns of Steel Creek delta.

Table 5-21. Changes in Area of Wetland Vegetation Classes in Steel Creek Corridor from L-Lake Dam to Steel Creek Delta. Estimates of Areas Covered (in hectares) by Wetland Vegetation Types in Steel Creek Corridor in 1985, 1986, and 1987

Vegetation	1985	1986	1987
Bottomland hardwood	162	160	151
Scrub-shrub	106	95	105
Emergent wetland	3	11	14
Open water	1	7	2
Total	272	273	272

Table 5-22. Changes in Area of Wetland Vegetation Classes in Steel Creek Delta in 1985, 1986, and 1987

Vegetation	1985	1986	1987
Deciduous bottomland forest	77	72	80
Deciduous swamp forest	108	100	105
Scrub-shrub	68	69	58
Nonpersistent emergent marsh	9	19	19
Persistent emergent marsh	14	<1	0
Parrots feather	0	13	8
Open water	11	13	15
Total	287	287	285

April 1985

April 1986

April 1988

May 1992

Figure 5-1. Vertical Aerial Photography of the Steel Creek Delta Area Before (1985), During (1986, 1988), and After (1992) L-Reactor Shutdown

References

- Borrell, J. "Geographical Information Systems". *Computer Graphic World*. 5:45-49 (1982).
- Brewster, S. B., Jr. and L. R. Tinney. *Vegetation Classification of the Savannah River Floodplain*. DOE/ONS-8404, EG&G Energy Measurements, Las Vegas, NV (December 1984).
- Broadfoot, W. M. and W. L. Williston. "Flooding Effects on Southern Forests". *J. Forestry*. 71:584-587 (1973).
- Burnside, C. D. *Mapping from Aerial Photographs*. John Wiley and Sons, New York, 304 pp (1979).
- Christensen, E. J., J. R. Jensen, E. W. Ramsey, and H. E. Mackey, Jr. "Aircraft MSS Data Registration and Vegetation Classification for Wetland Change Detection". *Int. J. Remote Sensing*. 9(1):23-38 (1988).
- Christensen, E. J., J. R. Jensen, E. W. Ramsey, and H. E. Mackey, Jr. "Wetland Vegetation Change Detection Using High Resolution Aircraft MSS Data". 1986 ASPRS-ACSM Fall Convention, Proceedings, September 28-October 3, Anchorage, Alaska, pp. 148-162 (1986).
- Christensen, E. J., M. E. Hodgson, J. R. Jensen, H. E. Mackey, and R. R. Sharitz. *An Evaluation of Steel Creek Delta Growth and Recovery Using Photogrammetric and Geographic Information System Techniques*. DPST-83-1027, Savannah River Laboratory, Aiken, SC (1984a).
- Christensen, E. J., M. E. Hodgson, J. R. Jensen, H. E. Mackey, and R. R. Sharitz. *Pen Branch Delta Expansion*. DPST-83-1087, Savannah River Laboratory, Aiken, SC (1984b).
- Christy, E. J. and R. R. Sharitz. "Characteristics of Three Populations of a Swamp Annual Under Different Temperature Regimes". *Ecology*. 61(3):454-460 (1980).
- Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. USDI Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-79-31. 103 pp.
- Curtis, J. T. and R. P. McIntosh. "The Interrelations of Certain Analytic and Synthetic Phytosociological Characters". *Ecology*. 31: 434-455 (1950).
- Dames and Moore. 1991. *Final Report. Task #14. Vegetation Sampling Study*. Westinghouse Savannah River Company, Aiken, SC 29808 (1984).
- Evans, D. W. and J. P. Giesy, Jr. "Trace Metal Concentrations in a Stream-Swamp System Receiving Coal Ash Effluent". In: *Ecology and Coal Resource Development*, Volume 2. M. K. Wali (ed.), pp. 782-790 (1978).
- Ezra, C. E., L. R. Tinney, and H. E. Mackey, Jr. *Pen Branch and Four Mile Creek Land Cover Data Base*, Savannah River Plant, Aiken, South Carolina. DOE(ONS-SRL)-8605, EG&G Energy Measurements, Inc., Las Vegas, NV, 54 pp. (1986).
- Fetters, T. T. 1990. *Logging Railroads of South Carolina*. Heimburger House Publishing Company, Forest Park, Illinois.
- Firth, P., J. R. O'Hop, B. Coler, and R. A. Green. *Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat, Analyses, and the Lower Food Chain Communities*. ESC-SR-26, report prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Aiken, SC (1986).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. R. Specht, and E. W. Wilde. *Comprehensive Cooling Water Study Annual Report, Volume V, Wetland Plant Communities*, Savannah River Plant. DP-1697-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).

- Guber, A. L. "Land Cover Mapping and GIS Processing for the Savannah River Site Database". In preparation, as EGG-11265-1016, EG&G Energy Measurements, Inc., PO Box 1912, Las Vegas, NV 89125.
- Herndon, M. G. 1979. Forest Products of Colonial Georgia. *Journal of Forest History*, 23(3):130-135.
- Hill, M. O. and H. G. Gauch. "Detrended Correspondence Analysis: An Improved Ordination Technique". *Vegetation*. 42:47-58 (1980).
- Hill, M. O. DECORANA--A FORTRAN Program for Detrended Correspondence Analysis and Reciprocal Averaging. Section of Ecology and Systematics, Cornell University, Ithaca, NY, 52 pp. (1979a).
- Hill, M. O. Twinspan - A FORTRAN Program for Arranging Multivariate Data in an Ordered Two-Way Table by Classification of the Individuals and Attributes. Section of Ecology and Systematics, Cornell University, Ithaca, NY (1979b).
- Howland, W. G. "Multispectral Aerial Photography for Wetland Vegetation Mapping." *Photogrammetric Engineering and Remote Sensing*. 46:87-99 (1980).
- Irwin, J. E., Structure of Stump Communities in a Stream Affected by Thermal Effluent. M. A. Thesis, University of North Carolina, Chapel Hill, NC, 23 pp. (1975).
- Jensen, J. R. An Introduction to Digital Image Processing. Academic Press, New York (1986).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. "Mapping of Thermally Altered Wetlands Using High Resolution Multispectral Scanner Data". *Proceedings of American Society of Photogrammetry*, May 22-27, 1983, Seattle, WA, pp. 318-336 (1983).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. "Nontidal Wetland Mapping in South Carolina Using Airborne Multispectral Scanner Data". *Remote Sensing of Environment*. 16:1-12 (1984b).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. SRP Swamp Vegetation Map. DPST-84-372, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1984a).
- Jensen, J. R., E. W. Ramsey, H. E. Mackey, Jr., E. J. Christensen, and R. R. Sharitz. "Inland Wetland Change Detection Using Aircraft MSS Data". *Photogrammetric Engineering and Remote Sensing*. 53(5):521-529 (1987).
- Jensen, J. R., M. E. Hodgson, E. J. Christensen, H. E. Mackey, Jr., L. R. Tinney, and R. R. Sharitz. "Remote Sensing Inland Wetland: A Multispectral Approach". *Photogrammetric Engineering and Remote Sensing*. 52(1):87-100 (1986a).
- Jensen, J. R., A. Hale, and H. E. Mackey. "Vegetation Stress Detection in a Southeastern Swamp Floodplain Using Remote Sensing and in situ Spectral Measurement". *Symposium on Freshwater Wetlands and Wildlife*, Charleston, SC, Savannah River Ecology Laboratory, Aiken, SC (1986b).
- Jensen, J. R., S. Narumalani, and H. E. Mackey, Jr. 1993. "Monitoring Commercial Forestry and Water Management Practices on a Cypress-Tupelo Swamp Forest in South Carolina Using 1938 to 1992 Panchromatic and Color Infrared Stereoscopic Aerial Photography". *Proceedings 14th Biennial Workshop on Color Photography and Videography in Resource Monitoring*, Utah State University, Logan, Utah. In Press. Abstract only.
- Mackey, H. E. - Coordinator. Environmental Information Document, L Reactor Reactivation. DPST-82-241, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1982).
- Mackey, H. E. 1993. "Application of Low Altitude Normal Color and False Color Infrared Photography for Delineation and Monitoring Wetland Restoration of a Large Carolina Bay". *Proceedings 14th Biennial Workshop on Color Photography and Videography in Resource Monitoring*, Utah State University, Logan, Utah. In Press. Abstract only.
- Mackey, H. E. Comprehensive Cooling Water Study, Final Report, Volume IV, Wetlands, Savannah River Plant. DP-1739-4, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1987).

- Mackey, H. E., 1990. "Monitoring Seasonal and Annual Wetland Changes in a Freshwater Marsh with SPOT HRV Data". Proceedings, 1990 ACSM-ASPRS Annual Convention, Denver, CO. Vol. 4, 283-292.
- Mackey, H. E., Jr., J. R. Jensen, M. E. Hodgson, and E. J. Christensen. Savannah River Plant Wetlands Map Update. DPST-85-661, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1985).
- Martin, C. E., E. J. Christy, and K. McLeod. "Changes in the Vegetation of a South Carolina Swamp Following Cessation of Thermal Pollution". Journal of the Mitchell Society. Winter: 173-176 (1977).
- McCaffrey, C. A., Effects of Flooding and Sedimentation on Germination and Survival of *Ludwigia leptocarpa*. M. S. Thesis, University of Georgia, Athens, GA (1982).
- McLeod, K. W., L. A. Donovan, N. J. Stumpff, and K. C. Sherrod, Jr. "Physiological Ecology of Woody Swamp Seedlings". In: Comprehensive Cooling Water Report, Volume 1: Wetlands. Savannah River Ecology Laboratory, Aiken, SC (1986).
- Mueller-Dombois, D. and H. Ellenberg. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York, NY, 547 pp. (1974).
- Newman, M. C., Comprehensive Cooling Water Report, Volume 2, Water Quality. Savannah River Ecology Laboratory, Aiken, SC (1986).
- Repaske, W. A. Effects of Heated Water Effluents on the Swamp Forest at the Savannah River Plant, South Carolina. M. S. Thesis, University of Georgia, Athens, GA (1981).
- Ruby, C. H., P. J. Reinhart, and C. L. Reel. Sedimentation and Erosion Trends of the Savannah River Plant Reactor Discharge Creeks. RPI/R/812422, Research and Planning Institute Report, Columbia, SC (1981).
- Scott, M. L., J. L. Haskins, and R. R. Sharitz. "Disturbance in a Cypress-Tupelo Wetland: An Interaction Between Thermal Loading and Hydrology". In: Comprehensive Cooling Water Report, Volume 1 Wetlands, Savannah River Ecology Laboratory, Aiken, SC (1986).
- Scott, M. L., R. R. Sharitz, and L. C. Lee. "Disturbance in a Cypress Tupelo-Wetland: An Interaction Between Thermal Loading and Hydrology". Wetlands. 5:53-68 (1985).
- Scott, R. V. 1979. American Railroads and the Promotion of Forestry. Journal of Forest History. 23(2):72-81.
- Sharitz, R. R., J. E. Irwin, and F. J. Christy. "Vegetation of a Swamp Receiving Reactor Effluents". Oikos. 24:7-13 (1974a).
- Sharitz, R. R., J. W. Gibbons, and S. C. Gause. "Impact of Production Reactor Effluent on Vegetation in a Southeastern Swamp Forest". In: Thermal Ecology, J. W. Gibbons and R. R. Sharitz (eds.). AEC Symp. Ser. CONF-730505, pp. 356-362 (1974b).
- Sharitz, R. R., K. W. Dyer, N. C. Martin, C. E. Mitchell, and R. L. Schneider. "Effects of SRP Cooling Water Discharges on Regeneration of Floodplain Forests". In: Comprehensive Cooling Water Report, Volume 1: Wetlands. Savannah River Ecology Laboratory, Aiken, SC (1986).
- Shields, J. D., N. D. Woody, A. S. Dicks, G. J. Hollod, J. Schalles, and G. J. Leversee. 1982. Locations and Areas of Ponds and Carolina Bays at the Savannah River Plant. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, USA.
- Shines, J. E. and L. R. Tinney. A Thermal Infrared Survey of the Savannah River Plant, Aiken, South Carolina: Winter Survey. EG&G/EM Letter Report DOE/ONS-8317, EG&G, Inc., Las Vegas, NV (1983).
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. An Evaluation of the Steel Creek Ecosystem in Relation to the Proposed Restart of the L Reactor. Savannah River Ecology Laboratory, SREL-9/UC-66e (1981).
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. An Evaluation of the Steel Creek Ecosystem in Relation to the Proposed Restart of the L Reactor: Interim Report. Savannah River Ecology Laboratory, SREL-12/UC-66e (1982).

- Stevenson, A. E. Geomorphic History of a Portion of the Savannah River Flood Plain, Barnwell County, South Carolina. M. S. Thesis, University of South Carolina, Columbia, SC (1982).
- Stewart, W. R., V. Carter, and P. Brooks. "Inland (Nontidal) Wetland Mapping". Photogrammetric Engineering and Remote Sensing. 46:617-628 (1980).
- Tinney, L. R., C. E. Ezra, and H. E. Mackey, Jr. Stream Corridor and Delta Wetlands Change Assessments, Savannah River Plant, Aiken, South Carolina. EG&G/EM Letter Report, EG&G, Inc., Las Vegas, NV, DOE(ONS-SRL)-8604 (1986).
- Townsend, J. R. G. Terrain Analysis and Remote Sensing. George Allen and Unwin, London, 232 pp. (1981).
- Whipple, S. A., L. Wellman, and B. Good. A Classification of Hardwood and Swamp Forest on the Savannah River Plant, South Carolina. National Environmental Research Park. Savannah River Ecology Laboratory, Aiken, SC, 36 pp. (1981).
- Whitlow, T. H. and R. W. Harris. Flood Tolerance in Plants: A State of the Art Review. Tech Rep. E-79-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 161 pp. plus Appendices (1979).
- Wolf, P. R. Elements of Photogrammetry. McGraw Hill, New York, NY, 562 pp. (1974).

Chapter 6

Pen Branch Wetland Changes, 1987-1992

Chapter Contents

Introduction (page 6-3)

Wetland Community Patterns, SPOT Data 1987-1992 (page 6-5)

Wetlands Change Detection from 1987-1991 in the Pen Branch Corridor and Delta

Using Airborne MSS Data (page 6-9)

References (page 6-19)

Introduction

The Pen Branch delta, like the other delta areas of the SRS Savannah River swamp, is a dynamic area undergoing seasonal and annual changes (Christensen 1987; Christensen et al. 1988; Jensen et al. 1987; Tinney et al. 1986). The extent of the development of the Pen Branch delta area and the wetland community types depends on a variety of factors, including previous K-Reactor flow, thermal conditions on the delta, and Savannah River flooding patterns (Tinney et al. 1986; Jensen et al. 1987; Repaske 1981; Christy and Sharitz 1980; Irwin 1975; Sharitz et al. 1974a, 1974b; Scott et al. 1985; Sharitz and Lee 1985; Jensen et al. 1987). In addition to these influences, when reactor operations have been halted, rapid colonization or revegetation of exposed mud flats and sand bar islands occurred on the delta areas of the SRS Savannah River swamp (Jensen et al. 1986a; Sharitz et al. 1974a, 1974b). The revegetation patterns include persistent and non-persistent wetland communities and scrub-shrub communities (Sharitz et al. 1974a, 1974b; Tinney et al. 1986; Smith et al. 1981, 1982). Thus heterogeneous mixtures of wetland communities could be found in the SRS Savannah River swamp, especially on the delta areas, within a few years following reactor shutdown (Christensen 1987; Jensen et al. 1983, 1986a; Christensen et al. 1988). Analysis of SPOT HRV data from 1987 through 1992 (Mackey 1990, 1993) and of airborne multi-spectral scanner (MSS) data from 1987 through 1991 (Blohm 1993) indicated continued rapid change in vegetation patterns on the Pen Branch delta after reactor operations were reduced in 1987 and ceased in 1988.

Wetland patterns of the Pen Branch corridor delta area were evaluated using aerial photographic surveys (Sharitz et al. 1974b; Repaske 1981; Tinney et al. 1986), MSS aircraft surveys (Christensen 1987; Christensen et al. 1986, 1988; Jensen et al. 1986a; Jensen et al. 1987), and ground-based surveys (Dunn and Scott 1987; Huenneke and Sharitz 1986; Scott et al. 1985, 1986; Sharitz and Lee 1985; Gladden et al. 1985; Christy and Sharitz 1980). These surveys generally indicate that the Pen Branch delta, at least through 1985, continued to expand at a rate of about 5 to 10 hectares per year (Tinney et al. 1986) primarily along a terrace bordering the northern edge of the SRS Savannah River swamp (Jensen et al. 1987; Scott et al. 1986). Expansion into this Pen Branch delta "tail" area may be primarily related to thermal effluent from Pen Branch being directed along the terrace edge in a southeast direction by flood waters during late spring and summer months (Scott et al. 1985, 1986; Jensen et al. 1987; Tinney et al. 1986).

Wetland Community Patterns, SPOT Data 1987-1992

Introduction

Follow up evaluations have continued on the Pen Branch delta wetland communities since the photographic and aircraft multispectral scanner (MSS) surveys of 1985. In 1985 a series of monthly (every two weeks in spring and fall of each year) phenological observations began on the Pen Branch delta (Mackey 1990, 1993; Blohm 1993) at the boardwalk and at the "tail" area (Figure 6-1). Data on percentage of leaf emergence and expansion (primarily of cypress trees) in these locations and data on principal herbaceous wetland plants at each location were recorded. These data included relative height, flowering and emergent status, and reference photography for each site. In addition to ground-based data, vertical aerial photography, airborne MSS data, and SPOT satellite data are available for the Pen Branch corridor and delta. Table 6-1 on page 6-6 summarizes the SPOT, vertical photography, and airborne MSS data available for the Pen Branch corridor and delta for 1987 to 1992. The last year of full-power operation of K Reactor was 1986, and 1987 was the last year of half-power operation.

Figure 6-1. Pen Branch Delta Area Evaluated for Wetlands Using SPOT HRV Data for 1987, 1988, and 1989, and the Location of Phenology Stations

Table 6-1. Dates of SPOT HRV Data, Supplementary Vertical Aerial Photography, and Airborne Scanner Data Used for Classification of Pen Branch Delta Wetlands

Year	SPOT HRV Data		Vertical Aerial Photography			Airborne Scanner Data
	Date	Date	Type	Scale	Source	
1987	Apr 09*	Apr 20	NC	1:16700	EG&G	Apr 21***
	Apr 24**	Apr 21	NC	1:20500	EG&G	
	May 04*	Apr 21	NC	1:20700	EG&G	
	Aug 22*	-	-	-	-	
	Oct 22*	Oct 27	FCIR	1:20000	NASA	
1988	Apr 17*	Apr 29	NC	1:15900	EG&G	Apr 29***
	May 02**	Apr 29	NC, FCIR	1:19900	EG&G	
	-	Apr 29	NC	1:7960	EG&G	
	May 08*	May 18	NC	1:19900	EG&G	
	Oct 25*	-	-	-	-	
1989	Jan 28*	Jan 28	NC	1:20000	FS	Apr 13***
	-	Mar 26	FCIR	1:40000	NAPP	
	-	Apr 27	NC	1:7540	EG&G	
	May 17**	May 02	NC	1:19000	EG&G	
	Nov 10	-	-	-	-	
1990	Jan 26	-	-	-	-	Apr 16***
	Apr 04*	Apr 12	FCIR	1:19900	EG&G	
	-	Apr 16	NC	1:19900	EG&G	
	May 11**	-	-	-	-	
	Sep 20	-	-	-	-	
1991	Oct 16	-	-	-	-	May 02***
	Feb 02	-	-	-	-	
	Mar 05	-	-	-	-	
	Apr 02	Apr 18	FCIR, NC	1:19500	EG&G	
	-	Apr 24	FCIR	1:3980	EG&G	
1992	-	Apr 24	FCIR	1:19900	EG&G	May 04
	May 02**	May 02	FCIR, NC	1:19900	EG&G	
	-	Sep 20	NC	1:19900	EG&G	
	-	Jan 31	FCIR	1:20000	FS	
	Mar 14	-	-	-	-	
1992	Apr 04	-	-	-	-	May 04
	-	Apr 23	FCIR	1:5970	EG&G	
	-	Apr 23	FCIR	1:9950	EG&G	
	-	Apr 23	FCIR	1:19900	EG&G	
	May 05**	May 02	FCIR	1:19900	EG&G	
1992	-	May 04	FICIR	1:19900	EG&G	

*Dates of SPOT HRV data analyzed

**Dates of SPOT HRV data summarized in Table 6-2

***Dates of Daedalus AADS1268 scanner data analyzed

NC - Natural Color

FCI - False Color Infrared

EG&G - EG&G Energy Measurements, Inc., Las Vegas, NV

FS - Forest Service, SRS, Aiken, SC

NASA - National Aeronautics and Space Administration

NAPP - National High Altitude Photographic Program

Changes in the Pen Branch Wetlands

Cover Types Found in the Pen Branch Wetlands

Mackey (1990, 1993) summarized the changes in the lower Pen Branch corridor and delta as evaluated from SPOT HRV data for 1987 through 1992. Other than bottomland hardwood and cypress-tupelo, four wetland cover types dominated the Pen Branch delta area. These include deep- and open-water areas, non-persistent emergent marsh (NPE), persistent marsh, and scrub-shrub communities, which consist primarily of willow (*Salix* spp.) and buttonbush (*Cephalanthus occidentalis*). Since *Ludwigia* frequently overgrows shallow water, mud flats, and sand bars on the Pen Branch delta by late summer or early fall, these cover types were included with the NPE cover class; areas of shallow-water covered by duckweed were also included in the NPE class. Late April to mid-May proved to be the best time of year to distinguish the wetland types from each other with discrimination in the summer and early fall more difficult (Jensen et al. 1986a; Mackey 1990).

Effects of Decreased Operation of K Reactor

In 1987, K Reactor operated at nominal half-power and there was an increase in the expansion of the *Ludwigia* and cattail (*Typha* spp.) communities. *Ludwigia* expanded into the shallow-water, mud-flat areas of the central delta and the cattails expanded primarily in the Pen Branch "tail" area.

Effects of the Shutdown of K Reactor

In mid-April 1988, K Reactor was shutdown for upgrades, and flows in Pen Branch decreased from levels near 400 cubic feet per second (CFS) to 50-60 CFS in 1989 and 1990. This decrease in flow was reflected in a decline in the deep- and open-water areas as evaluated with the SPOT HRV data (Table 6-2 on page 6-8). As the Pen Branch delta became drier in 1988 through 1990, it also became more difficult to distinguish areas of *Ludwigia* dominance from areas dominated by cattail beds. Part of this difficulty is the result of large beds of dead, brown biomass from the *Ludwigia* areas and cattail beds still present in the spring from the previous summertime growth. Furthermore, some areas in the lower Pen Branch stream corridor north of the upper delta began to resemble old-field sites. Similar invasion of old-field species has been observed in the drier portions of the Fourmile Branch corridor and delta on SRS since C Reactor shut down in late June 1985. Since 1990 the main portion of the Pen Branch delta has become increasingly dominated by persistent cattail beds and by invading scrub-shrub species, primarily willow and buttonbush (Table 6-2). The overall shift from wetland communities dominated by more thermally and flood tolerant herbaceous species to wetland communities dominated by persistent and scrub-shrub species is likely to continue as flow remains reduced in the Pen Branch delta following long-term shutdown of K Reactor.

Table 6-2. Major Wetland Cover Types based on Classification of SPOT HRV Date for the Pen Branch Delta, Spring 1987 through 1992 (units in hectares) (Mackey 1993)

Wetland Cover Type		Year and Date of SPOT HRV Data					
		1987 Apr 24	1988 May 02	1989 May 17	1990 May 11	1991 May 02	1992 May 5
1.	Deep/Open Water	13.1	4.0	0.0	1.1	23.2 ^b	26.2 ^b
2.	Non-Persistent Emergent Marsh (NPE)						
2a.	Shallow Water/Mud Flats	65.5	29.0	0.4	11.4	-	-
2b.	<i>Ludwigia</i> spp.	34.0	56.8	97.4 ^a	92.2	66.2 ^b	31.8 ^b
2c.	Duckweed	3.2	10.1	3.6	0.1	0.3	-
	Sub-Total NPE	102.7	95.9	101.4	103.7	66.5	31.8
3.	Persistent Emergent Marsh (PE), primarily Cattails (<i>Typha</i> spp.)	31.2	38.5	*	6.0	44.8	55.5
4.	Scrub-shrub	-	-	-	11.7	3.4	23.6
5.	Total	147.0	138.4	101.4	122.5	137.9	137.1

^a In May 1988, it was not possible to distinguish between the non-persistent beds of *Ludwigia* and stands of cattails in the SPOT HRV data.

^b In May 1991 and 1992, the Pen Branch delta was wetter from spring-time Savannah River flooding and moderate flows to Pen Branch, thus it was difficult to sort between shallow-water/mudflats and *Ludwigia* beds. This difficulty probably accounts for an apparent increase in deep water areas.

Wetlands Change Detection from 1987-1991 in the Pen Branch Corridor and Delta Using Airborne MSS Data

Introduction

Since SPOT HRV data are limited to three spectral bands and to a spacial resolution of 20x20 meter pixels (see page 6-5 for more details of SPOT HRV), a more detailed evaluation of the Pen Branch corridor and delta was conducted with airborne MSS data for 1987 to 1991 (Table 6-1 on page 6-6).

Methodology

Other studies (Brewster and Tinney 1984; Tinney et al. 1986; Wolf 1974; Burnside 1979; Christensen et al. 1984a, 1984b, 1986, 1987, 1988; Ezra et al. 1986; Jensen et al. 1983, 1984a, 1984b, 1986a, 1986b, 1987) of the Pen Branch delta used aerial photography, airborne MSS data, or SPOT satellite imagery. Each of these techniques or data sources has inherent limitations. With aerial photography, results from interpretation can be interpreter-specific, and some geometric distortion can be created as the interpretations are transferred to base maps. Aerial photographs also have limited spectral response due to the nature of the film itself. In the study by Christensen et al. (1988), airborne MSS data provided more spectral sensitivity than film, but because of the registration techniques used, only limited size areas of the Pen Branch delta could be registered together. In the Mackey (1990, 1993) study, the use of SPOT satellite data solved the inherent geometry distortions attributed to aircraft MSS data, but spatial resolution is low, especially for dealing with wetland species. SPOT satellite data also have limited spectral sensitivity. To document the wetland changes that occurred from 1987 to 1991 for the entire Pen Branch corridor and delta, numerous types and sources of data were used to evaluate the changes with airborne MSS data. These data include phenology photography, aerial photography, hydrologic data, and digital map data.

Wetlands Classification

Introduction

The airborne MSS data were grouped into clusters of data with similar characteristics. For the corridor datasets, the 1987 data produced 36 clusters, the 1988–1991 data produced 51 clusters each year. For the delta datasets, the 1987 data produced 44 clusters, while the 1988–1991 data produced 51 clusters in each year (Blohm 1993).

Factors Affecting Wetlands Classification

In the case of Pen Branch, there are many interactions occurring that must be taken into account when labelling the clusters. The wetland vegetation types that will be present in the corridor and delta in a given year at the time of scanner acquisition depend on several factors. The reactor flow will affect how much water is in the corridor and in the delta. The flow in the Savannah River will affect the wetness of the delta. The wetness of the corridor and delta will, in turn, influence both the timing of vegetation growth and the vegetation

types that will be favored. Finally, the development of vegetation in a given year may be affected by the presence of dead vegetation or biomass from the previous year (Mackey 1990, 1993).

As many of these factors as possible must be taken into account when labelling the wetlands classification clusters from the airborne MSS data. The amount and quality of ground truthing information available for this study becomes especially important. The hydrology or flow data for the Savannah River and Pen Branch are shown in Figure 6-2 on page 6-14 through Figure 6-4 on page 6-16. Phenology graphs for the three primary vegetation types are also shown in Figure 6-2 through Figure 6-4 for 1987 through 1991. These graphs show the relative height of the dead brown vegetation for the previous year in relation to the living green vegetation for the current year. These graphs are extremely valuable for estimating what the scanner would have been recording. The vertical aerial photography was used in conjunction with two-dimensional plots of the cluster means and standard deviations to identify the individual clusters. Figure 6-5 on page 6-17 shows representative vertical aerial photography of the Pen Branch delta for (1) a wet thermal delta (1987), (2) the delta just following K-Reactor shutdown (1988), and (3) after two relatively dry years (1990).

Pen Branch Wetland Classifications

The information classes or final regrouped clusters or wetland classes were the following:

- Bottomland Hardwood Forest
- Cypress-Tupelo Forest
- Deep Water
- Shallow Water
- Cattails
- Willow
- Scrub-Shrub
- *Ludwigia*
- Mud flat
- Duckweed
- Bare Soil

1987 Classification

Figure 6-2 on page 6-14 shows the Savannah River and Pen Branch flows for 1987. This figure shows that both the Savannah River and Pen Branch flows were high prior to and during the MSS acquisition. Therefore, the corridor and delta would have been very wet, with a corresponding effect on vegetation. The corresponding phenology graph (Figure 6-2) shows that cattails and *Ludwigia* were not very well developed at the time of MSS acquisition (see also Mackey 1990).

The 1987 wetland acreage values are given in Table 6-3 and Table 6-4 on page 6-18. For the corridor, the five largest classes were bottomland hardwood (47%), deep water (25%), willow (11%), shallow water (10%), and mud flat (4%). In the delta, the five largest classes were shallow water (48%), *Ludwigia* (32%), duckweed (9%), cattails (7%), and scrub-shrub (3%). These values are consistent with a wet, thermal corridor and delta (Mackey 1990, Blohm 1993).

1988 Classification

The Savannah River and Pen Branch flows are shown in Figure 6-2 on page 6-14. The phenology graph for 1988 is also shown in Figure 6-2. The flow of the Savannah River was lower than in 1987, and the reactor output flow was reduced approximately three weeks prior to the MSS acquisition, as K Reactor was shut down. The phenology graph shows that at the time of acquisition, the green-vegetation component was almost matched by that of the dead, brown vegetation from 1987. In this case, the scanner was probably viewing both living and dead vegetation. While the scanner can fairly easily differentiate living vegetation types, it cannot easily distinguish between different dead, brown vegetation types (Blohm 1993).

The 1988 wetland acreages are given in Tables 6-3 and 6-4. For the corridor, the five largest classes were bottomland hardwood (48%), mud flat (21%), deep water (12%), *Ludwigia* (10%), and willow (8%). For the delta, the five largest classes were *Ludwigia* (44%), shallow water (32%), deep water (9%), cypress (7%), and scrub-shrub (6%). These values show that the corridor and delta had begun to dry, as evidenced by the decreased amounts of deep and shallow water, but that the vegetation had not really had time to reestablish by the time of the MSS acquisition (Blohm 1993).

1989 Classification

The Savannah River and Pen Branch flows for 1989 are shown in Figure 6-3 on page 6-15. The phenology graph for 1989 is also shown in Figure 6-3. The Savannah River and Pen Branch flows for 1989 remained low. As the phenology graph shows, no disruptive flooding occurred to knock down or wash away the dead vegetation from the previous year; as a result, the dead vegetation was almost more dominant than the living vegetation at the time of MSS acquisition (Mackey 1990, Blohm 1993).

The 1989 wetland acreages are given in Table 6-3 and Table 6-4 on page 6-18. In the corridor, the five largest classes were bottomland hardwood (52%), deep water (13%), willow (13%), mud flat (8%), and *Ludwigia* (7%). For the delta, the five largest classes were *Ludwigia* (55%), shallow water (18%), cypress-tupelo (11%), scrub-shrub (8%), and cattails (5%). Because of the presence of so much dead vegetation, some confusion probably occurred between the dead *Ludwigia* and dead cattails in the delta (Mackey 1990). These acreage values show that as the delta and corridor continue to dry, the non-persistent vegetation such as dog fennel (Mackey 1993) began to increase in the delta, while the water and mud flat classes continue to decline (Blohm 1993).

1990 Classification

The Savannah River and Pen Branch flows are shown in Figure 6-3 on page 6-15. The phenology graph for 1990 is also shown in Figure 6-3. In 1990, there was increased flow and flooding in the Savannah River throughout the entire spring prior to the MSS acquisition. There was also increased Pen Branch flow approximately one month before the acquisition. However, the phenology graph shows that the increased river flow was, once again, not enough to eliminate the dead brown vegetation from the previous year. The graph shows that once again, the vegetation as viewed by the scanner probably consisted mostly of dead vegetation, and that most of the live vegetation was cattails.

The wetland acreages for 1990 are given in Table 6-3 and Table 6-4 on page 6-18. The five largest classes in the corridor were bottomland hardwood (56%), willow (15%), deep water (15%), mud flat (9%), and *Ludwigia* (6%). In the delta, the five largest classes were *Ludwigia* (57%), cattails (10%), deep water (10%), cypress-tupelo (9%), and scrub-shrub (8%). The large class of *Ludwigia* included a mixture of brown *Ludwigia*, cattails, and dog fennel (Mackey 1990, 1993). The sensitivity of the MSS data to wetness conditions is shown by the increases in deep water acreages in both the delta and corridor. For the most part, the corridor and delta continued to dry, allowing non-persistent species to continue to expand. As the drying continued, more persistent species such as cattails, willow, and scrub-shrub continued to become established. The confusion between dead vegetation types continues, however, and the large amount of *Ludwigia* present in the delta probably had a significant component of cattails hidden within it (Mackey 1990, 1993, Blohm 1993).

1991 Classification

The Savannah River and Pen Branch flows are shown in Figure 6-4 on page 6-16. The phenology graph for 1991 is also shown in Figure 6-4. The Savannah River flooded in the spring of 1991, with fairly high flow immediately prior to the MSS acquisition. Test runs at K Reactor also resulted in higher Pen Branch flows during the spring and just prior to the MSS acquisition. The phenology graph shows that cattails replaced areas formerly occupied by *Ludwigia*. The dead, brown vegetation appeared to be less prominent for 1991 than the previous two years, and appeared to contain about equal components of cattail and brown vegetation (Blohm 1993).

The wetland acreages for 1991 are given in Table 6-3 and Table 6-4 on page 6-18. The five largest classes in the corridor were bottomland hardwood (64%), willow (18%), scrub-shrub (10%), deep water (9%), and mud flat (6%). For the delta, the five largest classes were willow (36%), cattails (32%), shallow water (17%), scrub-shrub (9%), and deep water (4%). The increase in water-class acreages again shows the MSS sensitivity to the flooding indicated by the flow graphs. In 1991 two major displacements occurred. *Ludwigia* was extensively replaced by cattails and willow. Expansion of scrub-shrub (primarily willow and buttonbush) occurred in the delta. Willow also expanded in the corridor. The non-persistent vegetation gave way to the persistent and more permanent vegetation, which had a chance to become established due to the decrease in disruptive flooding and thermal discharges (Mackey 1990, 1993).

Summary of Changes

Table 6-3 and Table 6-4 on page 6-18 summarize trends in wetlands for the Pen Branch corridor and delta. After the reduction in K-Reactor operations in 1987, the shift was from non-persistent vegetation and water to more persistent vegetation and drier conditions. The area of willows and hardwoods increased tremendously, as the willows and scrub-shrub expanded down the corridor into the delta, gradually being replaced by other hardwoods or becoming large enough to have been classified as hardwoods. The area of shallow and deep water was large in the early years, but decreased substantially in the last 2-3 years, reflecting the drying of the corridor and delta. As the delta dried, vegetation such as *Ludwigia* and duckweed decreased, with *Ludwigia* declining markedly from 1990 to 1991. This allowed other vegetation, such as cattails, to increase dramatically by 1991 (Mackey 1993, Blohm 1993).

It should be noted that other factors can account for some of these changes. Any misclassifications can show up as change. Also, in the case of a multi-temporal comparison, any slight misregistration can cause the resulting overlay comparison of two images to show differences due to the misregistration itself, rather than to actual changes on the ground. In the case of Pen Branch, since only the data within the study boundaries were being classified, it was possible to concentrate the control point selection within and immediately around the study area, so that the registration would be the best within this area (Mackey 1990, 1993, Blohm 1993).

Figure 6-2. Savannah River Flow, Phenology Pattern in Pen Branch Delta, and Pen Branch Flow Data for 1987-1988

Figure 6-3. Savannah River Flow, Phenology Pattern in Pen Branch Delta, and Pen Branch Flow Data for 1989-1990

Figure 6-4. Savannah River Flow, Phenology Pattern in Pen Branch Delta, and Pen Branch Flow Data for 1991-1992

Approximate Area of Coverage

Spring 1987

Spring 1988

Spring 1990

Figure 6-5. Vertical Aerial Photography of the Pen Branch Delta in 1987, 1988, and 1990

Table 6-3. Pen Branch Delta Acreages 1987-1991 (Blohm 1993)

Classes	Years				
	1987	1988	1989	1990	1991
Bottomland Hardwood	0	0.10	1.36	0.44	0.89
Cypress-Tupelo	0	16.73	25.39	22.09	0
Deep Water	1.08	21.10	6.82	23.50	8.49
Shallow Water	113.46	74.43	41.46	0	40.86
Cattails	16.17	0	12.64	44.36	97.92
Willow	0	0	0	0	83.99
Scrub-Shrub	7.58	14.40	17.91	19.95	0
<i>Ludwigia</i>	76.02	102.97	128.74	112.12	0
Mud flat	0	0	0	0	0
Duckweed	20.00	4.59	0	0	2.13
Bare soil	0	0	0	0	0
Total	234.31	234.32	234.32	222.46	234.28

Table 6-4. Pen Branch Corridor Acreages - Excluding Buffer - 1987-1991

Classes	Years				
	1987	1988	1989	1990	1991
Bottomland Hardwood	105.05	107.08	130.27	137.82	161.86
Cypress-Tupelo	0	0	0	0	0
Deep Water	81.72	37.83	41.86	42.64	28.27
Shallow Water	34.04	0	0	0	5.24
Cattails	0	0	0	0	1.65
Willow	33.96	25.91	34.54	46.88	55.10
Scrub-Shrub	0	0	17.82	0	0
<i>Ludwigia</i>	0	32.03	23.84	18.22	0
Mud flat	14.64	69.38	24.64	28.08	20.02
Duckweed	0.95	0	0	0	0
Bare soil	4.03	2.15	1.41	0.74	2.23
Total	274.39	274.38	274.38	274.38	274.37

References

- Blohm, J. D. Wetlands Change Detection from 1987–1991 in a Creek Corridor and Freshwater Swamp Marsh Using Airborne Multispectral Scanner Data. Report Number, EGG-11265-1013, EG&G Energy Measurements, Las Vegas, NV 1993.
- Brewster, S. B., Jr. and L. R. Tinney. Vegetation Classification of the Savannah River Floodplain. DOE/ONS-8404, EG&G Energy Measurements, Las Vegas, NV 1984.
- Burnside, C. D. Mapping from Aerial Photographs. John Wiley and Sons, New York, 304 pp. 1979.
- Christensen, E. J. Digital Change Detection: A Quantitative Evaluation of Image Registration and Wetland Phenological Characteristics Using High Resolution Multispectral Scanner Data. Dissertation, Univ. South Carolina, Columbia, SC. 1987.
- Christensen, E. J., J. R. Jensen, E. W. Ramsey, and H. E. Mackey, Jr. "Aircraft MSS Data Registration and Vegetation Classification for Wetland Change Detection". *Int. J. Remote Sensing*. 9(1):23-38 (1988).
- Christensen, E. J., J. R. Jensen, E. W. Ramsey, and H. E. Mackey, Jr. "Wetland Vegetation Change Detection Using High Resolution Aircraft MSS Data". 1986 ASPRS-ACSM Fall Convention, Proceedings, September 28-October 3, Anchorage, Alaska, pp. 148-162 (1986).
- Christensen, E. J., M. E. Hodgson, J. R. Jensen, H. E. Mackey, and R. R. Sharitz. An Evaluation of Steel Creek Delta Growth and Recovery Using Photogrammetric and Geographic Information System Techniques. DPST-83-1027, Savannah River Laboratory, Aiken, SC (1984a).
- Christensen, E. J., M. E. Hodgson, J. R. Jensen, H. E. Mackey, and R. R. Sharitz. Pen Branch Delta Expansion. DPST-83-1087, Savannah River Laboratory, Aiken, SC (1984b).
- Christy, E. J. and R. R. Sharitz. "Characteristics of Three Populations of a Swamp Annual Under Different Temperature Regimes". *Ecology*. 61(3):454-460 (1980).
- Dunn, C. P. and M. L. Scott. "Response of wetland herbaceous communities gradients of light and substrate following disturbance by thermal pollution". *Vegetation*. 70:119-124 (1987).
- Ezra, C. E., L. R. Tinney, and H. E. Mackey, Jr. 1986. Pen Branch and Four Mile Creek Land Cover Data Base, Savannah River Plant, Aiken, South Carolina. Report No. DOE(ONS-SRL)-8605. EG&G Energy Measurements, Inc., PO Box 1912, Las Vegas, NV 89125.
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. R. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report, Volume V, Wetland Plant Communities, Savannah River Plant. DP-1697-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Huenneke, L. F. and R. R. Scharitz. "Microsite Abundance and Distribution of Woody Seedlings in a South Carolina Cypress-Tupelo Swamp". *The American Midland Naturalist*. 115(1):328-335 (1986).
- Irwin, J. E., Structure of Stump Communities in a Stream Affected by Thermal Effluent. M. A. Thesis, University of North Carolina, Chapel Hill, NC, 23 pp. (1975).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. "Mapping of Thermally Altered Wetlands Using High Resolution Multispectral Scanner Data". Proceedings of American Society of Photogrammetry, May 22-27, 1983, Seattle, WA, pp. 318-336 (1983).
- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. "Nontidal Wetland Mapping in South Carolina Using Airborne Multispectral Scanner Data". *Remote Sensing of Environment*. 16:1-12 (1984b).

- Jensen, J. R., E. J. Christensen, and R. R. Sharitz. SRP Swamp Vegetation Map. DPST-84-372, Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1984a).
- Jensen, J. R., E. W. Ramsey, H. E. Mackey, Jr., E. J. Christensen, and R. R. Sharitz. "Inland Wetland Change Detection Using Aircraft MSS Data". *Photogrammetric Engineering and Remote Sensing*. 53(5):521-529 (1987).
- Jensen, J. R., M. E. Hodgson, E. J. Christensen, H. E. Mackey, Jr., L. R. Tinney, and R. R. Sharitz. "Remote Sensing Inland Wetland: A Multispectral Approach". *Photogrammetric Engineering and Remote Sensing*. 52(1):87-100 (1986a).
- Jensen, J. R., A. Hale, and H. E. Mackey. "Vegetation Stress Detection in a Southeastern Swamp Floodplain Using Remote Sensing and in situ Spectral Measurement." *Symposium on Freshwater Wetlands and Wildlife*, Charleston, SC, Savannah River Ecology Laboratory, Aiken, SC (1986b).
- Mackey, H. E. 1993. "Application of Low Altitude Normal Color and False Color Infrared Photography for Delineation and Monitoring Wetland Restoration of a Large Carolina Bay". *Proceedings 14th Biennial Workshop on Color Photography and Videography in Resource Monitoring*, Utah State University, Logan, Utah. In Press. Abstract only.
- Mackey, H. E., 1990. "Monitoring Seasonal and Annual Wetland Changes in a Freshwater Marsh with SPOT HRV Data". *Proceedings, 1990 ACS' 1-ASPRS Annual Convention*, Denver, CO. Vol. 4. 283-292.
- Repaske, W. A. Effects of Heated Water Effluents on the Swamp Forest at the Savannah River Plant, South Carolina. M.S. Thesis, University of Georgia, Athens, GA (1981).
- Scott, M. L., R. R. Sharitz, and L. C. Lee. "Disturbance in a Cypress Tupelo-Wetland: An Interaction Between Thermal Loading and Hydrology". *Wetlands*. 5:53-68 (1985).
- Scott, M. L., J. L. Haskins, and R. R. Sharitz. "Disturbance in a Cypress-Tupelo Wetland: An Interaction Between Thermal Loading and Hydrology." In: *Comprehensive Cooling Water Report, Volume 1 Wetlands*, Savannah River Ecology Laboratory, Aiken, SC (1986).
- Sharitz, R. R. and L. C. Lee. "Limits on Regeneration Processes in Southeastern Riverine Wetlands". In: *Riparian Ecosystems and Their Management: Reconciling Conflicting Uses*. First North American Conference, April 16-18, 1985, Tucson, AZ, pp. 139-160 (1985).
- Sharitz, R. R., J. E. Irwin, and F. J. Christy. "Vegetation of a Swamp Receiving Reactor Effluents". *Oikos*. 24:7-13 (1974a).
- Sharitz, R. R., J. W. Gibbons, and S. C. Gause. "Impact of Production Reactor Effluent on Vegetation in a Southeastern Swamp Forest". In: *Thermal Ecology*, J. W. Gibbons and R. R. Sharitz (eds.). AEC Symp. Ser. CONF-730505, pp. 356-362 (1974b).
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. An Evaluation of the Steel Creek Ecosystem in Relation to the Proposed Restart of the L Reactor. Savannah River Ecology Laboratory, SREL-9/UC-66e (1981).
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. An Evaluation of the Steel Creek Ecosystem in Relation to the Proposed Restart of the L Reactor: Interim Report. Savannah River Ecology Laboratory, SREL-12/UC-66e (1982).
- Tinney, L. R., C. E. Ezra, and H. E. Mackey, Jr. Stream Corridor and Delta Wetlands Change Assessments, Savannah River Plant, Aiken, South Carolina. EG&G/EM Letter Report, EG&G, Inc., Las Vegas, NV, DOE(ONS-SRL)-8604 (1986).
- Wolf, P. R. *Elements of Photogrammetry*. McGraw Hill, New York, NY, 562 pp. (1974).

Chapter 7

Wetlands of L Lake

Chapter Contents

Introduction (page 7-3)

Habitat Formers (page 7-5)

Macrophyte Planting Program (page 7-7)

References (page 7-11)

Introduction

L Lake is a 400-hectare, once-through cooling reservoir constructed on SRS in 1985 to receive thermal effluent from L Reactor (Figure 7-1). (The water quality, limnology, and biology of L Lake are described in Chapter 14—L Lake and Steel Creek.) Aquatic macrophytes began invading the shoreline of L Lake through natural invasion upon completion of the lake (Firth and Irwin 1987; Firth 1988; Westbury 1989, 1990, 1991, 1992). Additionally, extensive macrophyte plantings were introduced along the L-Lake shoreline; these plantings have been reasonably successful (Wein and McCort 1988, Kroeger 1990, Wein et al. 1987). Survival and growth of the natural and introduced macrophytes along the L-Lake shoreline is likely to continue following the L-Reactor shutdown in 1988 and cessation of thermal discharges to the lake (Jensen et al. 1992).

Figure 7-1. Location of L Lake on SRS

Habitat Formers

Introduction

During construction of L Lake, most of the vegetation in the lake bed was removed or burned onsite. The shoreline was cleared to 3–5 ft above maximum pool elevation and seeded to control erosion. The shoreline vegetation above the cleared area was primarily planted pine.

The L-Lake habitat formers (macrophytes) portion of the L-Lake/Steel Creek biological monitoring program addressed the development and composition of the shoreline and littoral-zone plant communities (Westbury 1992). Monitoring was conducted at four study plots in L-Lake Regions 5 and 7, and on 100-line transects distributed in Regions 4-8 of the lake (Figure 7-1 on page 7-3). A variety of plants, some of which have been reported from thermal areas of SRS (Irwin 1975; Sharitz et al. 1974a, 1974b), were present in L Lake in 1987. Because the littoral community in L Lake was in an early successional stage, the diversity of the littoral plant community in L Lake was low in 1987 compared with Par Pond and other older lakes of similar morphometry and environmental characteristics in the southeast (Grace 1985a, 1985b; Dames and Moore 1984; Barry 1980).

Plant Community Composition

The total number of plants identified in each of the study plots was less in 1991 than in 1990 at all stations except Station 7E, where total taxa numbers for 1990 and 1991 were equal. In general, total taxa numbers increased from 1986 to 1989 and decreased in 1990 and 1991. Herbaceous plant taxa comprised the majority of plant taxa at all stations and accounted for most of the changes in plant taxa numbers (Westbury 1992).

Between 1986 and 1988 the number of plant taxa identified in each station increased every year (Table 7-1). In 1989 the number of taxa decreased at Station 5E but increased at all other stations. In 1991 taxa numbers decreased at all stations except 7E (Westbury 1992).

When the L-Lake basin was constructed, most of the shoreline was cleared and graded. In 1986 and 1987, the majority of plants encountered were terrestrial weeds typical of disturbed areas (Firth and Irwin 1987, Firth 1988). By 1988, plants adapted to wetland conditions had become established in the littoral zone of the lake (Westbury 1989).

Table 7-1. Total Number of Plant Taxa Identified at Each Station, January 1986–December 1991 (Westbury 1992)

Station	1986	1987	1988	1989	1990	1991
5E	54	79	91	80	73	64
5W	66	88	101	116	112	88
7E	57	94	104	118	104	105
7W	51	73	87	97	93	74

In general, between 1986 and 1991, approximately 75% of total plant taxa were herbaceous species, approximately 10% were tree and shrub species, and approximately 5% were woody vines and succulents (Westbury 1992).

The number of herbaceous plant taxa at each station increased from 1986 to 1989 except at station 5E where the number decreased in 1989. In 1990, the number of herbaceous taxa in each station was lower than it had been in 1989. In 1991, the number of herbaceous taxa in each station was lower than it had been in 1990. Changes in numbers of herbaceous taxa accounted for most of the year-to-year changes in number of taxa (Westbury 1992).

Tree taxa numbers increased in 1986 and 1987. Tree taxa numbers decreased or remained constant in 1989, 1990, and 1991 except at Station 7E where they increased in 1991. Shrub taxa numbers increased or remained the same at all stations through 1990. In 1991, shrub taxa numbers decreased at all stations except 7E where they increased. The number of other taxa decreased or remained the same at all stations in 1991 (Westbury 1992).

Areal Cover and Expansion

Between 1986 and 1990, the areal cover of aquatic macrophytes in the littoral zone of the survey plots of L Lake was low. The annual mean areal cover increased markedly, from 527.51 m²/ha in 1990 to 1359.9 m²/ha in 1991. *Vallisneria americana*, *Nelumbo lutea*, and *Potamogeton diversifolius* accounted for most of the increase in cover in the study plots. The mean extent of vegetation into the lake as measured along 100-line transects also increased from 13.59 m in 1990 to 21.15 m in 1991. In 1991, the mean total length of cover increased to 13.89 m from 8.68 m in 1990. The mean percent cover of the first 24 m increased from 28.39% in 1990 to 49.40% in 1991 (Westbury 1989, 1990, 1991, 1992).

Line Transects vs. Plots

Aquatic macrophyte coverage measured along the first 24 m of the 100-line transects was higher than the coverage within the monitoring-program study plots, none of which occurred in planted areas. The line transects included areas planted by SREL and covered more of the shoreline than did the plots. The transects were sampled in the summer near the time of maximum plant cover. When only summer data were considered for the study plots, the increase in percent cover from 1990 to 1991 was similar for both line transects and study plots. The summer-only percent cover of the study plots in 1991 was similar to the percent cover of the line transects in 1990 (Westbury 1992).

Littoral-Zone Change

In the six years since the creation of L Lake, plant cover in littoral-zone communities within the study plots increased. Plant taxa richness evidenced a change from post-disturbance increases in taxa numbers to early successional stages when plants best adapted to site conditions begin to dominate opportunistic plant taxa. While percent cover in areas that were planted was found to be greater than the percent cover in study plots, the plant cover in the study plots increased markedly in 1991 (Westbury 1992).

Macrophyte Planting Program

Introduction

The Savannah River Ecology Laboratory (SREL) of the University of Georgia conducted a wetlands planting program in L Lake in 1987. Plant material, either transplanted from Par Pond or obtained from commercial nurseries, was planted between January and August, 1987. Approximately 100,000 individual plants representing more than 40 species were planted along more than 4000 meters of the southern shoreline of L Lake (Table 7-2). A submersed/floating-leaved zone, an emergent zone, and an upper emergent/shrub zone were created. During the summers of 1987, 1988, and 1989, SREL sampled the vegetation in plots within permanent transects established in planted and unplanted areas. Details on species planted, source of plant material, and planting density are provided in Wein et al. (1987) and Kroeger (1990).

Submersed and Floating-leaved Zone (30 to 100-cm Water Depth)

Nine plant species were transplanted into the submersed and floating-leaved zone. *Nelumbo lutea* (American lotus), a floating-leaved species, and *Vallisneria americana* (water celery) a submersed plant, were the only surviving species in 1989. Wave action and low initial planting apparently made establishment difficult or impossible for some species (Kroeger 1990).

Vallisneria americana and *Nelumbo lutea* rapidly colonized empty plots within the submersed and floating-leaved zone and *Typha latifolia* (cattails) moved into the submersed and floating-leaved zone from the emergent zone. In 1987, 95% of the plots sampled contained no vegetation. By 1989, only 62% of the plots were empty. In 1987, mean cover per plot was 1%. However, by 1989, cover had increased to 22% (Kroeger 1990).

No submersed or floating-leaved plants were found in the unplanted areas in 1989 and most plots remained unvegetated. Two emergent species, *Typha latifolia* and *Hydrocotyle umbellata* (water pennywort) were found in a few of the unplanted plots (Kroeger 1990).

Emergent Zone (Waterline to 30-cm Water Depth)

Approximately 30 species were planted in the emergent zone. By 1989, most were still surviving. In 1987, 32% of the plots sampled in planted areas contained no vegetation. By 1989 only 16% of the plots had no vegetation. Mean cover per plot increased from 22% in 1987 to 40% in 1988 and remained the same in 1989 (Kroeger 1990).

Within the planted areas changes in emergent species from 1987 to 1989 included a gradual increase in relative frequency of *Eleocharis* spp. and *Typha latifolia*; a large increase in relative frequency of *Hydrocotyle umbellata* and *Vallisneria americana*; a gradual increase in relative frequency and relative cover of the *Panicum/Sacciolepis* group of grasses; and a large decrease in both relative frequency and cover of the shoreline grasses. *Nelumbo lutea* and *Vallisneria americana*, which grew into the emergent zone from the submersed and

floating-leaved zone, had become important components of the emergent zone by 1989 (Kroeger 1990).

In contrast to planted areas, emergent vegetation in unplanted shoreline areas was establishing slowly. The frequency of empty plots remained approximately 85% per year from 1987 to 1989. Those plots containing vegetation had low species diversity. *Alternanthera philoxeroides* (alligator weed), *Hydrocotyle umbellata* and *Typha* spp. were the only emergent species in unplanted areas with absolute frequencies greater than 5% in 1989 (Kroeger 1990).

Upper Emergent/Shrub Zone (Waterline to 30-cm Above Waterline)

All species planted in the upper emergent/shrub zone in 1987 were present in 1989. Sufficient cover by terrestrial species kept the proportion of empty plots low (15.6%) from 1987 to 1989. Mean cover per plot in planted areas increased from 59% in 1987 to 69% in 1988. In 1989 it decreased to 55% partly as a result of rooting by feral pigs (Kroeger 1990).

Changes in species from 1987 to 1989 included major growth of *Salix nigra* (Willow) shoots; a striking decrease in relative frequency and cover of shoreline grasses; a gradual increase in frequency and cover of *Panicum/Sacciolepis*; and a decrease in frequency and cover of *Typha latifolia*. *Salix nigra* and the *Panicum/Sacciolepis* grasses were the most important species in this vegetation zone. The emergents, *Juncus effusus*, *Polygonum* spp., *Sagittaria latifolia*, and *Typha latifolia*, were also important species in this zone (Kroeger 1990).

In unplanted areas, facultative emergent and terrestrial species were the most important components. No *Juncus effusus*, *Polygonum* spp., or *Panicum/Sacciolepis* was found. *Salix nigra* had a higher frequency in the unplanted areas than in the planted areas (Kroeger 1990).

Table 7-2. Species Planted at L Lake Between January and August 1987 (Kroeger 1990)

Scientific Name	Common Name
Submersed/Floating Leaved Zone	
<i>Brasenia schreberi</i>	water shield
<i>Eleocharis acicularis</i>	spike rush
<i>Najas gracillima</i>	bushy pondweed
<i>Nelumbo lutea</i>	American lotus
<i>Nymphaea odorata</i>	white waterlily
<i>Nymphoides aquatica</i>	floating heart
<i>Potamogeton pulcher</i>	pondweed
<i>Potamogeton vaseyi</i>	pondweed
<i>Vallisneria americana</i>	water celery
Emergent Zone	
<i>Axonopus sp.</i>	carpet grass
<i>Bacopa caroliniana</i>	bacopa
<i>Carex comosa</i>	sedge
<i>Carex glaucescens</i>	sedge
<i>Dulichium arundinaceum</i>	three-way sedge
<i>Echinochloa crusgalli</i>	wild millet
<i>Echinodorus cordifolius</i>	burhead
<i>Eleocharis equisetoides</i>	spike rush
<i>Eleocharis quadrangulata</i>	spike rush
<i>Erianthus giganteus</i>	beard grass
<i>Glyceria striata</i>	manna grass
<i>Hydrochloa caroliniensis</i>	grass
<i>Hydrocotyle umbellata</i>	water pennywort
<i>Juncus acuminatus</i>	rush
<i>Juncus brachycarpus</i>	rush
<i>Juncus effusus</i>	soft rush
<i>Juncus diffusissimus</i>	rush
<i>Leerisa oryoides</i>	rice cutgrass
<i>Lycopus nubellus</i>	water horehound
<i>Panicum hemitomon</i>	panic grass
<i>Paspalum virgatum</i>	switchgrass
<i>Paspalum distichum</i>	knotgrass
<i>Polygonum sp.</i>	smartweed
<i>Pontederia cordata</i>	pickerelweed
<i>Sagittaria latifolia</i>	arrowhead
<i>Scirpus cyperinus</i>	bulrush
<i>Sparganium americanum</i>	bur reed
<i>Typha domingensis</i>	cattail
<i>Typha latifolia</i>	cattail
Upper Emergent/Shrub Zone	
<i>Acer rubrum</i>	red maple
<i>Cephalanthus occidentalis</i>	buttonbush
<i>Mikania scandens</i>	climbing hempweed
<i>Nyssa sylvatica</i>	blackgum
<i>Salix nigra</i>	black willow
<i>Taxodium distichum</i>	cypress

References

- Barry, J. M. Natural Vegetation of South Carolina. USC Press, Columbia, SC (1980).
- Dames and Moore. Final Report, Task #14, Vegetation Sampling Study. Westinghouse Savannah River Company, Aiken, SC 29808.
- Firth, P. 1988. L-Lake Habitat Formers: L-Lake/Steel Creek Biological Monitoring Program. January 1986—December 1987. ECS-SR-62. Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours & Co., Aiken, SC.
- Firth, P. and J. E. Irwin. 1987. L-Lake Habitat Formers: L-Lake/Steel Creek Biological Monitoring Program. January—December 1986. ECS-SR-47. Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours & Co. Aiken, SC.
- Grace, J. B., A Summary of the Wetland Vegetation of Par Pond. DPST-85-257, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985a).
- Grace, J. B. Historic Macrophyte Development in Par Pond. DPST-85-841, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985b).
- Irwin, J. E., Structure of Stump Communities in a Steam Affected by Thermal Effluent. M. A. Thesis, University of North Carolina, Chapel Hill, NC, 23 pp. (1975).
- Jensen, J. R., S. Narumalani, O. Weatherbee, K. S. Morris, Jr., and H. E. Mackey, Jr. 1992. "Predictive Modeling of Cattail and Waterlily Distribution in a South Carolina Reservoir Using GIS." *Photogrammetric Engineering and Remote Sensing*. 58(11):1561-1568.
- Kroeger, S. R. 1990. Wetland Vegetation Establishment in L Lake, SREL-39, University of Georgia, Savannah River Ecology Laboratory, Aiken, SC.
- Sharitz, R. R., J. E. Irwin, and F. J. Christy. "Vegetation of a Swamp Receiving Reactor Effluents." *Oikos*. 24:7-13 (1974a).
- Sharitz, R. R., J. W. Gibbons, and S. C. Gause. "Impact of Production Reactor Effluent on Vegetation in a Southeastern Swamp Forest." In: *Thermal Ecology*, J. W. Gibbons and R. R. Sharitz (eds.). AEC Symp. Ser. CONF-730505, pp. 356-362 (1974b).
- Wein, G. R. and W. D. McCort. 1988. Sources of complexity in wetland mitigation. pp. 41-50. In J. Zelazny and J. S. Fierbend (eds.). *Proceedings of Wetlands: Increasing Our Wetland Resources*. National Wildlife Federation—Corporate Conservation Council. October 4-7, 1987, Washington, DC.
- Wein, G. R., S. Kroeger, and G. J. Pierce. 1987. Lacustrine vegetation establishment within a cooling reservoir. Proc. 14th Annual Conf. on Wetlands Restoration and Creation. Hillsborough Community College, FL.
- Westbury, M. 1989. L-Lake Habitat Formers: L-Lake/Steel Creek Biological Monitoring Program. January 1986—December 1988. NAI-SR-77. Prepared by NAI for Westinghouse Savannah River Company, Savannah River Laboratory, Aiken, SC.
- Westbury, M. 1990. L-Lake Habitat Formers: L-Lake/Steel Creek Biological Monitoring Program. January 1986—December 1989. NAI-SR-110. Prepared by NAI for Westinghouse Savannah River Company, Savannah River Laboratory, Aiken, SC.
- Westbury, M. 1991. L-Lake Habitat Formers: L-Lake/Steel Creek Biological Monitoring Program. January 1986—December 1990. NAI-SR-131. Prepared by NAI for Westinghouse Savannah River Company, Savannah River Laboratory, Aiken, SC.
- Westbury, M. 1992. L-Lake Habitat Formers: L-Lake/Steel Creek Biological Monitoring Program. January 1986—December 1991. NAI-SR-141. Prepared by NAI for Westinghouse Savannah River Company, Savannah River Laboratory, Aiken, SC.

Chapter 8

Wetlands of the Par Pond System

Chapter Contents

Introduction (page 8-3)

Macrophyte Distributions (page 8-5)

Thermal Effects on Par Pond Vegetation (page 8-9)

Changes in Par Pond Macrophyte Growth (page 8-11)

Par Pond Drawdown (page 8-17)

Pond B (page 8-21)

References (page 8-29)

Introduction

Par Pond, a 1012-ha reactor cooling-water reservoir, was created in 1958 by constructing an earthen dam (Cold Dam) on Lower Three Runs and was formed along the course of Poplar Branch, Joyce Branch, and the upper reach of the Lower Three Runs drainage system (Wilde and Tilly 1985).

Par Pond served as a recirculating cooling-water reservoir for R Reactor until 1963 and for P Reactor from 1961 until 1988. P Reactor operated approximately 70% of the time prior to 1988. During the summer months, the temperatures near the bubble-up in Par Pond (Figure 8-1) ranged from 22 to 42°C (Jones et al. 1979). Maximum shoreline water temperatures in the vicinity of the bubble-up ranged from 32 to 35°C (Liu et al. 1978). The thermal effluent cooled rapidly as it dispersed primarily through the southern half of the reservoir (Ezra and Tinney, 1985). The north and west arms of Par Pond had temperatures at or only slightly above typical for the region (Liu et al. 1978).

The water level of Par Pond remained relatively stable, fluctuating typically less than 0.15 m in most years. Natural invasion of macrophytes occurred over the 33-year history of the lake and the shoreline until mid-1991 when Par Pond was lowered from 200-ft above mean sea level (msl) to 181-ft above msl. Prior to lowering in 1991, Par Pond was bordered by extensive beds of persistent and non-persistent aquatic macrophytes. These beds often exceeded 20–40 m in width and in several areas exceeded 100 m.

Figure 8-1. Map of the Par Pond System

Macrophyte Distributions

Introduction

Several studies of the macrophytes of Par Pond were conducted during the 1970s. Wilde and Tilly (1985) presented the following conclusions derived from these studies:

1. A well-developed macrophyte community occurs in Par Pond.
2. Relatively stable water levels maintained by reactor operation enhance macrophyte development.
3. The dominant macrophyte species in Par Pond are typical of this geographical region.

Grace (1985a) provided a series of maps on wetlands vegetation observed in July 1984 at several sites throughout the reservoir (Table 8-1 and Figure 8-2 on page 8-6). Most of the species had been reported in earlier studies (Wilde and Tilly 1985). Grace (1985a) concluded that Par Pond wetlands were principally middle-to-late successional and relatively homogeneous.

Table 8-1. Plant Species Observed in Par Pond Wetlands in a July 1984 Survey

Species	Common Name
<i>Acer rubrum</i> L.	red maple
<i>Alnus serrulata</i> (Ait.) Willd.	tag alder
<i>Alternanthera philoxeroides</i> (Mart.) Griseb.	alligator-weed
<i>Bacopa caroliniana</i> (Walt.) Robins	Carolina bacopa
<i>Betula nigra</i> L.	river birch
<i>Boehmeria cylindrica</i> (L.) Sw.	false-nettle
<i>Brasenia schreberi</i> Gmel.	water shield
<i>Cephalanthus occidentalis</i> L. var. <i>occidentalis</i>	buttonbush
<i>Echinodorus cordifolius</i> (L.) Grisebach	creeping water plantain
<i>Eleocharis quadrangulata</i> (Michx.) R. & S.	square-stem spike-rush
<i>Erianthus giganteus</i> (Walt.) Muhl.	giant plume grass
<i>Hydrocotyle</i> sp.	pennywort
<i>Juncus effusus</i> var. <i>solutus</i> Fern. & Wieg.	rush
<i>Myrica gale</i> L.	sweet gale
<i>Nelumbo lutea</i> (Willd.) Pers.	water-lotus
<i>Nymphaea odorata</i> Ait.	water-lily
<i>Panicum hemitomon</i> Schult.	maidencane
<i>Peltandra virginica</i>	arrow-arum
<i>Polygonum</i> sp.	smartweed
<i>Pontederia cordata</i> L. var. <i>cordata</i>	pickerelweed
<i>Salix nigra</i> Marsh.	black willow
<i>Scirpus americanus</i> Pers.	three-angled bulrush
<i>Scirpus cyperinus</i> (L.) Kunth	bulrush
<i>Sphagnum</i> sp.	sphagnum moss
<i>Typha domingensis</i> Pers.	southern cattail
<i>Typha latifolia</i> L.	common cattail
<i>Woodwardia virginica</i> (L.) Smith	Virginia chain-fern

Source: Grace (1985a)

Figure 8-2. General Distribution, by Depth, of Macrophytes Along the Par Pond Shoreline

Scrub-Shrub Communities

The shoreline scrub-shrub communities along the lake include willow (*Salix* spp.), button-bush (*Cephalanthus occidentalis*), red maple (*Acer rubrum*), and alder (*Alnus serrulata*).

Cattails

Cattail beds exist year-round in Par Pond. Their phenological cycle is illustrated in Figure 8-4. They begin to “green-up” in early to mid April and often form a full, green canopy by late May. Cattails begin to senesce in late September or early October, remaining brown throughout the winter months. A similar pattern of cattail development has been documented in the SRS Savannah River swamp for Pen Branch delta (Mackey 1990, 1993). Cattails generally occupy the shallow water (1 m in depth or less) adjacent to the lake shoreline (Figure 8-2).

Non-Persistent Macrophytes

Water-lilies, lotus, and several other species along the Par Pond shoreline do not persist through the winter. They generally begin to appear at the outer edge of the cattails by late April or early May and reach full growth 6–8 weeks later. The water-lily beds generally continue to expand in areal coverage into the open-water areas of the lake through September and typically extend to depths of 2 to 5 m along the shoreline (Figure 8-2 and Figure 8-3). The beds persist until about mid-October to mid-November (Figure 8-4) with lotus beds declining before the water-lily beds. Thus, the best time of year to estimate the areal extent of these beds is from June until mid-October. These phenological or seasonal patterns are important when interpreting historical aerial photography or satellite remote sensing data of Par Pond (Jensen et al. 1991b, 1993).

Figure 8-3. Depth at Outer Edge Along Macrophyte Beds in Par Pond as Measured in 1988

Figure 8-4. Phenological Cycle of Cattails and Water-lilies in Par Pond (Source: Jensen et al. 1993)

Comparison of Par Pond Macrophyte Communities to Regional Reservoirs

There is relatively little data available to compare macrophyte communities in Par Pond to other coastal plain reservoirs. It appears, however, that the floating-leaved macrophyte communities of Par Pond are similar to those in other large coastal plain ponds and reservoirs with moderate or low turbidity (Wilde and Tilly 1985). Emergent macrophyte communities are generally similar except that stands of cattails (*Typha latifolia* and *T. domingensis*) and bulrush (*Scirpus* spp.) may be better developed in Par Pond.

Thermal Effects on Par Pond Vegetation

Changes in Phenological Cycle

One possible effect that exposure to thermal effluents has on macrophytes is a modification of their phenological cycle. Observations by Jensen et al. (1991b, 1993) indicated that there might have been an earlier emergence of macrophytes such as water-lilies and lotus in the warmer regions of Par Pond. Similar findings were reported by Grace and Tilly (1976) for the submerged macrophytes in Par Pond. In a recent study, early emergence of *Typha* spp. was observed by Mackey (1990) for moderately thermal portions of the SRS Savannah River swamp. Early development was observed in two species of semi-aquatic plants, swamp primrose (*Ludwigia leptocarpa*; Christy and Sharitz 1980) and swamp loose-strife (*Ammannia coccinea*; Gibbons and Sharitz 1981). These species were found to flower earlier and produce more fruits and seeds in warmer areas of the Savannah River swamp than in natural temperature habitats. Modification of senescence patterns has not been reported for Par Pond wetland species.

Floating-Leaved and Emergent Macrophytes

There appeared to be a slight enhancement of the relative abundance of both floating-leaved and emergent macrophytes within the warmer portion of Par Pond (Wilde and Tilly 1985). Grace and Tilly (1976) presented similar findings in a study of Par Pond submerged macrophytes. Their data suggested that conditions for *Myriophyllum spicatum*, the dominant submerged macrophyte species, were nearly optimal in the warmer region of Par Pond.

Community Alterations

Alterations of species composition, abundance, and diversity in aquatic communities may also result from exposure to thermal effluents. Most plants cannot survive for long periods at temperatures in excess of about 40° C when they are actively growing (Arnold 1977). This was evidenced in a study by Parker et al. (1973), in which aquatic vegetation in an ambient region of Par Pond was compared to that found in Pond C, which experienced temperatures in excess of 50° C during previous P-Reactor operations.

Flora Tolerant to Thermal Conditions

Studies from Par Pond have also indicated that some flora are more tolerant of exposure to thermal effluents. These more tolerant species may become abundant when temperatures are too high for the less tolerant species (Gibbons and Sharitz 1974). The nature of these tolerance mechanisms has been examined for *Typha* spp. in Par Pond. For example, Liu et al. (1978), examined the thermal sensitivities of two species of cattail (*T. latifolia* and *T. domingensis*) that occur along the shoreline of Par Pond. Their study concluded that *T. latifolia* was more thermally tolerant than *T. domingensis* and they presented a possible biochemical explanation for the differences in thermal tolerance. Both species, *T. latifolia* and *T. domingensis*, had six major malate dehydrogenase (MDH) isozymes. Three of the isozymes in *T. latifolia* were stable at 50° C; whereas, all six of the isozymes in *T. domin-*

genesis were denatured at this temperature. It was hypothesized that the apparent increased temperature tolerance of *T. latifolia* is related to the thermal stability of the MDH isozymes.

Changes in Par Pond Macrophyte Growth

Introduction

Surface macrophyte maps of Par Pond have been prepared from time to time using *in situ* measurements, aerial photography, MSS aircraft data, and SPOT satellite data (Ezra and Tinney 1985, Jensen et al. 1991b, Jensen et al. 1993). Other field studies examined the distribution and abundance of submerged macrophytes in Par Pond (Grace and Tilly 1976). More recent mapping of surface macrophytes was accomplished using photographic interpretation and satellite analysis techniques, and represents conditions in Par Pond from 1988 to mid-1991 (Jensen et al. 1993). Only the surface extent of aquatic macrophytes was examined in the more recent surveys. No attempt was made to evaluate species composition, diversity, or total biomass. Additionally, examination of photographs from 1958 to 1990 allowed for an estimation of developmental and growth trends for these communities over the 33-year history of Par Pond, prior to the recent 19-foot lowering of the Par Pond water level. The size and type of macrophyte bed are dependent on depth, slope, soil type, and exposure to wave and wind action (Jensen et al. 1993).

Photographic Studies, 1958 - 1990

Introduction

Thirty years of large scale, aerial photography was analyzed to (1) identify rates of aquatic macrophyte development from year-to-year or over the history of the lake, (2) compare *in situ* aquatic macrophyte data versus aquatic macrophyte data interpreted from aerial photography for specific recent years, and (3) document seasonal changes in aquatic macrophyte development.

Phenology data indicate that for many of the macrophyte species found in Par Pond, the September to October time-period covers the later stages of the growing season prior to leaf-drop and dormancy. During this period, the macrophytes are at or near their maximum areal coverage or extent (Figure 8-4 on page 8-7). Cowardin and Myers (1974) also found that spring and fall photography proved most useful for identification of wetland species.

Macrophyte Classification

Introduction

A detailed species inventory of Par Pond aquatic macrophytes was beyond the scope of the historical photographic survey. Thus the classification scheme used for the macrophyte mapping included only two general life-form categories; floating-leaved and emergent macrophytes. Table 8-2 on page 8-12 provides a list of the principal species in each of the two categories mapped for Par Pond.

Floating-Leaved Macrophytes

The floating-leaved macrophyte category consists of wetland dominated by plants that grow primarily on the surface of the water for most of the growing season. This category corre-

Table 8-2. Par Pond Macrophyte Species

Class	Species	Common Name
Floating-Leaved Macrophytes	<i>Brasenia schreberi</i> Gmelin	water shield
	<i>Nelumbo lutea</i> (Willd.) Persoon	water-lotus
	<i>Nymphaea odorata</i> Aiton	water-lily
Emergent Macrophytes	<i>Alternanthera philoxeroides</i> (Martius) Grisebach	alligator-weed
	<i>Bacopa caroliniana</i> (Walter) Robinson	Carolina bacopa
	<i>Boehmeria cylindrica</i> (L.) Swartz	false-nettle
	<i>Echinodorus cordifolius</i> (L.) Grisebach	creeping water plantain
	<i>Eleocharis quadrangula</i> (Michaux) R. & S.	square-stem spike-rush
	<i>Erianthus giganteus</i> (Walter) Muhl.	giant plume grass
	<i>Hydrocotyle</i> spp.	pennywort
	<i>Juncus effusus</i> var. <i>solutus</i> Fernald & Wiegand	rush
	<i>Panicum hemitomon</i> Schultes	maidencane
	<i>Peltandra virginica</i> (L.) Kunth	arum
	<i>Polygonum</i> spp.	smartweed
	<i>Pontederia cordata</i> L. var. <i>cordata</i>	pickerelweed
	<i>Scirpus americanus</i> Persoon	three-angled bulrush
	<i>Typha domingensis</i> Persoon	southern cattail
	<i>Typha latifolia</i> L.	common cattail

sponds with the rooted-vascular and floating-vascular subclasses of the Aquatic Bed class established in the U.S. Fish and Wildlife Wetlands and Deepwater Habitats classification scheme (Cowardin et al. 1979). These macrophytes are either attached to the substrate or float freely in the water on the surface. The floating-leaved macrophytes in Par Pond were dominated primarily by water-lotus (*Nelumbo lutea*) and water-lily (*Nymphaea odorata*), which are both in the rooted-vascular subclass.

Emergent Macrophytes

Emergent macrophyte species generally occurred between the upland scrub-shrub/tree boundary and the floating-leaved zone. The emergent macrophyte category consists of wetland dominated by erect, rooted, herbaceous plants that are present for most of the growing season. Emergent macrophytes, which are included in the emergent wetland class described by Cowardin et al. (1979), are generally species that are considered either persistent emergent or non-persistent emergent. Persistent emergent wetlands are dominated by species that normally remain standing at least until the beginning of the next growing season. Non-persistent emergent wetlands are dominated by plants that fall to the surface of the substrate or below the surface of the water at the end of the growing season so that, in certain seasons of the year, there is no obvious sign of emergent vegetation. The emergent macrophytes in Par Pond (Table 8-2) were dominated by persistent emergent beds comprising primarily cat-

tails (*Typha* spp.) and spike.ush (*Eleocharis quadrangulata*), and to a lesser extent panicum (*Panicum hemitomon*), pickerelweed (*Pontederia cordata*), and bulrush (*Scirpus americanus*). Figure 8-2 on page 8-6 and Figure 8-3 on page 8-7 show the general distribution by depth of typical emergent and floating-leaved macrophytes around the shoreline of Par Pond. Cattails extend to an average depth of slightly more than 1 meter and floating-leaved macrophytes to a depth of slightly more than 4 meters at their outer margins (Figure 8-3).

In Situ Data and Aerial Photographic Comparison for Par Pond

In situ aquatic macrophyte information was collected in the spring and fall from 1988 through 1991 to determine (1) the effectiveness of aerial photography and satellite imagery for mapping aquatic macrophytes versus *in situ* measurements, and (2) to document the seasonal trends (general phenology) of aquatic macrophyte beds in Par Pond (Jensen et al. 1991b, 1993). The *in situ* aquatic macrophyte bed widths as obtained on May 17, 1989, were highly correlated with measurements made using May 8, 1989, color infrared aerial photography. Therefore, it was possible to use the 30 years of photography of Par Pond to document trends in aquatic macrophyte development in Par Pond.

Macrophyte Succession and Stabilization

Rapid growth of the persistent beds of macrophytes along the Par Pond shoreline apparently did not begin until the early to mid-1970s and essentially stabilized by the early 1980s (Figure 8-5). Extensive growth of the non-persistent macrophytes began a few years after the persistent beds and stabilized by the early to mid-1980s. These results are valuable because they provide an estimate of how long succession takes to establish aquatic macrophytes and reach equilibrium in a relatively stable reservoir: such as Par Pond.

Figure 8-5. History of Par Pond Macrophyte Growth

Changes in Par Pond Wetland Macrophytes, 1975–1983

Grace (1985b), examined aerial photographs from 1975, 1980, and 1983 to evaluate the changes that occurred in the wetland vegetation of Par Pond. He also compared the aerial photographs with ground-level vegetation maps developed from field surveys conducted during July 1984 (Grace 1985a). Comparisons of photographs from August and December 1983 to evaluate seasonal changes showed that the main seasonal change in the coverage of wetland vegetation was the wintertime loss of nonpersistent species such as *Nelumbo lutea* and *Nymphaea odorata*. Comparisons between September 1980 and August 1983 showed that the lakeward extent of nonpersistent macrophytes increased by an average of 8.2 m, although not all sites changed equally. Between 1980 to 1983 a 20% change in width was noted in the non-persistent emergent beds. The extensive development of water-lily beds in Par Pond and the substantial spread of vegetation between 1975 and 1983 indicated the high suitability of the habitat in Par Pond for the growth of these aquatic plants (Grace 1985b). Grace (1985b) also found that for persistent macrophytes (principally *Typha* spp.), the average increase in lakeward extent between December 1975 and August 1983 was 3.5 m. Most of the cattail beds appear to have been well established by the mid-to-late 1970s with little expansion after the early 1980s (Jensen et al. 1993).

Seasonal and Annual Changes in Par Pond Macrophyte Beds, 1988–1990

Seasonal Changes

The phenological cycle of cattails and water-lilies provides a means to measure the areal extent of these two macrophyte communities in Par Pond. Cattail beds persist year-round in Par Pond and are generally found in shallow water (<1-m deep) adjacent to the shore. The phenological cycle of cattails is illustrated in Figure 8-4 on page 8-7. They begin “greening-up” in early April and often have a full, green canopy by late May (Workman and McLeod 1990). Cattails senesce in late September to early October, yet they are physically present and appear brown through the winter months (Mackey 1990, Gao and Coleman 1990). Conversely, water-lilies and other nonpersistent species do not live through the winter. They appear at the outermost edge of the cattails in May and reach full emergence 6–8 weeks later. The water-lily beds usually persist above water, sometimes into early November (Figure 8-4) at which time they disappear. An example of the 1988 distribution is shown in Figure 8-6.

The Multiple Year Changes in Aquatic Macrophyte Distribution

Because the 1988 and 1990 SPOT data were registered to a common map projection, it was possible to perform multi-year aquatic macrophyte change detection. Analysis using image differencing revealed that there were 192 ha of cattails present during the 1988 growing season, 179 ha in 1989, and 175 ha in 1990. There were 150 ha of water-lilies in 1988, 126 ha in 1989, and 149 ha in 1990.

Effects of Reduction in Cooling-Water Discharges

In situ and aerial photography data of Par Pond since early 1988 indicate that the aquatic vegetation, especially floating-leaved macrophytes, responded with decreased growth (bed-width) following reduction in discharge of cooling water to Par Pond Figure 8-5 on page 8-13). Spring-time emergence appears to have been delayed by approximately one month

from early to mid-April to mid- to late May, as measured by both percentage of cover and width of the macrophyte beds (Jensen et al. 1991b, 1993).

Figure 8-6. Change in Water-lily and Cattail Distribution in Par Pond Between April 17, 1988, and October 25, 1988 as Detected by SPOT Panchromatic Analysis (Source: Jensen et al. 1993)

Par Pond Drawdown

Beginning in June, 1991, Par Pond was lowered from 200 ft above msl to 181 ft above msl (Figure 8-7 and Figure 8-8 on page 8-18). Water was released and pumped to Lower Three Runs, Steel Creek, Pen Branch, and Fourmile Branch during this drawdown. This lowering was sufficient to expose both the emergent and non-emergent macrophyte beds of the Par Pond shoreline to drying conditions. Therefore, extensive macrophyte losses occurred. Initial surveys in August 1992 by Whicker (Savannah River Ecology Laboratory) indicated some re-invasion on the newly exposed shoreline. Plant succession was occurring on about 65% of the exposed lake bed with approximately 35% still barren. Grasses, sedges and rushes were the dominant forms with a mixture of old-field species including dog-fennel and daisy fleabane. Table 8-3 on page 8-19 summarizes the August 1992 survey data.

Figure 8-7. Par Pond Water-Level Change

6461-57

Location Map of Par Pond

Spring 1989

7132-061

August 1991

7180-013

October 1991

Figure 8-8. Vertical Aerial Photography Showing the Effects of the Drawdown of Par Pond

Table 8-3. Vegetation Cover, Par Pond Lake Bed, August 1992^a

Vegetation type	Cover (%)		Frequency, % of transects
	Mean	SEM	
Bare ground	35	4	95
<i>Juncus</i> spp. (Bog rushes)	15	2	86
<i>Panicum hematomon</i> (Maidencane)	13	2	95
<i>Scirpus cyperinus</i> (Bulrush)	7.6	1.9	62
<i>Eupatorium/Erigeron</i> (Dog-fennel/Daisy-flecbane)	7.2	1.4	76
<i>Cyperus erythrorhizos</i> (Sedge)	6.8	1.5	81
<i>Typha</i> - dead cattail beds	5.3	2.1	29
<i>Eleocharis acicularis</i> (Spike-rush)	2.0	0.9	24
<i>Pinus</i> spp. - seedling (Pine)	1.5	0.8	19
<i>Phytolacca americana</i> (Pokeweed)	1.3	0.6	24
<i>Polygonum</i> spp. (Smart weed)	1.2	0.5	24
Unidentified grasses	1.2	0.5	24
<i>Bacopa caroliniana</i> (Blue hyssop)	1.2	0.7	19
Unidentified forbs	0.8	0.4	19
<i>Typha</i> spp. (Cattail)	0.5	0.3	10
<i>Ludwigia</i> spp.	0.4	0.2	14
Unidentified shrubs	0.4	0.4	5
<i>Pontederia cordata</i> (Pickerelweed)	0.2	0.2	5
<i>Hydrocotyle umbellata</i> (Pennywort)	0.2	0.2	5
<i>Eleocharis equisetoides</i> (Spike-rush)	0.2	0.2	5

All areas represented except Pumpphouse Arm

Based on 21 point-intercept transects, 501 total points, running perpendicular from new to previous shoreline. Mean transect length = 99 meters.

Total length, all transects = 2079 m (1.29 miles).

^adata provided by Dr. Whicker of Savannah River Ecology Laboratory

Pond B

Site Description

Pond B, an 87-ha impoundment (Figure 8-9) constructed in 1960 as part of the Par Pond cooling-reservoir system, received cooling-water discharge until 1964. Since then, Pond B has equilibrated to a water chemistry determined by precipitation-dominated hydrologic inputs and has developed extensive stands of aquatic macrophytes (Kelly, 1989). A brief limnological description of Pond B and references to more detailed studies are provided in Kelly (1989) and Whicker et al. (1990).

Macrophytes

Introduction

Several Pond B studies conducted in the 1970s and 1980s examined different aspects of macrophyte vegetation. Parker et al. (1973), in a comparative study of thermally affected aquatic environments, surveyed the shoreline macrophytes of Pond B. Kelly (1989), as part of a larger study to assess the role of macrophytes in ^{137}Cs cycling in Pond B, described species composition, structure, and seasonal changes in the standing crop of macrophytes in Pond B. Whicker et al. (1990) sampled macrophyte standing crop as part of a survey of radioactive contaminants in the Pond B ecosystem.

Figure 8-9. Map of Pond B

Macrophyte Distribution and Standing Crop

Introduction

Kelly (1989) presents information on the species composition and structure of the vegetation in Pond B; documents seasonal changes in standing crop of dominant macrophytes; and compares the vegetation in Pond B with vegetation in other aquatic systems in the region including Par Pond.

Species composition and structure

Fourteen species of vascular plants, in four growth forms, occurred in quadrants sampled in 1986. No ferns, macroalgae or bryophytes were found. Three floating-leaved species, *Nymphaea odorata*, *Brasenia schreberi*, and *Nymphoides cordata*, which occurred primarily in the two shallowest sampling depths, comprised over half (51.8%) of the total standing crop harvested. Two species, *Utricularia floridana* and *Utricularia inflata*, both free-floating, non-rooted submerged forms, made up 32.0% of the total standing crop. The free-floating growth form (as *U. floridana*) was important at all sampling depths (Figure 8-10) and was most abundant at depths from 2.5 to 3.0 m. Rooted submerged species, principally *Cabomba caroliniana* and *Bacopa caroliniana* comprised 15.4 percent of the total standing crop. Other rooted submerged species included *Eleocharis acicularis*, *Najas guadalupensis*,

Figure 8-10. Standing Crop of Dominant Macrophyte Species at Four Sampling Depths and Three Sampling Periods During 1986 in Pond B.

Mayaca aubleti and *Myriophyllum heterophyllum*. Two emergent species, *Hydrocotyle umbellata* and *Sagittaria isoetiformis*, were infrequently encountered only at the 0.5-m sampling depth, and together comprised less than 1% of the standing crop (Kelly 1989).

Floating-Leaved Macrophytes

Nymphaea odorata

In 1986, *Nymphaea odorata* formed dense, monospecific stands in shallow areas of the narrow bays at the north end of Pond B. It also occurred in disjunct, variably sized patches along all shorelines. *Nymphaea* rhizome apices tended to be fairly widely separated (on the order of 1 m) so that rosettes of leaves usually did not overlap. Because of its patchy distribution and clumped growth form, *Nymphaea odorata* had a relatively low frequency (35%) within the 0.5- and 1.5-m sampling depths (Figure 8-10), but had large standing crops [up to 294 grams dry mass (GDM) m^{-2} , average of 130 GDM m^{-2}] in quadrats where it occurred (Kelly 1989).

Nymphaea odorata mean standing crops for the combined 0.5- and 1.5-m depths were 42 ± 84 GDM m^{-2} in May, 56 ± 97 GDM m^{-2} in July, and 36 ± 55 GDM m^{-2} in October 1986. The clumped distribution and resulting variation in biomass among plots made assessing seasonal changes in standing crop of *Nymphaea* difficult with the sampling regime used (Kelly 1989). Results from a related study (Kelly 1988) indicated that maximum standing crop of *Nymphaea* leaves occurred in late August.

The range of values for *Nymphaea odorata* standing crop at the 0.5- and 1.5-m depths in Pond B (Figure 8-10) is comparable to those reported for nymphaeids from other sites including the Okefenokee Swamp, the Chowan River in North Carolina, and the Ogeechee River in Georgia. Those values are higher than annual standing crop values reported for *Nymphaea* in an herbaceous Carolina bay (Kelly 1989).

Brasenia schreberi

Brasenia schreberi, in a 1986 survey of Pond B, had a frequency of 83.3% at the 0.5- and 1.5-m depths and a mean standing crop of 36 GDM m^{-2} (Figure 8-10) (Kelly 1989). It had a frequency of 26.6% at a depth of 2.5 m, and was the only floating-leaved species encountered at that depth. The standing crop of *Brasenia schreberi* increased in the 0.5-2.5 m sampling depths from the May to the October sampling. It was the only species for which average standing crop was significantly different by month. Mean standing crop for *Brasenia* across the 0.5-2.5-m depths was 16 ± 27 GDM m^{-2} in May, 25 ± 37 GDM m^{-2} in July and 49 ± 61 GDM m^{-2} in October. Mean standing crop of *Brasenia* for the 1.5-m depth was significantly different from the means of the 0.5-m depth and 2.5-m depth. Frequency of *Brasenia* in 0.5-2.5-m sampling depths increased from 60% in May to 75% in October; and in October *Brasenia* was encountered with 100% frequency at the 0.5- and 1.5-m depths (Figure 8-10) (Kelly 1989).

Field observations during the 1986 growing season indicated that *Brasenia schreberi* spread into progressively deeper zones so that by fall, there was a marked increase both in the amount of water surface covered by *Brasenia* leaves and in the extent of the floating-leaved zone at most shoreline locations (Kelly 1989). The stoloniferous growth habit of *Brasenia* is considered typical of pioneer nymphaeid species that are capable of rapid colonization of

large areas (Brock et al. 1983). The spread and increasing standing crop observed for *Brasenia* during 1986 may represent a typical annual cycle of establishment and spread from overwintering turions. According to Kelly (1989) it is more likely that 1986 was a favorable year for *Brasenia*, its establishment over large areas of the littoral zone of Pond B resulting, in part, from its response to a 0.15-m drop in lake levels over the summer. Schalles (1979) observed a similar rapid colonization (within a single growing season) by *Brasenia* of large, previously open areas in Thunder Bay, an herbaceous Carolina bay on SRS.

Nymphoides cordata

The third floating-leaved species, *Nymphoides cordata*, occurred only at 0.5- and 1.5-m sampling depths, with an overall frequency of 62% at these depths (Figure 8-10 on page 8-22). Mean standing crop values for the 0.5- and 1.5-m depths were not significantly different by month or depth, though standing crop decreased from May through October. The pattern of decreasing standing crop for *Nymphoides* during the 1986 growing season was also observed in a related Pond B study (Kelly 1988). Some of the larger standing crop of *Nymphoides* sampled in May possibly represented newly sprouted young plants which may not have established or persisted (Kelly 1989).

According to Kelly (1989) *Nymphoides cordata* may be undergoing a general decline in Pond B or becoming surpassed in importance by other species. In 1984, *Nymphoides* made up 51% of the system-wide standing crop of floating-leaved species; whereas, in May 1986, at its greatest abundance, *Nymphoides* made up only 30% of the total floating-leaved biomass. By October 1986, it made up less than 7%. In 1986, *Nymphoides* occurred interspersed with other species along all shorelines of Pond B, but was observed to be most abundant on broad, shallow (1-1.5 m deep) shelves extending into the main body of the lake where it existed as nearly monospecific stands of large, perennated individuals (Kelly 1989).

Keddy (1982) observed that in Axe Lake, Ontario, *Nymphoides cordata* was most abundant along more exposed shorelines. Also, Keddy (1983) proposed that *Nymphoides cordata* is relatively intolerant of competition. Therefore, the decrease in abundance of *Nymphoides* in Pond B may be related to the increase and spread of *Brasenia schreberi*, either through direct competition or through modification of wave-exposure regimes (Kelly 1989).

Nelumbo lutea and *Potamogeton* sp

Two other floating-leaved plants, *Nelumbo lutea* and *Potamogeton* sp., which in 1986 were observed growing as isolated individuals in one or two locations in Pond B, were not encountered during sampling (Kelly 1989).

Non-Rooted Submerged Macrophytes

Utricularia floridana

Utricularia floridana, listed as a threatened species by South Carolina, was the most common species of *Utricularia* found in 1986 and occurred at all four sampling depths with an overall frequency of 66% (Figure 8-10 on page 8-22) (Kelly 1989). Mean standing crop across all depths was 31 ± 44 GDM m⁻² in May, 23 ± 37 GDM m⁻² in July, and 21 ± 36 GDM m⁻² in October, with no significant differences between means for months or depths. *U. floridana* typically formed a loose mat along the bottom, occurring in shallow locations beneath the canopy of floating-leaved species, and at deeper locations, where it was the only

species present, forming mats of variable height. The consistently lower biomass for *U. floridana* at the 1.5-m depth (Figure 8-10 on page 8-22) may be related to shading by or competition with the floating-leaved species, which had maximum biomass at this depth (Kelly 1989).

In 1986, *U. floridana* was observed to be green and apparently actively growing in Pond B during December, when the canopy of floating-leaved species was much reduced. During late August when surface water temperatures were highest, *U. floridana* in shallow water was observed to senesce (Kelly 1989). Bosserman (1983) demonstrated a similar seasonal pattern of biomass dynamics for *Utricularia* spp. in the Okefenokee Swamp in south Georgia, where highest net production occurred in February and March, followed by declining biomass in summer when water temperatures and light levels were highest. Moeller (1980) found that although production of *U. purpurea* in New Hampshire was thermophilic and negligible in winter months, plants maintained a large proportion of their biomass throughout the winter. Similarly, the *Utricularia* spp. in Pond B may grow or maintain a large proportion of their biomass in winter (Kelly 1989).

Utricularia inflata

According to Kelly (1989), *Utricularia inflata* was primarily a deep water species in Pond B (Figure 8-10 on page 8-22). It was not encountered at the 0.5-m depth; it had the most biomass at 3.0 m; and its average standing crop was significantly different by depth. Mean standing crop at 1.5- and 3.0-m depths was similar for the three sampling periods: 6 ± 11 GDM m^{-2} in May, 8 ± 16 GDM m^{-2} in July, and 7 ± 20 GDM m^{-2} in October. Like *U. floridana*, *U. inflata* most often occurred in mats along the bottom. At deeper locations, *U. floridana* and *U. inflata* were often found growing intertwined in the same mat (Kelly 1989).

Utricularia olivacea

A third species, *Utricularia olivacea*, was sampled in October, 1986, in very small amounts in a back bay. This species grew in small clumps floating at the surface with *Cabomba caroliniana* (Kelly 1989).

Utricularia purpurea

A fourth species, *Utricularia purpurea*, was reported as growing in shallow water in at least one location in Pond B, but did not occur in any quadrants sampled in 1986 (Kelly 1989).

Rooted Submerged Macrophytes

Cabomba caroliniana

Kelly (1989) reported the mean standing crop of *Cabomba caroliniana* to be greatest at 2.5 and 3.0 m (Figure 8-10 on page 8-22). *Cabomba* was not encountered in the shallowest quadrats. At the 1.5- and 3.0-m depth, mean standing crop for *Cabomba* increased over the three sampling periods (7 ± 19 GDM m^{-2} in May, 16 ± 45 GDM m^{-2} in July, and 18 ± 44 GDM m^{-2} in October), but did not differ significantly by month (Kelly 1989). These numbers are similar to mean above-sediment biomass of 19.6 GDM m^{-2} reported for *Cabomba* in a permanently flooded site in the Okefenokee Swamp. In Pond B, *Cabomba* grew in dense, nearly monospecific stands in deep water within the channels of the narrow bays at the north end of the pond. In 1984, *Cabomba* had the deepest depth distribution of any spe-

cies in Pond B, its maximum standing crop occurring between 3 and 4 m. It occurred as deep as 6 m, the depth of the mid-summer thermocline and the maximum depth of epilimnetic sediments (Kelly 1989). Intact stems and leaves of *Cabomba* were visible 1-2 m below the surface in water more than 3 m deep as late as February. Like *Utricularia*, *Cabomba* may maintain significant amounts of biomass in winter in Pond B (Kelly 1989).

Bacopa caroliniana

Bacopa caroliniana was encountered only at the 0.5- and 1.5-m depths (Figure 8-10 on page 8-22.) and had significantly greater average standing crop at the 1.5-m depth (Kelly 1989). Mean standing crops for *Bacopa* were 9 ± 16 GDM m^{-2} in May, 10 ± 30 GDM m^{-2} in July, and 3 ± 5 GDM m^{-2} in October. This species tended to occur as large, mounded, many-stemmed individuals scattered among other species.

Myriophyllum heterophyllum

Myriophyllum heterophyllum was uncommon in Pond B and in 1986, occurred only as isolated plants or plant fragments in *Cabomba* stands. (Kelly 1989).

Emergent Macrophytes

The two emergent species, *Hydrocotyle umbellata* and *Sagittaria isoetiformis*, which occurred infrequently in samples collected at the 0.5-m depth, were fairly common along all shorelines of Pond B at depths shallower than those sampled (Kelly 1989). While a diversity of emergent species occurred at depths of less than 0.5 m, most emergents occurred in low densities in a narrow band along the shoreline. In 1986, a well-developed emergent zone was generally lacking in Pond B, except at the heads of bays and along shallow bars adjoining several small islands (Kelly 1989).

Typha spp. and *Scirpus* spp., once dominant in Pond B (Parker et al. 1973), were not encountered during 1986 sampling (Kelly 1989). *Typha* seedlings were observed in 1986 along segments of the shoreline, which had no mature stands, but whether this was a common occurrence or an unusual germination event is not certain. In 1986, a mature stand of *Typha* was observed in only one location in Pond B (Kelly 1989).

Comparison With Other Aquatic Systems

The macrophyte vegetation in shallow areas (<2.5 m deep) of Pond B was dominated in 1986 by an association of floating-leaved species and *Utricularia* spp. (Kelly 1989). Macrophyte vegetation in deeper areas was dominated by *Utricularia* spp. and *Cabomba caroliniana*. Similar associations of floating-leaved species and *Utricularia* have been described from numerous other permanently flooded freshwater habitats on the southeastern coastal plain, all of which have been described as having dilute water chemistry resulting from precipitation-dominated hydrologic inputs. These habitats include freshwater ponds and lagoons in southeastern Louisiana, parts of the Okefenokee Swamp, and permanently or semi-permanently flooded parts of herbaceous Carolina bays (Kelly 1989).

Comparison with Par Pond

Historically, the macrophyte vegetation of Pond B was similar to that in Par Pond, with *Typha* the dominant offshore macrophyte (Kelly 1989). In a 1971 survey, Parker et al.

(1973) listed a total of 19 vascular plant species. *Typha latifolia* occurred in large stands and was widely distributed over 39% of the shoreline. Low numbers of *Nymphaea odorata* occurred in two of the north coves. *Potamogeton diversifolius*, *Ceratophyllum*, and *Myriophyllum* were listed as present. However, macrophyte vegetation of Pond B as described by Kelly (1989) differed in several respects from that described by Grace (1985a), Wilde and Tilley (1985), and Liu et al. (1978) for Par Pond.

References

- Arnold, E., (ed), 1977. "High Temperature Tolerance". In: Chapter 6 of Plants and Temperature. Camelot Press Ltd., Southampton, Great Britain, pp. 49–55.
- Bosserman, R. W. 1983. Elemental composition of Utriculariaperiphyton ecosystems from Okefenokee Swamp. *Ecology* 64: 1637–1645.
- Brock, Th. C. M., G. H. P. Arts, I. L. M. Goosen, and A. H. M. Rutenfrans. 1983. Structure and annual biomass production of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae). *Aquat. Bot.* 17:167–188.
- Christy, E. J. and R. R. Sharitz. "Characteristics of Three Populations of a Swamp Annual Under Different Temperature Regimes". *Ecology*. 61(3):454–460 (1980).
- Cowardin, L. M. and V. I. Myers. 1974. "Remote Sensing for Identification and Classification of Wetland Vegetation". *Journal of Wildlife Management*. 38(2):308–314.
- Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. USDI Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-79-31. 103 pp.
- Ezra, C. E. and L. R. Tinney. Par Pond Macrophyte Study Savannah River Plant, Aiken, South Carolina. EG&G/EM Letter Report DOE (ONS-SRL)8513 (1985).
- Gao, T. and T. L. Coleman, 1990. "Use of Satellite Spectral Data for Mapping Aquatic Macrophytes and Nutrient Levels in Lakes". *Proceedings, International Geoscience & Remote Sensing Symposium*, (1):109–116.
- Gibbons, J. W. and R. R. Sharitz. 1981. "Thermal Ecology: Environmental Teachings of a Nuclear Reactor Site". *Bioscience*. 31(4):293–298.
- Grace, J. B. and L. J. Tilly. 1976. "Distribution and Abundance of Submerged Macrophytes, Including *Myriophyllum spicatum* L. (Angiospermae), in a Reactor Cooling Reservoir". *Archives of Hydrobiology*. 77(4):475–487.
- Grace, J. B., A Summary of the Wetland Vegetation of Par Pond. DPST-85-257, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985a).
- Grace, J. B. Historic Macrophyte Development in Par Pond. DPST-85-841, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985b).
- Jensen, J. R., S. Narumalani, O. Weatherbee, and H. E. Mackey, Jr., 1991b. "Remote Sensing Offers and Alternative for Mapping Wetlands". *Geo Info Systems*, (October):46–53.
- Jensen, J. R., S. Narumalani, O. Weatherbee, and H. E. Mackey, Jr., 1993. "Measurement of Seasonal and Yearly Cattail and Waterlily Changes Using Multidate SPOT Panchromatic Data". *Photogrammetric Engineering & Remote Sensing*. 59(4):519–525.
- Jones, J. C., J. F. Hancock and E. H. Liu. 1979. "Biochemical and Morphological Effects of Temperature on *Typha latifolia* L. (Typhaceae) Originating from Different Ends of a Thermal Gradient. I. Controlled Environmental Studies". *American Journal of Botany*, 66(8):902–906.
- Keddy, P. A. 1982. Quantifying within-like gradients of wave energy: Interrelationships of wave energy, substrate particle size, and shoreline plants in Axe Lake, Ontario. *Aquatic Bot.* 14:41–58.
- Keddy, P. A. 1983. Shoreline vegetation in Axe Lake, Ontario: Effects of exposure on zonation patterns. *Ecology* 64:331–344.
- Kelly, M. S. 1988. Biomass dynamics and ¹³⁷CS cycling in floating-leaved macrophytes in a nuclear-contaminated aquatic ecosystem. Dissertation. Univ. of Georgia, Athens, GA.
- Kelly, M. S. 1989. Distribution and biomass of aquatic macrophytes in an abandoned nuclear cooling reservoir. *Aquatic Botany*. 35:133–152.
- Liu, E. H., R. R. Sharitz, and M. H. Smith, 1978. "Thermal Sensitivities of Malate Dehydrogenase Isozymes in *Typha*". *American Journal of Botany*, 65(2):214–220.

- Mackey, H. E. 1990. "Monitoring Seasonal and Annual Wetland Changes in a Freshwater Marsh with SPOT HRV Data". Proceedings, 1990 ACSM-ASPRS Annual Convention, Denver, CO. Vol. 4. 283-292.
- Mackey, H. E. 1993. "Application of Low Altitude Normal Color and False Color Infrared Photography for Delineation and Monitoring Wetland Restoration of a Large Carolina Bay". Proceedings 14th Biennial Workshop on Color Photography and Videography in Resource Monitoring, Utah State University, Logan, Utah. In Press. Abstract only.
- Moeller, R. E. 1980. Temperature-determined growing season of a submerged hydrophyte: tissue chemistry and biomass turnover of *Utricularia purpurea*. *Freshwater Biol.* 10:391-400.
- Parker, E. D., M. F. Hirshfield, and J. W. Gibbons, 1973. "Ecological Comparisons of Thermally Affected Aquatic Environments". *Journal of the Water Pollution Control Federation.* 45(4):726-733.
- Schalles, J. R. 1979. Comparative Limnology and Ecosystem Analysis of Carolina bay Ponds on the Upper Coastal Plain of South Carolina. Ph.D. Dissertation, Emory University, Atlanta, Georgia, USA.
- Whicker, F. W., J. E. Pinder III, J. W. Bowling, J. J. Alberts, & I. L. Brisbin. 1990. Distribution of long-lived radionuclides in an abandoned reactor cooling reservoir, *Ecological Monographs.* 60(4):471-496.
- Wilde, E. W. and L. J. Tilly. Influence of P-Reactor Operation on the Aquatic Ecology of Par Pond-A Literature Review. DP-1698, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Workman, S. W. and K. W. McLeod. 1990. Vegetation of the Savannah River Site: Major Community Types, Aiken: Savannah River Ecology Laboratory, 137 p.

Chapter 9

Carolina Bays of SRS

Chapter Contents

Introduction (page 9-3)

Hydrology (page 9-5)

Water Chemistry (page 9-7)

Soils (page 9-11)

Vegetation (page 9-13)

Invertebrate Fauna (page 9-17)

Vertebrate Fauna (page 9-19)

Lost Lake Restoration (page 9-23)

References (page 9-31)

Introduction

General Characteristics of Carolina Bays

Much of this chapter was taken from the NERP report of the Carolina bays of SRS (Schalles et al. 1989). Carolina bays are a common feature of the SRS landscape (Figure 9-1 on page 9-4). The 194 bays identified by Shields et al. (1982) range from less than 0.1 ha to about 50 ha in size and support a variety of aquatic and wetland communities. Most of the bays have limited development of organic or peat substrates and the soils are typically sandy clay loam underlain by a clay hardpan. Many were ditched and drained for agricultural purposes prior to the construction of SRS (Chapter 4—Sitewide Wetland Resources) (Christel-Rose, 1993). Few have been actively disturbed since the early 1950s; therefore, most of the altered bays have undergone successional revegetation (Schalles et al. 1989).

Several physical characteristics of these wetlands dictate the development and status of their biota. Carolina bays are typically isolated wetlands that are largely fed by rainfall or shallow, low-solute groundwater (Schalles et al. 1989, Lide 1991). Thus, they have a nutrient-poor, softwater, acidic chemistry that, in turn, restricts primary and secondary productivity and use of these systems to tolerant species. In addition, fluctuations of their hydrology, make these bays relatively unpredictable habitats. Interpretations of successional status or development of the biota must take this unpredictability of hydrology into account and long-term observations are necessary to understand the role of these bays in supporting aquatic and wetland organisms (Kirkman 1992, Schalles et al. 1989).

Carolina bays on SRS have mineral soils with little or no peat accumulation. Most of the bays contain water, at least seasonally. Carolina bays on SRS have remained largely undisturbed since the construction of SRS in the early 1950s and are valuable examples of these ecosystems.

Previous Research on SRS Carolina Bays

Much of the research on the Carolina bays of SRS has focused on certain species or on environmental features. Different levels of detail exist for different groups of organisms and reflect the diverse interests of previous investigators. This chapter summarizes aspects of research to date and presents data from numerous studies, but it does not attempt to synthesize. The most complete ecosystem study and synthesis of the biotic and abiotic properties of a single bay is a study of Thunder Bay (Site 83) (Figure 9-1 on page 9-4) by Schalles and Shure (1989). The most extensive comparison of SRS bays with those found throughout the Southeast was provided by Sharitz and Gibbons (1982) (Schalles et al. 1989).

Size and Distribution of Carolina Bays on SRS

An inventory of the Carolina bays on SRS was made by examining false-color infrared photography (scale 1:15,840) (Shields et al. 1982). This inventory identified 194 confirmed or suspected bays (Figure 9-1 on page 9-4); each bay was assigned a number, and its position was located on a topographic map of SRS (USGS 1:48,000). The identification number, name, location, wetland surface area, and habitat type of each bay are presented in *Loca-*

tions and Areas of Ponds and Carolina bays at the Savannah River Plant (Shields et al. 1982). Carolina bays are distributed in clusters and broad bands across SRS (Figure 9-1 on page 9-4). The bays occur at elevations ranging from 36 to 104 m above mean sea level. The surface areas of bays on SRS range from less than 0.1 ha to about 50 ha. Aerial photography from the 1940s reveals that Sites 96, 97, and 98 (Figure 9-1) may be remnants of a very large bay covering about 220 ha. The median size of the SRS bays is about 0.8 ha; only 15 sites exceed 4 ha (Shields et al. 1982, Schalles et al. 1989).

Figure 9-1. Location Map of Carolina Bays on SRS (adapted from Shields et al. 1982)

Hydrology

Water chemistry of undisturbed Carolina bays on SRS is typical of precipitation-dominated systems (Schalles et al. 1989). Surface inflow channels are generally absent. Drainage channels occur commonly and many appear to have been man-made (see Chapter 4—Sitewide Wetland Resources). Today, through disuse, most of these channels are partially filled with sediments and discharge only during periods of high water.

Water levels in three extensively studied bays on SRS are compared in Figure 9-2. Although the water levels of these bays were generally related to the amount of precipitation, the amplitude and timing of changes differed. For example, Ellenton Bay and Thunder Bay had similar overall patterns; whereas, Rainbow Bay had greater fluctuation in water level. Schalles (1979) found that maximum water-level fluctuations over an annual cycle in 1974–1975 were between 35 and 83 cm in six local bays. Water level changes in excess of 50 cm from the summer of 1990 through the summer of 1992 were common at Lost Lake (Site 28) (Figure 9-3 on page 9-6). Hodge (1985) noted a similar range of 25–63 cm in the water-level changes of eight SRS and Barnwell County bays during 1984–1985. Continuous or temporary connection to near-surface groundwater is probably a common feature of Carolina bays (Lide 1991). Comparisons of surface-water levels to the piezometric levels in four adjacent monitoring wells (Schalles et al. 1989) revealed conditions favorable to almost continuous subsurface seepage loss and periodic groundwater recharge at Thunder Bay. Schalles (1979) proposed that most groundwater-surface water interactions occur laterally, around the margins of the depressions, and that these connections are often lost during periods of low water levels.

Figure 9-2. Surface Water Levels of Three Carolina Bays on SRS—Thunder Bay, 83; Ellenton Bay, 176; and Rainbow Bay, 189 (Schalles et al. 1989)

Figure 9-3. Water Level and Rainfall Data for Lost Lake Since August 1990

An impervious clay lens appears to underlie many of the SRS Carolina bays. Soils in the center of the bays contain higher percentages of clays and silts than those closer to the rims. Consequently, soils in the center are less permeable and more poorly drained (Hodge 1985). Many Carolina bays on SRS dry periodically. Many of the smaller bays contain surface water only during wet seasons, whereas some of the larger depressions dry only during prolonged drought [e.g., Craig's Pond (Site 77 in Figure 9-1 on page 9-4) and Ellenton Bay]. Ellenton Bay experienced severe drying with only a few deep holes holding water during droughts in 1968, 1981, 1987 and 1988 (Sharitz and Gibbons 1982, Schalles et al. 1989). Craig's Pond was dry to at least 20 cm below the soil surface in 1988 (Schalles et al. 1989).

Water Chemistry

General Chemical Characteristics

Several surveys of surface water chemistry in Carolina bays of SRS have been made (Newman and Schalles 1990). The surface waters of the surveyed bays were acidic (pH 3.8–5.5) with low levels of calcium and total inorganic solutes (conductivities of 20–40 μ mhos). Bay waters had low to moderate color and dissolved organic carbon (mean = 22 mg/l). The moderate levels of color and dissolved organic carbon (DOC) in the bays can be attributed to the low calcium levels, abundance of living and decaying plant materials, and the shallow depths of the ponds. No single element dominates cations in the bay ponds. In 1980 calcium was the most abundant cation (25% of total meq/l). However, sodium, magnesium, and hydrogen ions were also significant (Table 9-1). The relatively high monovalent/divalent cation ratios, low total inorganic solutes, and occurrence of moderate acidity and dissolved organic carbon in the bays are probably the result of sea salt contributions to atmospheric chemistry in the region, very restricted watersheds with sandy, leached soils, periodic exchanges with low solute strength shallow groundwater, and high nutrient retention by vegetation (Schalles et al. 1989). Overall, the SRS bays had lower total cation levels than did other coastal plain areas (Table 9-1). Manganese concentrations in the bays on SRS were about one order of magnitude greater than the freshwater, global average (0.0013 meq/l) reported by Livingston (1963). A possible source of the manganese is conifer litter (Wetzel 1983) from marginal pine forests; thus manganese concentrations in the bays may attest to the importance of exchange pathways between these bays and adjacent terrestrial habitats (Schalles et al. 1989).

Table 9-1. Cation proportions for various southeastern coastal plain surface waters (softwater, lentic systems). (Sources: ¹Tilly 1975, ²Daniel 1981, ³Auble 1984, ⁴Dierberg and Brezonik 1984, ⁵Lichtler and Walker 1979)

Cation (% meq/l) ^a	Schalles et al. 1989	SRS Farm Ponds ¹	North Carolina Pocosins ²	Georgia Okefenokee Swamp ³	Florida Cypress Dome ⁴	Virginia Lake Drummond, Dismal Swamp ⁵
Ca ⁺⁺	24.4	18.6	34.9	7.6	25.4	38.2
Mg ⁺⁺	17.4	21.0	16.6	9.4	20.1	16.9
Na ⁺	23.7	51.6	36.6	45.9	38.3	31.3
K ⁺	5.6	7.4	2.6	2.0	1.6	9.4
H ⁺	18.2		9.2	32.3	5.7	1.8
Fe ⁺⁺	5.9			2.6	3.4	2.4
Mn ⁺⁺	4.9		< 0.1	1.4	1.4	
Σ (meq/l)	0.261		0.573	0.392	0.561	0.875

^a Iron and manganese were probably present as colloids and thus do not contribute to total cation charge.

Detailed Chemical Analyses of Bays of SRS

Detailed chemical analyses of bays on SRS and others in the vicinity of SRS were made as part of a 1988 regional survey of 53 sites (Table 9-2 on page 9-9). Overall, solute levels were higher than levels seen in previous surveys of bays on SRS. Potassium levels were notably higher and hydrogen-ion levels lower. A dry period during the early and mid-1980s and corresponding ecosystem responses may account for these differences. Chloride was the dominant inorganic anion, with sulfate second in abundance (Table 9-2). Dissolved organic carbon averaged 14.1 mg/l and accounted for 39% of the total anionic charge. Dissolved silica values were moderate, but quite variable. The dilute acidic chemistry is a probable indicator of moderate to severe nutrient limitations in the bays. The acidic nature of the surface waters suggests a dystrophic condition. The acidity seems largely related to biological phenomena and low regional alkalinities. Interestingly, sphagnum moss, often implicated in bog acidity (Clymo 1964), is uncommon or absent from bay communities on SRS (Schalles et al. 1989).

Variation in Oxygen and Temperature

Spatial and temporal variability in oxygen and temperature were noted in the bays. Strong oxygen and temperature stratification often existed when emergent or floating-leaf vegetation was present, even in shallow waters (Figure 9-4). Bottom strata exhibited low oxygen levels (less than 0.5 mg/l) during most of the year. Stratification and destratification can occur almost daily. Horizontal patterns were demonstrated with *in situ* Hydrolab measurements made in December 1979 in Dry Bay (Site 31). Highest oxygen values were found in shallow water with abundant filamentous algae, while the lowest value was found in a macrophyte-shaded area with abundant detritus. In general, bay margins had the greatest overall physical-chemical variability. Thunder Bay (Site 83) displayed marked seasonal patterns (Schalles et al. 1989). Average water-column oxygen values ranged from about 7 to 8 mg/l in mid-winter to about 1.5 to 2 mg/l in late summer. Average water column temperatures varied from approximately 7°C in mid-winter to 27°C in mid-summer.

Figure 9-4. Vertical Profiles of Dissolved Oxygen and Temperature at Four Sampling Stations in Three Carolina Bays in 1974-75 (Schalles 1979)

Table 9-2. Detailed chemical analysis, including anion/cation charge balance, for surface waters in six Carolina bays sampled as part of a regional survey in January 1988.^a (Source: Schalles, et al., 1989)

Variable	$\bar{x}$ (range, by sites) mg/l		$\bar{x}$ meq/l	$\bar{x}$ % meq
DOC ^b	14.09	(8.08-21.71)	0.155	39.0
Cl ⁻	4.94	(3.44-7.99)	0.139	35.0
SO ₄ ⁻⁻	3.32	(0.50-10.34)	0.069	17.4
HCO ₃	2.07	(0.13-6.89)	0.034	8.6
Anions(Σ)	--		0.397	100.0
Na ⁺	3.08	(0.82-6.64)	0.134	32.8
Ca ⁺⁺	2.12	(0.72-4.53)	0.106	26.0
K ⁺	3.83	(1.09-14.5)	0.098	24.0
Mg ⁺⁺	0.78	(0.49-1.25)	0.064	15.7
H ⁺	0.006	(0.001-0.013)	0.006	1.5
Cations (Σ)	--		0.408	100.0
Sp. Conductance ^c	47.4	(28.6-98.2)		
pH	5.2	(4.9-6.1)		
SiO ₂	2.82	(0.10-9.24)		
Fe (reactive) ^d	0.35	(0.28-0.63)		
Mn (reactive) ^d	0.18	(0.09-0.32)		

^a The sites were: Flamingo Bay (Site 3), Enchantment Bay (Site 40), Thunder Bay (Site 83), Mathis Lake in Aiken County, and Sister Lake and an unnamed site near Williston in Barnwell County. Four replicates were collected per site. Anions were determined with ion chromatography, metals with atomic absorption spectrophotometry, silica with molybdenum blue method

^b dissolved organic carbon, charge estimated from the analysis of Perdue et al., 1984

^c $\mu\text{mhos/cm}$

^d from acid-pretreated samples, may be largely colloidal and values were not used in the charge balance analysis.

Soils

Bay soils generally grade from well-drained sands on the xeric rims to consolidated sandy loams in the wetland centers. Hodge (1985) observed two conditions in sandy surface soils of the bay rims and adjacent interbay areas on or near SRS. In one condition, the surface sand was 75–150 cm thick and was underlain by a sandy clay loam (Blanton series). In the second condition, the surface layer was excessively drained sand with depths exceeding 2 m (Lakeland series). Interior to the bay rims, Hodge found a narrow zone with loamy surface sands 15–35 cm thick overlying a sandy clay loam horizon about 45 cm thick and a third horizon of about 75 cm composed of sandy loams or loamy sands. The central floors of most bays on or near SRS have shallow, consolidated loamy soils which vary from 15–75 cm in thickness. A consolidated, gray clay hardpan is consistently found below the loamy stratum. Hodge (1985) determined that these hardpans averaged about 70 cm thick and that soils immediately below the hardpans were sandy clay loams. Organic horizons are generally thin, but often increase with increasing water depths and hydroperiods. The surface mineral soils of the bay interiors are typically dark and contain numerous fine charcoal fragments indicating earlier fires (Schalles 1979). Most soils occurring in the interiors of bays on SRS and vicinity fit an Ochraqult classification (Hodge 1985). Ochraqult soils have thin, dark peptones, thin to moderately thick argillic horizons, and base saturations of less than 50%. Such soils are inundated for at least three months of the year and have poor drainage. Soils of the SRS bays are largely Rembert and Ogeechee series loams, but also include Williman and Lumbee loamy sands (Hodge 1985). Interior to the sandy bay rims, soils of the following series are less frequently encountered: Duplin, Plummer, Faceville, Orangeburg, and Johnston (Hodge 1985).

Many bays of SRS have surface organic layers of less than 15 cm. However, the maximum thickness of peat in Site 142 exceeds 1 m. The occurrence of significant peat in Site 142 could reflect a more stable hydrology with almost continual groundwater recharge that reduces exposure to the atmosphere and enhances peat development. This bay is located between 42.7–45.9 m above mean sea level and is relatively close to Steel Creek and the Savannah River floodplain. However, other SRS bays with similar locations near streams or the floodplain lack significant peat buildup. Hodge (1985) found several Carolina bays on SRS and in adjacent Barnwell and Aiken Counties with peat layers of 50–100 cm.

Vegetation

Introduction

Several wetland community types typical of undrained coastal plain sites are found within bays of SRS. Topographical relief and hydrology are the principal determinants of vegetation composition in the bays. The duration and magnitude of inundation creates a range of conditions favoring different vegetation associations. Many Carolina bays are dominated by grasses and sedges that generally occur in monospecific stands. These stands change in area and in community dominance as water conditions change (Kirkman 1992, Schalles et al. 1989).

Vegetation Pattern Control

The hydrologic regime of Carolina bays is one of the most important factor that controls patterns of vegetation in the bay. Kirkman (1992) concluded that it was during extremes of the hydrologic regime (i.e., very wet or very dry conditions) that recruitment from the seed bank becomes a more significant factor influencing vegetation change. Species diversity and density of seed banks of Carolina bays are among the highest reported for wetlands; however, these seed banks do not necessarily reflect standing vegetation (Kirkman 1992, Schalles et al. 1989).

Vegetation Zones

A xeric to hydric gradient occurs from the peripheral sand rim to the center of the bays. Kelley and Batson (1955) described several concentric vegetational zones in Craig's Pond (Site 77, Figure 9-1 on page 9-4). The outermost zone lies along the sandy rim of the bay and is dominated by trees such as loblolly (*Pinus taeda*) and longleaf pines (*P. palustris*), black gum (*Nyssa sylvatica*), blackjack oak (*Quercus marilandica*), turkey oak (*Q. laevis*), and sweet gum (*Liquidambar styraciflua*). Several shrubs, such as sumac (*Rhus copallina*), gallberry (*Ilex glabra* and *I. coriacea*), and red bay (*Persea borbonia*) also occur here. Inside this zone of woody species are several bands of herbaceous vegetation, each of which is dominated by grass species. The first is characterized by broomsedge (*Andropogon virginicus*), but also contains numerous herbs including pitcher plants (*Sarracenia* spp.). Inside this zone is a band of vegetation dominated by threeawn grass (*Aristida affinis*) and in deeper water areas, surrounding the central pool of water, species of maidencane (*Panicum* spp.) are abundant. The pond in the middle of the bay contains typical floating-leaved aquatic plants such as the waterlilies (*Nymphaea odorata* and *Nymphoides aquaticum*). In a subsequent floristic study of Craig's Pond, Hodge (1985) found similar patterns, except in the area between the andropogon and maidencane zones (Figure 9-5 on page 9-14) (Schalles et al. 1989).

Community Types

Seventeen herbaceous community types were found in the eight Carolina bays studied by Hodge (1985). As many as six types were found in one bay (Craig's Pond). For Craig's

Figure 9-5. Wetland Vegetation Community Types at Craig's Pond (Site 77) (Source: Hodge 1985)

Figure 9-6. Wetland Vegetation Community Types at Ellenton Bay (Site 176) (Source: Hodge 1985)

Pond and Ellenton Bay (Site 176), the composition and distribution of herbaceous species in community types along the hydrologic gradient from the rim to the hydric center are illustrated in Figure 9-5 and Figure 9-6 (Schalles et al. 1989).

Short-Term Succession

Field observations and the results of the study by Hodge (1985) suggest that short-term succession from herbaceous to woody-dominated communities in bays of the Upper Coastal Plain occurs when water levels are low. After a bay has been ditched and drained, *Cephalanthus occidentalis*, *Diospyros virginiana*, or *Liquidambar styraciflua* commonly germinate on the exposed soil. A woody-dominated community soon becomes established. In undisturbed bays, organic material accumulates faster in the semipermanently to permanently inundated areas where conditions are at or approach anoxia throughout the year. In these deeper areas of the bays, peat may accumulate until it is exposed during periods of low water levels. During these periods, seeds of woody species may become established and initiate the development of a woody-dominated community (Schalles et al. 1989).

Invertebrate Fauna

Introduction

The invertebrate fauna has been described from only a few Carolina bays on SRS. Cross (1955) surveyed odonate distributions in Carolina bays and other aquatic habitats of SRS. Invertebrates were intensively surveyed in 1979 at Rainbow Bay (Site 189, Figure 9-1 on page 9-4) and Sun Bay (Site 45, no longer in existence, Figure 9-1), with detailed listings of taxa and their relative abundances (Savannah River Ecology Laboratory 1980). Intensive work at Sun Bay disclosed a diverse insect assemblage with 119 families from fourteen orders identified. Dipterans were the most abundant taxa at both Sun Bay and Rainbow Bay. Oligochaetes and isopods were relatively common in Rainbow Bay, but were not collected in Sun Bay (Table 9-3) (Schalles et al. 1989).

Macroinvertebrates

Macroinvertebrates were quantified from 1975–1977 at Thunder Bay (Site 83, Figure 9-1 on page 9-4) (Schalles and Shure 1989). Four insect orders dominated the invertebrates: odonates, dipterans, hemipterans, and coleopterans. Macroinvertebrates in Thunder Bay were similar in composition, but contributed only about 20% of the benthic biomass measured by Benke (1976) in an abandoned farm pond on SRS. The dystrophic bog chemistry and periodic drying apparently prevent or severely restrict the occurrence of several freshwater invertebrate groups in the Thunder Bay wetland community. Ephemeropterans, megalopterans, and trichopterans were infrequent and plecopterans, amphipods, isopods, decapod crustaceans, gastropods (except the limpet *Ferrisia*), bivalves, and oligochaetes were absent during that study. The low calcium levels in undisturbed, upper coastal plain bays may be the primary limiting factor for molluscs, decapods and other malacostracans, and perhaps annelids. Snails were frequently observed in two nearby Carolina bays at the Barnwell County Industrial Park. The bays had received runoff and sediments from a con-

Table 9-3. Density of Certain Insect Orders, Oligochaetes, and Isopods (Number of Individuals/20 cm²) Determined by Artificial Substrate Sampling at Rainbow Bay (Site 189) and Sun Bay (Site 45) (Source: Savannah River Ecology Laboratory 1980)

Microhabitat	Taxa							
	Ephemeroptera ^a	Coleoptera ^a	Diptera ^a	Hemiptera ^a	Odonata ^a	Tricoptera ^a	Oligochaeta	Isopoda
Rainbow Bay (189)								
deep open water	2.5	0	44.5	0.5	3	0	16.5	10.5
shallow water in button bush	4.5	1.3	9.6	3.3	1.6	0	5	15.3
Sun Bay (45)								
open disturbed pond	0	1.5	30.5	1	0	0	0	0
open weed-filled pond	0	2	59	1	0.5	0	0	0
pond in buttonbush	0	6.5	41	0	0	0	0	0
drainage ditch	3	1	38.5	0.5	0.5	0	0	
drainage ditch flowing	0	5	101	0	0	0	0	0

^a Insect order

struction area and had higher calcium levels (averages of 9.5 and 14 mg/l for the two sites) (Schalles et al. 1989).

Zooplankton

The zooplankton of Carolina bays on SRS are diverse, abundant, and at least moderately productive (Taylor et al. 1989). Calanoid and cyclopoid copepods, cladocerans, and rotifers are ubiquitous. Anostracans and conchostracans are sporadically distributed, but may be abundant where they occur. The community in Rainbow Bay showed marked changes in species composition during the wet season (Figure 9-7). In such bays, which function as temporary ponds, all of the zooplankton have resting stages that lie dormant in the sediments during the dry season. Varied times of emergence from these resting stages contribute to the succession of species in Rainbow Bay. Zooplankton comprise an important part of the diets of larval salamanders (Taylor et al. 1988). Insect larvae may also prey heavily on the zooplankton (Schalles et al. 1989).

Figure 9-7. Changes in Zooplankton Species Composition from January to September 1984 at Rainbow Bay (Site 189) (Source: Schalles et al. 1989)

Vertebrate Fauna

Introduction

Vertebrates are conspicuous and relatively abundant members of the fauna of Carolina bays. Perhaps because of the water-level oscillations and dry periods, no vertebrates found in bays of SRS are considered strictly endemic to these habitats. All aquatic and semi-aquatic vertebrates, except fish, apparently use migration or aestivation strategies during dry periods. For example, sirens (*Siren intermedia* and *Siren lacertina*) form cocoons and aestivate during dry-outs (Conant 1975). The mole salamander (*Ambystoma talpoideum*) is commonly terrestrial as an adult, but is paedogenic in situations where water is usually permanent. It may have evolved this pattern of metamorphosis in response to unpredictable water levels that may result in potentially ephemeral aquatic habitats becoming permanent ponds with no fish predators (Patterson 1978, Semlitsch 1985, Schalles et al. 1989).

Fishes

Fishes have been observed in several Carolina bays on SRS (Bennett and McFarlane 1983). The following fish were observed in four Carolina bays on SRS during 1978–1983: redbfin pickerel (*Esox americanus*), mud sunfish (*Acantharchus pomotis*), sunfish (*Lepomis* spp.), lake chubsucker (*Erimyzon sucetta*), and mosquitofish (*Gambusia affinis*). Fewer than 10% of the Carolina bays on SRS are known to have permanent fish populations, although overwash from neighboring swamps or streams may reestablish the ichthyofauna of formerly dry basins (Schalles et al. 1989).

Migration in Carolina Bays

Although fishes are not a dominant feature in most bays, other vertebrates are diverse. Several species of reptiles and amphibians are associated with Carolina bays on SRS (Gibbons and Patterson 1978, Gibbons and Semlitsch 1990). Gibbons (1970) observed over thirty species of amphibians and reptiles in and around Ellenton Bay. The use of bays by vertebrates is sometimes astonishing, as revealed by the high number of semi-aquatic animals migrating to and from the water. Rainbow Bay (Site 189) which has an aquatic perimeter of less than 450 m, had approximately 10,000 individuals of the southern leopard frog (*Rana utricularia*) migrating to or from this bay in one year (Schalles et al. 1989). This is an average of one frog for every 2 cm of pond margin. A similar calculation for Ellenton Bay, which is larger, indicates that one adult mole salamander (*Ambystoma talpoideum*) enters to breed each winter per 20 cm of perimeter (Patterson 1978) and as many as 11,000 metamorphosed individuals may exit during one week. Schalles and Shure (1989) obtained *in situ* estimates of salamander density and biomass in the aquatic area of Thunder Bay. Over an annual cycle in a 1-ha sampling grid *Siren intermedia*, *Notophthalmus viridescens*, and *Ambystoma talpoideum* populations averaged 0.15, 1.18 and 1.46 individuals/m² and 8.03, 3.12 and 1.23 kg dry wt/ha, respectively. During the same period, anuran larvae (primarily Ranidae) averaged 1.03 kg dry wt/ha. (Schalles et al. 1989).

Abundance in Altered Bays

The abundance of amphibians in Carolina bays altered by agricultural, forest management, or construction activities (e.g., Sun Bay, Site 45; Lost Lake, Site 28), may be higher than expected (Bennett et al. 1979). In 1979, more than 500 ornate chorus frogs (*Pseudacris ornata*), 5,000 southern leopard frogs, and 500 mole salamanders entered or left Sun Bay, a bay of less than 1 ha which had been drained by construction activity in the previous year. Similarly, Lost Lake on SRS had been altered by agricultural practices prior to the 1950s and, later, by the release of industrial by-products into the lake (Bennett et al. 1979). Extrapolation of captures by intermittent fencing and pitfall traps to the shoreline length bordered by a pine forest around the bay yielded estimates of 5,000 southern toads (*Bufo terrestris*), 2,000 mole salamanders, and 1,000 spadefoot toads (*Scaphiopus holbrookii*) that entered or left Lost Lake in one summer (Bennett et al. 1979).

Vertebrate Species that use Carolina Bays

Although amphibians are the prevalent terrestrial vertebrates using Carolina bays (Patterson 1978; Bennett et al. 1979; Semlitsch 1981) and are a major contributor to secondary productivity, other vertebrates may be important in these communities as well. The American alligator (*Alligator mississippiensis*), six species of aquatic turtles, and several species of snakes are reptiles common to bays (Table 9-4, Gibbons 1970, Gibbons et al. 1977, Gibbons and Patterson 1978, Gibbons and Semlitsch 1990). Though quantitative data are unavailable, mammals such as deer, raccoons, skunks, and opossums may use bays for water or feeding sites. Beaver (*Castor canadensis*) have been noted in Thunder Bay and several other sites and could be an important agent in hardwood species composition and abundance. In the sandhills regions of the Carolinas, many bird species including hawks, egrets, and migratory waterfowl use the bays at least part of the year. Wood storks, an endangered bird species, have been observed foraging in Ellenton Bay. In bays with standing water and mature trees with cavities for nesting sites, wood ducks (*Aix sponsa*) may also be found (Mayer et al. 1986). The use of wood duck boxes placed as nesting sites in Carolina bays is common in some years (Schalles et al. 1989).

Quantitative data are available for many small mammals using the periphery of Carolina bays (Table 9-4). Though shrews (*Blarina brevicauda* and *Sorex longirostris*) and small rodents (*Sigmodon hispidus*, *Peromyscus gossypinus*, and *Microtus pinetorum*) may be abundant, only certain species, e.g., the rice rat (*Oryzomys palustris*), actually inhabit the marshy areas. Many small mammals captured by drift fences and pitfall traps around Carolina bays are equally abundant in strictly terrestrial habitats in the region (Briese and Smith 1974, Brown 1980, Gibbons and Semlitsch 1982, Schalles et al. 1989).

Table 9-4. Use of Carolina Bay Habitats by Small Vertebrates^a (Source: Gibbons and Semlitsch 1982).

Species	Rainbow Bay				Sun Bay			
	Entering		Exiting		Entering		Exiting	
	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile
Class Amphibia								
Order Caudata								
<i>Ambystoma talpoideum</i>	1,750	154	499	3,856	6,028	0	938	0
<i>Ambystoma tigrinum</i>	129	46	42	992	57	1	4	
<i>Notophthalmus viridescens</i>	1,625	968	609	15,013	3,452	5	2,100	23
total of all salamanders	3,953	1,201	1,212	19,874	9,595	6	3,087	24
Order Anura								
<i>Scaphiopus holbrooki</i>	69	33	39	34	1,803	134	483	58
<i>Bufo terrestris</i>	424	644	79	689	580	375	98	622
<i>Hyla crucifer</i>	346	212	205	1,329	594	12	239	50
<i>Pseudacris ornata</i>	235	28	89	1,158	392	9	79	18
<i>Gastrophryne carolinensis</i>	1,122	18	418	15	887	1	420	0
<i>Rana clamitans</i>	27	30	19	1,136	27	35	1	7
<i>Rana utricularia</i>	699	2,024	610	52,287	154	29	24	7
total of all frogs	3,197	3,053	1,569	57,106	4,486	680	1,355	767
Class Reptilia								
Order Chelonia								
<i>Kinosternon subrubrum</i>	29	6	25	6	49	59	14	11
<i>Deirochelys reticularia</i>	8	9	10	2	14	14	4	1
total of all turtles	43	16	39	9	70	74	19	14
Order Squamata								
Suborder Sauria								
<i>Anolis carolinensis</i>	26	2	19	2	5	0	12	0
<i>Sceloporus undulatus</i>	18	1	8	3	9	3	5	6
<i>Cnemidophorus sexlineatus</i>	2	2	1	0	19	7	19	2
total of all lizards	53	7	43	5	36	11	40	9
Suborder Ophidia								
<i>Storeria occipitomaculata</i>	26	1	37	0	4	0	2	0
<i>Diadophis punctatus</i>	7	2	10	0	7	1	15	3
<i>Tantilla coronata</i>	17	0	11	0	42	0	46	0
total of all snakes	92	7	88	2	68	5	85	5
Class Mammalia								
<i>Blarina brevicauda</i>	68	1	40	0	26	0	20	0
<i>Reithrodontomys humulis</i>	16	0	146	8	1	0	0	0
<i>Sigmodon hispidus</i>	7	0	14	0	5	0	18	0
total of all mammals	168	3	251	9	76	1	63	1
total of all species	7,506	4,287	3,202	77,005	14,331	777	4,649	820

a. Numbers indicate selected vertebrate species captured (original and recaptured) in drift fences with pitfalls at Rainbow Bay and Sun Bay, for one year, March 1979-March 1980

Lost Lake Restoration

Introduction

Prior to 1943 until the early 1950s, Lost Lake (Bay 28, Figure 9-1 on page 9-4) was drained for agricultural production by a ditch to the south. After the land was removed from farming in the early 1950s, the watershed above the lake was planted to loblolly pine (*Pinus taeda*) for erosion control. Lacking ditch maintenance, Lost Lake began to refill and function as a wetland. Impacts to the watershed continued as the nearby M-Area industrial facility was installed with associated roads, drainage ditches, railroads, and soil-fill areas. In addition, Lost Lake received overflow from the M-Area settling basin until 1984 (Figure 9-8). Thus, Lost Lake was contaminated over the years by heavy metals, solvents, and cleaning fluids flowing into it from the M-Area settling basin (Figure 9-8 and Figure 9-9 on page 9-24). Restoration of the 10-ha lake was required as part of the closure plan for the M-Area settling basin and vicinity. One aspect of the closure plan was the restoration of this bay to a "natural wetland system". The closure plan was approved in July 1987 (U. S. DOE 1992). The closure plan detailed the decontamination process, but did not describe the restoration process.

Restoration Plan

The reclamation of Lost Lake was taken as an opportunity to restore a degraded natural area to a functional wetland; however, no specific plan for the restoration was included in the

Figure 9-8. Location of Lost Lake and the M-Area Settling Basin on SRS

Figure 9-9. Lost Lake and the M-Area Basin Prior to Cleanup (Vertical and Oblique Photography)

closure plan. The restoration was to be coordinated with Soil Conservation Service and the U. S. Forest Service, and was to result in a low maintenance, self-sustaining growth of vegetation. Despite the removal of up to 12 in. of soil, a sufficient clay layer remained to retain water in Lost Lake; therefore, reclamation as a wetland was considered feasible (Figure 9-10 on page 9-25) (U. S. DOE 1992). The project strategy that was selected emphasized restoring Carolina-bay-like conditions and stabilizing surrounding areas, the use of only native plant species, and filling an old drainage ditch south of the bay to restore hydrology. The restoration effort was divided into two parts: upland planting and wetland restoration. An extremely wet fall (Figure 9-3 on page 9-6) delayed soil preparation in those areas to be subsoiled and disked. The water level in Lost Lake was lowered in December 1990 (Figure 9-3) to facilitate soil treatment in January 1991. Trees were planted in the upland areas during late January and February and the planting was completed by March 1991. Macrophyte planting was staggered from early February through mid-April 1991. Erosion control was improved in the ditch leading from the M-Area Basin to Lost Lake in late April 1991 (U. S. DOE 1992).

Restoration Objectives

There were two major objectives in the reclamation plan for Lost Lake. First, and most importantly, was to restore the wetland ecosystem following hazardous waste cleanup. The second goal was to study and evaluate a restoration project. To this end, a research design was developed that would allow the evaluation of several wetland restoration levels-of-effort to determine minimum requirements to restore a disturbed Carolina bay. A third goal of the project was an opportunistic one. Aerial imagery is being developed throughout the scientific community as a tool for evaluating changes to the landscape over time. This

5975-106

1988—Vertical

5933-49

1988—Oblique

6400-018

1989—Vertical

6438-061

1989—Oblique

Figure 9-10. Lost Lake and the M-Area Basin During Cleanup (Vertical and Oblique Photography)

project was designed to study the success of using aerial imagery to monitor the re-establishment of the wetland community (Macdonald 1993).

Strategy Considerations

Treatment Scheme

A four-treatment scheme was developed to determine how much manipulation was necessary to successfully restore a functioning wetland. The bay was divided into eight treatment zones (Figure 9-11), with four treatments applied in duplicate. One of the treatments was no treatment. The initial treatment zones were rearranged when a sensitive plant species, little bur-head (*Echinodorus tenellus*), was found in significant numbers in one quadrant of the bay (Zone IIB, Figure 9-11). This plant does not grow well in fertile soils, so the area it occurred in received no treatment (U. S. DOE 1992).

Soil Conditions

In designing the restoration project, several factors had to be considered. Contaminated soils had been removed from the bay. The soil had been somewhat compacted from heavy equipment, and the lack of organic matter and the presence of debris in the subsoil caused concern. To improve soil conditions, topsoil was added to two of the treatment areas, and four of the treatment areas were disked. When spreading the topsoil, care was taken to minimize compaction from trucks and earth moving equipment (U. S. DOE 1992).

Hydrology

A significant factor in the restoration of Lost Lake to a functional wetland is complicated by the decision not to control the hydrologic regime, but to let it fluctuate naturally after initial planting of the vegetation in early 1991 (U. S. DOE 1992).

Monitoring

A final consideration in the plan was the ability to monitor the success and apply the information to future restorations. Low-altitude aerial photography, airborne multispectral scanner data, and, later, satellite imagery will be used to monitor the successful growth of the vegetation. Location and placement of plots (Figure 9-12) were designed to aid in the interpretation of future photographs (U. S. DOE 1992). In addition to remote sensing and vegetation monitoring, a cooperative program is in place with the University of South Carolina—Aiken campus to monitor and evaluate reptile and amphibian recolonization at Lost Lake.

Wetland Area Treatments

The four treatments zones are shown in Figure 9-11 and outlined as follows:

- no treatment (IIA, IIB) (i.e., controls)
- addition of fertilizer, gypsum, and plantings (IVA, IVB)
- subsoiling, disking, fertilizer, gypsum, and plantings (IIIA, IIIB)
- subsoiling, disking, gypsum, topsoiling, fertilizer, and plantings (IA, IB)

Figure 9-11. Planting Plan at the Lost Lake/M-Area Basin Restoration Site

Figure 9-12. Planting Scheme for Zone 1B at the Lost Lake/M-Area Basin Restoration Site. Zone 1B is Representative of the Eight Treatment Zones.

In all A zones there was more extensive soil removal during remediation, and in all B zones there was less soil removal during remediation.

Gypsum (calcium sulfate dihydrate) was added to all the zones that received any treatment, because the pH of the bay was approximately 6.0, and needed to be lowered slightly to mimic the acidic nature of natural bays in the region. There were two replicates of each treatment. Planting plots were sized and arranged within each treatment zone (Figure 9-12 on page 9-27) to facilitate future monitoring and to test the monitoring techniques (i.e., aerial photography).

Plantings

Ten tree and shrub species were planted on the upland areas. Regional nursery stock was used for these plantings. Five species of shallow water emergent herbaceous vegetation were planted. All the herbaceous plants were taken from aquatic habitats on SRS. Adequate numbers of all plants except duck potato (*Sagittaria latifolia*) were available at SRS to allow transplanting without depleting the donor stock. Lotus seeds (*Nelumbo lutea*) and water lily (*Nymphaea odorata*) were planted in the deeper plots. Because of the configuration of the treatment zones and the size of the bay, the original plot sizes and arrangements had to be slightly modified.

Initial Results

1991 Results

In 1991 it was too early to determine the success of the wetlands restoration and despite the unanticipated problems and delays in implementation, Lost Lake was beginning to resemble a natural Carolina bay (Figure 9-13 on page 9-29). Monitoring efforts started in the fall of 1991 and included measurements within each of the eight treatment zones of percent cover, density, and percentage of survival of wetland plants found in the experimental plots. Preliminary results from the fall of 1991 showed an 80–90 percent survival rate of the deep water species and 20–30% for the emergent species. Cattails invaded heavily in the areas with soil amendments and fertilizer. Of the macrophyte species planted, three were the most successful (*Panicum hemitomon*, *Eleocharis* sp., and *Pontederia cordata*). Successful naturally invading species included *Eleocharis acicularis*, *Eupatorium* sp., *Typha latifolia*, *Polygonum* sp., *Panicum dichotomiflorum*, and *Setaria* sp. Woody species [e.g., buttonbush (*Cephalanthus occidentalis*)] also occurred in some areas.

1992 Results

Subsequent monitoring in 1992 of percent cover, density, and percent survival indicate that of the different species planted, *Panicum* continues to be the most successful of the introduced species, with a density increase of $3,184\% \pm 1,598\%$. Other successful plants include *Eleocharis* and *Pontederia*, with density increases of $1,838\% \pm 435\%$ and $1,016\% \pm 412\%$, respectively (Youngblood et al. 1993a, 1993b). Analysis of hydrology data show that several periods of low water probably resulted in the non-establishment of *Nelumbo* from the germinated seeds and continued low occurrence of *Nymphaea*.

1990—Vertical

1990—Oblique

1991—Vertical

1991—Oblique

Figure 9-13. Lost Lake and the M-Area Basin During Early Restoration Activities (Vertical and Oblique Photography)

References

- Auble, G. T. 1984. Dissolved cation concentrations in Okefenokee Swamp surface water: spatial and temporal variation. Pages 320-332 in A. D. Cohen, D. J. Casagrande, M. J. Adrejko, and G. R. Best, editors. *The Okefenokee Swamp: its natural history, geology, and geochemistry*. Wetland Surveys, Los Alamos, New Mexico, USA.
- Benke, A. C. 1976. Dragonfly production and prey turnover. *Ecology* 57:915-927.
- Bennett, S. H., J. W. Gibbons, and J. Glanville. 1979. Terrestrial activity, abundance and diversity of amphibians in differently managed forest types. *Am. Midl. Nat.* 103:412-416.
- Bennett, D. H. and R. W. McFarlane. 1983. *The Fishes of the Savannah River Plant National Environmental Research Park*. National Environmental Research Park Publication. U.S. Department of Energy and Savannah River Ecology Laboratory, Aiken, SC.
- Briese, L. A. and M. H. Smith. 1974. Seasonal abundance and movement of nine species of small mammals. *J. Mammal.* 55:615-619.
- Brown, K. W. 1980. An analysis of herpetofaunal species diversity along a temporal gradient of loblolly pine stands in South Carolina. M.S. Thesis. Texas Christian University, Fort Worth, Texas, USA.
- Christel-Rose, L. M. "Historical Wetlands Mapping and GIS Processing for the Savannah River Site Database." In preparation, as EGG-11265-1018, EG&G Energy Measurements, Inc., P. O. Box 1912, Las Vegas, NV 89125.
- Clymo, R. S. 1964. The origin of acidity in bogs. *Bryologist* 67:427-431.
- Conant, R. 1975. *A field guide to reptiles and amphibians*. Houghton-Mifflin Company, Boston, Massachusetts, USA.
- Cross, W. H. 1955. Anisopteran Odonata of the Savannah River Plant, South Carolina. *J. Elisha Mitchell Sci. Soc.* 71:9-17.
- Daniel, C. 1981. Hydrology, geology, and soils of pocosins: a comparison of natural and altered systems. Pages 69-108 in C. J. Richardson, editor. *Pocosin Wetlands*. Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania, USA.
- Dierberg, F. E. and P. L. Brezonik. 1984. Water chemistry of a Florida cypress dome. Pages 34-50 in K. C. Ewel and H. T. Odum, editors. *Cypress Swamps*. University of Florida Press, Gainesville, Florida, USA.
- Gibbons, J. W. 1970. Terrestrial activity and the population dynamics of aquatic turtles. *Am. Midl. Nat.* 83:404-414.
- Gibbons, J. W. and K. K. Patterson. 1978. *The Reptiles and Amphibians of the Savannah River Plant*. National Environmental Research Park Publication. U.S. Department of Energy and Savannah River Ecology Laboratory, Aiken, SC.
- Gibbons, J. W. and R. D. Semlitsch. 1990. *A Guide to the Reptiles and Amphibians of the Savannah River Plant*. National Environmental Research Park Publication. U.S. Department of Energy and Savannah River Ecology Laboratory, Aiken, SC. (In Press)
- Gibbons, J. W., J. W. Coker, and T. M. Murphy. 1977. Selected aspects of the life history of the rainbow snake (*Farancia erytrogramma*). *Herpetologica* 33:271-281.
- Gibbons, J. W. and R. D. Semlitsch. 1982. Terrestrial drift fences with pitfall traps: an effective technique for quantitative sampling of animal populations. *Brimleyana* 1982(7):1-16.
- Hodge, A. E. 1985. Untitled draft M.S. Thesis on Carolina bays on and adjacent to SRS. Clemson University, Clemson, South Carolina, USA.
- Kelley, W. R. and W. T. Batson. 1955. An ecological study of the land plants and cold-blooded vertebrates of the Savannah River project area. Part VI. Conspicuous vegetational zonation in a "Carolina Bay". University of South Carolina Publication Series III. *Biology* 1:244-248.

- Kirkman, L. K. 1992. Cyclical Vegetation Dynamics in Carolina Bays Wetlands. Dissertation, University of Georgia, Athens, GA.
- Lichtler, W. F. and P. N. Walker. 1979. Hydrology of the Dismal Swamp. Pages 140-168 in P. W. Kirk, editor. The Great Dismal Swamp. The University of Virginia Press, Charlottesville, Virginia, USA.
- Lide, R. F. 1991. Hydrology of a Carolina Bay Located on the Upper Coastal Plain, Western South Carolina. Thesis. University of Georgia, Athens, GA.
- Livingstone, D. A. 1963. Chemical composition of rivers and lakes. Chapter 6. Data on Geochemistry, 6th edition. Professional Paper, United States Geological Survey 440-G, Washington, D.C., U.S.A.
- Mackey, H. E. 1993. "Application of Low Altitude Normal Color and False Color Infrared Photography for Delineation and Monitoring Wetland Restoration of a Large Carolina Bay." Proceedings 14th Biennial Workshop on Color Photography and Videography in Resource Monitoring, Utah State University, Logan, Utah. In Press. Abstract only.
- Mayer, J. J., R. A. Kennamer, and R. T. Hoppe. 1986. Waterfowl of the Savannah River Plant. Stress and Wildlife Ecology Division Report. Savannah River Ecology Laboratory, Aiken, SC.
- Newman, M. C., and J. F. Schalles. 1990. The water chemistry of Carolina Bays: A regional survey. Arch. Hydrobiol. 118 (2): 147-168.
- Patterson, K. 1978. Life history patterns of paedogenic populations of the mole salamander, *Ambystoma talpoideum*. Copeia 1978:649-655.
- Perdue, E. M., J. H. Reuter, and M. Ghosal. 1984. The Operational Nature of Acidic Functional Group Analysis and its Impact on Mathematical Descriptions of Acid-base Equilibria in Humic Substances. Geochemica et Cosmochimica Acta 44:1841-1851.
- Savannah River Ecology Laboratory. 1980. A biological inventory of the proposed site of the defense waste processing facility on the Savannah River Plant in Aiken, South Carolina. Annual Report. Savannah River Ecology Laboratory, Aiken, SC.
- Schalles, J. R. 1979. Comparative limnology and ecosystem analysis of Carolina Bay ponds on the upper coastal plain of South Carolina. Ph.D. Dissertation, Emory University, Atlanta, Georgia, USA.
- Schalles, J. F. 1989. Comparative chemical limnology of Carolina Bay wetlands on the upper coastal plain of South Carolina. In R. R. Sharitz and J. W. Gibbons, editors. Freshwater Wetlands and Wildlife: Perspectives on Natural, Managed, and Degraded Ecosystems. U.S. D.O.E. Symp. Ser. CONF 860130.
- Schalles, J. R. and D. J. Shure. 1989. Hydrology, community structure, and productivity of a dystrophic Carolina Bay wetland. Ecol. Monogr.
- Schalles, J. F., R. R. Sharitz, J. W. Gibbons, G. J. Leversee, and J. N. Knox. 1989. Carolina Bays of the Savannah River Plant. SRO-NERP-18, Savannah River Ecology Laboratory, Aiken, SC.
- Semlitsch, R. L., 1981. Terrestrial activity and summer home range of the mole salamander (*Ambystoma talpoideum*). Can. J. Zool. 59:315-322.
- Semlitsch, R. L., 1985. Reproductive strategy of a facultatively paedomorphic salamander *Ambystoma talpoideum*. Oecologia 65:305-313.
- Sharitz, R. R. and J. W. Gibbons. 1982. The ecology of southeastern shrub bogs (Pocosins) and Carolina bays: a community profile. Fish and Wildlife Service, United States Department of the Interior, Atlanta, Georgia, USA.
- Shields, J. D., N. D. Woody, A. S. Dicks, G. J. Hollod, J. Schalles, and G. J. Leversee. 1982. Locations and Areas of Ponds and Carolina bays at the Savannah River Plant. E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina, USA. DP-1525.
- Taylor, B. E., R. A. Estes, J. H. K. Pechmann, and R. O. Semlitsch. 1988. Trophic relations in a temporary pond: larval salamanders and their microinvertebrate prey. Can. J. Zool. 66:2191-2198.

- Taylor, B. E., D. L. Mahoney, and R. A. Estes. 1989. Zooplankton production in a Carolina Bay. In R. R. Sharitz and J. W. Gibbons, editors. *Freshwater Wetlands and Wildlife: Perspectives on Natural, Managed, and Degraded Ecosystems*. U.S. D.O.E. Symp. Ser. CONF 860130.
- Tilly, L. J. 1973. Comparative productivity of four Carolina lakes. *Am. Midl. Nat.* 90:356-365.
- U. S. Department of Energy (DOE). 1992. *Lost Lake/M-Basin Restoration Reference Guide*. U. S. DOE Savannah River Field Office, Aiken, South Carolina.
- Wetzel, R. G. 1983. *Limnology*. Second Edition. Saunders College Publishing, Philadelphia, Pennsylvania, USA.
- Youngblood, T. H. Ornes, H. E. Mackey, Jr., and R. S. Riley. 1993a. "Lost Lake Restoration and Wetlands Mitigation Monitoring." *Proceedings of Engineering for Wetland Restoration: A National Workshop*, US Army Engineer Waterways Experiment Station, St. Louis, MO. In Press. Abstract only.
- Youngblood, T., H. Ornes, H. E. Mackey, Jr., and R. S. Riley. 1993b. "Revegetation Strategies after the Cleanup of Lost Lake, a Contaminated Carolina Bay at the Savannah River Site, Aiken, South Carolina." *Proceedings of the 1993 South Carolina Aquatic Plant Management Society*, Charleston, South Carolina. In Press. Abstract only.

Part III

A q u a t i c R e s o u r c e s

The Southeastern United States has abundant freshwater resources, which provide diverse ecosystems. There are five main drainage basins located on the SRS. The five streams that originate on, or pass through the SRS before flowing into the Savannah River are: Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Steel Creek, and Lower Three Runs. A sixth stream, Pen Branch, does not flow directly into the Savannah River but joins Steel Creek in the Savannah River floodplain swamp. The upper reaches of Lower Three Runs were impounded in 1958 to form Par Pond. L Lake was formed in 1985 by damming Steel Creek above the Meyers Branch confluence. The purpose of Part III—Aquatic Resources is to describe and define the physical and biological characteristics of these systems and provide a source and synopsis of information from the many aquatic studies conducted through the years at SRS.

Chapter 10

Upper Three Runs

Chapter Contents

Drainage Description and Surface Hydrology (page 10-3)

Water Chemistry and Quality (page 10-7)

Algae (page 10-27)

Macrophytes (page 10-29)

Zooplankton (page 10-31)

Macroinvertebrates (page 10-33)

Fish (page 10-55)

References (page 10-61)

Drainage Description and Surface Hydrology

General Description

Upper Three Runs is a large, cool (annual maximum of 26.1°C), blackwater stream located in the northern part of SRS (Figure 10-1). With headwaters arising offsite, Upper Three Runs drains an area of approximately 545 km² and discharges directly into the Savannah River. Upper Three Runs is approximately 40-km long, with the lower 28 km located within the boundaries of SRS. Upper Three Runs receives more water from underground sources (Dublin-Midville aquifer system) than the other SRS streams; because of this it has low-conductivity, low-hardness, and low-pH values (Specht 1987).

Effluent Contribution

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

Figure 10-1. Location of Upper Three Runs on SRS

Flow Measurements

The U. S. Geological Survey measures flow at several locations on Upper Three Runs. Flow statistics of Upper Three Runs at SRS Road A, above SRS Road C, and near New Ellenton (Highway 278) (Figure 10-2) are summarized in Table 10-1. Records for the most downstream station (Upper Three Runs at Road A) date back to June 1974 (no records from February 1978 through September 1978). In water year 1991, the mean flow of Upper Three Runs at Road A was 8.2 m³/s (290 ft³/s). Over the period of record (water years 1974-1991) at Road A, the mean flow is 6.8 m³/s (239 ft³/s), the 7-day low flow is 2.4 m³/s (84 ft³/s), and the 7Q10 is 2.8 m³/s (100 ft³/s). The maximum, minimum, and mean daily flows for the periods of record at the three stations are shown in Figure 10-3 through Figure 10-5.

Table 10-1. Flow Summary for Upper Three Runs

Station Name	Station Number	Period of Record	Mean		Low		High		7Q10		7-Day Low Flow	
			cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)
near New Ellenton (Hwy 278)	02197300	1966-1991	2.9	104	1.5	53	13.7	485	1.7	61	1.6	55
above Road C at SRS	02197310	1974-1991	5.6	199	2.4	85	49.3	1740	2.8	99	2.4	86
at Road A at SRS	02197315	1974-1991	6.8	239	2.4	83	56.6	2000	2.8	100	2.4	84

cms = cubic meters per second

cfs = cubic feet per second

Map No.	Station Name
01	near New Ellenton (hwy 278)
02	above Road C at SRS
03	at Road A at SRS

Figure 10-2. Flow Measurement Sampling Stations for Upper Three Runs

Figure 10-3. Maximum, Mean, and Minimum Flow Measurements for Upper Three Runs at Station 02197300

Figure 10-4. Maximum, Mean, and Minimum Flow Measurements for Upper Three Runs at Station 02197310

Figure 10-5. Maximum, Mean, and Minimum Flow Measurements for Upper Three Runs at Station 02197315

Water Chemistry and Quality

Studies and Monitoring

Water-Quality Monitoring

The water quality of Upper Three Runs has been monitored by the WSRC Environmental Monitoring Section since 1973. Under the routine monitoring program, three sampling locations have been established on Upper Three Runs. These locations—Upper Three Runs at Highway 278, Tims Branch 5, and Upper Three Runs at Road A—are sampled monthly for physical and biological water quality parameters and for metals (Figure 10-5). Samples are also collected annually and analyzed for pesticides, herbicides, and PCBs. In 1990, the sampling location at Upper Three Runs Highway 278 was moved approximately one mile downstream to provide a better indication of contaminants originating above SRS; this new sampling location is designated Upper Three Runs 1A.

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

Comprehensive Cooling Water Study

From 1983 to 1985, Upper Three Runs and Tims Branch were studied as part of the Comprehensive Cooling Water Study (CCWS). This study was designed to assess the impact of current and proposed SRS activities on water quality. The CCWS included the following four locations on Upper Three Runs and Tims Branch (Figure 10-5):

Map No.	Station Name
01	U3R at 278
02	U3R at Road 8-1
03	U3R-1A
04	upstream Road C, TB-5, Site 1
05	A-014
06	A-015
07	M-out
08	TB-2
09	TB-0
10	TB-1
11	TB-3
12	TB-4, TB upstream of U3R, Tims Branch (F/H) and Tims Branch 5 (WQM)
13	TB-6, Site 2
14	Site 3
15	Site 4
16	Site 5
17	U3R at Road A
18	conf. w/SR

Figure 10-5. Water Chemistry and Quality Sampling Stations for Upper Three Runs

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

Comprehensive results and discussion of CCWS data can be found in the “Comprehensive Cooling Water Study, Volume II: Water Quality” (SREL 1986) and in the “Comprehensive Cooling Water Study, Final Report, Volume II: Water Quality” (Lower 1987).

Gladden et al. (1985) present a synopsis of Upper Three Runs and Tims Branch water quality data prior to the CCWS.

Priority Pollutants Survey

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

Chemical Assessment Studies

From 1985 to 1990, three special studies were conducted on the waters of Tims Branch and Upper Three Runs to determine impacts from specific SRS operations. These studies, which are summarized later in this chapter included:

- Effect of changes in M-Area effluent on Tims Branch (June 1985–December 1986)
- Effect of M-Area Liquid Effluent Treatment Facility on Tims Branch (September 1988–March 1990)
- Effect of F/H-Area Effluent Treatment Facility on Upper Three Runs (July 1987–February 1990)

Field Data

Water Temperature

The mean water temperature at sampling locations on Tims Branch and Upper Three Runs ranged from 15.2 to 17.3°C during the CCWS and routine monitoring program (Table 10-2). These temperatures are reflective of the nonthermal blackwater nature of this stream.

pH Measurements

The pH in the Upper Three Runs watershed is slightly acidic, with means ranging from 6.03 at the headwaters near Road 8-1 to 6.65 at the stream confluence with the Savannah River (Table 10-2). Throughout the CCWS and during routine monitoring, waters at all Upper Three Runs and tributary sites displayed wide pH variations over time (3.1 to 8.3).

Table 10-2. Upper Three Runs Field Data

	Water Temperature (°C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
<i>Upper Three Runs at Road 8-1 (CCWS)^a</i>				
Mean	16.5	6.03	181	42
Range	5.2 - 23.0	4.70 - 8.10	165 - 209	20 - 74
Samples	45	44	41	41
<i>Upper Three Runs upstream of Road C (CCWS)^a</i>				
Mean	16.0	6.34	69	51
Range	2.0 - 24.0	4.60 - 7.60	11 - 166	16 - 100
Samples	46	46	27	41
<i>Upper Three Runs at confluence with Savannah River (CCWS)^a</i>				
Mean	15.2	6.64	135	27
Range	0.8 - 23.5	4.90 - 8.00	83 - 338	5 - 52
Samples	46	46	26	39
<i>Tims Branch just upstream of Upper Three Runs (CCWS)^a</i>				
Mean	16.3	6.65	35	28
Range	3.3 - 23.0	5.30 - 7.80	6 - 126	2 - 82
Samples	46	46	36	41
<i>Upper Three Runs at Highway 278^b</i>				
Mean	17.3			
Range	9.5 - 26	3.1 - 7.6	NA	NA
Samples	41	41		
<i>Upper Three Runs 1A^b</i>				
Mean	17.3			
Range	10 - 22.6	5.2 - 8.2	NA	NA
Samples	19	19		
<i>Tims Branch 5^b</i>				
Mean	15.9			
Range	6.2 - 25	4.9 - 8.3	NA	NA
Samples	60	60		
<i>Upper Three Runs at Road A^b</i>				
Mean	16.8			
Range	7.3 - 32	4.7 - 8.0	NA	NA
Samples	60	60		

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Physical Characteristics and General Chemistry

Dissolved Oxygen

Mean dissolved oxygen concentrations ranged from 7.80 to 8.10 mg O₂/l throughout Upper Three Runs during the CCWS (Table 10-3). Dissolved oxygen concentrations measured since the CCWS have been slightly higher, with ranges from 8.33 to 8.98 mg O₂/l.

Conductivity

During the CCWS, specific conductance in Upper Three Runs and Tims Branch was low compared to other onsite streams and the Savannah River (SREL 1986). Specific conductance ranged from 1.4 to 20.1 µmhos/cm at the headmost waters of Upper Three Runs and increased in range from 20.6 to 68.9 µmhos/cm near the confluence with the Savannah River (Table 10-3). Specific conductances measured from 1987 to 1991 were highest at Tims Branch 5 (mean 51.2 µmhos/cm) and lowest at the upstream location, Upper Three Runs 1A (mean 21.5 µmhos/cm).

Suspended Solids and Turbidity

Mean concentrations of suspended solids and turbidity were highest and most variable during the CCWS (Table 10-3). The range in maximum suspended solids concentrations varied considerably (46.8 mg/l to 892 mg/l) throughout the watershed. Maximum turbidities ranged from 32 to 352 NTU. Suspended solids and turbidity concentrations have been lower since the CCWS. From 1987 to 1991, maximum suspended solids concentrations have ranged from 6.0 to 32 mg/l and turbidities have ranged from 3.9 to 120 NTU.

Major Anions and Cations

Alkalinity, Chloride, and Sulfate

Alkalinity, chloride, and sulfate concentrations in Upper Three Runs increased with distance downstream during the CCWS (Table 10-4 on page 10-12). The waters near the confluence with the Savannah River had mean alkalinity concentrations of 5.09 mg CaCO₃/l, chloride concentrations of 2.05 mg/l, and sulfate concentrations of 1.18 mg/l. Except for alkalinity in Tim's Branch, similar concentrations of alkalinity, chloride, and sulfate have been measured in Upper Three Runs in the years following the CCWS. Alkalinity in Tim's Branch has averaged 14.2 mg CaCO₃/l since the CCWS.

Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, sodium, and potassium in Beaver Dam Creek waters during the CCWS and as part of routine monitoring are given in Table 10-5 on page 10-13. It was determined during the CCWS that most of the calcium, magnesium, and sodium was in the dissolved phase (SREL 1986). Mean potassium concentrations were below detection limits during CCWS and were not measured as part of the routine monitoring program. All monitoring data indicate that concentrations of these cations are low, but increase with distance downstream. Tims Branch tended to have slightly higher concentrations of these cations relative to the mainstream Upper Three Runs.

Aluminum, Manganese, and Iron

Concentrations of total aluminum, manganese, and iron measured during the CCWS and routine monitoring program are given in Table 10-5 on page 10-13. The highest concentrations of these cations were measured during the CCWS. It was determined during the CCWS that most of the aluminum (91%) and iron (90%) was transported in the solid phase. Solid-phase associated manganese comprised 34% at the furthest upstream site and increased to 47% near the stream mouth (SREL 1986). Concentrations of aluminum, manganese, and iron have been lower since the CCWS (Table 10-5).

Table 10-3. Upper Three Runs Physical Characteristics and General Chemistry

	Dissolved Oxygen (mg/l)	Specific Conductance (mmhos/cm)	Turbidity (NTU)	Total Suspended Solids (mg/l)
<i>Upper Three Runs at Road 8-1 (CCWS)^a</i>				
Mean	8.07	14.7	5.7	9.89
Range	5.60 - 11.0	1.4 - 20.1	0.2 - 30.0	0.25 - 55.2
Samples	46	38	43	44
<i>Upper Three Runs upstream of Road C (CCWS)^a</i>				
Mean	8.00	19.9	24.7	18.5
Range	5.10 - 11.6	10.5 - 22.9	1.9 - 352	0.25 - 333
Samples	46	38	43	45
<i>Upper Three Runs at confluence with Savannah River (CCWS)^a</i>				
Mean	7.80	28.2	13.0	26.9
Range	4.40 - 11.9	20.6 - 68.9	2.5 - 75.0	0.25 - 892
Samples	45	38	43	
<i>Tims Branch just upstream of Upper Three Runs (CCWS)^a</i>				
Mean	8.10	25.0	8.0	7.21
Range	4.80 - 11.1	13.8 - 67.2	2.3 - 32.0	0.25 - 46.8
Samples	46	38	43	44
<i>Upper Three Runs at Highway 278^b</i>				
Mean	8.33	22.5	5.73	4.63
Range	6.2 - 10	7.0 - 76	<1.0 - 120	2.0 - 19
Samples	41	41	41	41
<i>Upper Three Runs 1A^b</i>				
Mean	8.60	21.5	1.75	3.85
Range	7.4 - 9.8	15 - 30	0.82 - 3.9	1.0 - 6.0
Samples	19	19	19	19
<i>Tims Branch 5^b</i>				
Mean	8.98	51.2	7.52	9.02
Range	6.0 - 13	12 - 165	3.0 - 25	2.0 - 32
Samples	60	60	60	60
<i>Upper Three Runs at Road A^b</i>				
Mean	8.36	24.5	5.24	10.2
Range	4.9 - 12	3.0 - 41	1.0 - 22	2.0 - 97
Samples	60	60	60	60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 10-4. Upper Three Runs Major Anions

	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg/l)
<i>Upper Three Runs at Road 8-1 (CCWS)^a</i>			
Mean	0.93	1.63	0.34
Range	0.16 - 6.70	0.20 - 2.00	0.01 - 1.92
Samples	45	46	26
<i>Upper Three Runs upstream of Road C (CCWS)^a</i>			
Mean	2.69	1.73	0.63
Range	0.49 - 4.48	0.20 - 2.20	0.06 - 2.24
Samples	45	46	26
<i>Upper Three Runs at confluence with Savannah River (CCWS)^a</i>			
Mean	5.09	2.05	1.18
Range	1.99 - 18.1	0.20 - 3.90	0.13 - 6.93
Samples	45	46	27
<i>Tims Branch just upstream of Upper Three Runs (CCWS)^a</i>			
Mean	5.22	1.85	0.60
Range	1.10 - 8.90	0.20 - 3.40	0.06 - 8.4 ^c
Samples	45	46	25
<i>Upper Three Runs at Highway 278^b</i>			
Mean	3.13	1.9	2.83
Range	1.0 - 37	0.05 - 4.5	0.05 - 1.1
Samples	41	41	41
<i>Upper Three Runs 1A^b</i>			
Mean	2.15	2.2	2.7
Range	<1.0 - 2.0	1.1 - 3.6	1.0 - 5.0
Samples	19	19	19
<i>Tims Branch 5^b</i>			
Mean	14.2	2.98	4.1
Range	9.0 - 29	0.54 - 7.3	<1.0 - 31
Samples	60	60	60
<i>Upper Three Runs at Road A^b</i>			
Mean	4.9	1.94	2.96
Range	1.0 - 19	0.31 - 8.8	0.50 - 7.0
Samples	60	60	60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 10-5. Upper Three Runs Major Cations (Total)

	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Aluminum (mg/l)	Iron (mg/l)	Manganese (mg/l)
<i>Upper Three Runs at Road 8-1 (CCWS)^a</i>							
Mean	0.512	0.333	1.06	<0.368	0.514	0.593	0.033
Range	0.245 - 1.45	0.179 - 0.443	0.535 - 1.90	<0.368 - 0.719	0.099 - 1.36	0.192 - 1.48	<0.0004 - 0.092
Samples	39	39	39	39	39	39	17
<i>Upper Three Runs upstream of Road C (CCWS)^a</i>							
Mean	1.89	0.397	1.48	<0.368	1.32	0.903	0.039
Range	0.265 - 13.5	0.286 - 1.3639	0.842 - 8.95	<0.368 - 1.54	0.134 - 21.4	0.218 - 5.72	<0.0004 - 0.108
Samples	39	39	39	39	39	39	17
<i>Upper Three Runs at confluence with Savannah River (CCWS)^a</i>							
Mean	1.90	0.527	1.69	<0.368	0.685	0.921	0.075
Range	1.45 - 4.13	0.341 - 1.57	0.778 - 7.82	<0.368 - 1.53	0.132 - 4.07	0.287 - 3.14	<0.0004 - 0.331
Samples	38	38	38	38	38	38	17
<i>Tims Branch just upstream of Upper Three Runs (CCWS)^a</i>							
Mean	1.40	0.429	1.82	<0.368	0.473	1.31	0.100
Range	0.45 - 2.28	0.348 - 0.561	1.16 - 4.78	<0.368 - 0.890	0.108 - 2.99	0.588 - 3.08	<0.0004 - 0.198
Samples	39	39	39	39	39	39	17
<i>Upper Three Runs at Highway 278^b</i>							
Mean							
Range	0.22 - 0.69	0.17 - 0.37	0.29 - 1.5	NA	<0.01 - 0.10	<0.01 - 0.71	<0.01 - 0.02
Samples	13	13	12		12	13	13
<i>Upper Three Runs 1A^b</i>							
Mean							
Range	0.39 - 0.49	0.26 - 0.36	1.02 - 1.5	NA	0.07 - 0.15	0.19 - 0.59	<0.005 - 0.01
Samples	5	5	7		7	7	5
<i>Tims Branch 5^b</i>							
Mean							
Range	0.67 - 2.6	0.37 - 0.70	6.0 - 18	NA	0.02 - 1.9	0.11 - 2.6	<0.01 - 0.40
Samples	16	16	14		15	16	16
<i>Upper Three Runs at Road A^b</i>							
Mean							
Range	0.69 - 2.3	0.17 - 0.40	0.69 - 2.2	NA	<0.05 - 0.23	0.07 - 0.71	<0.01 - 0.03
Samples	16	16	15		15	16	16

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Nutrients

Phosphorus

Concentrations of nutrients in Upper Three Runs were low relative to the Savannah River despite the influx of nutrients from offsite agricultural areas (Lower 1987). Mean total phosphorus ranged from 0.034 mg P/l to 0.052 mg P/l during the CCWS. Since 1987, mean total phosphorus has ranged from 0.016 mg P/l to 0.072 mg P/l (Table 10-6).

Nitrogen

The major nitrogen species in Upper Three Runs waters during the CCWS was nitrate-nitrogen (40%) and total Kjeldahl nitrogen (50%). Concentrations of nitrogen (as NO_2 - NO_3) measured as part of the routine monitoring program have been higher than concentrations measured during the CCWS; and this difference is probably the result of changes in 300-M Area effluent (see Chemical Assessment Studies Section below). The maximum mean nitrogen concentration measured during routine monitoring (0.57 mg N/l) was in Tims Branch (Table 10-6).

Trace Elements

Low levels of trace elements were measured during the CCWS. The detection limits reported for the routine monitoring program are higher than the concentrations measured during the CCWS; therefore, only CCWS data is discussed in this section (Table 10-7 on page 10-16). Mean total concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc in Upper Three Runs and Tims Branch during the CCWS reflected the ambient and largely undisturbed nature of these waters and the lack of significant quantities of these materials discharged from SRS operations. Mean concentrations ranged between the watershed headwaters and the creek mouth as follows: arsenic 1.4 to 1.3 $\mu\text{g/l}$; cadmium, 0.54 to 0.32 $\mu\text{g/l}$; chromium, 8.1 to 6.1 $\mu\text{g/l}$; copper, 1.9 to 2.1 $\mu\text{g/l}$; lead, 2.2 to 2.1 $\mu\text{g/l}$; nickel, 2.7 to 3.8 $\mu\text{g/l}$; and zinc, 4.5 to 4.6 $\mu\text{g/l}$. Neither mercury nor uranium was detected in Upper Three Runs or Tims Branch during the CCWS.

Organic Carbon

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

Priority Pollutants

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

Table 10-6. Upper Three Runs Nutrients

	Total Phosphorus (mg P/l)	Total Ortho- Phosphate (mg PO ₄ -P/l)	Organic Nitrogen (mg N/l)	Total Kjeldhal Nitrogen (mg N/l)	Ammonia (mg NH ₃ -N/l)	Nitrite (mg NO ₂ -N/l)	Nitrate (mg NO ₃ -N/l)
<i>Upper Three Runs at Road 8-1 (CCWS)^a</i>							
Mean	0.034	0.009		0.227	0.024	0.002	0.186
Range	<0.010 - 0.162	<0.001 - 0.061		0.022 - 0.930	0.005 - 0.220	<0.001 - 0.006	0.024 - 0.321
Samples	46	41		46	46	44	42
<i>Upper Three Runs upstream of Road C (CCWS)^a</i>							
Mean	0.052	0.015		0.221	0.024	0.002	0.136
Range	0.014 - 0.693	0.003 - 0.048		0.015 - 0.750	0.005 - 0.220	<0.001 - 0.007	0.026 - 0.278
Samples	46	41		46	46	44	43
<i>Upper Three Runs at confluence with Savannah River (CCWS)^a</i>							
Mean	0.045	0.021		0.211	0.030	0.003	0.118
Range	<0.010 - 0.258	0.010 - 0.063		0.030 - 0.900	0.005 - 0.180	<0.001 - 0.010	0.023 - 0.239
Samples	46	41		46	46	44	43
<i>Tims Branch just upstream of Upper Three Runs (CCWS)^a</i>							
Mean	0.042	0.023		0.217	0.029	0.003	0.159
Range	<0.010 - 0.148	0.005 - 0.092		0.026 - 0.585	0.005 - 0.180	<0.001 - 0.012	0.004 - 0.293
Samples	46	41		46	46	42	41
<i>Upper Three Runs at Highway 278^b</i>							
Mean	0.016				0.023		0.24
Range	<0.01 - 0.07	NA	NA	NA	<0.01 - 0.08	NA	0.05 - 1.1
Samples	41				41		41
<i>Upper Three Runs 1A^b</i>							
Mean	0.037				0.091		0.22
Range	0.01 - 0.10	NA	NA	NA	0.01 - 0.46	NA	0.15 - 0.40
Samples	19				19		19
<i>Tims Branch 5^b</i>							
Mean	0.072		0.27		0.068		0.57
Range	0.01 - 0.44	NA	<0.01 - 1.6	NA	<0.01 - 0.23	NA	0.02 - 2.7
Samples	60		60		60		60
<i>Upper Three Runs at Road A^b</i>							
Mean	0.026		0.31		0.035		0.15
Range	0.01 - 0.12	NA	<0.10 - 2.8	NA	<0.01 - 0.14	NA	0.04 - 0.91
Samples	60		60		60		60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 10-7. Upper Three Runs Trace Elements (Total)

	Arsenic (µg/l)	Cadmium (µg/l)	Chromium (µg/l)	Copper (µg/l)	Lead (µg/l)	Nickel (µg/l)	Zinc (µg/l)
<i>Upper Three Runs at Road 8-1 (CCWS)^a</i>							
Mean	1.4	0.54	8.1	1.9	2.2	2.7	4.5
Range	<0.4 - 5.7	<0.04 - 4.30	<0.4 - 67.0	<0.4 - 4.1	<0.4 - 9.3	<0.4 - 10.9	<0.4 - 18.2
Samples	17	17	17	17	17	17	17
<i>Upper Three Runs upstream of Road C (CCWS)^a</i>							
Mean	1.0	0.36	14.1	2.1	2.8	2.7	5.1
Range	<0.4 - 5.0	<0.04 - 1.41	<0.4 - 71.0	<0.4 - 5.1	<0.4 - 16.5	<4 - 14.0	<0.4 - 17.4
Samples	17	17	17	17	17	17	17
<i>Upper Three Runs at confluence with Savannah River (CCWS)^a</i>							
Mean	1.3	0.32	6.1	2.1	2.1	3.8	4.6
Range	<0.4 - 5.4	<0.04 - 1.50	<0.4 - 47.0	<0.4 - 7.8	<0.4 - 3.7	<0.4 - 17.3	<0.4 - 18.1
Samples	17	17	17	17	17	17	17
<i>Tims Branch just upstream of Upper Three Runs (CCWS)^a</i>							
Mean	1.7	0.30	8.1	2.0	1.7	5.1	3.6
Range	<0.4 - 8.6	<0.04 - 1.55	<0.4 - 50.0	<0.4 - 4.1	<0.4 - 8.7	<0.4 - 15.0	<0.4 - 11.2
Samples	17	17	17	17	17	17	17
<i>Upper Three Runs at Highway 278^b</i>							
Mean							
Range	NA	<10	<10 - <50	<10 - <50	<3 - 60	<10 - <20	<10 - <20
Samples		13	13	13	13	13	13
<i>Upper Three Runs 1A^b</i>							
Mean							
Range	NA	<10	<20	<10 - 20	<3 - 70	<50	<10
Samples		7	7	7	7	7	7
<i>Tims Branch 5^b</i>							
Mean							
Range	NA	<10	<10 - 30	<10 - <50	<3 - 190	<10 - 70	<10 - 20
Samples		16	16	16	16	14	16
<i>Upper Three Runs at Road A^b</i>							
Mean							
Range	NA	<10	<10 - <50	<10 - <50	<3 - 100	<10 - 80	<10 - <20
Samples		16	16	16	16	15	16

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, and 1990.

1990 - 1991 - Data taken from SRS Environmental Reports for 1990 and 1991.

Pesticides, Herbicides, and PCBs

Water samples are also collected annually from Tims Branch and Upper Three Runs as part of the routine monitoring program and analyzed for pesticides, herbicides, and PCBs. From 1987 to 1991, no analytes have been detected in UTR.

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 Assessment Studies

M-Area Liquid Effluent Treatment Facility

A chemical and biological assessment was conducted to address the effects of the M-Area Liquid Effluent Treatment Facility on the chemistry and biota of Tims Branch and Upper Three Runs. Eight locations (Figure 10-6 on page 10-7) along Tims Branch and Upper Three Runs were sampled monthly for chemical parameters. The results of this study are documented in "Biological and Chemical Assessment of M-Area Process Discharge to Tims Branch, June 1985–December 1986". The data collected during this study are summarized in Table 10-8 on page 10-18 (Environmental and Chemical Sciences 1987).

Results of the study indicated that the water chemistry at site TB-2 (Figure 10-6 on page 10-7) was greatly influenced by a beaver pond immediately upstream. High organic-matter concentrations in the waters of upstream sites TB-2, TB-0, and TB-1 created low dissolved oxygen conditions. Sites TB-3, TB-4, TB-5, and TB-6 had much higher mean dissolved oxygen concentrations.

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

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

Traces of trichloroethylene were observed frequently at M-out, with an overall mean concentration of 0.0029 mg/l. No detectable levels of tetrachloroethylene or 1,1,1-trichloroethylene were measured.

Changes in M-Area Effluent

A chemical and biological study was conducted in Tims Branch from September 1988 to March 1990 to determine if changes to the discharges of the A-014 and A-015 outfalls had an adverse effect on communities in Tims Branch. Seven locations (Figure 10-6 on page 10-7) were sampled semi-monthly for chemical parameters. The results of this study are documented in "Biological and Chemical Assessment of M-Area Discharge on Tims Branch,

Table 10-8. Water Quality Parameters for Biological and Chemical Assessment of M-Area Discharge

Site		Temperature (C)	Dissolved Oxygen (mg/l)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Conductance (µS/cm)	TSS (mg/l)
TB-2	Mean	20.22	2.95	5.55	5.62	13.4	36.2	13.52
	Standard Error	1.17	0.34	0.06	0.33	1.4	6.4	1.37
	No. Samples	31	31	31	31	31	31	31
TB-0	Mean	21.18	4.40	6.13	16.63	13.42	111.33	12.56
	Standard Error	1.22	0.74	0.18	2.61	2.00	22.88	2.93
	No. Samples	39	39	39	39	39	39	39
M-Out	Mean	22.52	8.52	6.76	13.88	17.2	122.8	2.62
	Standard Error	0.33	0.06	0.12	1.75	1.5	18.2	0.54
	No. Samples	31	31	31	31	31	31	31
TB-1	Mean	21.04	5.78	6.26	16.19	14.7	95.2	9.68
	Standard Error	0.58	0.37	0.07	1.48	0.9	10.2	1.21
	No. Samples	31	31	31	31	31	31	31
TB-3	Mean	20.40	7.91	6.45	1.35	12.3	58.5	2.94
	Standard Error	0.86	0.27	0.06	31	1.0	3.3	0.55
	No. Samples	31	31	31	17.69	31	31	31
TB-4	Mean	18.39	8.11	6.30	1.01	10.4	34.7	7.23
	Standard Error	0.77	0.21	0.07	31	0.9	2.1	0.78
	No. Samples	31	31	31	10.17	31	31	31
TB-5	Mean	18.64	7.79	5.95	0.33	9.9	20.0	7.13
	Standard Error	0.75	0.19	0.06	31	0.8	0.6	0.98
	No. Samples	31	31	31	2.91	31	31	31
TB-6	Mean	18.66	7.86	6.09	0.17	10.8	21.3	6.97
	Standard Error	0.75	0.21	0.06	31	1.0	0.7	0.80
	No. Samples	31	31	31	3.39	31	31	31
Road A	Mean	19.29	8.20	6.08	NA	NA	20.27	NA
	Standard Error	0.93	0.19	0.08			0.68	
	No. Samples	22	22	22			22	

NA - Not Analyzed

Table 10-8. (cont)

Site		TOC (mg/l)	Nitrate (mg N/l)	Nitrite (mg N/l)	Ammonium (mg N/l)	TKN (mg N/l)	Total P (mg/l)	Trichloroethylene (mg/l)
TB-2	Mean	9.81	0.055	0.0022	0.063	0.460	0.0358	<0.00012
	Standard Error	0.60	0.006	0.0004	0.016	0.045	0.0036	
	No. Samples	31	31	31	31	31	31	16
TB-0	Mean	4.49	5.88	0.0242	0.038	0.129	0.0412	NA
	Standard Error	1.10	2.25	0.0120	0.005	0.035	0.0071	
	No. Samples	9	9	9	9	9	9	
M-Out	Mean	0.94	9.44	0.0501	0.019	0.070	0.0451	0.00292
	Standard Error	0.12	1.78	0.0236	0.003	0.009	0.0221	0.00074
	No. Samples	31	30	31	31	31	31	25
TB-1	Mean	3.15	5.86	0.0229	0.056	0.111	0.0296	<0.00012
	Standard Error	0.54	0.99	0.0091	0.008	0.028	0.0031	
	No. Samples	31	31	31	31	31	31	16
TB-3	Mean	2.69	1.43	0.0024	0.041	0.165	0.0546	<0.00012
	Standard Error	0.21	0.24	0.0003	0.004	0.020	0.043	
	No. Samples	31	31	31	31	31	31	16
TB-4	Mean	3.03	0.634	0.0026	0.029	0.176	0.0443	<0.00012
	Standard Error	0.24	0.112	0.0003	0.003	0.021	0.0033	
	No. Samples	31	31	31	31	31	31	16
TB-5	Mean	3.59	0.146	0.0015	0.025	0.172	0.0367	<0.00012
	Standard Error	0.30	0.009	0.0001	0.004	0.020	0.0023	
	No. Samples	31	31	31	31	31	31	16
TB-6	Mean	3.69	0.188	0.0016	0.023	0.176	0.0377	<0.00012
	Standard Error	0.26	0.016	0.0001	0.003	0.023	0.0021	
	No. Samples	31	31	31	31	31	31	16
Road A	Mean	NA4.74	0.149	0.0017	0.020	0.205	NA	NA
	Standard Error	0.37	0.009	0.0002	0.005	0.026		
	No. Samples	25	22	21	22	21		

NA - Not Analyzed

Table 10-8. (cont)

Site		Total Fe (mg/l)	Diss. Fe (mg/l)	Total Al (mg/l)	Diss. Al (mg/l)	Total Zn (mg/l)	Diss. Zn (mg/l)	Total Hg (mg/l)	Diss. Hg (mg/l)
TB-2	Mean	4.74	0.78	0.118	<0.1	0.111	0.128	0.00004	0.0022
	Standard Error	0.37	0.13	0.016		0.031	0.064	0.00001	0.0008
	No. Samples	25	25	25	25	25	16	15	25
TB-0	Mean	2.30	0.31	0.247	<0.1	0.045	NA	NA	0.0030
	Standard Error	0.70	0.09	0.040		0.009			0.0011
	No. Samples	9	9	9	9	9			9
M-Out	Mean	0.15	0.02	0.262	0.117	1.162	2.175	<0.00004	0.0027
	Standard Error	0.03	0.00	0.033	0.036	0.725	1.444		0.0007
	No. Samples	25	25	25	25	25	16	15	25
TB-1	Mean	2.30	0.31	0.236	<0.1	0.839	0.765	<0.00004	0.0031
	Standard Error	0.51	0.05	0.040		0.365	0.375		0.0011
	No. Samples	25	25	25	25	25	16	15	25
TB-3	Mean	1.28	0.64	0.097	<0.1	0.073	0.111	<0.00004	<0.002
	Standard Error	0.14	0.07	0.014		0.056	0.047		
	No. Samples	25	25	25	25	25	16	15	25
TB-4	Mean	1.39	0.25	0.149	<0.1	0.174	0.210	0.00004	<0.002
	Standard Error	0.10	0.03	0.021		0.071	0.118	0.00002	
	No. Samples	25	25	25	25	25	16	15	25
TB-5	Mean	0.59	0.14	0.262	<0.1	0.049	0.066	0.00005	0.0026
	Standard Error	0.08	0.01	0.071		0.013	0.029	0.00002	0.0007
	No. Samples	25	25	25	25	25	16	15	25
TB-6	Mean	0.69	0.16	0.280	<0.1	0.039	0.019	<0.00004	<0.002
	Standard Error	0.07	0.02	0.070		0.008	0.006		
	No. Samples	25	25	25	25	25	16	15	25
Road A	Mean	NA	NA	NA	NA	NA	NA	NA	NA
	Standard Error								
	No. Samples								

NA - Not Analyzed

Savannah River Site, Aiken, South Carolina, September 1988 - March 1990" (Environmental and Chemical Sciences 1990). Table 10-9 on page 10-22 summarizes the data obtained in this study.

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

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

F/H Area Effluent Treatment Facility

In anticipation of the fall 1988 startup of effluent discharges into Upper Three Runs by the F/H Area Effluent Treatment Facility (ETF) of SRS, a 30-month biological study was initiated in June 1987. Five sites were sampled, including one site upstream of the Road C bridge and four sites downstream of the Road C bridge (Figure 10-6 on page 10-7). The discharge point for the ETF effluent (H-016) is at Road C. The results of this study are documented in "Biological Monitoring of Upper Three Runs, Savannah River Plant, Aiken, South Carolina. Final Report on Macroinvertebrate Stream Assessments for F/H Area ETF Effluent Discharge, July 1987 - February 1990" (Environmental and Chemical Sciences 1990). The results of this study are presented in Table 10-10 on page 10-23.

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

Table 10-9. Water Quality Parameters for Biological and Chemical Assessment of M-Area Discharge on Tims Branch
(September 1988–September 1990)

Site		TSS (mg/l)	Ammonia (mg N/l)	Nitrite (mg N/l)	Total Kjeldahl Nitrogen (mg/l)	Nitrate (mg N/l)	Ortho- phosphate (mg/l)	Total Phosphate (mg/l)
A-014	Mean	<4	NA	0.03	<1	6.85	0.34	0.26
	Pre-Op.							
A-015	Mean	13.7	0.82	0.03	0.44	6.40	0.43	0.48
	Pre-Op.	2.6		0.05	0.07	9.44		0.45
TB-0	Mean	45.8	NA	0.06	0.41	5.89	0.42	0.57
	Pre-Op.	12.6		0.020	0.13	5.88		0.41
TB-1	Mean	27.5	NA	0.10	0.28	4.33	0.25	0.32
	Pre-Op.	9.7		0.020	0.11	5.85		0.03
TB-2	Mean	15.7	NA	<0.01	0.44	0.45	0.05	0.06
	Pre-Op.	13.5		0.002	0.46	0.05		0.04
TB-3	Mean	9.9	NA	0.03	0.37	1.39	0.11	0.15
	Pre-Op.	2.9		0.002	0.17	1.42		0.05
TB-4	Mean	11.2	NA	<0.01	0.20	0.85	0.05	0.07
	Pre-Op.	7.2		0.002	0.18	0.63		0.04

Site		Sodium (mg/l)	Dissolved Oxygen (mg/l)	pH	Conductivity (µmhos/cm)	Temperature (C)
A-014	Mean	22.64	8.61	6.85	108	20
	Pre-Op.					
A-015	Mean	43.74	8.50	7.29	135	20
	Pre-Op.		8.52	6.76	123	21.2
TB-0	Mean	25.44	8.18	6.94	131	20
	Pre-Op.		4.4	6.13		21.2
TB-1	Mean	20.01	7.23	6.21	98	18
	Pre-Op.		5.78	6.26	95	21
TB-2	Mean	3.84	5.26	5.71	33	16
	Pre-Op.		2.95	5.55	36	20.2
TB-3	Mean	17.29	7.96	6.39	76	17
	Pre-Op.		7.91	6.45	50	20.4
TB-4	Mean	10.77	8.23	6.51	43	16
	Pre-Op.		8.11	6.30	35	18.4

Table 10-10. Water Quality Parameters for Stream Assessments for F/H Area ETF Effluent Discharge (July 1987 - February 1990)

	Temperature	pH	Dissolved Oxygen (mg/l)	Conductivity (µmhos/cm)	Alkalinity	Residual Chlorine (mg/l)	TSS (mg/l)
<i>Site 1</i>							
Mean	15.6	5.93	8.95	23.13	4.18		4.67
Std. Dev.	5.0	0.41	1.2	5.03	1.21		3.46
Range	6.0 - 23.0	5.2 - 6.9	7.0 - 11.3	11 - 31	3 - 8	<0.05 - <0.01	<4 - 11
<i>Site 2</i>							
Mean	15.7	6.05	9.03	22.73	5.15		6.14
Std. Dev.	5.0	0.62	1.5	4.73	5.33		7.31
Range	6.0 - 23.0	5.0 - 7.5	7.0 - 12.6	11 - 32	2 - 24	<0.5	<4 - 28
<i>Site 3</i>							
Mean	15.8	6.23	9.12	23.4	4.77		4.93
Std. Dev.	5.1	0.51	1.5	5.49	1.58		3.73
Range	6.0 - 22.5	5.2 - 7.2	6.9 - 12.0	12 - 32	2 - 8	<0.05 - <0.1	<4 - 11
<i>Site 4</i>							
Mean	15.6	6.14	9.45	23.1	4.24		6.73
Std. Dev.	5.1	0.57	1.6	4.73	1.10		4.18
Range	6.0 - 22.5	5.0 - 7.3	7.8 - 11.4	12 - 30	1 - 5.4	<0.05 - <0.1	<5 - 14
<i>Site 5</i>							
Mean	15.4	6.20	9.4	20.6	4.45		9.93
Std. Dev.	5.0	0.64	1.7	8.78	0.716		5.99
Range	6.0 - 22.0	5.2 - 7.6	7.5 - 13.8	19 - 30	3 - 6	<0.05 - <0.2	<5 - 22
<i>Tims Branch</i>							
Mean	15.6	6.42	9.4	NA	NA	NA	NA
Std. Dev.	5.5	0.46	1.3				
Range	5.0 - 24	5.6 - 7.5	7.5 - 12.1				

NA - Not Analyzed

Table 10-10. (cont)

	Ortho-Phosphate (mg/l)	Total Phosphate (mg/l)	Nitrate (mg N/l)	Nitrite (mg N/l)	Ammonia (mg/l)
<i>Site 1</i>					
Mean	0.0186	0.0587	0.22		
Std. Dev.	0.0083	0.122	0.69		
Range	<0.01 - 0.03	0.01 - 0.05	<0.2 - 2.7	<0.01	<0.1 - <1
<i>Site 2</i>					
Mean	0.034	0.038	0.227		
Std. Dev.	0.049	0.025	0.743		
Range	<0.01 - 0.2	0.02 - 0.11	<0.1 - 2.9	<0.01	<0.1 - <1
<i>Site 3</i>					
Mean	0.0177	0.0323	0.32		
Std. Dev.	0.0094	0.0132	0.947		
Range	<0.01 - 0.03	0.02 - 0.06	<0.2 - 0.5	<0.01	<0.1 - <1
<i>Site 4</i>					
Mean	0.020	0.0356	0.207		
Std. Dev.	0.0113	0.0184	0.534		
Range	<0.01 - 0.04	<0.25 - 0.07	<0.2 - 0.3	<0.01	<0.1 - <1
<i>Site 5</i>					
Mean	0.023	0.042	0.24		
Std. Dev.	0.016	0.016	0.689		
Range	<0.01 - 0.06	0.02 - 0.07	<0.2 - 2.7	<0.01	<0.1 - <1
<i>Tims Branch</i>					
Mean	NA	0.066	1.01	NA	NA
Std. Dev.		0.042	1.49		
Range		0.03 - 0.18	0.3 - 6.1		

NA - Not Analyzed

Table 10-10. (cont)

	Total Cr (mg/l)	Total Cu (mg/l)	Total Pb (mg/l)	Total Mn (mg/l)	Total Hg (µg/l)	Total Na (mg/l)	Total U (mg/l)	Total Zn (mg/l)
<i>Site 1</i>								
Mean	<0.005			0.022		1.34		0.0204
Std. Dev.				0.017		0.15		0.056
Range	<0.005 - 0.005	<0.05 - <0.005	<0.001 - <0.01	<0.005 - 0.071	<0.5 - <0.8	1.1 - 1.6	<0.001	<0.005 - 0.220
<i>Site 2</i>								
Mean	<0.005			0.0264		1.34	<0.001	0.0233
Std. Dev.				0.0355		0.184		0.061
Range	<0.005 - 0.005	<0.05 - <0.005	<0.001 - <0.01	<0.001 - 0.074	<0.5	1.1 - 1.8	<0.001 - 0.002	<0.005 - 0.299
<i>Site 3</i>								
Mean	<0.005			0.0249		1.613	<0.001	0.0219
Std. Dev.				0.0180		0.290		0.0517
Range	<0.005 - 0.005	<0.05 - <0.005	<0.001 - <0.01	<0.005 - 0.069	<0.5	1.1 - 2.4	<0.001 - 0.003	<0.005 - 0.207
<i>Site 4</i>								
Mean	0.0004	0.001		0.0271		1.64	<0.001	0.0321
Std. Dev.	0.0126	0.0026		0.019		0.206	0.0705	0.0705
Range	<0.005 - 0.049	<0.005 - 0.008	<0.001 - <0.01	<0.005 - 0.077	<0.5	1.2 - 2.0	<0.005 - 0.261	<0.005 - 0.261
<i>Site 5</i>								
Mean	<0.005	<0.005		0.0295		1.55	<0.001	0.0404
Std. Dev.				0.0187		0.245		0.097
Range	<0.005 - 0.017	<0.005 - 0.005	<0.001 - <0.01	<0.005 - 0.079	<0.5 - <1	1.1 - 2.1	<0.001 - 0.001	<0.005 - 0.380
<i>Tims Branch</i>								
Mean	<0.005	<0.005	NA	NA		NA	NA	0.0263
Std. Dev.								<0.005 - 0.245
Range	<0.005 - 0.015	<0.005 - 0.006			<0.5			

NA - Not Analyzed

Algae

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

Macrophytes

Introduction

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

Comprehensive Cooling Water Study

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

Zooplankton

No studies have been conducted on the zooplankton population in Upper Three Runs.

Macroinvertebrates

Sampling Locations and Methods

Aquatic Insects Survey

An extensive sampling program for aquatic insects was conducted by Morse et al. (1980) at six locations adjacent in the Upper Three Runs drainage basin from September 1976 through August 1987. Sampling was conducted at Upper Three Runs at Roads 8-1 and F, Tinker Creek at Road 8-1, Mill Creek at Road E-2, Mill Creek at an unnamed fork 2.75 km upstream from Road E-2, and Boggy Gut at U.S.F.S. Road 781-4 (Figure 10-7). At each station, aquatic insects were collected biweekly from natural substrates and by light trapping. Details of sampling methods can be found in Morse et al. (1980).

Comprehensive Cooling Water Study

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

Figure 10-7. Macroinvertebrate Sampling Stations for Upper Three Runs

F/H Effluent Treatment Facility Monitoring Program

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

Tims Branch Monitoring Program

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

Results

Aquatic Insects Survey

A total of 34,206 aquatic insects were collected during the one-year study (Morse et al. 1980, 1983). At least 551 species of aquatic insects, including at least 52 species and 2 genera new to science were identified. Several other species were collected from Upper Three Runs that are either rarely collected or were never reported before this study in South Carolina. The species list that Morse et al. (1980, 1983) compiled for Upper Three Runs contains more species than have ever been reported for any other North American streams of comparable size.

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

Comprehensive Cooling Water Study

Introduction

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

Taxa Collected

A total of 62 macroinvertebrate taxa were collected from multiplate samplers near Road C during the 1984-1985 program. However, these data are not directly comparable to the data collected by Morse et al. (1980, 1983) or to data from the ETF monitoring program, since there were differences in the level of taxonomic resolution among the studies.

The mean density of organisms on the multiplate samplers near Road C was 582.7 organisms/m² in 1984-1985, while densities in the creek mouth were much higher, averaging 2839.5 organisms/m² (Table 10-11). However, biomass was higher at Road C (0.500 g/m²) than in the creek mouth (0.190 g/m²; Table 10-11). The number of taxa collected per sampler was similar at the two stations, averaging 15.1 taxa/sampler at Road C and 16.1 taxa/sampler in the creek mouth (Table 10-11). The macroinvertebrate collections from multiplate samplers at Road C were overwhelmingly dominated by tanytarsine chironomids (70.1%; Firth et al. 1986). Other abundant taxa included unidentified chironomids (21.6%) and the mayfly, *Stenonema modestum* (1.6%). Dominant taxa in the creek mouth were orthoclad chironomids (28.0%), chironomini chironomids (16.7%), tanytarsine chironomids (8.5%), brachycentrid and hydropsychid caddisflies (3.1% for each taxa; Chimney and Cody 1986).

Macroinvertebrate drift densities were much higher at Road C (6848.9 organisms/1000 m³; Firth et al. 1986) than in the creek mouth (377.6 organisms/1000 m³; Chimney and Cody 1986). Taxa that were abundant in the drift at Road C included chironomids (21.0%), hydropsychid caddisflies (10.5%), baetid mayflies (8.7%), blackfly larvae (6.7%), and the stonefly *Taeniopteryx longicera* (6.5%; Firth et al. 1986). The composition of drift in the creek mouth was dominated more by chironomids (52.9%), but also included relatively high abundances of baetid mayflies (12.3%), hydropsychid caddisflies (1.4%) and blackfly larvae (7.4%; Chimney and Cody 1986).

Table 10-11. Summary Statistics for Macroinvertebrate Data from Hester Dendy Multiplate Samplers, Upper Three Runs, October 1984-September 1985

Parameter	Road C	Creek Mouth
Density (No./m ²)	582.7	2839.5
Biomass (g/m ²)	0.500	0.190
Number of Taxa/Sampler	15.1	16.1
Total Number of Taxa	62	72

Effluent Treatment Facility Monitoring Program

Taxa Collected

During the course of the five-year monitoring program, 292 macroinvertebrate taxa were collected from Upper Three Runs from quantitative sampling (Hester-Dendy multiplate samplers) and sampling of natural substrates combined (Table 10-21 on page 10-43). Of these taxa, 96 were collected exclusively from natural substrates.

Dominant Taxa

Introduction

Table 10-12 presents the relative abundance of major taxonomic groups of macroinvertebrates at each sampling station.

Chironomids

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

Trichoptera

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

Table 10-12. Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987–July 1991

Taxon	Station				
	1	2	3	4	5
Ephemeroptera	7.9	7.7	9.4	7.5	7.2
Plecoptera	11.4	11.4	12.7	12.2	13.2
Trichoptera	13.4	11.5	11.0	12.5	13.2
Coleoptera	5.6	10.7	7.4	6.2	7.7
Diptera (Non Chir.)	6.4	5.0	3.8	11.3	7.9
Chironomidae	54.7	53.0	55.3	49.9	50.3
Other	0.6	0.7	0.4	0.4	0.5
Total	100.0	100.0	100.0	100.0	100.0

Plecoptera

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

Ephemeroptera and Coleoptera

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

Mean Number of Taxa and Density of Organisms

The mean number of taxa collected from multiplate samplers at a given station (all multiplates combined) ranged from 27.0 to 45.0 during the five year study (Table 10-13), while the mean number of taxa per sampler ranged from 12.3 to 22.9 (Table 10-14). Mean densities of organisms ranged from 213.9 to 799.2 organisms/m² (Table 10-15 on page 10-38), which is lower than the densities reported for most other SRS streams. However, macroinvertebrate biomass (ash-free dry mass) was comparable to most other streams, ranging from 0.1399 to 0.6860 g/m² (Table 10-16 on page 10-38). Distinct seasonal variations in biomass

Table 10-13. Mean Number of Taxa Collected During Each Sampling Period from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991

Year	Station				
	1	2	3	4	5
1987	37.5	44.0	45.0	40.5	42.0
1988	39.5	45.0	43.2	44.5	42.0
1989	35.2	37.8	34.2	32.8	33.0
1990	30.2	31.5	33.0	27.0	30.0
1991	31.0	34.3	-	-	33.7

Table 10-14. Mean Number of Taxa Collected Per Hester-Dendy Multiplate Sampler, Upper Three Runs, July 1987-July 1991

Year	Station				
	1	2	3	4	5
1987	18.9	21.9	22.9	20.8	21.1
1988	18.0	21.4	19.6	21.6	20.4
1989	15.8	16.6	15.8	15.4	14.8
1990	12.3	13.8	17.0	13.5	12.8
1991	14.8	16.6	-	-	16.2

Table 10-15. Mean Density of Macroinvertebrates (No./m²) Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991

Year	Station				
	1	2	3	4	5
1987	779.2	799.2	629.6	522.4	607.2
1988	472.4	566.6	538.4	648.0	540.4
1989	356.3	414.1	432.6	366.3	312.9
1990	213.9	238.8	336.8	331.2	246.2
1991	374.3	500.3	-	-	406.3

Table 10-16. Mean Biomass (g/m²) of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991

Year	Station				
	1	2	3	4	5
1987	0.1763	0.3925	0.2288	0.1399	0.2142
1988	0.4873	0.4023	0.6942	0.3696	0.5014
1989	0.4228	0.4982	0.3554	0.2904	0.2987
1990	0.4501	0.6066	0.6025	0.3865	0.4594
1991	0.4482	0.3781			0.6860

Table 10-17. Shannon-Weaver Diversity of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers, Upper Three Runs, July 1987-July 1991

Year	Station				
	1	2	3	4	5
1987	4.22	4.42	4.50	4.56	4.48
1988	4.38	4.59	4.56	4.46	4.38
1989	4.42	4.35	4.08	4.15	4.22
1990	4.16	4.31	4.31	3.90	4.28
1991	4.08	4.17			4.12

were observed, with biomass peaking in the spring as organisms reached their maximum size and declining over summer, just after the period of peak emergence.

Macroinvertebrate diversity, as calculated by the Shannon-Weaver diversity index was very high at all stations, ranging from 3.90 to 4.59 (Table 10-17). Generally, diversity values above 3 are indicative of unimpacted streams.

Temporal Trends

During the course of the five-year study, declines in the mean number of taxa per station, mean number of taxa per sampler, mean density of organisms, and diversity were observed at all stations (Table 10-13, Table 10-14, Table 10-15, and Table 10-17). The decline in density of organisms was the most dramatic, with mean density for all stations combined declining from 667.5 organisms/m² in 1987 to 273.8 organisms/m² in 1990. In 1991 densities increased somewhat to an average of 427.0 organisms/m². Taxa that exhibited the greatest declines in abundance were primarily chironomids, such as the orthoclads,

Rheocricotopus robacki, *Thienemanniella* spp., *Tvetenia discoloripes*, *Orthocladus* spp., and *Cricotopus* spp.; the Chironomini midge, *Polypedilum convictum*; and the tanytarsine midge, *Rheotanytarsus* spp. Species richness among Ephemeroptera, Plecoptera, and Trichoptera, which are generally considered to be pollution-intolerant organisms, did not decrease significantly, and the relative abundance of Plecoptera and Trichoptera actually increased, although overall densities of these orders remained relatively constant. It is important to note that although densities declined, the total biomass of the macroinvertebrate community did not decrease over time (Table 10-16), which indicates that larger organisms were being collected.

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

Tims Branch Monitoring Program

1985-1986 Sampling Program

During the 1985–1986 sampling program, 147 macroinvertebrate taxa were collected in Tims Branch, including 97 taxa collected from multiplate samplers and 50 taxa collected exclusively from natural substrates during qualitative sampling efforts (Table 10-22 on page 10-50). The fewest total number of taxa (23) was collected from multiplate samplers at Station 2, which was located upstream from the M-Area effluent discharge but just downstream from a stagnant pond. Outflow from the pond often had no detectable levels of dissolved oxygen, and the macroinvertebrate community of this station was typical of streams with high organic loading. The mean number of taxa collected per sampler was also lowest at Station 2 (7.5 taxa/ sampler; Table 10-18), and increased in a downstream direction to 12.8 taxa per sampler in the mouth of the creek (Station 4). Dominant groups of macroinverte-

Table 10-18. Summary Statistics for Macroinvertebrate Data from Hester-Dendy Multiplate Samplers, Tim's Branch, 1985-1990

Parameter	Station				
	2	0	1	3	4
<i>Taxa richness (No./sampler)</i>					
1985-1986	5	8.4	10.6	9.7	12.8
1988-1990	3.6	-	7.3	7.5	9.0
<i>Density of Organisms (No./m²)</i>					
1985-1986	3679.1	1387.6	1754.7	1116.4	584.0
1988-1990	421.1	-	1147.1	1094.6	763.5
<i>Biomass (g/m²)</i>					
1985-1986	0.253	0.045	0.072	0.123	0.207
1988-1990	0.042	-	0.267	0.280	0.251

brates at Station 2 included oligochaetes (66.4%), and chironomids from the tribe Chironomini (23.1%; Table 10-19). The macroinvertebrate community downstream from the M-Area effluent discharge gradually improved to a community more typical of less impacted streams, with the oligochaetes and Chironomini being replaced by orthoclad and tanytarsine chironomids, as well as Coleoptera (beetles), Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). At Station 4, a total of 57 taxa were collected from multiple samplers. Mayflies composed 19.5% of the total organisms collected; stoneflies 3.6%; caddisflies, 4.8%; beetles, 5.5%; orthoclads, 30.9%; and tanytarsine chironomids 16.6% (Table 10-19).

The total density of organisms in 1985–1986 was highest at Station 2 (3679.1 organisms/m²), and generally declined in a downstream direction to 584.0 organisms/m² at Station 4 (Table 10-18 on page 10-39). Total biomass was also highest at Station 2 (0.253 g/m²), declined to 0.072 g/m² at Station 1, and then increased to 0.123 and 0.207 g/m² at Stations 3 and 4, respectively (Table 10-18).

1988–1990 Sampling Program

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

The macroinvertebrate community in Tims Branch in 1988–1990 differed somewhat from that of 1985–1986. Station 2 was still dominated by pollution tolerant taxa, but had shifted from a community dominated by oligochaetes to one dominated by pollution-tolerant chi-

Table 10-19. Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates, Tim's Branch, June 1985–December 1986

Taxon	Station						
	2	0	1	3	4	5	6
Ephemeroptera	<0.1	0.6	0.3	0.1	19.5	5.3	6.7
Plecoptera	<0.1	<0.1	<0.1	0.1	3.6	7.1	6.5
Trichoptera	0.1	0.2	3.5	10.4	4.8	8.1	7.0
Coleoptera	0.1	<0.1	0.1	0.2	5.5	2.4	2.6
Odonata	0.3	1.0	0.3	0.1	0.2	<0.1	0.0
Diptera ^a	32.2	34.0	75.4	83.7	63.8	75.5	75.5
Chironomini	(23.1)	(12.9)	(14.0)	(14.0)	(12.2)	(12.2)	(13.2)
Orthoclaadiinae	(0.5)	(1.5)	(20.3)	(17.8)	(30.9)	(37.3)	(37.4)
Tanytarsini	(1.5)	(13.1)	(29.2)	(21.2)	(16.6)	(12.6)	(13.8)
Tanypodinae	(1.8)	(5.4)	(7.9)	(4.3)	(1.7)	(4.4)	(3.3)
Simuliidae	(5.1)	(<0.1)	(2.4)	(22.5)	(0.8)	(7.3)	(5.6)
Turbellaria	0.1	1.3	<0.1	0.2	<0.1	<0.1	0.0
Oligochaeta	66.4	60.0	15.9	3.6	1.3	0.8	0.8
Gastropoda	0.5	2.0	2.7	<0.1	0.0	<0.1	0.1
Other	0.2	0.8	1.7	1.6	1.3	0.7	0.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

^a Includes subtaxa values in parentheses

ronomids of the tribe Chironomini, which comprised 90.7% of the organisms collected from multiplate samplers at this station (Table 10-20). At the most downstream station (Station 4), mayflies and caddisflies were less abundant than in 1985–1986, composing 14.5% and 1.2%, respectively of the macroinvertebrates on the multiplate samplers, while stoneflies were more abundant, comprising 14.3% of the organisms collected in 1988–1990 (Table 10-20), as compared to just 3.6% in 1985–1986.

The density of organisms was much lower at Station 2 in 1988–1990 (421.1 organisms/m², as compared to 3679.1 in 1985–1986). Densities at Stations 1 and 3 were also somewhat lower, while mean densities at Station 4 were higher (763.5 organisms/m², as compared to 584.0 in 1985–1986; Table 10-18 on page 10-39). At present, there is no explanation for the observed declines. The decline in density of organisms is of particular concern, since densities were observed to decline steadily during the last year of the sampling program (Figure 10-8 on page 10-42).

In contrast to the decline in macroinvertebrate densities, macroinvertebrate biomass was higher at three of the four sampling stations in 1988–1990 than in 1985–1986 (Table 10-18 on page 10-39). The increased biomass with decreased densities indicates that the relative size of the organisms has increased, possibly due to shifts in species composition.

Table 10-20. Relative Abundance (Percent Composition) of Major Taxonomic Groups of Macroinvertebrates, Tim's Branch, September 1988-March 1990

Taxon	Station			
	1	2	3	4
Ephemeroptera	0.1	<0.1	1.4	14.5
Plecoptera	0.1	0.0	1.0	14.3
Trichoptera	14.7	<0.1	5.6	1.2
Coleoptera	0.4	0.7	2.5	4.8
Odonata	0.3	0.3	0.3	<0.1
Diptera ^a	82.6	97.6	88.9	64.2
Chironomini	(15.9)	(90.7)	(7.6)	(13.9)
Orthocladiinae	(17.6)	(1.2)	(22.6)	(38.9)
Tanytarsini	(15.6)	(2.5)	(22.6)	(5.4)
Tanypodinae	(16.9)	(2.6)	(11.1)	(3.5)
Simuliidae	(15.1)	(0.3)	(23.7)	(1.4)
Turbellaria	0.0	0.0	0.0	0.0
Oligochaeta	0.7	1.0	0.1	0.1
Gastropoda	0.2	<0.1	0.0	0.0
Other	0.9	0.4	0.2	0.9
Total	100.0	100.0	100.0	100.0

^a Includes subtaxa values in parentheses

Figure 10-7. Density of Macroinvertebrates in Upper Three Runs, 1985–1990

Table 10-21. Macroinvertebrate Taxa Collected from Hester Dendy Multiplate Samplers and by Qualitative Sampling, Upper Three Runs, July 1987-July 1991

Taxon	Quantitative	Qualitative
Ephemeroptera		
<i>Acerpenna pygmaeus</i>	X	X
<i>Baetis ephippiatus</i>	X	X
<i>Baetis frondalis</i>		X
<i>Baetis intercalaris</i>	X	X
<i>Baetis propinquus</i>		X
<i>Caenis</i> sp.	X	X
<i>Callibaetis</i> sp.	X	X
<i>Centroptilum</i> sp.		X
<i>Dannella simplex</i>	X	X
<i>Dolania americana</i>		X
<i>Ephemerella argo</i>	X	X
<i>Ephemerella catawba</i> sp..		X
<i>Ephemerella dorothea</i>	X	X
<i>Ephemerella inconstans</i>	X	X
<i>Ephemerella invaria/rotunda</i>	X	X
<i>Eurylophella doris</i>	X	X
<i>Eurolophella</i> nt. <i>bicolor</i>	X	X
<i>Eurolophella prudentialis</i>		X
<i>Eurolophella temporalis</i>		X
<i>Heptagenia flavescens</i>	X	X
<i>Hexagenia limbata</i>		X
<i>Hexagenia munda</i>	X	X
<i>Isonychia</i> sp.	X	X
<i>Leptophlebia</i> sp.	X	X
<i>Neophemera youngi</i>	X	X
<i>Paraleptophlebia guttata</i>		X
<i>Pseudocloeon bimaculatus</i>	X	X
<i>Pseudocloeon dubium</i>	X	X
<i>Pseudocloeon punctiventris</i>	X	X
<i>Serratella serratoides</i>	X	
<i>Stenonema modestum/smithae</i>	X	X
<i>Tricorythodes</i> sp.	X	X
Odonata		
<i>Argia</i> sp.	X	X
<i>Boyeria vinosa</i>	X	X
<i>Calopteryx dimidiata</i>		X
<i>Calopteryx maculata</i>	X	X
<i>Enallagma</i> sp.		X
<i>Gomphus lividus</i>		X
<i>Hagenius brevistylus</i>		
<i>Helocordulia selysii</i>	X	
<i>Neurocordulia</i> sp.		X
<i>Perithemis</i> sp.	X	X
<i>Progomphus</i> sp.		X
<i>Tetragoneuria costalis/cynosura</i>		X
<i>Tetragoneuria semiaquea</i>		X
<i>Tetragoneuria</i> sp.	X	X

Table 10-21. (cont)

Taxon	Quantitative	Qualitative
Plecoptera		
<i>Acroneuria abnormis</i>	X	X
<i>Acroneuria mela</i>	X	X
<i>Agnetina capitata</i>	X	
<i>Allocapnia</i> sp.		X
<i>Alloperla</i> sp.	X	
<i>Amphinemura delosa</i>		X
<i>Haploperla brevis</i>	X	X
<i>Helopicus subvarians</i>	X	X
<i>Isoperla bilineata</i>	X	X
<i>Isoperla decala</i>	X	X
<i>Isoperla holochlorallata</i>	X	X
<i>Isoperla nt. nana</i>	X	X
<i>Isoperla orata/dicala</i>	X	X
<i>Leuctra</i> sp.	X	X
<i>Neoperla</i> prob. <i>carlsoni</i>	X	
<i>Paragnetina fumosa</i>	X	X
<i>Paragnetina kansensis</i>	X	X
<i>Perlesta placida</i>	X	X
<i>Perlinella drymo</i>	X	X
<i>Perlinella ephyre</i>	X	X
<i>Pteronarcys dorsata</i>	X	X
<i>Taeniopteryx nt. lita</i>	X	X
Hemiptera		
<i>Gerris remigis</i>		X
<i>Hesperocorixa minor</i>		X
<i>Metrobates hesperius</i>		X
<i>Ochterus</i> sp.		X
<i>Rhagovelia obesa</i>		X
Megaloptera		
<i>Chauliodes rasticornis</i>		X
<i>Corydalus cornutus</i>	X	X
<i>Nigronia serricornis</i>	X	X
<i>Sialis</i> prob. <i>vagans</i>	X	X
Trichoptera		
<i>Agarodes libalis</i>	X	X
<i>Anisocentropus pyraloides</i>	X	X
<i>Brachycentrus nigrosoma</i>	X	
<i>Brachycentrus numerosus</i>	X	X
<i>Ceraclea resurgens</i>		X
<i>Cheumatopsyche</i> spp.	X	X
<i>Chimarra</i> sp.	X	X
<i>Cyrnellus fraternus</i>	X	
<i>Diplectrona modesta</i>	X	X
<i>Hydropsyche elissoma</i>	X	X
<i>Hydropsyche</i> sp.	X	
<i>Hydroptila</i> sp.	X	X

Table 10-21. (cont)

Taxon	Quantitative	Qualitative
<i>Lepidistoma</i> sp.	X	X
<i>Lype diversa</i>	X	X
<i>Macrostemum carolina</i>		X
<i>Mayatrichia ayama</i>	X	
<i>Micrasema rusticum</i>	X	X
<i>Micrasema wataga</i>	X	X
<i>Nectopsyche pavida</i>		X
<i>Neureclipsis</i> sp.	X	X
<i>Nyctiophylax</i> sp.	X	
<i>Oecetis</i> sp.	X	X
<i>Oxyethira</i> sp.	X	
<i>Phylocentropus</i> sp.	X	X
<i>Polycentropus</i> sp.	X	X
<i>Psilotreta</i> sp.	X	X
<i>Pycnopsyche</i> sp.	X	X
<i>Triaenodes</i> nr. <i>injuncta</i>		X
<i>Triaenodes</i> nr. <i>taenia</i>		X
<i>Triaenodes</i> sp. 2	X	X
Lepidoptera		
<i>Parapoynx obscuralis</i>	X	X
Coleoptera		
<i>Anchytarsus bicolor</i>	X	X
<i>Ancyronyx variegatus</i>	X	X
<i>Copelatus glyphicus</i>		X
<i>Cyphon</i> sp.		X
<i>Dineutus assimilis</i>		X
<i>Dineutus ciliatus</i>		X
<i>Dineutis discolor</i>		X
<i>Dineutis larvae</i>	X	X
<i>Dubiraphia quadrinotata</i>	X	X
<i>Ectopria nervosa</i>	X	X
<i>Enochrus cinctus</i>	X	
<i>Enochrus ochraceus</i>		X
<i>Gonielmis dietrichi</i>	X	X
<i>Gyrinus aenolus</i>	X	X
<i>Hydaticus</i> sp.		X
<i>Hydroporus pilatei</i>		X
<i>Macronychus glabratus</i>	X	X
<i>Microcylloepus pusillus</i>	X	X
<i>Optioservus</i> sp.	X	X
<i>Oulimnius latisculus</i>		X
<i>Peltodytes</i> sp.		X
<i>Sperchopsis tessellatus</i>	X	X
<i>Stenelmis antennalis</i>	X	
<i>Stenelmis convexula</i>	X	
<i>Stenelmis crenata</i>	X	
<i>Stenelmis markeli</i>	X	X
<i>Stenelmis sinuata</i>	X	X

Table 10-21. (cont)

Taxon	Quantitative	Qualitative
<i>Stenelmis</i> sp. 3	X	
Diptera		
<i>Antocha</i> sp.	X	X
<i>Atherix lantha</i>	X	X
<i>Atrichopogon</i> sp.	X	X
<i>Bezzia</i> sp. 2	X	X
<i>Bezzia</i> sp. 6		X
<i>Bezzia</i> sp. 7	X	X
<i>Chelifera</i> sp.	X	
<i>Clinocera</i> sp.	X	
<i>Chrysops</i> sp.	X	X
<i>Culicoides</i> sp.		X
<i>Culex</i> sp.		X
<i>Dixa</i> sp.	X	
Dolichopodidae*		X
<i>Ectemnia invenusta</i>	X	X
Empididae*	X	X
<i>Erioptera/Ormosia</i> sp.		X
<i>Forcipomyia</i> sp.	X	X
<i>Hemerodromia</i> sp. 1	X	X
<i>Hemerodromia</i> sp. 2		X
<i>Hexatoma (Eriocera) cinerea</i>	X	X
<i>Limonia</i> sp.	X	
<i>Palpomyia</i> sp. 1	X	X
<i>Palpomyia</i> sp. 3		X
<i>Palpomyia</i> sp. 4		X
<i>Palpomyia</i> sp. 5	X	X
<i>Pilaria</i> sp.		X
<i>Probezzia</i> sp.		X
Sciomyzidae*		X
<i>Simulium jonesi</i>	X	X
<i>Simulium slossonae</i>	X	X
<i>Simulium snowi</i>		X
<i>Simulium tuberosum</i>	X	X
<i>Simulium verecundum</i>	X	X
<i>Stilobezzia</i> sp.		X
<i>Telmatoscopus</i> sp.	X	
<i>Tipula</i> sp. A		X
<i>Tipula</i> sp. 1		X
<i>Tipula (Yamato.)</i> sp. 7		X
<i>Tipula (Yamato.)</i> nr. <i>strepens</i>		X
<i>Wiedemannia</i> sp.		X
Tanypodinae		
<i>Ablabesmyia janta/parajanta</i>		X
<i>Ablabesmyia mallochi</i>	X	X
<i>Apsectrotanypus johnsoni</i>		X
<i>Clinotanypus pinguis</i>		X
<i>Conchapelopia</i> sp.	X	X
<i>Labrundinia pilosella</i>		X

Table 10-21. (cont)

Taxon	Quantitative	Qualitative
<i>Meropelopia</i> sp.	X	X
<i>Nilotanypus fimbriatus</i>	X	X
<i>Paramerina</i> sp.	X	X
<i>Procladius</i> sp.	X	X
<i>Zavreliomyia</i> sp.		X
Orthoclaudiini		
<i>Brillia flavifrons</i>	X	X
<i>Brillia parva</i>	X	X
<i>Corynoneura</i> nt. <i>coronata</i>	X	X
<i>Corynoneura</i> nt. <i>taris</i>	X	X
<i>Corynoneura</i> sp. 3	X	X
<i>Corynoneura</i> sp. 4	X	X
<i>Cricotopus bicinctus</i>	X	X
<i>Cricotopus</i> sp. 5 pupa	X	
<i>Cricotopus trifasciatus</i> gp.	X	
<i>Cricotopus vierriensis</i>	X	X
<i>Euliefferiella</i> sp.	X	
<i>Gymnometriocnemus</i> sp.		X
<i>Heterotrissocladius marcidus</i>		X
<i>Limnophyes</i> sp.	X	
<i>Lopescladius</i> sp.		X
<i>Metriocnemus fuscipes</i>	X	
<i>Nanocladius distinctus</i>	X	
<i>Nanocladius</i> nr. <i>alternantherae</i>	X	X
<i>Nanocladius rectinervis</i>	X	X
<i>Orthocladus annectens</i>	X	
<i>Orthocladus carlatus</i>		X
<i>Orthocladus curtiseta</i>	X	X
<i>Orthocladus dentifer</i>	X	X
<i>Orthocladus lignicola</i>	X	X
<i>Orthocladus obumbratus</i>	X	
<i>Orthocladus</i> (<i>Eudactylocladius</i>) sp.	X	
<i>Paracricotopus</i> sp.		X
<i>Parakiefferiella</i> sp. A	X	X
<i>Parakiefferiella</i> sp. B	X	X
<i>Parakiefferiella</i> sp. 4	X	X
<i>Parametriocnemus lunbecki</i>	X	X
<i>Parametriocnemus</i> sp. C	X	X
<i>Parametriocnemus</i> sp. D		X
<i>Psectrocladius</i> (<i>Mesopsectro.</i>) sp.		X
<i>Pseudorthocladus</i> sp.		X
<i>Rheocricotopus robacki</i>	X	X
<i>Rheocricotopus tuberculatus</i>	X	
<i>Rheosmittia</i> sp.	X	X
<i>Symposiocladius lignicola</i>	X	X
<i>Synorthocladus semivirens</i>	X	X
<i>Thienemanniella fusca</i> gp.	X	X
<i>Thienemanniella xena</i> gp.	X	X
<i>Tvetenia discoloripes</i> gp.	X	X
<i>Tvetenia paucunca/vitracies</i>	X	X

Table 10-21. (cont)

Taxon	Quantitative	Qualitative
<i>Unniella multiivirga</i>	X	X
Diamesinae		
<i>Odontomesa fulva</i>		X
<i>Potthastia longimana</i>	X	X
Tanytarsini		
<i>Cladotanytarsus</i> sp. A	X	X
<i>Cladotanytarsus</i> sp. B		X
<i>Micropsectra</i> sp.	X	X
<i>Paratanytarsus</i> sp.	X	
<i>Rheotanytarsus distinctissimus</i> gp.	X	X
<i>Rheotanytarsus exiguus</i> gp.	X	X
<i>Stempellinella</i> sp.	X	X
<i>Tanytarsus chinyensis</i> gp. (pupa)	X	
<i>Tanytarsus glabrescens</i> gp.	X	X
<i>Tanytarsus</i> sp. I Cantrell		X
<i>Tanytarsus</i> sp. IX Rutter	X	X
<i>Tanytarsus</i> sp. XI Rutter	X	X
<i>Tanytarsus</i> sp. XII Rutter		X
<i>Tanytarsus</i> sp. XIII Rutter	X	X
<i>Tanytarsus</i> sp. XIV Rutter	X	X
<i>Tanytarsus</i> sp. XVI Rutter	X	X
<i>Tanytarsus</i> sp. XVII Rutter	X	X
<i>Tanytarsus</i> sp. XVIII Rutter		X
Chironomini		
<i>Cryptochironomus blarina</i>		X
<i>Cryptochironomus fulvus</i> gp.	X	X
<i>Demicryptochironomus cuneatus</i>		X
<i>Einfeldia</i> sp. A	X	
<i>Kloosia dorsenna</i>		X
<i>Lauterborniella agrayloides</i>		X
<i>Microtendipes pedellus</i>		X
<i>Microtendipes</i> nt. rydalensis	X	X
<i>Nilothauma babiye</i>	X	X
<i>Pagastiella ostansa</i>	X	X
<i>Paracladopelma doris</i>		X
<i>Paracladopelma loganae</i>		X
<i>Paracladopelma undine</i>		X
<i>Paralauterborniella nigrohalteralis</i>	X	X
<i>Paratendipes</i> nr. nudisquama		X
<i>Phaenopsectra flavipes</i>	X	X
<i>Polypedilum aviceps</i>	X	
<i>Polypedilum braseniae</i>		X
<i>Polypedilum convictum</i>	X	X
<i>Polypedilum fallax</i>	X	X
<i>Polypedilum halterale</i>	X	X
<i>Polypedilum illinoense</i>	X	X
<i>Polypedilum scalaenum</i>	X	X
<i>Pseudochironomus</i> sp.	X	
<i>Robackia claviger</i>		X
<i>Robackia demeijerei</i>	X	X

Table 10-21. (cont)

Taxon	Quantitative	Qualitative
<i>Stelechomyia perpulchra</i>	X	X
<i>Stenochironomus hilaris</i>	X	X
<i>Tribelos jucundus</i>	X	X
Crustacea		
<i>Asellus</i>		X
<i>Caecidotea</i> sp.		X
<i>Cambarinae</i>		X
<i>Crangonyx serratus</i>		X
<i>Palaemonetes paludosus</i>		X
Acari		
Hydracarina	X	X
<i>Annelida</i>		
<i>Lumbriculidae</i>		X
<i>Naididae</i> *	X	X
<i>Nais</i> sp.	X	
<i>Pristina/Stephensoniana</i> sp.	X	X
<i>Spirosperma</i> sp.		X
<i>Tubificidae</i>	X	X
<i>Mollusca</i>		
<i>Campeloma</i> sp.		X
<i>Elliptio</i> sp.		X
<i>Ferrissia</i> sp.	X	
<i>Gillia altilis</i>	X	X
<i>Sphaerium</i> sp.		X
<i>Viviparus subpurpureus</i>		X

*Specimen not identifiable to genus.

Table 10-22. Macroinvertebrate Taxa Collected from Hester-Dendy Multiplate Samplers and by Qualitative Sampling, Tim's Branch, 1985-1986

	Quantitative	Qualitative
<i>Collembola</i>	X	
<i>Ephemeroptera</i>		
<i>Baetis</i>	X	X
<i>Caenis</i>	X	X
<i>Callibaetis</i>	X	
<i>Habrophlebiodes</i>		X
<i>Heptagenia</i>	X	X
<i>Leptophlebia</i>	X	
<i>Paraleptophlebia debilis</i>		X
<i>Stenonema modestum</i>	X	X
<i>Tricorythodes</i>	X	
<i>Plecoptera</i>		
<i>Acroneuria abnormis</i>	X	X
<i>Allocaonia sp.</i>		X
<i>Clioperla clio</i>	X	
<i>Isoperla spp.</i>		X
<i>Leuctra</i>	X	
<i>Nemocaonia carolina</i>	X	X
<i>Neoperla</i>	X	
<i>Paragnetina fumosa</i>	X	
<i>Paragnetina sp.</i>	X	
<i>Perlesta placida</i>	X	X
<i>Taeniopteryx robbiae</i>	X	
<i>Taeniopteryx sp.</i>	X	
<i>Megaloptera</i>		
<i>Chauliodes</i>	X	
<i>Corydalus cornutus</i>	X	
<i>Nigronia sp.</i>	X	
<i>Sialis</i>	X	
<i>Trichoptera</i>		
<i>Agrypnia vestita</i>		X
<i>Aniscentropus</i>	X	X
<i>Cernotina</i>	X	
<i>Cheumatopsyche spp.</i>	X	X
<i>Chimarra</i>	X	
<i>Diplectrona modesta</i>	X	
<i>Hydropsyche betteni</i>		X
<i>Hydropsyche rossi</i>		X
<i>Hydropsyche spp.</i>	X	X
<i>Hydroptila</i>	X	X
<i>Lepidistoma</i>	X	X
<i>Lype diversa</i>	X	X
<i>Macrostemum carolina</i>	X	
<i>Mayatrichia</i>	X	
<i>Micrasema</i>	X	X

Table 10-22. (cont)

	Quantitative	Qualitative
<i>Nectopsyche</i> sp.		X
<i>Oecetis</i>	X	X
<i>Oxyethira</i>	X	X
<i>Phylocentropus</i> sp.		X
<i>Polycentropus</i> spp.	X	
<i>Pycnopsyche scabripennis</i>		X
<i>Trienodes marginatus</i>		X
<i>Trienodes tardus</i>		X
<i>Odonata</i>		
<i>Argia</i> spp.	X	X
<i>Boyeria vinosa</i>		X
<i>Calopteryx dimidiata</i>	X	X
<i>Cordulegaster maculata</i>		X
<i>Dromogomphus spinosus</i>		X
<i>Enallagma</i> spp.	X	X
<i>Epicordulia regina</i>	X	
<i>Erythemis simplicicollis</i>	X	X
<i>Haegenius brevistylus</i>		X
<i>Hetaerina</i> spp.	X	
<i>Ischnura prognatha</i>		X
<i>Libellula cyanea</i>		X
<i>Pachydiplax longipennis</i>	X	X
<i>Progomphus obscurus</i>		X
<i>Somatochlora</i>		X
<i>Stylurus</i>		X
<i>Lepidoptera</i>		
<i>Munroessa</i>	X	
<i>Parapoynx</i>	X	
<i>Coleoptera</i>		
<i>Ancyronyx variegatus</i>	X	X
<i>Berosus</i> sp.		X
<i>Celina</i> sp.		X
<i>Cyphon</i>		X
<i>Dineutus</i>	X	
<i>Dubiraphia</i>	X	
<i>Ectopria nervosa</i>		X
<i>Gonielmis dietrichi</i>	X	X
<i>Gyrinus</i>	X	
<i>Haliphus fasciatus</i>		X
<i>Haliphus pantherinus</i>		X
<i>Haliphus triopsis</i>		X
<i>Helobata striata</i>		X
<i>Helochares</i>	X	
<i>Hydrocanthus oblongus</i>	X	
<i>Hydrochus inaequalis</i>		X
<i>Hydroporus aulicus</i>		X
<i>Hydroporus mixtus</i>		X

Table 10-22. (cont)

	Quantitative	Qualitative
<i>Hydroporus</i> sp.	X	X
<i>Hygrotus</i>		X
<i>Macronychus glabratus</i>	X	X
<i>Pelodytes bradleyi</i>		X
<i>Pelodytes shermani</i>		X
<i>Pyrrhalta nymphaeae</i>	X	X
<i>Stenelmis</i>	X	X
<i>Suphisellus puncticollis</i>	X	
<i>Heteroptera</i>		
<i>Belostoma</i>	X	X
<i>Corixidae</i>	X	
<i>Hesperocorixa semilucida</i>		X
<i>Merragata brunnea</i>	X	X
<i>Mesovelia mulsanti</i>	X	
<i>Microvelia americana</i>		X
<i>Neoplea striola</i>	X	X
<i>Ochterus</i>	X	
<i>Pelocoris femoratus</i>		X
<i>Trichocorixa sexcinta</i>		X
<i>Diptera</i>		
<i>Non-Chironomids</i>		
<i>Anopheles</i>	X	
<i>Antocha</i>	X	
<i>Atherix</i>	X	
<i>Ceratopogoninae</i>	X	X
<i>Chaoborus punctipennis</i>	X	X
<i>Chrysops</i> sp.	X	X
<i>Dixa</i> sp.		X
<i>Empididae</i>	X	X
<i>Ephydriidae</i>		X
<i>Erioptera</i>		X
<i>Forcipomyiinae</i>	X	
<i>Hexatoma</i>	X	
<i>Pericoma</i> sp.	X	
<i>Pilaria</i> sp.		X
<i>Pseudolimnophila</i> sp.		X
<i>Simulium decorum</i>		X
<i>Simulium venustum</i>		X
<i>Simulium vittatum</i>		X
<i>Simulium</i> sp.	X	X
<i>Tabanus</i> sp.		X
<i>Tipula</i>		X
<i>Chironomidae</i>		
<i>Chironomini</i>	X	X
<i>Stenochironomus</i>	X	X
<i>Diamesinae</i>	X	
<i>Orthocladiinae</i>	X	X
<i>Tanypodiinae</i>	X	X

Table 10-22. (cont)

	Quantitative	Qualitative
<i>Tanytarsini</i>	X	X
<i>Crustacea</i>		
<i>Procambarus</i>	X	X
<i>Crangonyx</i> sp.		X
<i>Gammarus fasciatus</i>	X	X
<i>Hyaella azteca</i>	X	X
<i>Palaemonetes paludosus</i>	X	X
<i>Acari</i>		
<i>Arrenurus</i> sp.		X
<i>Hydracarina</i>	X	X
<i>Oligochaeta</i>	X	X
<i>Hirudinea</i>	X	X
<i>Nematoda</i>	X	X
<i>Turbellaria</i>	X	
<i>Dugesia tigrina</i>		X
<i>Gastropoda</i>		
<i>Amnicola</i>	X	X
<i>Ancylidae</i>	X	
<i>Elmia</i> (=Goniobasis)	X	
<i>Ferrissia rivularis</i>		X
<i>Gyraulus parvus</i>	X	
<i>Helisoma trivolvis</i>	X	X
<i>Menetus dilitatus</i>	X	
<i>Physella</i> spp.	X	X
<i>Pseudosuccinea columnella</i>	X	X
<i>Succinea</i> spp.	X	
<i>Pelecypoda</i>		
<i>Corbicula fluminea</i>	X	
<i>Sphaeriidae</i>	X	X

Fish

Introduction

Upper Three Runs was sampled in 1984–1985, 1992, and 1993. The 1984–1985 samples were taken as part of the CCWS. These samples included ichthyoplankton collections from the lower reaches of the stream. The 1992 samples were taken as part of a dual effort to characterize stream fish assemblages on SRS and assess possible impacts resulting from the outcropping of contaminated ground water from F and H areas into Upper Three Runs. During 1993 fish were collected for the assessment of body burdens of heavy metals and other possible contaminants from F and H Area. The results of the 1993 sampling efforts were not available at the time of publication; results from the other studies are presented in the following sections.

Sampling Conducted During the Comprehensive Cooling Water Study

Introduction

Most of the sampling effort in Upper Three Runs during the CCWS was devoted to the collection of ichthyoplankton from sample stations at Road C, Road A, and in the creek mouth (Figure 10-9). Samples were collected with 0.505-mm mesh nets weekly from February through July during 1984 and 1985 (Paller 1985, Paller et al. 1986). Samples were collected during daylight hours.

Figure 10-9. Fish Sampling Stations for Upper Three Runs

Ichthyoplankton Taxa Collected

Paller (1985) collected 358 ichthyoplankters from Upper Three Runs during 1984, and Paller et al. (1986) collected 217 during 1985 (Table 10-23 and Table 10-24). The dominant taxa during both years was spotted sucker (*Minytrema melanops*). Other relatively abundant taxa were darters (*Etheostoma* spp.), crappie (*Pomoxis nigromaculatus*), minnows (primarily *Notropis* spp.), blueback herring (*Alosa aestivalis*), and American shad (*Alosa sapidissima*). The occurrence of American shad in Upper Three Runs reflects the relatively large size and substantial flow of this creek that make it a suitable spawning area for this species. Perhaps the most unusual feature of the ichthyoplankton assemblage in Upper Three Runs was the relatively high abundance of spotted sucker larvae. Larvae of this species were not found in such numbers in any of the other SRS creeks, suggesting that Upper Three Runs is an important spawning site for spotted sucker.

Table 10-23. Number and Percent Composition of Ichthyoplankton Collected from Upper Three Runs, March 14–June 3, 1984

Taxa	Number	Percent
gizzard and/or threadfin shad	12	3.4
blueback herring	4	1.1
unidentified herring or shad	4	1.1
spotted sucker	234	65.4
unidentified suckers	3	0.8
sunfish and/or bass	4	1.1
crappie	51	14.2
yellow perch	2	0.6
darters	20	5.6
minnows	17	4.7
carp	2	0.6
unidentified ichthyoplankton	5	1.4
total	358	100.0

Table 10-24. Number and Percent Composition of Ichthyoplankton Collected from Upper Three Runs, February–July 1985.

Taxa	Number	Percent
blueback herring	11	5.1
American shad	9	4.1
unidentified clupeid	2	0.9
minnows	4	1.8
spotted sucker	116	53.5
sucker	6	2.8
sunfish and/or bass	3	1.4
crappie	2	0.9
darters	48	22.1
unidentified ichthyoplankton	16	7.4
total	217	100.0

Program ICDEN6T was used to compute the data presented in this table.

Ichthyoplankton Densities

Mean ichthyoplankton densities at the three sample stations in Upper Three Runs ranged from 29/1000 m³ to 69/1000 m³ during 1984 (Figure 10-10). Mean densities during 1985 ranged from 21/1000 m³ to 41/1000 m³. These densities were low to moderate compared with densities in the other unimpacted creeks sampled during the Comprehensive Cooling Water Study (Paller 1985, Paller et al. 1986). There were few consistent differences among sample stations except that the sample station in the creek mouth supported more taxa, partly because of the accessibility of this sample station to riverine taxa such as the anadromous American shad and blueback herring.

Studies to Assess Impacts from F- and H-Areas

Introduction

Paller (1993) electrofished sample sites on Upper Three Runs, several tributary streams, and a control stream, Hollow Creek, to assess possible impacts of the F- and H- area seepage basins on fish assemblages in Upper Three Runs. The tributaries include two third order streams: Cedar Creek, located north of the SRS, and Tinker Creek, which joins Upper Three Runs upstream from the F- and H- area seepage basins. The third tributary was Crouch Branch, a small first order tributary of Upper Three Runs that drains F and H Areas. The control stream, Hollow Creek, was selected because of its proximity to Upper Three Runs and its generally similar size, bottom substrate, channel morphometry, and water quality.

There were eight sample stations on Upper Three Runs (Figure 10-9 on page 10-55), four (Stations 4-8) downstream from and four upstream from the waste management area. There was one sample station on Cedar Creek (Station 9), one sample station on Tinker Creek

Figure 10-10

(Station 10), one sample station on Crouch Branch (Station 11), and three sample stations (Stations 12–14) on Hollow Creek. Each sample station consisted of three 100-m stream reaches. Repeated electrofishing passes (usually seven) were made through each reach until no or very few fish were collected. Habitat data were also collected consisting of stream width, stream depth, current velocity, number of logs and stumps, substrate type, dissolved oxygen concentration, pH, temperature, and conductivity. Percentages of stream bottom area covered or overhung by submerged debris (leaves, twigs, and wood fragments), submerged brush/snags, submerged root masses, aquatic macrophytes, and low-growing riparian vegetation were visually estimated.

Comparison to Other SRS Streams

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

Differences Among Sample Stations

Differences in number of species and number of individuals among sample stations did not indicate degradation of the fish assemblages downstream from the waste management areas. Three of the five highest mean species numbers were observed at sample stations that were downstream from F and H Areas (Table 10-25). The lowest mean species numbers were observed upstream from the confluence of Upper Three Runs and Tinker Creek, possibly reflecting smaller stream size, other habitat factors, or offsite impacts. There were no significant differences in total number of fish per sample stations; densities at the stations downstream from F and H Areas were within the range or higher than numbers at the stations upstream of the waste F and H Areas.

Canonical discriminant analysis was used to assess differences among sample stations based on the number of the 10 most abundant species. Sample stations were divided into three groups: Upper Three Runs upstream from the waste management area, Upper Three Runs downstream from the waste management area, and Hollow Creek. Differences among the three station groups were significant at $P < 0.05$. Upper Three Runs stations downstream from the waste management area differed from Upper Three Runs sample stations upstream from the waste management area in possessing higher numbers of many species and from Hollow Creek sample stations in possessing lower densities of coastal shiner, dusky shiner and redbreast sunfish.

Differences Among Different Habitats

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

Table 10-25. Fishes Collected by Electrofishing from Sample Stations in Upper Three Runs, Hollow Creek, and Several Tributaries.

Species	1 UTR- 114	2 UTR- 8.1	3 UTR- TB	4 UTR- F.5	5 UTR- F.4	6 UTR- C	7 UTR- Ca	8 UTR- A	9 HOL- PJ	10 HOL- 125	11 HOL- ??	Tinker	Cedar	Crouch
dusky shiner	0	13	83	39	67	47	71	20	2	8	38	106	0	0
yellowfin shiner	0	14	21	35	10	60	17	14	12	2	0	276	103	249
sailfin shiner	0	19	84	9	0	2	1	1	1	1	29	12	10	0
American eel	3	10	8	10	16	4	16	12	3	7	10	1	13	4
redbreast sunfish	2	1	1	25	21	22	15	10	5	3	2	17	0	0
pirate perch	2	2	0	17	12	3	7	3	19	3	4	28	25	7
spotted sucker	0	7	0	0	17	9	0	13	0	3	30	0	0	0
bluegill	0	3	0	24	18	9	4	2	13	2	7	0	0	0
spotted sunfish	0	1	0	10	14	3	2	4	16	2	20	5	1	0
speckled madtom	1	1	0	2	3	2	2	1	15	1	11	19	13	4
coastal shiner	7	0	4	3	17	13	9	6	0	0	0	0	0	0
chain pickerel	2	5	0	4	3	5	5	7	7	1	7	0	0	0
redfin pickerel	0	0	1	4	3	0	0	1	5	3	8	16	5	0
largemouth bass	1	3	2	1	0	5	2	2	3	0	10	2	0	0
teselated darter	0	0	0	0	2	2	0	0	5	0	2	5	13	7
lake chubsucker	1	5	2	2	0	1	0	0	1	0	2	0	9	0
blackbanded darter	0	1	0	2	0	2	1	2	2	1	11	14	0	0
ironcolor shiner	0	1	0	8	5	1	0	0	0	0	0	3	6	0
redeer sunfish	1	2	0	0	11	0	0	0	0	1	2	1	3	1
bluehead chub	0	0	0	3	0	2	1	2	0	0	0	5	13	104
warmouth	0	2	0	3	1	1	1	2	3	0	3	0	4	0
northern hogsucker	1	1	0	1	0	1	0	3	0	2	4	2	0	0
yellow bullhead	1	0	0	2	1	0	0	0	3	0	0	5	6	9
silver redhorse	0	0	4	0	4	0	1	2	0	2	0	1	0	0
christmas darter	1	0	0	0	0	0	0	0	3	0	6	2	2	0
dollar sunfish	0	0	0	0	0	0	0	0	2	0	0	0	10	0
bowfin	0	1	1	0	1	1	3	2	1	1	2	0	0	0
brown bullhead	0	1	0	2	0	1	2	1	1	0	2	5	0	0
yellow perch	0	2	1	0	0	0	0	4	0	0	0	0	0	0
savannah darter	0	0	1	1	0	1	0	0	1	0	0	1	3	0
tadpole madtom	1	0	0	1	1	0	0	0	3	0	0	3	1	8
mosquitofish	0	0	0	0	6	1	1	0	0	0	0	0	0	0
brook silverside	0	0	0	2	0	1	1	3	0	0	0	0	0	0
golden shiner	0	1	1	0	2	0	0	0	0	0	0	0	0	0
creek chub	0	0	0	0	0	0	0	0	0	0	0	1	4	0
black crappie	0	0	2	0	0	1	0	0	0	0	0	0	0	0
longnose gar	0	0	0	0	0	0	0	3	0	0	0	0	0	0
blackbanded sunfish	0	1	0	0	0	0	0	0	1	0	0	0	0	0
creek chubsucker	0	2	0	0	0	0	0	0	0	0	0	6	0	45
shiner (<i>Notropis</i>) spp.	0	0	1	0	0	1	0	0	0	0	0	0	0	0
channel catfish	0	0	0	1	0	0	1	1	0	0	0	0	0	0
white crappie	0	0	0	1	0	1	0	0	0	0	0	0	0	0
spottail shiner	0	0	0	0	2	0	0	0	0	0	0	0	0	0
banded pygmy sunfish	0	1	0	0	0	0	0	0	0	0	0	0	0	0
white catfish	0	0	0	0	0	0	0	1	0	0	0	0	0	0
American shad	0	0	0	0	0	0	0	1	0	0	0	0	0	0
madtom (<i>Noturus</i>) spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0
marginated madtom	0	0	0	0	0	0	0	0	0	0	0	1	0	0
flier	0	0	0	0	0	0	0	0	0	0	0	1	0	0
total no. fish	24	100	217	212	238	202	163	123	127	43	210	538	244	438
total no. species	13	25	16	26	24	28	21	27	24	17	21	26	19	10

can exert strong influences on fish assemblage structure and fish-capture probability and were probably responsible for the observed differences among station groups.

Effects of F- and H-Area Operations

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

References

- Arnett et al. 1992 Arnett, N. W., L. K. Karapatakis, A. R. Mamatey, J. L. Todd. Savannah River Site Environmental Report for 1991. WSRC-TR-92-186, Westinghouse Savannah River Company, Savannah River Site, Siken, SC (1992)
- Chimney, J. J. and W. R. Cody. Distribution and Abundance of Zooplankton at Selected Locations on the Savannah River and from Tributaries of the Savannah River Plant: December 1984-August 1985. ECS-SR-41. Report prepared by Environmental & Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1986).
- Cummins, C. L., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1989, WSRC-IM-90-60, Volume II, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1990).
- Cummins, C. L., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1990, WSRC-IM-91-28, Volume I, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1991).
- Davis, H. A., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1988. WSRC-RP-89-59-1, Volume II, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1989).
- ECS 1987 - Environmental & Chemical Sciences, Inc. Biological and Chemical Assessment of M-Area Process Discharge to Tims Branch, June 1985 - December 1986. Prepared for Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1987).
- ECS 1990 - Environmental & Chemical Sciences, Inc. Biological and Chemical Assessment of M-Area Discharge on Tims Branch, September 1988 - March 1990. Prepared for Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1990).
- Firth, P., J. R. O'Hop, B. Coler, and R. A. Green. Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat Analyses and the Lower Food Chain Communities. ECS-SR-26, Prepared for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1986).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report, Vol. III, Water Quality. DP-1697, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Lower, M. W. Comprehensive Cooling Water Study Final Report, Volume II, Water Quality. DP-1739-2, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Meffe, G. K., and A. L. Sheldon. 1988. The influence of habitat structure on fish assemblage composition in southeastern blackwater streams. *American Midland Naturalist* 119(2):225-240.
- Mikol, S. C., L. T. Burkhalter, J. L. Todd, and D. K. Martin. U.S. Department of Energy Savannah River Plant Environmental Report for 1987. DPSU-88-30-1, Volume II, E.I. duPont de Nemours and Company, Savannah River Plant, Aiken, SC (1988).
- Morse, J. C., J. W. Chapin, D. D. Herlong, and R. S. Harvey. 1980. Aquatic Insects of Upper Three Runs, Savannah River Plant, South Carolina, Part I: Orders other than Diptera. *J. Georgia Entomol. Soc.* 15:73-101.
- Morse, J. C., J. W. Chapin, D. D. Herlong, and R. S. Harvey. 1983. Aquatic Insects of Upper Three Runs, Savannah River Plant, South Carolina, Part II: Diptera. *J. Georgia Entomol. Soc.* 18(3):303-316.
- Newman, M. C., A. Dancewicz, B. Davis, K. Anderson, R. Bayer, R. Lew, R. Mealy, S. Sandhu, S. Presnell, and J. Knox. *Comprehensive Cooling Water Study Water Report, Volume 2, Water Quality*, SREL (1986).

- O'Hop, J. R., L. J. Tilly, M. J. Chimney, and W. B. Painter. Annual Report on the Savannah River Aquatic Ecology Program: October 1983 - September 1984, Volume III - Macroinvertebrates, Periphyton, and Water Quality, DPST-86-795, prepared by Environmental and Chemical Sciences, Inc., ECS-SR-23, for E. I. du Pont de Nemours and Company, Aiken, SC (1985).
- Paller, M. H. 1984. Summary of the ichthyoplankton sampling data from the creeks and swamps of the Savannah River Plant. ECS-SR-10. Environmental and Chemical Sciences, Inc., Aiken, S.C. 41 pp.
- Paller, M. H. 1992. Stream fisheries characterization study. WSRC-RP-92-1034. Westinghouse Savannah River Company, Aiken, SC
- Paller, M. H. 1993. Assessment of the effects of F- and H-Areas on fish assemblage structure in Upper Three Runs. WSRC-RP-DRAFT.
- Paller, M. H. A Report of the Ichthyoplankton Sampling Data from the Creeks and Swamps of the Savannah River Plant, March 14, 1984 Through July 31, 1984. ECS-SR-16, Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC (1985).
- Paller, M. H. and B. M. Saul. 1986. The distribution of ichthyoplankton in thermal and non-thermal streams and swamps on the Savannah River Plant. ECS-SR-25. Environmental & Chemical Sciences, Inc. Aiken, SC. 203 pp.
- Patrick and Reimer 1966 - Patrick, R., C. W. Reimer. 1966. The Diatoms of the United States, Vol. 1. Monograph No. 13, Acad. Nat. Sci., Philadelphia. 688 pp.
- Specht, W. L. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. DP-1739-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).

Chapter 11

Beaver Dam Creek

Chapter Contents

Drainage Description and Surface Hydrology (page 11-3)

Water Quality (page 11-7)

Algae (page 11-17)

Macrophytes (page 11-19)

Zooplankton (page 11-21)

Macroinvertebrates (page 11-23)

Fish (page 11-35)

References (page 11-55)

Drainage Description and Surface Hydrology

General Description

Beaver Dam Creek, which is approximately 5 km long and drains an area of approximately 2.2 km², originates at the effluent outfall canal of D Area and flows south, parallel to Four-mile Branch, to the Savannah River (Figure 11-1). The discharge of Beaver Dam Creek mixes with a portion of Fourmile Branch discharge in the Savannah River floodplain swamp before entering the Savannah River. Beaver Dam Creek is deep, narrow, and channelized in its headwaters and near its mouth and opens into a slough-like channel in its midreaches (Firth et al. 1986).

Effluents Contribution

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

Figure 11-1. Location of Beaver Dam Creek on SRS

Flow Measurements

The U. S. Geological Survey measures flow at 400-D at SRS (Figure 11-2). Flow statistics of Beaver Dam Creek at 400-D are summarized in Table 11-1; records for the station at 400-D date back to June 1974. In water year 1991, the mean flow of Beaver Dam Creek at 400-D was $2.6 \text{ m}^3/\text{s}$ ($93 \text{ ft}^3/\text{s}$). Over the period of record (water years 1974-1991) at 400-D, the mean flow was $2.4 \text{ m}^3/\text{s}$ ($84 \text{ ft}^3/\text{s}$), the 7-day low flow was $0.46 \text{ m}^3/\text{s}$ ($16.3 \text{ ft}^3/\text{s}$), and the 7Q10 was $0.99 \text{ m}^3/\text{s}$ ($35 \text{ ft}^3/\text{s}$). The maximum, minimum, and mean daily flows for the period of record at 400-D are shown in Figure 11-3.

Figure 11-2. Flow Sampling Stations on Beaver Dam Creek

Table 11-1. Flow Summary for Beaver Dam Creek

Station Name	Station Number	Period of Record	Mean		Range		7Q10		7-Day Low Flow	
			cms	(cfs)	Low cms	High (cfs)	cms	(cfs)	cms	(cfs)
at 400-D	02197326	1974-1991	2.4	84	0.40	14	3.7	130	0.99	35
									0.46	16.3

Figure 11-3. Maximum, Mean, and Minimum Flow Measurements for Beaver Dam Creek at Station 02197326

Water Quality

Studies and Monitoring

Water-Quality Monitoring

Routine water-quality monitoring of Beaver Dam Creek was conducted by the Environmental Monitoring Section (EMS) from 1973 to 1986. EMS monitored one location on Beaver Dam Creek near the Savannah River Swamp (Figure 11-4) monthly for physical and biological water quality indicators and quarterly for metals. Since 1986 water-quality measurements have been taken hourly downstream of D-Area discharge and consist of water temperature, pH, dissolved oxygen, conductivity, and oxidation/reduction potential. Water quality monitoring results for Beaver Dam Creek from 1983–1985 are summarized in Lower (1987). All routine water quality monitoring data reported in the following sections can be found in the SRS Environmental Reports, which are published annually.

Comprehensive Cooling-Water Study

From 1983 to 1985, three locations on Beaver Dam Creek were studied as part of the Comprehensive Cooling Water Study (CCWS). This study was designed to assess the impact of current and proposed SRS activities on water quality. The Beaver Dam Creek sampling locations, which are shown in Figure 11-4, included:

- Beaver Dam Creek at 400-D outfall prior to ash basin effluent
- Beaver Dam Creek downstream of 400-D ash basin effluent
- Beaver Dam Creek near confluence with Savannah River

Figure 11-4. Water Chemistry and Quality Sampling Stations for Beaver Dam Creek

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

Comprehensive results and discussion of CCWS data can be found in the "Comprehensive Cooling Water Study, Volume II: Water Quality" (SREL 1986) or in the "Comprehensive Cooling Water Study, Final Report, Volume II: Water Quality" (Lower 1987).

Priority Pollutants Survey

In 1984, a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral organic compounds in Beaver Dam Creek. One location in Beaver Dam Creek, downstream of 400-D effluent, was sampled (Figure 11-4 on page 11-7). The results of this study are documented in the "Comprehensive Cooling Water Study Final Report, Volume 2" (Lower 1987). Also reported in this document are the results of analyses for pesticides and PCBs in Beaver Dam Creek.

Chemical Assessment Studies

A 316(a) Demonstration special study was conducted in 1988 on the waters of Beaver Dam Creek to determine impacts from specific SRS operations. The data collected during the 316(a) Demonstration are reflective of the thermal flow regimes that exist when D Area is operating at a reduced power level, and is most reflective of current conditions in Beaver Dam Creek.

This study, documented in "Compliance of the Savannah River Site D-Area Cooling System with Environmental Regulations" (Specht et al. 1990), is discussed later in this chapter.

Field data

Water Temperature

Stream water temperatures at the mainstream Beaver Dam Creek sites during the CCWS ranged from 11.2 to 34.0°C, with an average temperature of 25.5°C (Table 11-2). These temperatures reflected the moderate thermal effluent associated with the stream. In Beaver Dam Creek near the confluence with the Savannah River, the temperatures were slightly lower than at the upstream sites. However, the range of temperatures was greater, reflecting river water inputs during high water conditions in the winter and the input of thermal effluents from Four Mile Creek during the spring and summer (Lower 1987). Routine monitoring on Beaver Dam Creek near the Savannah River Swamp from 1987 to 1991 indicated temperatures were comparable to those measured during the CCWS at the same location (Table 11-3). Hourly temperature measurements ranged from 5 to 32°C, with a mean temperature of 22°C.

pH Measurements

The pH measurements at all locations during the CCWS ranged from 6.00 to 7.70, with an average near 7.0 (Table 11-2). These values reflected Savannah River source water concentrations. From 1987 to 1991, hourly pH measurements ranged from 4.9 to 10.9 (Table 11-3).

Table 11-2. Water Quality Measurements in Beaver Dam Creek (1987–1991)

	Temperature (°C)	pH	Dissolved Oxygen (mg/l)	Conductivity (µmhos/cm)	Oxidation/ Reduction Potential (mV)
<i>Quarter 1 (January 1–March 31)</i>					
Hourly Maximum	28	10.9	11.9	195	446
Hourly Minimum	5	4.9	5.0	59	229
Hourly Average	16.6		9.02	112	311
<i>Quarter 2 (April 1–June 30)</i>					
Hourly Maximum	32	8.8	9.9	176	456
Hourly Minimum	13.9	5.7	4.5	44	173
Hourly Average	24.4		7.36	109	324
<i>Quarter 3 (July 1–September 30)</i>					
Hourly Maximum	31.7	8.4	9.3	302	465
Hourly Minimum	21.7	5.3	5.1	54	260
Hourly Average	26.9		6.68	105	327
<i>Quarter 4 (October 1–December 31)</i>					
Hourly Maximum	29.4	9.0	13	239	513
Hourly Minimum	7.7	5.4	2.6	54	244
Hourly Average	18.8		8.35	103	324

Blank Spaces - Mean not calculated due to insufficient data in report.

Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 11-3. Beaver Dam Creek Field Data

	Water Temperature (°C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
<i>Beaver Dam Creek at 400-D outfall prior to ash basin effluent (CCWS)</i>				
Mean	26.1	7.02	109	67
Range	14.5 - 34	6.20 - 7.60	96 - 132	23 - 106
Samples	46	46	35	41
<i>Beaver Dam Creek downstream of 400-D ash basin effluent (CCWS)</i>				
Mean	25.2	6.90	132	65
Range	11.2 - 33.3	6.20 - 7.60	113 - 159	17 - 92
Samples	45	46	39	41
<i>Beaver Dam Creek near confluence with Savannah River (CCWS)</i>				
Mean	22.1	6.81	213	44
Range	8.3 - 38.0	6.0 - 7.70	157 - 409	-45 - 118
Samples	46	46	26	39

Blank Spaces - Mean not calculated due to insufficient data in report.

CCWS - Comprehensive Cooling Water Study (SREL 1986).

Physical Characteristics and General Chemistry

Dissolved Oxygen

The mean dissolved oxygen concentration in the mainstream waters of Beaver Dam Creek was 7.25 mg O₂/l, with ranges of 5.40 to 10.0 mg O₂/l during the CCWS (Table 11-4). Near the confluence with the Savannah River (swamp), the mean dissolved oxygen concentration was much lower (5.53 mg O₂/l). The lower dissolved oxygen concentration in the swamp was likely the result of thermal input from Fourmile Branch. From 1987 to 1991, concentrations of dissolved oxygen (mean 7.85 mg O₂/l) have continued to reflect concentrations measured during the CCWS (Table 11-3).

Suspended Solids and Turbidity

Mean turbidity and total suspended solids concentrations measured during the CCWS were elevated compared to Savannah River source water concentrations (SREL 1986). SREL (1986) documented that the source water contributions and the mainstream velocity regime contributed to the conditions in Beaver Dam Creek. Suspended solids and turbidity are not measured as part of the routine monitoring program.

Conductivity

Mean specific conductance in Beaver Dam Creek ranged from 79.1 to 91.1 µmhos/cm during the CCWS (Table 11-4). These values are reflective of the specific conductance of Savannah River source water. Hourly specific conductance measurements from 1987 to 1991 ranged from 44 to 302 µmhos/cm, with a mean of 107 µmhos/cm.

Table 11-4. Beaver Dam Creek Physical Characteristics and General Chemistry

	Dissolved Oxygen (mg/l)	Specific Conductance (µmhos/cm)	Turbidity (NTU)	Total Suspended Solids (mg/l)
<i>Beaver Dam Creek at 400-D outfall prior to ash basin effluent (CCWS)</i>				
Mean	7.35	79.1	19.8	10.5
Range	5.80 - 10.0	53.0 - 96.8	6.6 - 82.3	1.0 - 31.8
Samples	46	38	43	45
<i>Beaver Dam Creek downstream of 400-D ash basin effluent (CCWS)</i>				
Mean	7.15	91.1	20.3	13.0
Range	5.40 - 9.80	20.2 - 126.0	4.7 - 78.9	0.25 - 50.0
Samples	46	38	43	45
<i>Beaver Dam Creek near confluence with Savannah River (CCWS)</i>				
Mean	5.53	79.5	21.3	16.0
Range	2.90 - 10.2	50.2 - 103.7	7.8 - 67.0	2.00 - 60.8
Samples	46	38	43	44

Blank Spaces - Mean not calculated due to insufficient data in report
CCWS - Comprehensive Cooling Water Study (SREL 1986)

Major Anions and Cations

Alkalinity, Chloride and Sulfate

Concentrations of alkalinity, chloride and sulfate in Beaver Dam Creek during the CCWS are given in Table 11-5. Total alkalinity and chloride concentrations measured during the CCWS reflected concentrations of Savannah River water. Mean total alkalinity concentrations in Beaver Dam Creek ranged from 16.7 to 18.1 mg CaCO₃/l; Savannah River concentrations ranged from 16.5 to 19.6 mg CaCO₃/l (Lower 1987). Mean chloride concentrations in Beaver Dam Creek ranged from 5.70 to 6.38 mg/l, while Savannah River concentrations ranged from 5.53 to 6.29 mg/l (Lower 1987). Sulfate concentrations during the CCWS were higher downstream (mean 11.3 mg/l) than at the upstream location (mean 6.77 mg/l). Sulfate concentrations in the Beaver Dam Creek swamp waters (mean 8.40 mg/l) were slightly reduced from the downstream location, but were elevated compared to the upstream location, and were attributed to ash basin effluent entering BDC. Total alkalinity, chloride, and sulfate are not measured as part of the routine monitoring program.

Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, sodium, and potassium in Beaver Dam Creek waters during the CCWS are given in Table 11-5 on page 11-11. Data collected during the CCWS indicated that the transport of these cations in Beaver Dam Creek was almost entirely in the dissolved phase (SREL 1986). Calcium, magnesium, sodium, and potassium are not measured as part of the routine monitoring program.

Aluminum, Manganese, and Iron

Concentrations of total aluminum, manganese, and iron measured during the CCWS are given in Table 11-6 on page 11-12. Approximately 94% of the aluminum was associated

Table 11-5. Beaver Dam Creek Major Anions

	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg/l)
<i>Beaver Dam Creek at 400-D outfall prior to ash basin effluent (CCWS)</i>			
Mean	18.1	6.27	6.77
Range	10.3 - 24.6	2.40 - 8.60	3.98 - 13.1
Samples	45	46	28
<i>Beaver Dam Creek downstream of 400-D ash basin effluent (CCWS)</i>			
Mean	17.0	6.38	11.3
Range	5.5 - 25.4	2.90 - 8.60	5.82 - 23.7
Samples	45	46	28
<i>Beaver Dam Creek near confluence with Savannah River (CCWS)</i>			
Mean	16.7	5.70	8.40
Range	10.5 - 21.8	2.90 - 7.90	2.88 - 19.0
Samples	44	46	27

Blank Spaces - Mean not calculated due to insufficient data in report
CCWS - Comprehensive Cooling Water Study (SREL 1986)

with the solid phase, 86% of the iron was in the solid phase, and about 25 to 40% of the manganese was in the solid phase (Newman 1986). The concentrations of these elements were reflective of Savannah River source water. Aluminum, manganese, and iron are not measured as part of the routine monitoring program.

Nutrients

Phosphorus

During the CCWS all phosphorus species in Beaver Dam Creek waters were found in concentrations similar to those of its source water, the Savannah River (Table 11-7). Mean concentrations of total phosphorus and total orthophosphate in the mainstream waters during the CCWS were 0.130 mg P/l and 0.100 mg P/l, respectively. In the Beaver Dam Creek swamp waters, mean concentrations of total phosphorus (0.092 mg P/l) and total orthophosphate (0.064 mg P/l) were slightly lower than at the mainstream locations. Phosphorus species are not measured as part of the routine monitoring program.

Nitrogen

During the CCWS all nitrogen species in Beaver Dam Creek waters were found in concentrations similar to those of its source water, the Savannah River (Table 11-7). Concentrations of nitrite and ammonia were lowest at the Beaver Dam Creek swamp location. Mean concentrations of nitrate were similar at all three locations, with a range of 0.310 to 0.325 mg NO₃-N/l (Table 11-7). SREL (1986) documented that at the mainstream locations, mean percentages of total nitrogen and nitrate, ammonia, and organic nitrogen were 40%, 20%,

Table 11-6. Beaver Dam Creek Major Cations (Total)

	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Aluminum (mg/l)	Iron (mg/l)	Manganese (mg/l)
<i>Beaver Dam Creek at 400-D outfall prior to ash basin effluent (CCWS)</i>							
Mean	3.37	1.35	7.66	1.04	1.09	1.16	0.113
Range	2.68 - 4.41	1.02 - 1.82	3.83 - 10.6	<0.368 - 1.73	0.359 - 4.14	0.567 - 3.81	<0.0004 - 0.412
Samples	39	39	39	39	39	39	16
<i>Beaver Dam Creek downstream of 400-D ash basin effluent (CCWS)</i>							
Mean	3.80	1.42	8.65	1.27	1.17	1.18	0.105
Range	1.34 - 4.92	0.494 - 1.92	1.83 - 12.3	<0.368 - 2.51	0.442 - 4.07	0.607 - 3.76	<0.0004 - 0.352
Samples	38	38	38	39	38	38	17
<i>Beaver Dam Creek near confluence with Savannah River (CCWS)</i>							
Mean	3.79	1.34	7.73	1.10	1.25	1.400	0.106
Range	2.70 - 12.7	0.562 - 1.66	2.58 - 11.5	<0.368 - 2.23	0.341 - 5.09	0.601 - 3.59	<0.0004 - 0.240
Samples	39	39	39	39	39	39	17

Blank Spaces - Mean not calculated due to insufficient data in report

CCWS - Comprehensive Cooling Water Study (SREL 1986)

and 40%, respectively. Nitrogen species are not measured as part of the routine monitoring program.

Trace Elements

Total trace elemental concentrations measured in Beaver Dam Creek during the CCWS largely reflected Savannah River source water concentrations (Table 11-8 on page 11-14). During the CCWS mean total arsenic concentrations ranged from 2.7 to 3.7 µg/l; total cadmium ranged from 0.55 to 0.77 µg/l; total chromium ranged from 7.7 to 11.8 µg/l; total copper ranged from 2.8 to 5.4 µg/l; total lead ranged from 2.1 to 3.1 µg/l; and total zinc ranged from 4.8 to 5.3 µg/l.

Total nickel concentrations were sometimes elevated during the CCWS, with ranges from 3.2 to 4.6 µg/l. Although not known for sure, the elevated nickel concentrations may have been the result of the 400-D Area powerhouse and ash sluicing operations (Lower 1987).

Total mercury and uranium concentrations were consistently below the analytical detection limits for those elements during the CCWS. Trace elements are not measured as part of the routine monitoring program.

Organic Carbon

Total organic carbon concentrations in Beaver Dam Creek were similar to concentrations in the Savannah River. Mean total organic carbon concentrations ranged from 5.65 to 6.75 mg C/l in Beaver Dam Creek, while the Savannah River average was

Table 11-7. Beaver Dam Creek Nutrients

	Total Phosphorus (mg P/l)	Total Ortho-phosphate (mg PO ₄ -P/l)	Organic Nitrogen (mg N/l)	Total Kjeldhal Nitrogen (mg N/l)	Ammonia (mg NH ₃ -N/l)	Nitrite (mg NO ₂ -l)	Nitrate (mg NO ₃ -N/l)
<i>Beaver Dam Creek at 400-D outfall prior to ash basin effluent (CCWS)</i>							
Mean	0.133	0.113	0.232	0.374	0.163	0.017	0.314
Range	<0.010 - 1.50	0.025 - 1.40	0.010 - 0.810	0.130 - 0.950	0.048 - 0.400	0.002 - 0.054	0.107 - 0.467
Samples	46	41	45	45	45	44	43
<i>Beaver Dam Creek downstream of 400-D ash basin effluent (CCWS)</i>							
Mean	0.127	0.096	0.204	0.330	0.133	0.018	0.325
Range	0.045 - 0.739	0.032 - 0.591	0.015 - 0.685	0.100 - 0.850	0.042 - 0.310	0.002 - 0.052	0.049 - 0.484
Samples	45	41	44	45	45	44	43
<i>Beaver Dam Creek near confluence with Savannah River (CCWS)</i>							
Mean	0.092	0.064	0.220	0.263	0.064	0.007	0.310
Range	<0.010 - 0.205	0.017 - 0.127	0.016 - 0.968	0.035 - 0.990	0.015 - 0.320	0.001 - 0.021	0.005 - 0.728
Samples	45	41	41	45	45	44	43

Blank Spaces - Mean not calculated due to insufficient data in report
CCWS - Comprehensive Cooling Water Study (SREL 1986)

6.10 mg C/l. Approximately 72 to 84% of the organic carbon was present in the dissolved phase (SREL 1986).

Priority Pollutants

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

Pesticides, Herbicides, and PCBs

Pesticides, herbicides, and PCBs are not measured in Beaver Dam Creek as part of the routine water quality monitoring program.

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 Assessment Studies

316(a) Demonstration

In 1988, a 316(a) Demonstration was initiated to determine whether a balanced indigenous biological community could be supported in Beaver Dam Creek because temperature limits

Table 11-8. Beaver Dam Creek Trace Elements (Total)

	Arsenic (µg/l)	Cadmium (µg/l)	Chromium (µg/l)	Copper (µg/l)	Lead (µg/l)	Nickel (µg/l)	Zinc (µg/l)
<i>Beaver Dam Creek at 400-D outfall prior to ash basin effluent (CCWS)</i>							
Mean	2.7	0.77	10.5	5.4	3.1	4.6	5.3
Range	<0.4 - 15.1	<0.04 - 2.52	<0.4 - 68.0	<0.4 - 14.0	<0.4 - 15.3	<0.4 - 15.4	<0.4 - 17.2
Samples	16	16	16	16	16	16	16
<i>Beaver Dam Creek downstream of 400-D ash basin effluent (CCWS)</i>							
Mean	3.7	0.55	7.7	5.4	2.1	4.6	4.8
Range	<0.4 - 21.3	<0.04 - 2.50	<0.4 - 38.0	<0.4 - 37.3	<0.4 - 5.7	<0.4 - 15.0	<0.4 - 15.0
Samples	17	17	17	17	17	17	17
<i>Beaver Dam Creek near confluence with Savannah River (CCWS)</i>							
Mean	3.2	0.57	11.8	2.8	2.4	3.2	5.2
Range	<0.4 - 23.9	<0.04 - 4.60	<0.04 - 69.0	<0.4 - 7.3	<0.4 - 10.1	<0.4 - 14.0	<0.4 - 18.0
Samples	17	17	17	17	17	17	17

Blank Spaces - Mean not calculated due to insufficient data in report

CCWS - Comprehensive Cooling Water Study (SREL 1986)

set forth in the National Pollution Discharge Elimination System permit were exceeded during D-Area operations. Seven sampling locations were selected on Beaver Dam Creek to represent different habitats of the stream. These sampling locations are shown in Figure 11-4 on page 11-7.

Forty water quality parameters were assessed monthly at the sampling stations in Beaver Dam Creek. These data are presented in Table 11-9 on page 11-16. The data show that the water quality of Beaver Dam Creek is greatly influenced by operations in 400-D Area. Generally, water quality parameters at Station 1A were consistently different from all other stations on Beaver Dam Creek. Station 1A was located in the original intermittent stream channel of the creek, upstream of the confluence of the 400-D Area discharge canal. However, this station was usually dry, except after periods of heavy rainfall, and the water collected was reflective of rainwater runoff.

Station 1A had the lowest mean values for pH, conductivity, dissolved oxygen, temperature, ortho-phosphorus, sulfate, nitrate, total phosphorus, and dissolved and total strontium. Means for total hardness, total suspended solids, turbidity, dissolved and total aluminum, dissolved and total barium, dissolved and total iron, total lead, dissolved and total manganese, and total zinc were higher at Station 1A than at the other stations. Excluding Station 1A means for the study period were generally similar among stations on Beaver Dam Creek (Table 11-9).

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

Table 11-9. Mean Values for Water Chemistry Parameters at Stations Sampled in Beaver Dam Creek (Source: Specht et al. 1990)

Parameter	Station						
	1	1A ^a	2	3	4	5	6
temperature (°C)	19.9	13.2	19.8	19.4	19.1	18.8	18.7
pH	6.76	4.42	6.68	6.60	6.58	6.50	6.51
dissolved oxygen (mg/l)	8.43	6.21	8.34	8.00	7.76	7.70	7.92
conductivity (mS/cm)	129	57	131	128	127	128	124
turbidity (NTU)	16.7	98.1	13.6	13.8	12.8	13.4	17.0
total suspended solids (mg/l)	17	105	14	19	14	16	22
total hardness (mg CaCO ₃ /l)	22.1	25.6	22.4	23.1	22.7	23.4	22.4
sulfate (mg SO ₄ /l)	19.8	9.7	19.1	18.7	18.4	17.8	17.0
total aluminum (µg/l)	611	1776	596	630	641	710	802
total iron (µg/l)	906	2362	982	1129	1039	1094	1286
total manganese (µg/l)	96	421	97	108	104	108	131
total phosphorus (mg P/l)	0.137	0.060	0.134	0.136	0.130	0.127	0.135
orthophosphate (mg P/l)	0.076	0.007	0.077	0.075	0.072	0.069	0.069
nitrate (mg N/l)	0.41	0.04	0.42	0.43	0.42	0.42	0.40
total arsenic (µg/l)	3.4	0.8	3.9	3.3	3.1	2.9	2.7
total barium (µg/l)	26.9	56.9	27.8	28.3	28.4	27.7	28.3
total cadmium (µg/l)	1	1	0.1	1	1	1	0
total chromium (µg/l)	3	4	5	3	4	3	3
total copper (µg/l)	1	3	3	3	3	3	4
total lead (µg/l)	3.8	6.1	3.0	1.7	1.9	2.8	2.1
total mercury (µg/l)	0.04	0.05	0.05	0.05	0.05	0.20	0.03
total selenium (µg/l)	1.2	0.8	1.0	1.0	1.1	0.9	0.8
total silver (µg/l)	0.06	0.05	0.12	0.10	0.82	0.06	0.05
total strontium (µg/l)	45.9	19.9	46.9	46.1	46.7	45.2	43.7
total zinc (µg/l)	1.0	21	10	10	11	8	9

^aFive sampling dates

Algae

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

Macrophytes

Introduction

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

Clean Water Act Compliance Study

Although the Beaver Dam Creek ecosystem was examined from September 1988–February 1990 for compliance of the D-Area cooling system with section 316(a) of the Clean Water Act (Specht et al. 1990), the aquatic macrophyte communities were not closely examined. A larger-scale evaluation of the condition and development of wetland vegetation from that document serves as an indicator of conditions existing for the development of the aquatic macrophyte community. Wetland vegetation data indicate that the Beaver Dam Creek delta (and, by inference, the entire Beaver Dam Creek system) is revegetating. These gains can most likely be attributed to the declines in temperature and flows within the system since the early 1970s (Specht et al. 1990).

Comprehensive Cooling Water Study

The Beaver Dam Creek aquatic macrophyte community was also examined during the CCWS (Volume IV, Specht 1987). Data from the only station sampled for macrophytes in 1983–1984 show 28 taxa total; of the 28 taxa, 4 were found growing in the stream channel, and the remainder were found growing in the riparian area. Macrophyte data from a different single station were collected during October 1984–September 1985. Eight taxa were found in measurable quantities (Table 11-10 on page 11-20). Differences were found between spring–summer values and those of fall–winter sampling periods. Most aquatic macrophyte growth was in backwaters and along the creek margins (Volume IV, Specht 1987). The number of taxa and population parameters compare favorably with those for at least one nonthermal stream location surveyed during the same sampling period.

Effects of Reduced Power Plant Operation

Normal successional patterns and development of macrophyte beds would be expected to continue in suitable sections of Beaver Dam Creek with the reduced operation of the D Area power plant. This expectation will not be able to be supported or refuted due to the lack of future observations and data. There may be adequate justification for either resampling of the areas studied during the CCWS or a survey of the entire stream to document the development of the macrophyte community.

Table 11-10. The Annual Mean, Number of Reaches Mapped During Year (M) and Standard Deviation (s) October 1984–September 1985 (Source: Firth et al. 1986)

Species	Station 7 (BD-t)								
	Area m ² /m ²		Volume m ³ /m ²		Biomass g/m ²		Percent Cover		N
	Mean	s	Mean	s	Mean	s	Mean	s	
<i>Alternanthera philoxeroides</i>	0.0133	0.0310	0.0015	0.0035	1.437	3.269	1.333	3.097	20
<i>Callitriche heterophylla</i>	0.0008	0.0015	0.0002	0.0003	0.0905	0.1731	0.1048	0.1905	20
<i>Ceratophyllum demersum</i>	0.0849	0.0464	0.0220	0.0167	11.62	9.322	8.824	6.067	20
<i>Hydrocotyle ranunculoides</i>	0.0001	0.0002	<0.0001	<0.0001	0.0015	0.0058	0.0062	0.2444	20
<i>Leersia</i> sp.	0.0026	0.0063	0.0002	0.0007	0.3085	0.7610	0.2643	0.6326	20
<i>Lemna</i> spp. (and occasional <i>Spirodela fronds</i>)	0.0038	0.0062	-	-	0.5661	1.113	0.4621	0.7724	20
Unidentified	0.0033	0.0060	-	-	-	-	0.3305	0.6017	20
<i>Polygonus</i> spp.	0.0078	0.0161	-	-	3.486	7.210	0.8340	1.696	20

Zooplankton

Comprehensive Cooling Water Study

Chimney and Cody (1986) studied the zooplankton in Beaver Dam Creek for regulatory compliance issues covered by the Clean Water Act (Sections 316a). The study documented the temporal and spatial characteristics of zooplankton species based on quarterly sampling from December 1984 to August 1985. Surface-water grab samples were collected at two stations approximately one-third distance down the channel. Species richness was comprised of 7 Protozoa, 15 Rotifera, 14 Cladocera, 4 Copepoda, and one Ostracoda; Steel Creek was the only stream on SRS with a higher species richness. Figure 11-5 indicates that the greatest densities occurred during March 1985 and May 1985. During March 1985 Cladocera dominated the assemblage, and during May 1985 Protozoa and Copepods were most abundant.

Regulatory Compliance Study

Specht et al. (1990) performed a study in Beaver Dam Creek from September 1988 to February 1990 to meet regulatory compliance of the D-Area cooling system. Results were based on seven sampling stations distributed throughout the length of the stream at approximately equal intervals. Species richness during these years averaged 26 Protozoa, 27 Rotifera, 7 Cladocera, 8 Copepoda, and one Ostracoda. Figure 11-6 on page 11-22 illustrates the mean monthly zooplankton densities. Seasonal patterns were different from the results in 1985, probably due to sampling differences and large natural variability in abundances. Note the large and typical standard errors associated with this variation. These results are representative of most zooplankton populations in flowing water habitats.

Figure 11-5. Mean Density Total Zooplankton in Beaver Dam Creek, 1984–1985

Figure 11-6. Mean Density Total Zooplankton in Beaver Dam Creek, 1988–1990

Macroinvertebrates

Sampling Locations and Methods

Comprehensive Cooling Water Study

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

From November 1983 through September 1985, as part of the Comprehensive Cooling Water Study, macroinvertebrates were sampled monthly at five stations in Beaver Dam Creek (Figure 11-7) using Hester-Dendy multiplate samplers, leaf bags, and drift nets; at three of these five stations, macroinvertebrates were also collected from aquatic macrophytes (Kondratieff and Kondratieff 1984, 1985; Firth et al. 1986). The Comprehensive Cooling Water Study macroinvertebrate data was summarized by Specht (1987).

Clean Water Act Compliance Study

In support of a 316(a) Demonstration, macroinvertebrate sampling was also conducted monthly at six stations in Beaver Dam Creek (Figure 11-7) from September 1988 through February 1990 using Hester-Dendy multiplate samplers and quarterly using drift nets and dip nets (Specht et al. 1990). Detailed sampling methods for the 1988–1990 program can be found in Nagle et al. (1990). Stream temperatures in Beaver Dam Creek averaged several degrees cooler during the 1988–1990 study than during the 1983–1985 study, due to reduced power production at the D-Area power house.

Figure 11-7. Macroinvertebrate Sampling Stations for Beaver Dam Creek

Results

Introduction

The thermal regime that existed in 1988–1990 is similar to that of present (1993) conditions; therefore, the macroinvertebrate data from 1988–1990 should be representative of present conditions. Most of the data presented and discussed in this section are Hester-Dendy data from the 1984–1985 and 1988–1990 sampling programs, since these are the most comparable data sets, with respect to sampling methods and stations.

Number of Taxa

In 1984–1985, the total number of macroinvertebrate taxa collected on Hester-Dendy multiplate samplers at each of the five sampling stations ranged from 36 to 61, while in 1988–1990, excluding chironomid genera, the number of taxa collected at the six sampling stations was slightly higher, ranging from 41 to 64 (Table 11-11). In both sampling programs, the most upstream station had the fewest taxa, while the slough-like area (Station 7 in 1984–1985, Station 4 in 1988–1990) had the most taxa.

For all sampling methods combined, 163 macroinvertebrate taxa were collected from Beaver Dam Creek during the 1988–1990 sampling program (Table 11-16 on page 11-29). Of these taxa, 124 were collected on the multiplate samplers and 39 were collected exclusively by the supplemental sampling methods. Taxa that were most likely to be missed or under-represented by the multiplate samplers included some species of mollusks (Gastropoda and Pelecypoda), dragonflies and damselflies (Odonata), most aquatic bugs (Hemiptera), and many aquatic beetles (Coleoptera). Many of these taxa are exclusively benthic and do not readily colonize artificial substrates that are above the stream bottom. Taxa that are likely to be over-represented on the multiplate samplers include many species of chironomids, at least one of which (*Stenochironomus*) actively burrowed into the plates of the multiplate samplers in large numbers, but was rarely collected on natural substrates in Beaver Dam Creek.

Table 11-11. Total Number of Macroinvertebrate Taxa Collected on Multiplate Samplers in Beaver Dam Creek (October 1984–September 1985, September 1988–February 1990 (Source: Specht et al. 1990)

Beaver Dam Creek Station		All Taxa		Taxa Richness Less Chironomidae
1984–1985 ^a	1988–1990 ^b	1984–1985 ^a	1988–1990 ^b	1988–1990 ^b
5 ^c	—	36	—	—
—	1	—	67	41
—	2	—	69	47
6	3	42	71	44
7	4	61	92	64
8	5	50	68	46
9 ^d	6	47 ^c	82	57

Source: ^a Specht (1987)

^b Specht et al. (1990)

^c Station 5 was located approximately 0.8 km upstream from Station 1 (1988–1990), in the D-area discharge canal.

^d Chimney and Cody (1986b)

Densities

The mean density of macroinvertebrates collected on multiplate samplers ranged from 921.2 to 1776.5 organisms/m² in 1984–1985 and from 773.7 to 2348.0 organisms/m² in 1988–1990 (Table 11-12). Densities at upstream stations (1, 2, and 3) were generally higher than at downstream stations (4, 5, and 6) throughout the sampling programs. Densities were fairly comparable between studies for any given station. The mean biomass of macroinvertebrates ranged from 0.076 to 0.220 g ash-free dry-mass (AFDM)/m² in 1984–1985, while biomass in 1988–1990 was substantially higher at most stations, ranging from 0.200 to 0.409 g AFDM/m² (Table 11-12).

Dominant Species

As a group, Chironomidae were by far the most common macroinvertebrates in Beaver Dam Creek in 1988–1990, comprising from 51.1% (Station 5) to 75.9% (Station 1) of the organisms collected from the multiplate samplers (Table 11-13 on page 11-27). At Stations 1 through 4, the chironomid subfamily Orthocladiinae was the most abundant macroinvertebrate taxon, accounting for 22.4 to 29.6% of the organisms collected, while at Stations 5 and 6, chironomids of the tribe Chironomini were most abundant (20.6 and 25.1%, respectively). Tanytarsini chironomids were also abundant at all stations comprising 8.4 to 19.9% of the organisms collected. Other groups of macroinvertebrates that contributed at least 5% to the total density at one or more stations included mayflies (Ephemeroptera; 0.8 to 26.5%), caddisflies (Trichoptera; 2.1 to 11.8%), beetles (Coleoptera; 1.0 to 11.9%), oligochaete worms (1.4 to 6.6%), and non-chironomid dipterans (0.8 to 5.6%; Table 11-13).

Differences Among Sampling Stations

In 1988–1990, Station 1 had fewer macroinvertebrate taxa and slightly lower biomass than the other sampling stations (Table 11-11 on page 11-24 and Table 11-12), but was similar to the other sampling stations with respect to densities of organisms and mean number of taxa

Table 11-12. Mean Density and Biomass of Macroinvertebrates Collected on Multiplate Samples in Beaver Dam Creek (October 1984–September 1985, September 1988–February 1990) (Source: Specht et al. 1990)

Beaver Dam Creek Station		Mean Density (No./m ²)		Mean Biomass (g AFDM/m ²)	
1984–1985 ^a	1988–1990 ^b	1984–1985 ^a	1988–1990 ^b	1984–1985 ^a	1988–1990 ^b
5 ^c	—	1626.9	—	0.118	—
—	1	—	1636.0	—	0.185
—	2	—	2348.0	—	0.273
6	3	1776.5	1867.2	0.076	0.225
7	4	1131.9	1451.8	0.173	0.394
8	5	921.2	773.8	0.170	0.215
9	6	1253.6	1295.8	0.220	0.222

Source: ^a Specht (1987). Station numbers used in the 1984–1985 study differ from those used in the 1989–1990 study.

^b Specht et al. (1990)

^c Station 5 was located approximately 0.8 km upstream from Station 1 (1988–1990), in the D-Area discharge canal.

(Table 11-14). There were some indications of longitudinal changes in the relative abundances of macroinvertebrate taxonomic groups in Beaver Dam Creek. Station 1 had the lowest relative abundance of mayflies (0.8%) and the highest relative abundance of chironomids (75.9%; Table 11-13) of all of the stations. In general, the relative abundance of mayflies increased in a downstream direction and beetles (Coleoptera) were much more abundant at Stations 5 and 6 (11.9 and 5.1%, respectively) than at the four upstream stations (1.0 to 2.1%; Table 11-13). Conversely, trichopterans were more abundant at the three upstream stations (5.9 to 11.8%) than at the three downstream stations (2.1 to 4.8%; Table 11-13).

Taxonomic Composition Changes Since 1984–1985

The taxonomic composition of Beaver Dam Creek has changed substantially since 1984–1985, with most stations exhibiting increases in the relative abundance of mayflies (*Ephemeroptera*), snails (*Gastropoda*), beetles (*Coleoptera*), caddisflies (*Trichoptera*), and Tanytarsini chironomids, and an overall decline in the relative abundance of Chironomini chironomids Table 11-13 and Table 11-15 on page 11-28). Many species of Chironomini are generally considered to be pollution-tolerant (Beck 1977), while most species of mayflies and caddisflies are intolerant of poor water quality (Hynes 1970). Therefore it appears that, with respect to taxonomic composition, the macroinvertebrate community of Beaver Dam Creek has undergone substantial improvement since 1984–1985.

Table 11-13. Mean Relative Abundance (Percent Composition) of Higher Order Taxonomic Groups of Macroinvertebrates from Quantitative Sampling in Beaver Dam Creek, September 1988–February 1990
(Source: Specht et al. 1990)

Taxon	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6
Coelenterata	<0.01	0.00	<0.01	0.00	0.01	0.00
Turbellaria	0.08	0.09	0.20	0.34	0.33	0.06
Nematoda	0.40	0.52	0.24	0.20	0.08	0.17
Polychaeta	0.00	<0.01	<0.01	<0.01	0.00	0.00
Oligochaeta	5.30	6.55	4.68	4.59	1.35	3.26
Hirudinea	0.01	0.01	0.01	0.05	0.00	0.02
Gastropoda	3.93	3.20	1.78	1.85	3.33	1.49
Pelecypoda	0.00	0.00	0.00	0.01	0.00	0.00
Hydracarina	0.25	0.62	0.47	0.45	0.43	0.44
Isopoda	0.00	0.00	0.06	0.18	0.02	0.00
Amphipoda	0.03	0.01	0.06	0.53	0.08	0.16
Decapoda	0.00	0.00	0.00	0.28	0.00	0.00
Collembola	0.00	0.04	0.00	0.01	0.03	0.00
Ephemeroptera	0.75	9.06	12.42	12.14	26.52	18.72
Odonata	0.08	0.17	0.24	1.28	0.18	0.30
Plecoptera	0.00	0.00	0.01	0.00	0.01	0.10
Hemiptera	0.00	<0.01	0.00	0.00	0.00	0.00
Coleoptera	1.72	1.04	2.09	1.29	11.87	5.09
Megaloptera	0.17	0.20	0.16	0.25	0.24	0.12
Neuroptera	0.00	0.00	0.00	0.00	0.00	0.01
Trichoptera	5.86	11.80	6.02	4.83	2.09	4.03
Lepidoptera	<0.01	0.03	0.05	0.18	0.07	0.01
Non-chir. Diptera	5.55	3.94	2.35	0.82	2.25	1.92
Chironomidae (unid.)	8.51	4.05	4.24	6.62	3.02	6.53
Orthocladiinae	27.54	28.99	29.64	22.43	18.12	15.87
Tanypodinae	1.35	1.30	1.73	2.81	0.90	1.65
Tanytarsini	14.43	15.01	19.93	19.72	8.43	15.02
Chirononini	24.01	13.24	13.53	18.87	20.64	25.00
Diamesiinae	0.02	0.16	0.08	0.25	0.01	0.05
Totals	100.00	100.00	100.00	100.00	100.00	100.00

Table 11-14. Descriptive Statistics for Total Macroinvertebrate Densities (Organisms/m²) and Mean Number of Taxa from Quantitative (Multiplate) Sampling in Beaver Dam Creek, September 1988–February 1990 (Source: Specht et al. 1990)

Station	Mean	Med ^a	N	SD ^a	CV ^a	Min ^a	Max ^a	Mean No. of Taxa
1	1636.0	1273.7	90	1179.4	72.1	5.6	6463.7	16.2
2	2348.0	2069.8	90	1272.3	54.2	597.8	6257.0	22.2
3	1867.3	1379.9	89 ^b	1392.2	74.6	162.0	6011.2	19.6
4	1451.8	1125.7	90	1241.8	85.5	44.7	6430.2	21.2
5	773.8	698.3	90	534.4	69.1	50.3	2910.6	14.3
6	1295.8	1167.6	85 ^c	707.9	54.6	273.7	3804.5	18.4

^a Abbreviations: Med - Median; N - Total number of samples analyzed; SD - Standard Deviation; CV - Coefficient of Variation; Min - Minimum; Max - Maximum.

^b Only four samples were collected at Station 3 in January 1989.

^c Samples were not retrieved from Station 6 in February 1990 due to high water levels.

Table 11-15. Mean Relative Abundance (Percent Composition) of Higher Order Taxonomic Groups of Macroinvertebrates Collected on Hester Dendy Multiplate Samplers, October 1984–September 1985 (Source: Specht et al. 1990)

Taxon	Station				
	5	6	7	8	9
Coelenterata	0.00	0.00	0.00	0.00	0.0
Turbellaria	0.02	0.33	3.98	1.63	0.2
Nematoda	0.56	0.3 ^a	0.30	0.60	0.2
Polychaeta	0.00	0.00	0.00	0.00	0.0
Oligochaeta	7.60	4.69	16.64	6.44	2.0
Hirudinea	0.00	0.00	0.07	0.06	<0.1
Gastropoda	0.74	1.86	1.14	1.20	<0.1
Pelecypoda	0.00	0.00	0.02	0.02	<0.1
Hydracarina	0.10	0.64	0.80	0.52	0.7
Isopoda	0.00	0.05	0.12	0.16	<0.1
Amphipoda	0.02	0.24	0.89	0.30	<0.1
Decapoda	0.00	0.00	0.00	0.00	0.0
Collembola	0.00	0.00	0.00	0.00	0.0
Ephemeroptera	0.64	3.47	10.28	18.62	12.4
Odonata	0.09	0.14	1.07	0.14	<0.1
Plecoptera	0.00	0.00	0.02	0.05	0.2
Hemiptera	0.00	0.00	0.00	0.00	0.0
Coleoptera	0.15	0.04	0.54	3.02	5.5
Megaloptera	0.07	0.02	0.16	0.22	2.2
Neuroptera	0.00	0.00	0.00	0.00	0.0
Trichoptera	0.31	0.59	3.43	9.81	3.2
Lepidoptera	0.00	0.01	0.14	0.05	0.0
Non-chir. Diptera	2.13	4.50	1.64	1.58	2.7
Chironomidae (unid.)	7.36	6.47	3.29	2.91	48.5
Orthocladiinae	8.58	27.60	6.45	15.27	a
Tanypodinae	0.67	1.68	4.73	1.53	1.3
Tanytarsini	4.91	9.06	7.07	10.19	20.7
Chironomini	66.05	38.23	37.20	25.65	a
Diamesiinae	0.00	0.00	0.02	0.02	a
Total ^b	100.00	100.01	100.00	99.99	99.8

^a Taxa were grouped in "Chironomidae"

^b Some totals may not equal 100.00 due to rounding

Source: Stations 5, 6, 7, 8 calculated from Firth et. al. (1986)

Station 9 calculated from Chimney and Cody (1966b)

Table 11-16. Macroinvertebrate Taxa Found in Beaver Dam Creek, All Sampling Methods Combined. "X" Denotes Quantitative (Multiplate) Sampling and "*" Denotes Qualitative Sampling (Dip Nets and Drift) Only (September 1988–February 1990) (Source: Specht et al. 1990)

Class/Order	Taxon	Station					
		1	2	3	4	5	6
Coelenterata	<i>Hydra</i>	X	*	X	*	X	
Platyhelminthe	Class Turbellaria	X	X	X	X	X	X
Nematoda	Phylum Nematoda	X	X	X	X	X	X
Polychaeta	<i>Manayunkia</i> sp.	*	X	X	X	*	
Oligochaeta	Class Oligochaeta (unid.)	X	X	X	X	X	X
Hirudinea	Class Hirudinea	X	X	X	X	*	X
Gastropoda	Class Gastropoda (unid.)	X	X	X	X	X	X
Gastropoda	Family Ancyliidae (unid.)	X	X	X	X	X	X
Gastropoda	<i>Amnicola</i> spp.		X		X	X	X
Gastropoda	<i>Pseudosuccinea coumella</i>		*	*	*	*	X
Gastropoda	<i>Physella heterostrophia</i>	X	X	X	X	X	X
Gastropoda	Family Planorbidae (unid.)	*				*	*
Gastropoda	<i>Helisoma</i> spp				*		
Gastropoda	<i>Helisoma trivolvis</i>				X		
Gastropoda	<i>Menetus dilatatus</i>		*	X	X		X
Gastropoda	<i>Campeloma decisum</i>				*		*
Gastropoda	<i>Succinea</i> sp.		*		*		
Pelecypoda	Class Pelecypoda (unid.)	X		X	X		
Pelecypoda	<i>Corbicula fluminea</i>	*	*	*	*		*
Pelecypoda	Family Sphaeriidae				X		
Isopoda	Order Isopoda (unid.)			X			
Isopoda	<i>Asellus</i> sp.			X	X	X	
Amphipoda	Order Amphipoda (unid.)	X	X	X	X	X	X
Amphipoda	<i>Gammarus fasciatus</i>	X	X	X	X	X	X
Amphipoda	<i>Hyaella azteca</i>	*	*	X	X	X	X
Decapoda	<i>Palaemonetes paludosus</i>	*	*	*	X	*	*
Decapoda	Family Cambaridae (unid.)		*		X		
Decapoda	<i>Procambarus</i> sp.	*	*	*	X	*	*
Collembola	Order Collembola	*	X	*	X	X	*
Hydracarina	Order Hydracarina	X	X	X	X	X	X
Ephemeroptera	Order Ephemeroptera (unid.)	X	X	X	X	X	X
Ephemeroptera	Family Baetidae (unid.)	X	X	X	X	X	X
Ephemeroptera	<i>Baetis</i> sp.	X	X	X	X	X	X
Ephemeroptera	<i>Pseudocloeon</i> sp.				*		
Ephemeroptera	<i>Caenis</i> sp.	X	X	X	X	*	X
Ephemeroptera	Family Ephemerellidae (unid.)	X	X	*			
Ephemeroptera	<i>Ephemerella</i> sp.						X
Ephemeroptera	<i>Eurylophella</i> spp.		X	*	X	*	X
Ephemeroptera	<i>Eurylophella temporalis</i>				X		X
Ephemeroptera	Family Heptageniidae (unid.)	X	X	X	X	X	X
Ephemeroptera	<i>Heptagenia</i> sp.					X	X
Ephemeroptera	<i>Pseudiron</i> sp.						X
Ephemeroptera	<i>Stenacron</i> sp.					X	X
Ephemeroptera	<i>Stenonema</i> sp.	X	X	X	X	X	X
Ephemeroptera	<i>Tricorythodes</i> sp.	X	X	X	X	X	X
Odonata	Order Odonata (unid.)	X		X	X		

Table 11-16. (cont)

Class/Order	Taxon	Station					
		1	2	3	4	5	6
Odonata	Suborder Anisoptera (unid.)	*	X	X	X	X	X
Odonata	<i>Boyeria</i> spp.	X		X		*	
Odonata	<i>Boyeria vinosa</i>					*	X
Odonata	<i>Neurocordulia molesta</i>	X					
Odonata	<i>Tetragoneuria</i> sp.				X		
Odonata	Family Gomphidae (unid.)	*			X		*
Odonata	<i>Dromogomphus</i> sp.	*	*		*		
Odonata	<i>Dromogomphus spinosus</i>						*
Odonata	<i>Gomphus</i> spp.	*	*	*	*		*
Odonata	<i>Progomphus</i> sp.	*					
Odonata	Family Libellulidae (unid.)			X	X		
Odonata	<i>Erythemis simplicicollis</i>			*	X		
Odonata	<i>Erythrodiplax</i> spp.				X		
Odonata	<i>Libellula</i> spp.		*		*		
Odonata	<i>Didymops transversa</i>		X	X			X
Odonata	<i>Macromia</i> spp.	*		*	X		X
Odonata	Suborder Zygoptera (unid.)	X	X	X	X	X	X
Odonata	Family Calopterygidae (unid.)	X	X	X	X	X	X
Odonata	<i>Calopteryx augustipennis</i>		*				
Odonata	<i>Hetaerina</i> spp.	*	X	X	X	X	X
Odonata	<i>Hetaerina titia</i>	X	X	X	X	X	
Odonata	Family Coenagrionidae (unid.)	*	X	X	X	X	X
Odonata	<i>Argia</i> spp.	X	X	X	X	X	X
Odonata	<i>Enallagma</i> spp.	*	*	*	X	X	X
Odonata	<i>Ischnura</i> spp.			*	X		
Odonata	<i>Nehalennia</i> spp.			*	*		
Plecoptera	Order Plecoptera (unid.)			X			X
Plecoptera	Family Nemouridae						X
Plecoptera	Family Perlidae (unid.)						X
Plecoptera	<i>Acroneuria abnormis</i>					X	
Plecoptera	<i>Perlesta</i> spp.						X
Hemiptera	Order Hemiptera (unid.)			*			*
Hemiptera	<i>Belostoma</i> sp.		*	*	*		
Hemiptera	Family Corixidae (unid.)		X	*	*	*	*
Hemiptera	<i>Trichocorixa</i> spp.						*
Hemiptera	Family Gerridae (unid.)		*			*	*
Hemiptera	<i>Merragata</i> sp.			*			*
Hemiptera	<i>Hydrometra</i> sp.	*					*
Hemiptera	<i>Mesovelia</i> sp.				*		
Hemiptera	<i>Paravelia</i> sp.				*		
Coleoptera	Order Coleoptera (unid.)		*		X		
Coleoptera	Family Chrysomelidae		*				
Coleoptera	Family Curculionidae		X	X	*	X	X
Coleoptera	Family Dytiscidae (unid.)		X	*	*	*	
Coleoptera	<i>Agabates acuductus</i>			*			
Coleoptera	<i>Hydroporus</i> sp.		*		X		X
Coleoptera	<i>Laccophilus</i> sp.						*
Coleoptera	Family Elmidae (unid.)	X	X	X	X	X	X
Coleoptera	<i>Ancyronyx variegatus</i>	X	X	X	X	X	X

Table 11-16. (cont)

Class/Order	Taxon	Station					
		1	2	3	4	5	6
Coleoptera	<i>Macronychus glabratus</i>	X	X	X	X	X	X
Coleoptera	<i>Microcylloepus pusillus</i>	X	X	X	X	X	X
Coleoptera	<i>Stenelmis</i> sp.	X	X	X	X	X	X
Coleoptera	<i>Ectopria nervosa</i>					*	
Coleoptera	Family Gyrinidae (unid.)				X		X
Coleoptera	<i>Dineutus</i> sp.	X	X	X	X	X	X
Coleoptera	<i>Gyrinus</i> sp.			*		*	X
Coleoptera	<i>Halipus</i> spp.						*
Coleoptera	<i>Pelodytes</i> spp.		*	*	X	*	*
Coleoptera	Family Helodidae (unid.)		*				
Coleoptera	<i>Hydrochus</i> spp.			*	X		
Coleoptera	Family Hydrophilidae (unid.)		X	*			
Coleoptera	<i>Berosus</i> sp.		*		X		*
Coleoptera	<i>Enochrus</i> spp.					*	
Coleoptera	<i>Sperchopsis</i> sp.					*	
Coleoptera	Family Noteridae (unid.)		X				
Coleoptera	<i>Hydrocanthus</i> sp.				*	X	
Coleoptera	<i>Notomicrus</i> sp.	*					
Coleoptera	<i>Suphisellus</i> sp.	*	*	*	*		
Megaloptera	Family Corydalidae (unid.)	X	X	X	X	X	X
Megaloptera	<i>Chauliodes</i> sp.	*		*	X	*	
Megaloptera	<i>Corydalus cornutus</i>	X	X	X	X	X	X
Neuroptera	<i>Climacia areolaris</i>						X
Trichoptera	Order Trichoptera (unid.)	X	X	X	X	X	X
Trichoptera	Family Hydropsychidae (unid.)	X	X	X	X	X	X
Trichoptera	<i>Cheumatopsyche</i> spp.	X	X	X	X	X	X
Trichoptera	<i>Hydropsyche</i> spp.	X	X	X	X	X	X
Trichoptera	<i>Macrostemum carolina</i>				X		
Trichoptera	Family Hydroptilidae (unid.)	X	X	X	X	X	X
Trichoptera	<i>Hydroptila</i> sp.	X	X	X	X	X	X
Trichoptera	<i>Mayatrichia</i> sp.		X				
Trichoptera	<i>Orthotrichia</i> sp.		*				
Trichoptera	<i>Oxyethira</i> sp.		X	*	X		*
Trichoptera	Family Leptoceridae (unid.)		X	X	X		X
Trichoptera	<i>Ceraclea</i> sp.				X		
Trichoptera	<i>Nectopsyche</i> sp.	X	X	X	X	X	X
Trichoptera	<i>Nectopsyche candida</i>	*	*	*	*	*	
Trichoptera	<i>Oecetis</i> sp.	X	X	X	X	X	X
Trichoptera	<i>Triaenodes</i> spp.	X	X	X	X	*	X
Trichoptera	<i>Pycnopsyche</i> sp.		*	*			
Trichoptera	Family Philopotamidae (unid.)					X	
Trichoptera	<i>Chimarra</i> sp.	X	X	X	X	X	X
Trichoptera	Family Polycentropodidae	X	X	X	X	X	X
Trichoptera	<i>Cernotina</i> sp.	*			X		X
Trichoptera	<i>Cyrnellus</i> sp.						X
Trichoptera	<i>Neureclipsis</i> sp.	X	X	X	X	X	X
Trichoptera	<i>Polycentropus</i> sp.				X		
Lepidoptera	Order Lepidoptera (unid.)		X	X	X		
Lepidoptera	Family Pyralidae (unid.)	X	X	X	X	X	

Table 11-16. (cont)

Class/Order	Taxon	Station					
		1	2	3	4	5	6
Lepidoptera	<i>Munroessa</i> sp.				X		
Lepidoptera	<i>Neargyactis</i> sp.		*	*	X		
Lepidoptera	<i>Paraponyx</i> sp.		X	X	X	X	X
Lepidoptera	<i>Synclita</i> sp.		*	*	*	*	
Diptera	Order Diptera (unid.)		*	X	*	X	*
Diptera	Family Tipulidae (unid.)						*
Diptera	<i>Helius</i> sp.					*	
Diptera	<i>Limonia</i> sp.	X					
Diptera	<i>Tipula</i> sp.		X			X	
Diptera	<i>Telmatoctopus</i> sp.	X	X			X	
Diptera	<i>Chaoborus punctipennis</i>	X	X	X	X	X	*
Diptera	Family Culicidae (unid.)			*	*		*
Diptera	<i>Aedes</i> sp.			*			
Diptera	<i>Anopheles</i> sp.			*	*		*
Diptera	<i>Simulium</i> sp.	X	X	X	X	X	X
Diptera	Family Ceratopogonidae (unid.)	*	X		X		*
Diptera	Subfamily Ceratopogoniinae	X	X	X	X	X	X
Diptera	Subfamily Forcipomyiinae	X	X	X	X	X	X
Diptera	Family Chironomidae (unid.)	X	X	X	X	X	X
Diptera	Subfamily Tanypodinae (unid.)	X	X	X	X	X	X
Diptera	<i>Clinotanypus</i> sp.		*	*	X		*
Diptera	<i>Coelotanypus</i> sp.		*				
Diptera	<i>Nilotanypus</i> sp.		X				X
Diptera	<i>Procladius</i> sp.		*	*	X		*
Diptera	Tribe Pentaneuriini (unid.)		*				
Diptera	<i>Ablabesmyia</i> sp.	X	X	X	X	X	X
Diptera	<i>Conchapelopia</i> gr.	X		X		X	
Diptera	<i>Labrundinia</i> sp.	X	X	X	X	X	X
Diptera	<i>Larsia</i> sp.	X	X				
Diptera	<i>Monopelopia</i> sp.	X	X	X	X	X	X
Diptera	<i>Potthastia</i> sp.	X	X	X	X	X	X
Diptera	Subfamily Orthocladiinae	X	X	X	X	X	X
Diptera	<i>Brillia</i> sp.	X	X	X	X	X	X
Diptera	<i>Cardiocladius</i> sp.	X					
Diptera	<i>Cricotopus</i> sp.	X	X	X	X	X	X
Diptera	<i>Cricotopus bicinctus</i> gr.	X	X	X	X		X
Diptera	<i>Nanocladius</i> sp.	X	X	X	X	X	X
Diptera	<i>Parakiefferiella</i> sp.	*		X			
Diptera	<i>Parametriocnemus</i> sp.	X	X	X	X	X	X
Diptera	<i>Rheocricotopus</i> sp.	X	X	X	X	X	X
Diptera	<i>Symposiocladius</i> sp.	X	X	X	X	X	X
Diptera	<i>Tvetenia</i> sp.	X	X	X	X	X	X
Diptera	<i>Corynoneura</i> sp.	X	X	X	X	X	X
Diptera	<i>Thienemanniella</i> sp.	X	X	X	X	X	X
Diptera	Tribe Chironomini (unid.)	X	X	X	X	X	X
Diptera	<i>Chironomus</i> sp.	X	X	X	X	X	X
Diptera	<i>Cladopelma</i> sp.			X	*		
Diptera	<i>Cryptochironomus</i> sp.	X	X	X	X		X
Diptera	<i>Dicrotendipes</i> sp.	X	X	X	X	X	X

Table 11-16. (cont)

Class/Order	Taxon	Station					
		1	2	3	4	5	6
Diptera	<i>Glyptotendipes</i> sp.			X			
Diptera	<i>Microtendipes</i> sp.				X		
Diptera	<i>Nilothauma</i> sp.			X			
Diptera	<i>Parachironomus</i> sp.						X
Diptera	<i>Phaenopsectra</i> sp.	X	X	X	X	X	X
Diptera	<i>Polypedilum</i> sp.	X	X	X	X	X	X
Diptera	<i>Saetheria</i> sp.				X		
Diptera	<i>Stelechomyia</i> app.	X			X	X	X
Diptera	<i>Stelechomyia perpulchra</i>				X	X	X
Diptera	<i>Stenochironomus</i> sp.	X	X	X	X	X	X
Diptera	<i>Stictochironomus</i>					*	
Diptera	<i>Tribelos</i> sp.	X	X	X	X	X	X
Diptera	<i>Pseudochironomus</i> sp.	X				X	
Diptera	Tribe Tanytarsini (unid.)	X	X	X	X	X	X
Diptera	<i>Nimbocera</i> sp.			X	X		
Diptera	<i>Rheotanytarsus</i> sp.	X	X	X	X	X	X
Diptera	<i>Tanytarsus</i> (T.) spp.	X	X	X	X	X	X
Diptera	Family Tabanidae (unid.)						X
Diptera	<i>Chrysops</i> sp.			*	*	*	
Diptera	<i>Tabanus</i> sp.		*	*			
Diptera	<i>Odontomyia</i> sp.	*	*	*	*		
Diptera	Family Empididae (unid.)	X	X	X	X	X	X
Diptera	<i>Chelifera</i> sp.	X	X	X	X	X	X
Diptera	<i>Dolichocephala</i> sp.	X	X				
Diptera	<i>Hemerodromia</i> sp.	X	X	X	X	X	X
Diptera	Family Sciomyzidae		*	*	*		
Diptera	Family Ephydriidae	*	*			X	
Total taxa station (all sampling methods combined) ^a		88	102	106	116	92	102
Percent taxa collected by qualitative sampling		21	32	35	24	24	21
Total taxa/study ^a		163					

^a Higher level taxa not included in count if a lower level taxon was present.

Fish

Introduction

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

Studies conducted during the D-Area 316(a) Demonstration

Introduction

Six stations located from the upper reaches to the mouth of Beaver dam creek were electro-fished monthly from September 1988 through February 1990 (Specht et al. 1990). These stations encompassed a range of habitats from wide, deep, slow-flowing areas near the creek mouth (Station 6) to narrower, more swiftly flowing channels (Stations 1, 2, and 3). Some portions of the creek were heavily overgrown with aquatic vegetation, particularly the slough-like habitat represented by Station 4. Initially, all stations were also sampled monthly by hoopnetting. However, hoopnet sampling was discontinued at Stations 2, 3, and 4 to prevent the accidental trapping of alligators. Hoopnet sampling was also suspended at all sample stations during April and May, the months of maximum alligator movement.

Adult Fish

Forty-five species were collected by electrofishing and hoopnetting during the 18-month study (Specht et al. 1990). The number of fish collected by electrofishing ranged from 561 at Station 2 and 532 at Station 5 to 167 at Station 1 (Table 11-17 on page 11-37). The number of species collected from each station was less variable ranging from 25–32. Electro-fishing catches varied on a monthly basis, and long-term patterns were not evident.

Fewer taxa were collected at Station 1 than at the other stations (Table 11-17). Station 1 was located closest to the D-Area outfall and had highest flow rates than the other sample stations. A major portion of the sample area at Station 1 was strongly channelized with little vegetation or instream structure to serve as foraging or refuge areas for fish. Stations 2, 4, and 5, in contrast generally had open canopies with abundant aquatic and shoreline vegetation.

The electrofishing data were converted to catch per unit effort (CPUE, expressed as number caught per 100 m) by dividing the number caught in each transect by the transect length. Total (all species) mean CPUE ranged from approximately 10.4 fish/100 m at Station 2 to approximately 3.1 fish/100 m at Station 1 (Table 11-18 on page 11-38). CPUE fluctuated widely on a monthly basis (Figure 11-8 on page 11-36). Low CPUE occurred when Stations

3, 4, 5, and 6 were inundated by Savannah River flood waters. Flooding greatly increased water depth at these stations and allowed fish to disperse into the surrounding floodplain.

Statistical testing indicated that CPUE was significantly lower at Station 1 than at the other stations. The low CPUE at Station 1 was probably a result of high current velocities and relatively poor habitat. Other differences were probably the result of local variations in instream structure, vegetation, substrate, current velocity, flooding, and other factors that influenced habitat quality and sampling efficiency.

The most abundant species (by number) collected by electrofishing were spotted sucker (*Minytrema melanops*), coastal shiner (*Notropis petersoni*), redbreast sunfish (*Lepomis auritus*), largemouth bass (*Micropterus salmoides*), and spotted sunfish (*Lepomis punctatus*). Sunfish (Centrarchidae) were the most abundant family, composing nearly 40% of the fish collected from Beaver Dam Creek. Minnows and shiners (Cyprinidae) (26%) and suckers (Catostomidae) (17.3%) were also abundant (Table 11-19 on page 11-40). Several taxa, including the bannerfin shiner, blackbanded darter, and channel catfish, exhibited a distinct longitudinal zonation, being more abundant either towards the headwaters or towards the stream mouth. Most of the more common species, however, were abundant throughout the stream.

Seventeen species were collected by hoopnetting (Table 11-20 on page 11-41). The greatest number of fish (96) and greatest number of species (13) were collected from Station 6, located in the mouth of Beaver Dam Creek. While Stations 2, 3, and 4 were sampled for only four months due to the high potential for alligator mortality, they yielded a total of 13 species and 99 individuals indicating that fish were abundant at these stations.

For further analysis, the hoopnetting data were converted to catch per unit effort (CPUE expressed as number caught per net per day, Table 11-21 on page 11-42). Mean CPUE was

Figure 11-8. Fish Sampling Stations for Beaver Dam Creek

Table 11-17. Total Number of Fish and Species Collected by Electrofishing in Beaver Dam Creek, September 1988–February 1990

Species	Stations						All Stations
	1	2	3	4	5	6	Combined
longnose gar		1	8	9	10	13	41
Florida gar		7	3	18	3		31
bowfin	4	19	2	16		2	43
American eel	1	2	1	2	5	3	14
American shad				3		12	15
gizzard shad	2		3	16	5	7	33
threadfin shad		3			4	3	10
redfin pickerel	1				2		3
chain pickerel	2	5			1		8
Cyprinidae ^a					1		1
common carp					1	1	2
golden shiner		2			2		4
bannerfin shiner	4	1	5		37	53	100
dusky shiner			1	1	16		18
spottail shiner	2	2	3		12	16	35
whitefin shiner	1	13	18	1	28	24	85
yellowfin shiner	1				4		5
coastal shiner	20	77	58	27	131	34	347
creek chubsucker		2					2
lake chubsucker	3	15			2		20
northern hogsucker	2						2
spotted sucker	38	102	56	76	31	64	367
silver redhorse		1		1	1	4	7
white catfish				1	1		2
yellow bullhead	1	6	1	1			9
flat bullhead		1	1		5	5	12
channel catfish	1	3	1	2	4	19	30
tadpole madtom							1
speckled madtom							1
lined topminnow		2		3			5
mosquitofish	1			1			2
brook silverside	1		2	4	2		9
striped bass						1	1
redbreast sunfish	32	69	87	29	87	23	327
warmouth	1	11	7	11	1		31
bluegill	5	11	1	22	8	3	50
dollar sunfish	1	15	4	5			25
redeer sunfish	3	5	2	15	7	6	38
spotted sunfish	14	102	11	34	48	5	214
largemouth bass	7	56	35	62	36	18	214
black crappie		1	2	5	2	1	11
yellow perch	1					1	2
blackbanded darter	8	22	7	5	10	2	54
striped mullet	10	5	8	8	24	8	63
total number	167	561	327	378	532	329	2294
total number of species	27	29	25	27	32	26	43

^a Not included in taxa count.

Table 11-18. Electrofishing CPUE (no./100 m) at Stations 1 - 6 in Beaver Dam Creek. September 1988–February 1990

Species	Stations						All Stations Combined
	1	2	3	4	5	6	
longnose gar		0.02	0.15	0.17	0.19	0.24	0.13
Florida gar		0.13	0.06	0.33	0.06		0.10
bowfin	0.07	0.35	0.04	0.30		0.04	0.13
American eel	0.02	0.04	0.02	0.04	0.09	0.06	0.04
American shad				0.06		0.22	0.05
gizzard shad	0.04		0.06	0.30	0.09	0.13	0.10
threadfin shad		0.06			0.07	0.06	0.03
redfin pickerel	0.02				0.04		0.01
chain pickerel	0.04	0.09			0.02		0.02
Cyprinidae					0.02		<0.01
common carp					0.02	0.02	0.01
golden shiner		0.04			0.04		0.01
bannerfin shiner	0.07	0.02	0.09		0.69	0.98	0.31
dusky shiner			0.02	0.02	0.30		0.06
spottail shiner	0.04	0.04	0.06		0.22	0.30	0.11
whitefin shiner	0.02	0.24	0.33	0.02	0.52	0.44	0.26
yellowfin shiner	0.02				0.07		0.02
coastal shiner	0.37	1.43	1.07	0.50	2.43	0.63	1.07
creek chubsucker		0.04					0.01
lake chubsucker	0.06	0.28			0.04		0.06
northern hogsucker	0.04						0.01
spotted sucker	0.70	1.89	1.04	1.41	0.57	1.19	1.13
silver redhorse		0.02		0.02	0.02	0.07	0.02
white catfish				0.02	0.02		0.01
yellow bullhead	0.02	0.11	0.02	0.02			0.03
flat bullhead		0.02	0.02		0.09	0.09	0.04
channel catfish	0.02	0.06	0.02	0.04	0.07	0.35	0.09
tadpole madtom					0.02		<0.01
speckled madtom						0.02	<0.01
lined topminnow		0.04		0.06			0.02
mosquitofish	0.02			0.02			0.01
brook silverside	0.02		0.04	0.07	0.04		0.03
striped bass						0.02	<0.01
redbreast sunfish	0.59	1.28	1.61	0.54	1.61	0.43	1.01
warmouth	0.02	0.20	0.13	0.20	0.02		0.10
bluegill	0.09	0.20	0.02	0.41	0.16	0.06	0.15
dollar sunfish	0.02	0.28	0.07	0.09			0.08
redeer sunfish	0.06	0.09	0.04	0.28	0.13	0.11	0.12
spotted sunfish	0.26	1.89	0.20	0.63	0.89	0.09	0.66
largemouth bass	0.13	1.04	0.65	1.15	0.67	0.33	0.66
black crappie		0.02	0.04	0.09	0.04	0.02	0.03
yellow perch	0.02					0.02	0.01
blackbanded darter	0.15	0.41	0.13	0.09	0.19	0.04	0.17
striped mullet	0.19	0.09	0.15	0.15	0.4	0.15	0.19
total no. fish/100 m	3.09	10.39	6.05	7.00	9.85	6.09	7.08

highly variable. However, catch rates were generally higher during the warmer months. Zero catch rates occurred most often during the fall and winter of 1988–1989, especially at Station 1 (Figure 11-9), probably because of seasonal reductions in fish activity and movement.

Channel catfish (*Ictalurus punctatus*) constituted 60% of the total hoopnetting catch, followed by redbreast sunfish (10.5%), bluegill (*Lepomis macrochirus*) (5.1%), and flat bullhead (*Ictalurus platycephalus*) (4.2%) (Table 11-23 on page 11-44). In addition, white catfish (*Ictalurus catus*) were abundant at Station 1 and Station 2 because this species entered the lower reaches of Beaver Dam Creek from the Savannah River.

One objective of the 316 (a) study was to determine the health of the Beaver Dam Creek fish community. This was done by comparing fish communities in Beaver Dam Creek to fish communities in relatively unimpacted streams. These included several non-thermal streams on the SRS and several other southeastern streams described in the literature (summarized in Paller et al. 1988) (Table 11-18 on page 11-38).

Total number of species ranged from 21 in Upper Three Runs Creek to 59 in Steel Creek. The total in Beaver Dam Creek, 45, was near the maximum. The high species number in Beaver Dam Creek was partly a function of sampling effort, but also reflects the habitat diversity of this stream which contains swamp, slough, and stream environments.

Sunfishes and black bass dominated the fish assemblage in Beaver Dam Creek (38% of the collections), followed by minnows (23%), suckers (15%), and catfishes (11%) (Table 11-23 on page 11-44). The relative abundance of minnows and sunfishes was within the range of the other southeastern streams, but the relative abundance of suckers and catfishes was greater. The relative abundance of catfishes in Beaver Dam Creek was due, in part, to the intense net sampling effort in this stream but also indicates the abundance of

Figure 11-9. Monthly Mean Hoopnetting Catch Per Unit Effort (No./Net Day) in Beaver Dam Creek, September 1988–February 1990

Table 11-19. Relative Abundance (Percent Composition) of Species Collected by Electrofishing at Stations 1–6 in Beaver Dam Creek, September 1988–February 1990

Species	Stations						All Stations
	1	2	3	4	5	6	Combined
longnose gar		0.18	2.45	2.38	1.88	3.95	1.79
Florida gar		1.25	0.92	4.76	0.56		1.35
bowfin	2.40	3.39	0.61	4.23		0.61	1.87
American eel	0.60	0.36	0.31	0.53	0.94	0.91	0.61
American shad				0.79		3.65	0.65
gizzard shad	1.20		0.92	4.23	0.94	2.13	1.44
threadfin shad		0.53			0.75	0.91	0.44
redfin pickerel	0.60				0.38		0.13
chain pickerel	1.20	0.89			0.19		0.35
Cyprinidae					0.19		0.04
common carp					0.19	0.30	0.09
golden shiner		0.36			0.38		0.17
bannerfin shiner	2.40	0.18	1.53		6.95	16.11	4.36
dusky shiner			0.31	0.26	3.01		0.78
spottail shiner	1.20	0.36	0.92		2.26	4.86	1.53
whitefin shiner	0.60	2.32	5.5	0.26	5.26	7.29	3.71
yellowfin shiner	0.60				0.75		0.22
coastal shiner	11.98	13.73	17.74	7.14	24.62	10.33	15.13
creek chubsucker		0.36					0.09
lake chubsucker	1.80	2.67			0.38		0.87
northern hogsucker	1.20						0.09
spotted sucker	22.75	18.18	17.13	20.11	5.83	19.45	16.00
silver redhorse		0.18		0.26	0.19	1.22	0.31
white catfish				0.26	0.19		0.09
yellow bullhead	0.60	1.07	0.31	0.26			0.39
flat bullhead		0.18	0.31		0.94	1.52	0.52
channel catfish	0.60	0.53	0.31	0.53	0.75	5.78	1.31
tadpole madtom					0.19		0.04
speckled madtom						0.30	0.04
lined topminnow		0.36		0.79			0.22
mosquitofish	0.60			0.26			0.09
brook silverside	0.60		0.61	1.06	0.38		0.39
striped bass						0.30	0.04
redbreast sunfish	19.16	12.30	26.61	7.67	16.35	6.99	14.25
warmouth	0.60	1.96	2.14	2.91	0.19		1.35
bluegill	2.99	1.96	0.31	5.82	1.50	0.91	2.18
dollar sunfish	0.60	2.67	1.22	1.32			1.09
redeer sunfish	1.80	0.89	0.61	3.97	1.32	1.82	1.66
spotted sunfish	8.38	18.18	3.36	8.99	9.02	1.52	9.33
largemouth bass	4.19	9.98	10.70	16.40	6.77	5.47	9.33
black crappie		0.18	0.61	1.32	0.38	0.30	0.48
yellow perch	0.60					0.30	0.09
blackbanded darter	4.79	3.92	2.14	1.32	1.88	0.61	2.35
striped mullet	5.99	0.89	2.45	2.12	4.51	2.43	2.75
total percent	100.03	100.01	100.03	99.95	100.02	99.97	100.01
total number	167	561	327	378	532	329	2294

Table 11-20. Total Number of Fish and Species Collected by Hoopnetting in Beaver Dam Creek. No Hoopnets Were Set During March and April, 1989. September 1988–February 1990

Species	Stations						All Stations Combined
	1	2 ^a	3 ^a	4 ^a	5	6	
longnose gar					1	3	4
Florida gar	1		1	1		1	4
gizzard shad						1	1
chain pickerel						1	1
spotted sucker				1			1
snail bullhead	1					7	8
white catfish	1				3	7	11
yellow bullhead	1	4		1		1	7
flat bullhead		3		1	4	6	14
channel catfish	54	20	14	6	50	56	200
hybrid Morone						1	1
flier				1			1
<i>Lepomis</i> sp. ^b	1			1			2
redbreast sunfish	3	20		1	5	6	35
bluegill	1	4	1	4	3	4	17
redeer sunfish	1	3		1	1	2	8
spotted sunfish	3			1	2		6
<i>Pomoxis</i> sp. ^b		1					1
black crappie	1	4		5	1		11
total number	68	59	16	24	70	96	333
total no. species	10	7	3	11	9	13	17

^a Sampling at these stations was discontinued after December due to the danger hoopnets present to the large alligator population at these stations.

^b Not included in taxa count.

Table 11-21. Hoopnetting CPUE (no./net day) at Stations 1-6 in Beaver Dam Creek September 1988–February 1990^a

Species	Stations					
	1	2 ^a	3 ^a	4 ^a	5	6
longnose gar					0.01	0.03
Florida gar	0.01		0.04	0.04		0.01
gizzard shad						0.01
chain pickerel						0.01
spotted sucker				0.04		
snail bullhead	0.01					0.07
white catfish	0.01				0.03	0.07
yellow bullhead	0.01	0.17		0.04		0.01
flat bullhead		0.13		0.04	0.04	0.06
channel catfish	0.56	0.83	0.58	0.25	0.52	0.58
hybrid Morone flier				0.04		0.01
<i>Lepomis</i> sp.	0.01			0.04		
redbreast sunfish	0.03	0.83		0.04	0.05	0.06
bluegill	0.01	0.17	0.04	0.17	0.03	0.04
redeer sunfish	0.01	0.13		0.04	0.01	0.02
spotted sunfish	0.03			0.04	0.02	
<i>Pomoxis</i> sp.		0.04				
black crappie	0.01	0.17		0.21	0.01	
total CPUE	0.71	246	0.67	1.00	0.73	1.00

^a Stations 2, 3, and 4 discontinued after four months. No nets were set in March or April, 1989.

Table 11-22. Relative Abundance (Percent Composition) of Species Collected by Hoopnetting at Stations 1–6 in Beaver Dam Creek, September 1988–February 1990^a

Species	Stations						All Stations Combined
	1	2 ^a	3 ^a	4 ^a	5	6	
longnose gar					1.43	3.13	1.20
Florida gar	1.47		6.25	4.17		1.04	1.20
gizzard shad						1.04	0.30
chain pickerel						1.04	0.30
spotted sucker				4.17			0.30
snail bullhead	1.47					7.29	2.40
white catfish	1.47				4.29	7.29	3.30
yellow bullhead	1.47	6.78		4.17		1.04	2.10
flat bullhead		5.08		4.17	5.71	6.25	4.20
channel catfish	79.41	33.90	87.50	25.00	71.43	58.33	60.06
hybrid Morone						1.04	0.30
flier				4.17			0.30
<i>Lepomis</i> sp.	1.47			4.17			0.60
redbreast	4.41	33.90		4.17	7.14	6.25	10.51
bluegill	1.47	6.78	6.25	16.66	4.29	4.17	5.10
redeer sunfish	1.47	5.08		4.17	1.43	2.08	2.40
spotted sunfish	4.41			4.17	2.86		1.80
<i>Pomoxis</i> sp.		1.69					0.30
black crappie	1.47	6.78		20.83	1.43		3.30
total percent	99.99	99.99	100.00	100.02	100.01	99.99	99.97
total number	68	59	16	24	70	96	333

^a Stations 2, 3, and 4 discontinued after four months. No nets were set in March or April, 1989.

Table 11-23. Species Number and Relative Abundance (% Composition) of Fishes in Nine Southeastern Streams. Relative Abundances are Based on the Number of Individual Fish in Each Family

Family	Beaver Dam Creek ^a		Shoal Creek, AL ^b		Barbaree Creek, AL ^c		Tombigbee Waterway, TN ^d		Duke Swamp, NC ^e	
	No.	%	No.	%	No.	%	No.	%	No.	%
bowfin	1	2							1	1
gars	2	3					1	<1	1	<1
freshwater eels	1	<1					1	<1	1	2
herrings	3	2	1	<1			1	<1		
mudminnow									1	4
piques	2	<1	1	<1					2	28
suckers	5	15	3	7	2	3	4	2	1	10
minnows	8	23	14	55	10	81	18	72	1	3
catfishes	7	11	2	1	1	<1	4	4	3	10
needlefishes										
killifishes	1	<1	1	<1			2	2		
livebearers	1	<1					1	5	1	<1
pirate perch									1	21
cavefishes									1	2
silversides	1	<1								
temperate basses	2	<1								
sunfishes and black basses	9	38	11	23	6	2	6	7	9	18
perches	2	2	7	9	5	11	11	6	1	<1
drums							1	2		
mulletts	1	2								
sculpins			1	5	1	3				
total	46		41		25		49		24	

^aSpecht et al. 1990, electrofishing and hoopnetting combined

^bKelly et al. 1981

^cBoschung and O'Neil 1981

^dMundy and Boschung 1981

^ePardue and Huish 1981

Table 11-23. (cont)

Family	Haggard Mill Creek ^f		Steel Creek ^g		Lower Three Runs ^h		Upper Three Runs ^h	
	No.	%	No.	%	No.	%	No.	%
bowfin	1	<1	1	1	1	1	1	3
gars			2	1	1	<1		
freshwater eels	1	6	1	1	1	6	1	10
herrings	1	1	2	<1			1	2
mudminnow	1	10	1	<1	1	<1		
piques	2	11	1	1	1	1	1	2
suckers	1	3	4	6	3	8	3	13
minnows	2	1	10	40	5	1	2	16
catfishes	3	4	9	2	5	2	2	2
needlefishes			1	<1	1	<1		
killifishes			2	<1			1	2
livebearers	1	8	1	2	1	1		
pirate perch	1	24	1	2	1	4	1	4
cavefishes	1	8	1	<1				
silversides			1	1	1	<1	1	1
temperate basses			1	<1				
sunfishes and black basses	11	22	13	39	9	69	7	46
perches	2	4	6	3	4	6		
drums								
mulletts			1	<1				
sculpins			1	<1				
total	28		59		35		21	

^fPardue and Huish 1981.

^gPaller et al. 1988.

^hPaller and Saul 1986.

these fish. Catfishes and spotted sucker may enter Beaver Dam Creek from the Savannah River where both are common (Paller and Saul 1987).

Comparisons of CPUE were restricted to the onsite streams where sampling methods were relatively consistent and similar to those in the 316(a) study. Electrofishing CPUE in Upper Three Runs Creek, Steel Creek, and Lower Three Runs Creek ranged from 0.3–26.7/100 m. CPUE in Beaver Dam Creek (0.7–16.6/100 m) fell within this range. Mean quarterly hoop-netting CPUE ranged from 0.43 fish/net day in Upper Three Runs to 0.75 fish/net day in Lower Three Runs. Mean hoopnetting CPUE in Beaver Dam Creek was somewhat higher (1.38 fish/net day), reflecting the abundance of catfishes in Beaver Dam Creek.

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

Ichthyoplankton

Plankton nets (0.505-mm mesh) were used to collect ichthyoplankton (drifting fish larvae and eggs) on a weekly basis. Only one complete spawning season (February through July 1989) was surveyed.

A total of 82 larval fish and 15 fish eggs, representing at least nine taxa, were collected from Beaver Dam Creek during February through July 1989 (Table 11-24). Station 6 had the most ichthyoplankton and the most taxa, followed by Station 5. Stations 1 and 3 had only five specimens each. The greatest ichthyoplankton catches were in April (55 specimens) and May (17 specimens) (Table 11-25). Centrarchids [primarily *Lepomis* spp., bluegill, and pygmy sunfish (*Elassoma* spp.)] were the most abundant group, composing approximately 53% of the total number of larvae and eggs. Other relatively abundant taxa were percids (19.0%) and suckers (12.4%).

Mean ichthyoplankton densities ranged from 1.7/1000 m³ at Station 3 to 15.8/1000 m³ at Station 6 (Table 11-26 on page 11-48). The highest average monthly density for the creek as a whole was in April (21.4/1000 m³). Average densities for the other months ranged from 1.6/1000 m³ in July to 6.4/1000 m³ in May.

As with the adult fish, the ichthyoplankton assemblage in Beaver Dam Creek was compared to ichthyoplankton assemblages in other creeks. The nonthermal streams included in this comparison were Steel Creek, Upper Three Runs, and Lower Three Runs. The number of taxa collected from these streams during 1984 and 1985 ranged from 8–15 compared with the 9 taxa collected from Beaver Dam Creek in 1989 (Table 11-27 on page 11-48). Relative abundance in Beaver Dam Creek during 1989 was similar to relative abundance in the other streams during 1984 (dominant taxa were sunfishes, darters, and suckers) but not 1985. However, all streams exhibited high interannual variability in species composition and numbers (Table 11-27) making it difficult to evaluate the significance of differences among streams.

Table 11-24. Total Number of Ichthyoplankton Collected from Stations 1-6 in Beaver Dam Creek February–July 1989

Taxon	Stage	Stations						Total No.
		1	2	3	4	5	6	
Clupeidae	Larva						1	1
Catostomidae	Larva		1		1		2	4
Erimvzon	Larva					1		1
spotted sucker	Larva				2	3	1	7
Cyprinidae	Larva		1					1
common carp	Larva	1						1
ironcolor shiner	Larva		1				1	2
Centrarchidae	Larva					1	19	20
Elassoma	Larva						11	11
Lepomis	Larva	1	5	1		2		9
bluegill	Larva	1	1	1	3	2	1	9
Pomoxis	Larva						2	2
Percidae	Larva						1	1
Percina, darter ^a	Larva			1	3	2	1	7
	Egg		4	1		6		11
unknown	Larva	2	1			2	1	6
unknown	Egg				1	2	1	4
total number		5	14	5	10	21	42	97
total taxa ^b		2	4	3	3	4	7	9

^a Darter = Percina sp. or Etheostoma sp.

^b Higher taxon not counted in total, if lower taxon present.

Table 11-25. Monthly Ichthyoplankton Collections from Beaver Dam Creek. February–July 1989

Taxa	Feb	Mar	Apr	May	Jun	Jul
darters	6	3	5	3	2	0
sunfish	0	0	31	11	3	4
minnow	0	0	1	0	2	0
sucker	0	0	11	1	0	0
other	0	5	7	2	0	0
total no.	6	8	55	17	7	4

Table 11-26. Average Densities (Organisms/1000m³) of Ichthyoplankton Collected from stations 1–6 in Beaver Dam Creek. February–July 1989

Species	Stage	Station						Total Density
		1	2	3	4	5	6	
Clupeidae	Larva						0.38	0.06
Catostomidae	Larva		0.36		0.31		0.78	0.24
Erimyzon	Larva					0.37		0.06
spotted sucker	Larva			0.38	0.76	1.02	0.41	0.43
Cyprinidae	Larva		0.50					0.08
common carp	Larva	0.37						0.06
ironcolor shiner	Larva		0.34				0.35	0.11
Centrarchidae	Larva					0.34	6.86	1.20
Elassoma	Larva						4.45	0.74
Lepomis	Larva	0.32	1.75	0.37		0.64		0.51
bluegill	Larva	0.37	0.34	0.35	1.06	0.63	0.40	0.52
Pomoxis	Larva						0.73	0.12
Percidae	Larva						0.28	0.05
Percina	Larva			0.27	1.06	0.67	0.43	0.40
darer	Egg		1.16	0.32		1.83		0.55
unknown	Larva	0.76	0.34			0.72	0.35	0.36
unknown	Egg				0.32	0.71	0.41	0.24
Mean Total Density ^a		1.82	4.79	1.70	3.52	6.93	15.84	5.73
Standard Deviation		5.6	11.34	5.30	8.99	13.39	53.81	

^aDifferences are due to rounding error.

Table 11-27. Number and Percent Composition of Ichthyoplankton Collected from Steel Creek, Upper Three Runs, and Lower Three Runs, 1984–1985 (Source: Specht 1987)

Taxa	Steel Creek				Upper Three Runs				Lower Three Runs			
	1984		1985		1984		1985		1984		1985	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Clupeidae</i>												
American shad	15	1.0	103	15.1			9	4.7	1	0.1	2	0.4
gizzard shad and/or threadfin shad	12	0.8			12	3.4			25	1.6		
blueback herring	65	4.3	116	17.1	4	1.1	10	5.2	20	1.3	5	1.1
unidentified herring or shad	14	0.9	6	0.9	4	1.1	2	1.0	16	1.1		
<i>Catostomidae</i>												
spotted sucker	14	0.9	7	1.0	234	65.4	101	52.3	7	0.5	5	1.1
unidentified suckers	57	3.8	2	0.3	3	0.8	2	1.0	15	1.0	1	0.2
<i>Aphredoderidae</i>												
pirate perch	42	2.8	1	0.1								

Taxa	Steel Creek				Upper Three Runs				Lower Three Runs			
	1984		1985		1984		1985		1984		1985	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
<i>Centrarchidae</i>												
sunfish and bass	449	29.6	79	11.6	4	1.1	2	1.0	671	45.2	57	12.8
crappie	34	2.2	7	1.0	51	14.2	2	1.0	266	17.9	46	10.3
<i>Percidae</i>												
yellow perch	14	0.9	11	1.6	2	0.6			29	2.0	7	1.6
darters	186	12.2	170	25.0	20	5.6	47	24.4	160	10.8	84	18.9
<i>Umbridae</i>												
mudminnow	5	0.3										
<i>Amblyopsidae</i>												
swampfish	8	0.5	1	0.1								
<i>Cyprinidae</i>												
minnows	420	25.7	105	15.4	17	4.7	4	2.1	24	1.6	26	5.8
topminnow			1	0.1								
carp			2	0.3	2	0.6						
<i>Esocidae</i>												
pickereel	2	0.1	1	0.1								
<i>Atherinidae</i>												
brook silverside	32	2.1	11	1.6					78	5.3	96	21.6
<i>Ictaluridae</i>												
catfish and bull-head	4	0.3	1	0.1								
<i>Belonidae</i>												
needlefish	2	0.1										
<i>Percichthyidae</i>												
striped bass			1	0.1								
unidentified ichthyoplankton ^a	138	9.1	55	8.1	5	1.4	14	7.3	172	11.6	115	25.8
total	1519 ^b	99.5	680	100.00	358	100.00	193	100.00	1483	100.1	446	100.00
total taxa ^c	15		15		8		8		11		11	

^aprincipally eggs

^btotal incorrect in original table; actual total is 1513

^chigher taxon not counted if lower taxa were present

Comprehensive Cooling Water Studies (1984-1986)

Adult and Juvenile fish

The Comprehensive Cooling Water Study involved two adult/juvenile fish sampling programs on Beaver Dam Creek—one quarterly and one reporting on the distribution of fish during the winter (Paller and Osteen 1985, Paller and Saul 1986). For the quarterly study, two hoopnets were placed in the mouth of Beaver Dam Creek and five sites were electrofished four times a year. Four of the electrofishing sites corresponded to Stations 3-6 of the 316(a) study. The overwintering study included one electrofishing sample station in the mouth of Beaver Dam Creek during 1984 and three in the mouth (Station 6), lower reaches of the floodplain swamp (roughly analogous to Station 5), and upper reaches of the floodplain (roughly analogous to Station 2) during 1985. In addition, hoopnets were set in the mouth of the creek during the 1985 overwintering study.

Electrofishing CPUE near the mouth of Beaver Dan Creek was considerably lower during the quarterly (1.6/100 m) and overwintering (1.4/100 m) studies than during the 316(a) study (7.1/100 m). Similar trends were also observed at Stations 2, 3, 4, 5, and 6. The same sampling methods and equipment were used during all of the studies, suggesting that differences in sampling efficiency were not responsible for the differences in CPUE.

Electrofishing data from the overwintering study indicated that the dominant species, in rank order, at Stations 2, 5, and 6 were spotted sunfish, redbreast sunfish, largemouth bass, bowfin, and gizzard shad (Table 4-28). Dominant species at the same stations during the 316(a) study were spotted sucker, redbreast sunfish, largemouth bass, spotted sunfish, striped mullet, and bluegill. Definite reasons for these differences are unknown but interannual variations in recruitment and changes in habitat between studies (e.g., aquatic plant growth) are possible causes as in sampling error.

Mean overall hoopnetting CPUE for the overwintering study (1.2 fish/net day) was approximately the same as for the 316(a) study (1.0 fish/net day); CPUE during both studies was

Table 4-28. Dominant Species^a Collected from Beaver Dam Creek by Electrofishing at Stations 2,5, and 6 During the CCWS (1983), Overwintering Study (1984–1985), and at Each station During the Specht et al. (1990) Study

Species	
November 1984– April 1985 ^b	September 1988– February 1990
spotted sunfish (21.5%)	spotted sucker (16.0%)
redbreast sunfish (19.7%)	redbreast sunfish (14.3%)
largemouth bass (9.0%)	largemouth bass (9.3%)
bowfin (7.4%)	spotted sunfish (9.3%)
gizzard shad (6.9%)	striped mullet (2.8%)
bluegill ^c (2.7%)	bluegill (2.2%)

^aExcluding minnows and other small fishes

^bPaller and Saul (1986)

^cbluegill ranked eighth

higher than during the quarterly study (0.6 fish/net day). Channel catfish were dominant during the over-wintering program, but flat bullhead, black crappie (*Pomoxis nigromaculatus*), redear sunfish, and blueback herring (*Alosa aestivalis*) constituted substantial proportions of the catch (Table 11-29 on page 11-52). Channel catfish were also strongly dominant during the 316(a) study. In general, all these studies revealed the presence of diverse fish assemblages in Beaver Dam Creek over time.

Ichthyoplankton

Larval fish and fish eggs were collected from five sample stations in Beaver Dam Creek during the 1984–1985 Comprehensive Cooling Water Study. Four of these sample stations were analogous to the stations sampled in the 316a study in 1989 (Stations 6, 5, 4, and 3). Sampling methodology and effort was similar for both studies.

More ichthyoplankton were collected in 1984 (334 individuals) (Table 11-30 on page 11-53) and 1985 (253 individuals, Table 11-31 on page 11-54) than in 1989 (97 individuals). This may be an effect of low water levels during the 1989 spawning season since many species spawn most successfully when floodwaters inundate terrestrial areas (Martin et al. 1981). Relative abundance also differed among years. While sunfishes (Centrarchidae) were dominant during 1984 and 1989 (Table 11-24 on page 11-47 and Table 11-30 on page 11-53), they constituted a comparatively small proportion of the total catch in 1985 (11.4%) (Table 11-31 on page 11-54). Similarly, the relative abundance of clupeids (herring and shad), suckers, darters, and brook silversides varied substantially among years.

Mean ichthyoplankton densities in 1984, 1985, and 1989 were highest in the creek mouth and the stations (4 and 5) in the lower reaches of Beaver Dam Creek (Table 11-26 on page 11-48). The lowest densities occurred in the upper reaches of Beaver Dam Creek during all years.

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

Table 11-29. Dominant Species Collected from Hoopnets at Station 6 During the CCWS Overwintering Study (1984–1985) and the Specht et al. (1990) Study

Species	Relative Abundance (%)	
	Nov 1984– Apr 1985 ^a	Sept 1988– Feb 1990
channel catfish	23.3	58.3
snail bullhead		7.3
white catfish		7.3
flat bullhead	17.8	6.2
black crappie	13.7	
redeer sunfish	8.2	
redbreast sunfish		6.2
blueback herring	8.2	
bluegill ^b	(2.7)	4.2

^aPaller and Saul (1986)

^bBluegill ranked tenth in abundance for November 1984–April 1985, and sixth for September 1988–February 1990.

Table 11-30. Number and Percent Composition of Ichthyoplankton Collected from Beaver Dam Creek 1984.
(Source: Specht et al. 1987)

Taxa	Number	Percent	Percent by Family ^a
Clupeidae			10.2
American shad	1	0.3	
gizzard shad and threadfin shad	19	5.7	
blueback herring	9	2.7	
unid. herring or shad	5	1.5	
Catostomidae			1.2
spotted sucker	4	1.2	
Aphredoderidae			
pirate perch	3	0.9	
Centrarchidae			60.5
sunfish and bass	177	53.0	
crappie	25	7.5	
Percidae			6.6
yellowperch	1	0.3	
darters	21	6.3	
Cyprinidae			6.6
minnows	19	5.7	
topminnow	2	0.6	
carp	1	0.3	
Atherinidae			
brook silverside	11	3.3	
Percichthyidae			
striped bass	1	0.3	
unidentified ichthyoplankton ^b	35	10.5	
to	334	100.0	

^aCalculated by NAI to compare with current program.

^bPrincipally eggs.

Table 11-31. Number and Percent Composition of Ichthyoplankton Collected from Beaver Dam Creek 1985. (Source: Specht et al. 1987)

Taxa	Number	Percent	Percent by Family ^a
Clupeidae			33.2
American shad	7	2.8	
blueback herring	74	29.2	
unid. herring or shad	3	1.2	
Catostomidae			2.0
spotted sucker	5	2.0	
unid. suckers			
Centrarchidae			11.4
sunfish and bass	13	5.1	
crappie	16	6.3	
Percidae			4.0
yellow perch	1	0.4	
darter	9	3.6	
Cyprinidae			1.6
minnows	2	0.8	
topminnow	1	0.4	
carp	1	0.4	
Esocidae			
pickerel	1	0.4	
Ictaluridae			
catfish and bullhead	1	0.4	
unidentified ichthyoplankton ^b	118	46.6	
total	253	100.0	

^aCalculated by NAI to compare with current program.

^bprincipally eggs.

References

- Arnett, N. W., L. K. Karapatakis, A. R. Mamatey, J. L. Todd. Savannah River Site Environmental Report for 1991. WSRC-TR-92-186, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1992).
- Beck, W. M., Jr. Environmental Requirements and Pollution Tolerance of Common Freshwater Chironomidae. EPA-600/4-77-024. (1977)
- Boschung, H. and P. O'Neil. "The Effects of Forest Clear-Cutting on Fishes and Macroinvertebrates in an Alabama Stream." In: Krumholz, L. A., (ed.). The Warmwater Stream Symposium - A National Symposium on Fisheries Aspects of Warmwater Streams. Southern Division, Am. Fish. Soc., Allen Press, Lawrence, KS (1981)
- Chimney and Cody 1986 database code: A322555
- Cummins, C. L., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1989, WSRC-IM-90-60, Volume II, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1990).
- Cummins, C. L., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1990, WSRC-IM-91-28, Volume I, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1991).
- Davis, H. A., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1988. WSRC-RP-89-59-1, Volume II, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1989).
- Firth P., J. R. O'Hop, B. Coler and R.A. Green. Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat Analyses and the Lower Food Chain Communities. Prepared for E.I. Du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC by Environmental and Chemical Sciences, Inc., Aiken, SC. DPST-86-797. (1986)
- Firth, P., J. R. O'Hop, B. Coler, and R. A. Green. Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat Analyses and the Lower Food Chain Communities. ECS-SR-26, Prepared for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1986).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report, Vol. III, Water Quality. DP-1697, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Hynes, H. B. N. The Ecology of Running Waters University of Toronto Press, Toronto, Ontario. 555 pp. (1970)
- Kelly, H. D., E. D. Catchings, and V. W. E. Payne, Jr. "Fish Populations and Water Quality of an Upland Stream Having Two Impoundments with Coolwater Releases." In: Krumholz, L. A. (ed.). The Warmwater Stream Symposium - A National Symposium on Fisheries Aspects of Warmwater Streams, Southern Division, Am. Fish. Soc., Allen Press, Lawrence, KS (1981).
- Kondratieff, P. F. and B. C. Kondratieff. A Lower Food Chain Community Study: Thermal Effects and Post-Thermal Recovery in the Streams and Swamps of the Savannah River Plant, November 1983 - May 1984. DPST-85-218, Prepared by Environmental and Chemical Sciences, Inc. for the Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1984).
- Lower, M. W. Comprehensive Cooling Water Study Final Report, Volume II, Water Quality. DP-1739-2, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Martin, D. B., L. J. Mengel, J. F. Novotny, C. H. Walburg. Spring and Summer Water Levels in a Missouri River Reservoir: Effects on Age-0 Fish and Zooplankton. Trans. Amer. Fish. Soc. 110:370-381 (1981)

- Mikol, S. C., L. T. Burkhalter, J. L. Todd, and D. K. Martin. U.S. Department of Energy Savannah River Plant Environmental Report for 1987. DPSU-88-30-1, Volume II, E. I. duPont de Nemours and Company, Savannah River Plant, Aiken, SC (1988).
- Mundy, P. R. and H. T. Boschung. "An Analysis of the Distribution of Lotic Fishes with Application to Fisheries Management." In: Krumholz, L. A., (ed.). The Warmwater Stream Symposium - A National Symposium on Fisheries Aspects of Warmwater Streams, Southern Division, Am. Fish. Soc., Allen Press, Lawrence, KS (1981).
- Nagle, J. H., G. D. Grunzel, M. K. Herring, K. L. Hooker, M. C. Scott, W. M. Starkel, K. E. Trapp, and J. G. Wollis. Beaver Dam Creek Final Report, September 1988–February 1990. Prepared for Westinghouse Savannah River Company, Savannah River Laboratory, Aiken, SC by Normandeau Associates, Inc., Aiken, SC. NAI-SR-125. (1990)
- Newman, M. C., A. Danciewicz, B. Davis, K. Anderson, R. Bayer, R. Lew, R. Mealy, S. Sandhu, S. Presnell, and J. Knox. Comprehensive Cooling Water Study Water Report, Volume 2, Water Quality, SREL (1986).
- Paller, M.H., and B.M. Saul. 1986. Effects of thermal discharges on the distribution and abundance of adult fishes in the Savannah River and selected tributaries. Annual Report. November 1984 - August 1985. ECS-SR-28. Prepared by Environmental & Chemical Sciences, Inc. for E.I. du Pont de Nemours & Company. DPST-8. Aiken, SC.
- Paller, M. H., J. H. Heuer, L. A. Kissick., Steel Creek Fish: L-Lake/Steel Creek Biological Monitoring Program. January 1986 - December 1987. ECS-SR-72. Report prepared by Environmental and Chemical Sciences, Inc. for E. I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988)
- Paller, M. H. and B. M. Saul. Effects of Thermal Discharges on the Distribution and Abundance of Adult Fishes in the Savannah River and Selected Tributaries, Annual Report, November 1984 - August 1985. ECS-SR-28, report prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1986).
- Paller, M. H. and D. V. Osteen. Annual Report on the Savannah River Aquatic Ecology Program, November 1983 - August 1984, Volume I Adult Fish. DPST-85-375, Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Specht, W. L., H. E. Mackey, M. H. Paller, L. D. Wike, and E. W. Wilde. 1990. Compliance of the Savannah River Site D-Area Cooling System with Environmental Regulations(U), Demonstration in Accordance with Section 316(a) of the Clean Water Act September 1988–February 1990. Westinghouse Savannah River Company, Savannah River Laboratory, Aiken, SC 29808, Prepared for the U.S. Dept. of Energy under Contract No. DE-AC09-89SR18035.
- Specht, W. L. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. DP-1739-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).

Chapter 12

Fourmile Branch

Chapter Contents

Drainage Description and Surface Hydrology (page 12-3)

Water Chemistry and Quality (page 12-7)

Algae (page 12-17)

Macrophytes (page 12-19)

Zooplankton (page 12-21)

Macroinvertebrates (page 12-23)

Fish (page 12-37)

References (page 12-57)

Drainage Description and Surface Hydrology

General Description

Fourmile Branch originates near the center of SRS and follows a southwesterly path for approximately 24 km (Figure 12-1). The watershed, which drains about 57 km², includes several SRS facilities: C Area (reactor), F and H Areas (separations and seepage basins), and the Solid Waste Disposal Facility (SWDF). In its headwaters, Fourmile Branch is a small blackwater stream that is relatively unimpacted by SRS operations (Specht 1987).

Effluents Contributions

Fourmile Branch receives effluents from F, H, and C Areas. Before C-Reactor standby in 1985 (C Reactor was shut down in 1987), heated Savannah River water (as hot as 70°C) was discharged from C Reactor into Fourmile Branch via Castor Creek. This discharge resulted in water temperatures in excess of 60°C in Fourmile Branch just downstream of its confluence with Castor Creek. With the contribution of C-Reactor cooling water, the flow in Fourmile Branch measured about 11.3 m³/s (400 ft³/s) (Murphy et al. 1991).

Delta

In its lower reaches, Fourmile Branch broadens and flows through a delta that has been formed by the deposition of sediments. Although most of the flow through the delta is in one main channel, the delta has numerous standing dead trees, logs, stumps, and cypress trees,

Figure 12-1. Location of Fourmile Branch on SRS

which provide structure and reduce water velocity in some areas. Downstream of the delta the creek flows in one main channel and the majority of the flow discharges into the Savannah River at RM 152.1, while a small portion of the creek flows west and enters Beaver Dam Creek. When the Savannah River floods, water from Fourmile Branch flows along the northern boundary of the floodplain swamp and joins with Steel Creek and Pen Branch instead of flowing directly into the river (Specht 1987).

Flow Measurements

The U. S. Geological Survey measures flow at several locations on Fourmile Branch. Flow statistics of Fourmile Branch at Site No. 7 and at SRS Road A-12.2 (Figure ***) are summarized in Table FMB.1. Records for the most downstream station (Fourmile Branch at Road A-12.2) date back to November 1976. In water year 1991, the mean flow of Fourmile Branch at Road A-12.2 was $1.8 \text{ m}^3/\text{s}$ ($63.1 \text{ ft}^3/\text{s}$). Over the period of record (water years 1977-1991) at Road A-12.2, the mean flow is $5.9 \text{ m}^3/\text{s}$ ($208 \text{ ft}^3/\text{s}$), the 7-day low flow is $0.22 \text{ m}^3/\text{s}$ ($7.6 \text{ ft}^3/\text{s}$), and the 7Q10 is $0.31 \text{ m}^3/\text{s}$ ($11.1 \text{ ft}^3/\text{s}$). The maximum, minimum, and mean daily flows for the periods of record are shown in Figures FMB.1 and FMB.2.

Figure 12-2. Flow Measurement Sampling Stations for Fourmile Branch

Table 10-1 Flow Summary for Fourmile Branch

Station Name	Station Number	Period of Record	Mean		Low		High		7Q10		7-Day Low Flow	
			cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)
Site No. 7 at SRS	02197342	1972-1991	0.50	17.8	0.08	2.7	23.5	830	0.14	4.9	0.09	3.2
at Road A-12.2	02197344	1976-1991	5.9	208	0.19	6.7	34.0	1200	0.31	11.1	0.22	7.6

cms = cubic meters per second

cfs = cubic feet per second

Figure 12-3. Maximum, Mean, and Minimum Flow Measurements at Station XX

Figure 12-4. Maximum, Mean, and Minimum Flow Measurements at Station XX

Water Chemistry and Quality

Studies and Monitoring

Water-Quality Monitoring

Routine water-quality monitoring has been conducted in Fourmile Branch by the WSRC Environmental Monitoring Section since 1973. Two locations on Fourmile Branch—near Road A-7 and near Road A—are sampled monthly for physical and biological parameters and quarterly for metals (see Figure 12-5). The Environmental Monitoring section also collects an additional sample annually from the same locations and analyzes them for pesticides, herbicides, and PCBs. All routine water quality monitoring data reported in the following sections can be found in the annual SRS Environmental Reports.

Comprehensive Cooling Water Study

From 1983 to 1985, Fourmile Branch was studied by the Savannah River Ecology Laboratory as part of the Comprehensive Cooling Water Study (CCWS). SREL designed the study to provide “an assessment of the potential effects of present and proposed SRS activities on the quality of waters used for cooling at the SRS” (SREL 1986). The following four locations were sampled on Fourmile Branch (see Figure 12-5):

1. Fourmile Branch at Road E-1
2. Fourmile Branch at Road 3, near Fourmile Branch at Road A-7
3. Fourmile Branch in Castor Creek
4. Fourmile Branch at Road A-12.2, near Fourmile Branch at Road A

Figure 12-5. Water-Quality Monitoring Sampling Stations on Fourmile Branch

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

Gladden et al. (1985) presents a synopsis of historical water quality monitoring of the Fourmile Branch system prior to the CCWS. Comprehensive results and discussion of CCWS data can be found in the "Comprehensive Cooling Water Study, Volumes II: Water Quality" (SREL 1986) or in the "Comprehensive Cooling Water Study, Final Report, Volume II: Water Quality" (Lower 1987).

Priority Pollutant Study

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

Chemical Assessment Studies

Since 1985, three special studies have been conducted on Fourmile Branch to determine the impacts of specific SRS operations. The Savannah River Technology Center conducted two studies aimed at characterizing the shallow groundwater outcropping into Fourmile Branch and its associated seepage in 1988 and 1989 (Looney et al. 1988, Haselow et al. 1990). The third study, which began in 1991, is a continuation of the 1988 and 1989 study aimed at determining whether annual rainfall and natural groundwater flow will dilute and flush the remaining contaminant plume out of the shallow groundwater and Fourmile Branch wetland over time. The results of these studies are summarized later in this chapter.

Field Data

Water Temperature

When C Reactor was operating, temperatures in Castor Creek reached an excess of 70°C, while temperatures in the non-thermal portions of Fourmile Branch averaged 16.9°C at Fourmile Branch near Road 3 (Table FMB.1). After the thermal and nonthermal waters of this system blended, the mean temperature was 39.4°C (Fourmile Branch at Road A-12.2), and then reduced to 28°C near the confluence with the Savannah River.

Since the shutdown of C Reactor, temperatures in Fourmile Branch at Road A ranged from 6.2°C to 31°C and averaged 18.5°C (Table 12-2). The wide fluctuations in temperature reflect seasonal temperature differences. Temperatures upstream at Road A-7 reflect a similar range of 6.4°C to 27°C and an average of 17°C.

pH Measurements

Since 1988, the pH in Fourmile Branch has varied from 5.4 to 8.1 at Road A-7 and from 3.1 to 8.5 at Road A (Table 12-2). The pH measurements from the CCWS also fell within these

ranges. These changes in pH can be attributed, in part, to the change in ionization constant ($K_w = [H^+][OH^-]$) associated with the change in water temperature (SREL 1986).

Physical Characteristics and General Chemistry

Dissolved Oxygen

Concentrations of dissolved oxygen are strongly correlated to water temperature. Because there has been no thermal input near Road A-7, dissolved oxygen concentrations measured since 1987 (mean 8.4 mg/l) have been similar to those measured during the CCWS (mean 7.8 mg/l) (Table 12-3 on page 12-10). During the CCWS, the mean dissolved oxygen concentration upstream of Road 3 at the swampy headwater pool (Road E1) was 6.4 mg/l. Dissolved oxygen concentrations near Road A12-2 (mean 5.99 mg/l) were lower during the CCWS than the period following cessation of reactor operations (mean 7.9 mg/l, at Road A), due to the thermal input to the system.

Conductivity

Specific conductance in the Fourmile Branch region since 1987 averaged 56.5 μ mhos/cm at Fourmile Branch near Road A-7 and 44.3 μ mhos/cm at Fourmile Branch near Road A (Table 12-3 on page 12-10). During the CCWS, mean conductance in Fourmile Branch near

Table 12-2. Field Data Identified in Fourmile Branch Studies (Source: SREL 1986, SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991)

Sampling Location	Water Temperature (C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
Fourmile Branch at Road E-1 (CCWS)				
Mean	16.8	6.32	48	73
Range	1.3 - 28.5	5.10 - 8.10	19 - 199	7 - 250
Samples	46	46	33	41
FMC at Road 3 (CCWS)				
Mean	16.9	6.81	147	9
Range	0.1 - 27.0	5.30 - 8.30	121 - 193	1 - 45
Samples	46	46	36	37
FMC at Road A-7 (1987-1991)				
Mean	17			
Range	6.4 - 26	5.4 - 8.1	NA	NA
Samples	60	60		
FMC at Road A-12.2 (CCWS)				
Mean	39.4	7.42		73
Range	9.6 - 52.0	5.90 - 9.05	NA	14 - 100
Samples	46	46		41
FMC at Road A (1987-1991)				
Mean	18.5			
Range	6.2 - 31	3.1 - 8.5		
Samples	60	60	NA	NA

Blank spaces - mean not calculated due to insufficient data in report

NA - Not analyzed

Road A-12.2 was 66 $\mu\text{mhos/cm}$. This higher conductivity resulted from using Savannah River water to cool C Reactor.

Suspended Solids and Turbidity

Turbidity and suspended solids have been lower in Fourmile Branch since cessation of C Reactor operations (Table 12-3). Mean turbidities and suspended solids near Road A-7 since 1987 were 8.2 NTU and 5.1 mg/l, respectively. However, during the CCWS, the mean turbidity near Road 3 was 20.8 NTU and the mean suspended solids concentration was 7.82 mg/l. Since 1987 near Road A, mean turbidities and suspended solids have been 5.2 NTU and 3.1 mg/l, respectively. During the CCWS, the mean turbidity near Road A12.2 was 18.5 NTU and the mean suspended solids concentration was 9.31 mg/l.

Major Anions and Cations

Alkalinity, Chloride, and Sulfate

Monitoring data from 1987 to 1991 indicate that mean concentrations of total alkalinity are similar in waters near Road A-7 (9.65 mg CaCO_3/l) and near Road A (10.3 mg CaCO_3/l) (Table 12-4 on page 12-11). These mean concentrations are also similar to those measured during the CCWS (8.52 mg CaCO_3/l at Road 3 and 14.14 mg CaCO_3/l near Road A12-2).

Table 12-3. Physical Characteristics and General Chemistry Identified in Fourmile Branch Studies (Sources: SREL 1986, SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991)

	Dissolved Oxygen (mg/l)	Specific Conductance ($\mu\text{mhos/cm}$)	Turbidity (NTU)	Total Suspended Solids (mg/l)
Fourmile Branch at Road E-1 (CCWS)				
Mean	6.79	24.3	10.1	13.8
Range	2.30 - 11.6	12.5 - 40.7	1.3 - 60	0.25 - 270
Samples	46	38	43	45
FMC at Road 3 (CCWS)				
Mean	7.81	70.0	20.8	7.82
Range	5.20 - 12.40	31.5 - 96.9	0.3 - 394.0	0.25 - 152.10
Samples	46	38	43	44
FMC at Road A-7 (1987-1991)				
Mean	8.4	56.5	8.2	5.1
Range	5.0 - 12	0.15 - 112	1.0 - 42	0.0 - 27
Samples	60	60	60	60
FMC at Road A-12.2 (CCWS)				
Mean	5.99	87.0	18.5	9.31
Range	3.50 - 11.8	59.3 - 108.2	4.3 - 118.0	0.25 - 109.70
Samples	46	45	43	45
FMC at Road A (1987-1991)				
Mean	7.9	44.3	5.2	3.1
Range	6.5 - 12	11 - 103	1.0 - 23	1.0 - 47
Samples	60	60	60	60

Blank spaces - mean not calculated due to insufficient data in report

Mean chloride concentrations between 1987 and 1991 were higher at Road A-7 (5.7 mg/l) than at Road A (3.2 mg/l), which may reflect groundwater outcroppings from the F- and H-Area seepage basins. Mean sulfate concentrations were highest near Road A-7, also reflecting groundwater input from the F- and H-Area seepage basins. Higher sulfate and chloride concentrations were also observed during the CCWS.

Calcium, Magnesium, Sodium, and Potassium

Concentrations of calcium, magnesium, sodium, and potassium near Road A-7 and Road A remain similar to the concentrations measured during the CCWS (Table 12-5). Like other onsite systems, calcium, magnesium, and sodium are transported almost entirely in the dissolved phase throughout Fourmile Branch (SREL 1986). Mean concentrations of potassium were generally below the detection limits in the nonthermal portion of Fourmile Branch, but increased to about 1 mg/l in downstream thermal waters, reflecting Savannah River source waters. Potassium is not measured as part of the routine SRS water-quality monitoring program.

Aluminum, Manganese, and Iron

Concentrations of aluminum, manganese, and iron are presented in Table 12-5 on page 12-12. During the CCWS, concentrations of aluminum were highest near Road A12.2, reflecting concentrations of the Savannah River. Concentrations of manganese and iron were highest at the upstream location (Road E-1). The high concentrations of iron (mean 3.59

Table 12-4. Major Anions Identified in Fourmile Branch Studies (Source: SREL 1986, SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991)

Sampling Location	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg SO ₄ /l)
Fourmile Branch at Road E-1 (CCWS)			
Mean	4.28	2.60	1.16
Range	0.49 - 11.9	1.40 - 3.40	0.03 - 11.5
Samples	45	46	27
FMC at Road 3 (CCWS)			
Mean	8.52	2.91	7.66
Range	3.24 - 16.62	0.20 - 4.70	1.83 - 18.97
Samples	44	46	28
FMC at Road A-7 (1987-1991)			
Mean	9.7	5.7	7.2
Range	5.0 - 24	1.2 - 15	3.0 - 17
Samples	60	60	60
FMC at Road A-12.2 (CCWS)			
Mean	14.14	5.10	5.09
Range	5.70 - 21.4	2.10 - 7.60	0.25 - 8.92
Samples	45	46	28
FMC at Road A (1987-1991)			
Mean	10.3	3.2	5.9
Range	2.0 - 32	1.2 - 6	3.0 - 22
Samples	60	60	60

Blank spaces - mean not calculated due to insufficient data in report

mg/l) measured at the upstream Fourmile Branch location were attributed to a large amount of iron oxide deposition in the marshy area.

From 1987 to 1991, the maximum aluminum and manganese concentrations were measured near Road A-7 (maximum 0.37 mg/l). The maximum iron concentration, 1.7 mg/l, was measured near Road A.

Nutrients

Phosphorus

Concentrations of phosphorus are presented in Table 12-6 on page 12-13. The mean concentrations of phosphorus species in Fourmile Branch waters during the CCWS were higher near Road A12.2 (0.089 mg P/l) than the concentrations near Road 3 (0.023 mg P/l). Analysis determined that the larger percentage of the phosphorus was dissolved orthophosphate. From 1987 to 1991, mean concentrations of phosphorus have been lower near Road A than near Road A-7 (0.075 mg P/l near Road A-7 and 0.028 mg P/l near Road A).

Nitrogen

Organic nitrogen and nitrite concentrations during the CCWS were similar at all Fourmile Branch sites (Table 12-6 on page 12-13). Nitrite is not measured in the routine water-quality

Table 12-5. Major Cations (Total) Identified in Fourmile Branch Studies (Source: (SREL 1986), SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991)

	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Aluminum (mg/l)	Iron (mg/l)	Manganese (mg/l)
Fourmile Branch at Road E-1(CCWS)							
Mean	1.60	0.52	1.89	<0.368	0.49	3.59	0.23
Range	0.69 - 8.82	0.21 - 0.82	1.09 - 6.56	<0.368 - 1.09	0.076 - 2.09	0.46 - 14.5	<0.0004 - 1.10
Samples	39	39	39	39	39	39	17
FMC at Road 3 (CCWS)							
Mean	2.87	0.68	7.60	0.51	0.74	0.784	0.092
Range	2.03 - 4.16	0.53 - 1.23	3.72 - 10.3	<0.368 - 1.77	0.057 - 4.97	0.195 - 4.81	<0.0004 - 0.183
Samples	38	38	38	38	38	38	17
FMC at Road A-7 (1987-1991)							
Mean							
Range	2.1 - 3.9	0.27 - 0.78	6.6 - 15	NA	0.01 - 0.37	0.04 - 1.7	<0.01 - 0.21
Samples	18	18	20	NA	20	20	18
FMC at Road A-12.2 (CCWS)							
Mean	2.99	1.08	6.11	0.92	0.91	1.03	0.11
Range	0.89 - 4.21	0.49 - 1.35	1.32 - 8.73	<0.368 - 2.57	0.248	0.11 - 3.42	<0.0004 - 0.299
Samples	38	38	38	38	38	38	17
FMC at Road A (1987-1991)							
Mean							
Range	1.8 - 4.1	0.51 - 0.73	4.8 - 10	NA	<0.01 - 0.20	<0.003 - 0.66	<0.01 - 0.04
Samples	18	18	19	NA	20	20	18

Blank spaces - mean not calculated due to insufficient data in report

monitoring program, and organic nitrogen is measured only near Road A-7. The concentrations of organic nitrogen measured near Road A-7 were similar to those measured in the CCWS. Ammonia concentrations were highest in the most upstream location (Road E1) and decreased with distance downstream.

Extremely high concentrations of nitrate (2.5 mg NO₃-N/l) were measured near Road 3 during the CCWS. These elevated concentrations can be attributed to the outcropping of water from the F-and H-Area seepage basins (Fenimore and Horton 1973).

Trace Elements

SREL measured low levels of trace elements in Fourmile Branch during the CCWS. The detection limits reported for the routine monitoring program are higher than the concentrations measured during the CCWS; therefore, only the CCWS data is discussed below. All data are presented in Table 12-7. The highest mean concentrations of arsenic (2.5 µg/l), cadmium (0.45 µg/l), copper (3.7 µg/l), and nickel (3.6 µg/l) were measured in Fourmile Branch near Road A12-2. Fourmile Branch near Road 3 had the highest mean concentration of chromium (9.1 µg/l), while the most upstream location, Road E1 had the highest mean concentration of lead (2.2 µg/l) and zinc (8.2 µg/l).

Table 12-6. Nutrients Identified in Fourmile Branch Studies (Source: (SREL 1986), SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991)

	Total Phosphorus (mg P/l)	Total Orthophosphate (mg PO ₄ -P/l)	Organic Nitrogen (mg N/l)	Total Kjeldahl Nitrogen (mg N/l)	Ammonia (mg NH ₃ -N/l)	Nitrite (mg NO ₂ -N/l)	Nitrate (mg NO ₃ -N/l)
Fourmile Branch at Road E-1 (CCWS)							
Mean	0.023	0.006	0.248	0.264	0.031	0.002	0.019
Range	<0.010 - 0.195	<0.001 - 0.033	0.030 - 0.862	0.017 - 0.890	0.005 - 0.180	<0.001 - 0.009	<0.001 - 0.082
Samples	46	40	44	46	46	44	43
FMC at Road 3 (CCWS)							
Mean	0.023	0.010	0.246	0.265	0.027	0.003	2.325
Range	<0.010 - 0.144	0.002 - 0.104	0.020 - 0.681	0.019 - 0.700	<0.005 - 0.110	<0.001 - 0.006	0.589 - 3.870
Samples	46	41	45	46	46	44	43
FMC at Road A-7 (1987-1991)							
Mean	0.075	NA	0.27	NA	0.13	NA	2.3
Range	<0.02 - 0.14	NA	<0.01 - 2.7	NA	<0.01 - 0.42	NA	0.47 - 8.2
Samples	60	NA	60	NA	60	NA	60
FMC at Road A-12.2 (CCWS)							
Mean	0.089	0.066	0.230	0.258	0.047	0.011	0.441
Range	0.024 - 0.170	0.005 - 0.178	0.045 - 0.756	0.012 - 0.800	<0.005 - 0.420	<0.001 - 0.045	0.146 - 0.774
Samples	46	41	44	46	46	44	42
FMC at Road A (1987-1991)							
Mean	0.028	NA	NA	NA	0.059	NA	0.24
Range	0.0 - 0.11	NA	NA	NA	0.0 - 0.29	NA	0.04 - 5.1
Samples	60	NA	NA	NA	60	NA	60

NA - Not Analyzed

Organic Carbon

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

Priority Pollutants

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

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

Table 12-7. Trace Elements (Total) Identified in Fourmile Branch Studies (Source: (SREL 1986), SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991)

	Arsenic (µg/l)	Cadmium (µg/l)	Chromium (µg/l)	Copper (µg/l)	Lead (µg/l)	Nickel (µg/l)	Zinc (µg/l)
Upstream, FMCMS100 (CCWS)							
Mean	1.2	0.34	7.1	2.0	2.2	2.7	8.2
Range	<0.4 - 9.1	<0.04 - 2.48	<0.4 - 46.0	<0.4 - 6.0	<0.4 - 9.0	<0.4 - 8.3	<0.4 - 53.0
Samples	17	17	17	17	17	17	17
FMC at Road A-7 (CCWS)							
Mean	1.5	0.44	0.9.1	2.6	1.5	3.4	5.3
Range	<0.4 - 7.3	<0.04 - 2.41	<0.4 - 77	<0.4 - 5.7	<0.4 - 6.0	<0.4 - 15	<0.4 - 23
Samples	17	17	17	17	17	17	17
FMC at Road A-7 (1987-1991)							
Mean							
Range	NA	<10	<10 - 10	<10 - <50	<3 - 110	<10 - 50	<10 - 20
Samples	NA	20	20	20	20	20	20
FMC at Road A (CCWS)							
Mean	2.5	0.45	8.0	3.8	2.0	3.6	5.0
Range	<0.4 - 17.3	<0.04 - 2.45	<0.4 - 49	<0.4 - 10	<0.4 - 9.3	<0.4 - 10.7	<0.4 - 16.8
Samples	17	17	17	17	17	17	17
FMC at Road A (1987-1991)							
Mean							
Range	NA	<10	<10 - 10	<10 - 300	<3 - 60	<10 - 70	<10 - 20
Samples	NA	20	20	20	20	19	20

Blank spaces - mean not calculated due to insufficient data in report

NA - Not analyzed

Pesticides, Herbicides, and PCBs

Pesticides, herbicides, and PCBs are also measured as part of the routine water-quality monitoring program. No pesticides, herbicides, or PCBs have been detected in Fourmile Branch.

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 Assessment Studies

Seepage Sampling Study, 1987

In 1987, SRTC initiated a sampling and analysis program in the vicinity of the F- and H-Area seepage basins because observations downgradient of the basins suggested that water outcropping along the seepage line was impacting a small area of the terrestrial/wetlands environment along Fourmile Branch. Samples were collected upstream and downstream from both F and H Areas (Figure 12-5 on page 12-7) and analyzed for selected metals, inorganic constituents, pH, conductivity, nitrate, and nitrite. The results of this study are presented in Table 12-8 on page 12-16.

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

Seepage Sampling Study, 1988 and 1989

Haselow et al. (1990) collected soil cores, stream, and seepage water samples from Fourmile Branch in 1988 and 1989 as a follow-up to the Looney et al. (1988) study. These samples were also analyzed for selected metals, inorganic constituents, pH, conductivity, nitrate, and nitrite. The results of this study are presented in Table 12-8 on page 12-16.

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

Seepage Sampling Study, 1991 and 1992

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

To investigate this hypothesis and to monitor the post basin closure temporal changes in the contaminant levels outcropping along the Fourmile Branch seepage line, a semi-annual program for monitoring Appendix IX metals and various inorganics was initiated. Samples were collected from five seepage line locations in F Area, five seepage line locations in H Area, and three stream locations on FMB. Analytical results for the seepage line and stream locations are presented in Hixon and Rogers (1993).

Table 12-8 Results from Seepage Sampling Study of Fourmile Branch (Source: Haselwell et al. 1990)

	88CW-1	88CW-2	88CW-3	88CW-4	89HW-2	89HW-4	89HW-7	89HW-8
pH	NA	NA	NA	NA	6.30	7.21	6.37	5.34
Conductivity (mV/cm)	NA	NA	NA	NA	93.5	320	91.6	35.9
Alkalinity (mg/l)	NA	NA	NA	NA	ND	148	8.0	ND
Total Hardness	NA	NA	NA	NA	139	73.3	196	196
Chloride (mg/l)	NA	NA	NA	NA	4.6	1.2	5.5	5.7
Nitrate (mg/l)	NA	NA	NA	NA	1.4	8.9	5.7	0.15
Silver (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.004	<0.004	<0.004	<0.004
Aluminum (mg/l)	<0.2	<0.2	<0.2	<0.2	0.05	0.08	0.47	0.07
Arsenic (mg/l)	NA	NA	NA	NA	<0.003	<0.003	<0.003	<0.003
Cadmium (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.006	<0.006	<0.006	<0.006
Chromium (mg/l)	<0.01	<0.01	<0.01	0.018	<0.003	<0.003	0.021	<0.003
Copper (mg/l)	<0.025	<0.025	<0.025	<0.025	<0.007	<0.007	<0.007	<0.007
Mercury (mg/l)	<0.0002	<0.0002	0.0003	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Sodium (mg/l)	14	14	12	2.9	11.7	63.3	10.2	25.9
Nickel (mg/l)	<0.04	<0.04	<0.04	<0.04	<0.034	<0.034	<0.034	<0.034
Lead (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.003	<0.003	<0.003	<0.003
Selenium (mg/l)	NA	NA	NA	NA	<0.002	<0.002	<0.002	<0.002
Zinc (mg/l)	<0.02	<0.02	0.059	0.029	<0.009	<0.009	0.028	0.009

NA - Not Analyzed

Blank spaces - mean not calculated due to insufficient data in report

ND - Not Detected

Algae

Phytoplankton

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

Periphyton

The periphyton of Fourmile Branch were studied from 1983-85. Methods and sampling locations can be found in Specht (1987). During 1983 and 1984, periphyton stream sampling was carried out in the winter and spring. Biomass and standing crop results are presented in Table 12-9 and Table 12-10, respectively. Results of the 1984-1985 periphyton sampling associated with the CCWS are shown in Table 12-11 on page 12-18.

Table 12-9. Periphyton Biomass (g dry wet/m²) at Two Stations in Fourmile Branch During Winter and Spring Sampling 1983-1984^a (Source: Specht 1987)

Location	Station	Mean (range)	n	CV
<i>Winter</i>				
FM	2	9.18 (0.0-26.14)	37	73.51
FM	3	13.26 (0.25-32.70)	42	83.92
<i>Spring</i>				
FM-t	2	14.42 (0.0-47.40)	45	96.59
FM-t	3	20.83 (0.53-38.18)	45	55.42

^a Mean, range, number of samples (n), and coefficient of variation (CV) are given.

Table 12-10. Organic Standing Crop (g AFDW/m²) at Each 1983-1984 Station (Winter and Spring 1984)^a (Source: Specht 1987)

Location	Station	Mean (range)	n	CV
<i>Winter</i>				
FM-t	2	2346.7 (887.6-4976.6)	30	44.2
FM-t	3	653.0 (0.0-1771.3)	27	90.4
<i>Spring</i>				
FM-t	2	1508.8 (122.6-3667.1)	30	63.0
FM-t	3	1298.2 (224.7-2978.1)	30	76.9

^a Mean, range, number of samples (n), and coefficient of variation (CV) are given.

Table 12-11. Periphyton Biomass (g/m^2) Mean, n, Standard Error, Coefficient of Variation (CV) and Minimum and Maximum Values for Each 1984–1985 Station (October 1984–September 1985) (Source: Specht 1987)

Station	Location/ Thermal Regime	Mean	n	Standard Error	CV	Minimum	Maximum
14	FMD-t	0.2517	72	0.0347	116.8	0.0354	1.780
15	FMD-t	0.1030	48	0.0117	78.83	0.0104	0.4352
17	FMD-t	0.1191	54	0.0237	146.3	0.0334	1.222
18	FM-t	0.1368	71	0.0296	182.2	0.0121	1.713

Macrophytes

Introduction

Although rooted aquatic macrophytes are an important component of the structure and function of many aquatic systems, they tend to be less important in flowing waters. These vascular plants provide important stream structure, substrate for periphyton development, cover and substrate for smaller animals, and a source of carbon for the stream system. Macrophytes cannot colonize the channels of systems like Fourmile Branch during the large thermal and flow impacts from reactor operations. A certain amount of colonization of the slower reaches and backwaters of the stream would be expected since the cessation of C-Reactor operation in 1985, unfortunately there are no data dealing with the invasion of submerged macrophytes in Fourmile Branch. There is some research, started in 1987 (Sharitz et al. 1993), addressing vegetational succession in the Fourmile Branch corridor that does deal with the emergent and wetland species colonizing the stream banks.

Comprehensive Cooling Water Study

The only data dealing with aquatic macrophytes in Fourmile Branch comes for the Comprehensive Cooling Water Study (Volume V, Specht 1987) and was collected during the 1984–1985 sampling period. The CCWS data are not representative of the current status of aquatic macrophytes in the Fourmile Branch system because they were collected at only two station locations, both of which had been impacted by reactor operations. The data showed fewer total number of taxa than post-thermal and reference streams and had no taxa growing in the stream channel. Area, volume, biomass, and percent cover for aquatic macrophytes at the two stations are shown in Table 12-12.

Expectations Since the Cessation of C Reactor Operation

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

Table 12-12. Annual Mean, N, and Standard Deviation are Presented for the Following Vegetation Parameters on a per m² Basis at Each Mapped 1984–1985 Station: Aquatic Vascular Plant (AVP) Area (m²/m²; AVP Volume (m³/m²); AVP Biomass (g/m²) and AVP Percent Cover (October 1984–September 1985) (Source: Firth et al. 1986)

AVP Area		AVP Volumes		AVP Biomass		Percent Cover		N
Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
0.0010	0.0031	—	—	0.0047	0.0189	0.0189	0.3070	16
0.0127	0.0288	0.0055	0.0156	4.107	13.04	1.268	2.880	15

Zooplankton

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

The data in Figure 12-6 indicate that the greatest densities occurred during March 1985. With the exception of December 1984, Protozoa and Rotifera comprised greater than 80% of the monthly total densities. This result is typical of zooplankton populations, which are warm-water, summer species (Hutchinson 1967).

Figure 12-6. Mean Density of Total Zooplankton in Fourmile Branch

Macroinvertebrates

Sampling

Locations

Macroinvertebrates were sampled monthly in the mouth of Fourmile Branch from September 1982 to August 1983 (Specht et al. 1984), monthly at 3 locations in Fourmile Branch from November 1983 through September 1984 (Kondratieff and Kondratieff 1984, 1985; O'Hop et al. 1985), and monthly at 6 locations in Fourmile Branch from October 1984 through September 1985 (Figure 12-7) (Specht 1987). Because C-Reactor, which discharged to Fourmile Branch, was placed on cold standby in June 1985, these data primarily represent the macroinvertebrate community that existed when C Reactor was operating at full power, but also document early recovery of thermal stations between June and September 1985. After the shut-down of C Reactor in June 1985, Lauritsen and Starkel (1989) collected macroinvertebrate samples at one location in Fourmile Branch from June 1985 to September 1987 to document macroinvertebrate recolonization. During the recolonization study, they collected samples at time intervals ranging from one day to two weeks in June through August 1985 and monthly from October 1985 to September 1987.

Methods

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

Figure 12-7. Location of the Fourmile Branch Macroinvertebrates Sampling Station

were sampled in the other years. Table 12-13 identifies the locations of all sampling stations and the sampling methods employed in each study.

Results

Introduction

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

Macroinvertebrate Community During Operation of C Reactor

Non-Thermal Areas

Station 12 was located at Road A-7, upstream from the discharge of thermal effluent into Fourmile Branch. Macroinvertebrate data collected from Hester-Dendy multiplate samplers (Table 12-14 on page 12-25) indicate that this station was similar to other non-thermal SRS streams with respect to density of organisms, biomass, average number of taxa, and total number of taxa collected. Dominant taxa at Station 12 included leeches (Hirudinea), the mayfly *Stenonema modestum*, blackflies, tanytarsine and orthoclad chironomids, and several species of hydropsychid caddisflies (Table 12-15 on page 12-25 and Table 12-17 on page 12-29). The taxonomic composition of Station 12 differed from most other non-ther-

Table 12-13. Locations of Macroinvertebrate Sampling Stations and Sampling Methods in Fourmile Branch. 1982-1987

1982-1983	1983-1984	1984-1985	1985-1987
Creek mouth (HD, D) (St. C150.6)	Road A-13.2 (St. 2) (HD, LB, SN, SB, M)	Road A-7 (nonther- mal) (St. 12) (HD, D, LB)	Road A-13.2 (HD)
	SREL Boardwalk off Road A-13 (St. 3) (HD, LB, SN, SB, M)	SREL Boardwalk off Road A-13 (St. 14 upper delta) (HD, LB, D)	
	Creek mouth (HD, D) (St. C150.6)	Delta (St. 15, 16, 17) (HD, LB, D) Creek mouth (St. 18) (HD, D)	
HD - Hester-Dendy multiplate samplers D - Drift LB - Leaf bags		SN - Artificial snags SB - Substrate M - Macrophyte	

mal stream stations sampled during the CCWS in that it was overwhelmingly dominated by filter feeders. (See Table 12-16 on page 12-26.) The domination of filter feeders makes Station 12 most similar to the macroinvertebrate communities found downstream from L Lake and Par Pond. Fourmile Branch receives nutrient inputs from several small sanitary wastewater treatment plants as well as nitrogen inputs from the F/H seep line. The creek also supports numerous beavers, which dam the creek. It is likely that ponding from beaver activity occurred upstream from Station 12 and that the nutrient inputs from SRS sources stimulated

Table 12-14. Mean Number of Taxa, Density, and Biomass for Macroinvertebrates Collected on Hester Dandy Multiplate Samplers in Fourmile Branch (October 1984 – September 1985) (Source: Firth et al. 1986, O'Hop et al. 1986)

Parameter	Station					
	12	14	15	16	17	18
Mean number of taxa/sampler	19.0	6.3	8.2	8.5	8.7	9.8
Mean density/m ²	2109.3	1012.1	1532.8	1517.7	1230.0	1433.7
Mean biomass/m ² (g)	0.351	0.191	0.097	0.121	0.097	0.100
Mean biomass/individual (mg)	0.166	0.189	0.063	0.080	0.079	0.070
Total number of taxa collected	67	45	35	38	41	38

Table 12-15. Percent Composition of Macroinvertebrate Taxa Collected on Hester Dandy Multiplate Samplers in Fourmile Branch (October 1984 – September 1985) (Source: Firth et al. 1986, O'Hop et al. 1986)

Taxa	Station					
	12	14	15	16	17	18
Turbellaria	0.73	0.00	0.01	0.02	0.00	0.01
Nematoda	0.57	0.49	16.78	3.75	11.36	0.62
Oligochaeta	4.61	13.49	21.84	27.42	32.40	12.11
Gastropoda	0.14	1.02	0.49	0.04	2.58	1.19
Arachnida	1.42	0.06	0.14	0.09	0.04	0.10
Ephemeroptera	5.80	4.65	7.45	4.79	5.11	8.76
Coleoptera	1.28	0.21	0.03	0.07	0.05	0.12
Trichoptera	39.40	20.08	2.50	4.05	1.48	2.21
Diptera*	44.67	59.77	50.62	59.56	46.55	74.69
Chironomini	(2.59)	(28.74)	(26.90)	(35.50)	(30.57)	-**
Tanytarsini	(18.60)	(7.54)	(7.53)	(8.72)	(2.18)	(5.01)
Orthocladinae	(9.83)	(7.36)	(4.30)	(3.60)	(1.59)	-**
Tanypodinae	(1.73)	(11.36)	(7.00)	(5.18)	(7.88)	-**
Other	1.38	0.23	0.14	0.21	0.43	0.19
Total	100.00	100.00	100.00	100.00	100.00	100.00

* Includes subtaxa in parentheses.

** Subtaxa not differentiated.

Table 12-16. Relative Abundance (%) of Macroinvertebrate Functional Groups in Four-mile Branch (October 1984–September 1985) (Source: Firth et al. 1986, O'Hop et al. 1986)

Functional Group	Station					
	12	14	15	16	17	18
Collector-gatherers	25.53	57.69	80.94	79.61	84.41	65.76
Collector-filterers	67.91	28.37	10.17	13.79	3.65	28.66
Scrapers	0.23	1.06	0.51	0.04	2.69	0.15
Predators	5.92	12.67	8.16	6.48	9.15	5.33
Piercer-herbivores	0.13	0.21	0.22	0.07	0.09	0.05
Shredders	0.28	0.00	0.01	0.00	0.00	0.05
Total ^a	100.00	100.00	100.01	99.99	99.99	100.00

^aTotals not equalling 100.00% are due to rounding error.

algal production, which resulted in an abundant source of food for filter-feeding macroinvertebrates.

Delta

During reactor operation few macroinvertebrates were found in the water column of Four-mile Branch. Only a few species of oligochaetes, nematodes, and chironomids survived deep in the sediments. During reactor outages the thermal portion of the stream was quickly colonized by several species of mayflies, caddisflies and beetles. Gastropods were also collected at the thermal stations during reactor outages. The gastropods probably moved into the main channels of the creek from cooler side channels. Thus the resident number of taxa, density of organisms, and biomass during reactor operation were much lower than suggested by the data in Table 12-14 on page 12-25 and Table 12-17 on page 12-29, which include data collected during reactor outages.

Creek Mouth

During reactor operation, water temperatures in the mouth of Fourmile Branch were always at least several degrees warmer than the Savannah River, except when the creek was flooded by high river levels. During reactor operation, water temperatures in the creek mouth exceeded 35°C beginning in May and approached 40°C in July. The macroinvertebrate community in the mouth of Fourmile Branch was far more diverse than that of the delta, but still exhibited strong evidence of thermal perturbation. The community was dominated by dipterans (primarily chironomids Table 12-17 on page 12-29). Some species, such as *Hyalella azteca* (Amphipoda) and *Caenis* spp. (Ephemeroptera) were abundant during the winter and spring months. *Physella heterostropha* (Gastropoda) was abundant from January to April, especially on the multiplate samplers positioned near the creek bottom. From June to October, densities of all macroinvertebrates were low and the fauna consisted mostly of *Cheumatopsyche* spp. (Trichoptera), *Simulium* spp. (Diptera), and Nematoda. When river levels were high and the Savannah River swamp was flooded, the number of taxa and densities increased on multiplate samplers in the mouth of Fourmile Branch. When compared to the mouths of the other four creeks that drain SRS, Fourmile Branch had far lower mean densities, taxa richness, and biomass.

Recovery of Macroinvertebrate Community After Shutdown of C Reactor

Introduction

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

Recolonization

Following the shutdown of C Reactor in June 1985, macroinvertebrates rapidly colonized the stream. Within two months of reactor shutdown, macroinvertebrate taxa richness in Fourmile Branch (mean of 20 taxa/sampler) was comparable to that of non-thermal SRS streams sampled during the CCWS (19.7–25.9 taxa/sampler). In subsequent months, the number of taxa collected was variable, but increased slightly over time—to about 23 taxa/sampler when sampling ended in September 1987. (See Figure 12-8 on page 12-28.) Mean densities of macroinvertebrates were very low during the first few weeks after reactor shutdown. However, in July 1985 densities increased sharply and peaked at 23,631.3 organisms/m² (Figure 12-17 on page 12-51), which was the highest density reported during the recolonization study.

Taxa Collected

Table 6 lists all macroinvertebrate taxa collected during the recolonization study. The dominant organisms found during the first months of recovery were Orthoclaadiinae, Tanytarsini, and other early instar chironomid larvae, which comprised up to 98.8% of the macroinvertebrates collected. Chironomids are often among the first colonizers of aquatic habitats that have been severely stressed. These data indicate that recolonization of Fourmile Branch following reactor shutdown was very rapid for certain groups of aquatic insects. Other insects, such as caddisflies and mayflies, were somewhat slower to colonize, but were still present in relatively large numbers within two months of reactor shutdown. Mean macroinvertebrate biomass was similar to nonthermal streams within a month of reactor shutdown, and the distribution of biomass in functional groups was similar to most nonthermal streams at SRS.

Figure 12-8. Macroinvertebrate Taxa richness in Fourmile Branch Following C-Reactor Shutdown

Figure 12-9. Total Macroinvertebrate Mean Density (no./m²) in Fourmile Branch Following C-Reactor Shutdown

Table 12-17. Mean Invertebrate Density/m at Each Station in Fourmile Branch for Each Taxon Collected on Hester-Dendy Multiplate Samplers (October 1984–September 1985)

Taxa	Stations					
	12	14	15	16	17	18
Turbellaria	15.3		0.2	0.3		0.2
Nematoda	12.1	5.0	257.3	58.6	139.8	8.6
Oligochaeta	97.2	136.6	334.9	428.1	398.8	165.5
Hirudinea						0.2
Gastropoda	0.5	0.3	1.0	0.2	5.0	2.1
Family Ancyliidae						9.4
<i>Ferrissia rivularis</i>	0.3				0.3	
Family Hydrobiidae						
<i>Amnicola</i> sp.	0.3		0.2			0.3
Family Lymnaeidae						
<i>Pseudosuccinea columella</i>	0.2	0.2				
Family Physidae						
<i>Physella heterostrophia</i>	1.0	9.8	6.3	0.5	26.5	4.9
Family Planorbidae						
<i>Gyraulus parvus</i>	0.2					
<i>Helisoma trivolvis</i>	0.5					
Amphipoda						
Family Gammaridae						
<i>Gammarus fasciatus</i>				0.3	0.2	
Family Talitridae						
<i>Hyaella azteca</i>	1.1		0.3	0.2	0.2	0.3
Arachnida						
Hydracarina	30.0	0.6	2.2	1.4	0.5	1.4
Insecta						
Collembola						0.2
Family Entomobryidae						
<i>Entomobrya</i> sp.					0.2	
Family Isotomidae	0.2					
Family Poduridae						
<i>Podura aquatica</i>	2.4					
Ephemeroptera						
Family Baetidae						
<i>Baetis</i> sp.	16.4	29.0	71.1	48.8	14.6	21.7
Family Caenidae						
<i>Caenis</i> sp.	0.6	8.4	27.6	4.8	40.0	40.7
Family Ephemerellidae	0.3					
<i>Dannella simplex</i>		0.2				
<i>Ephemerella invaria</i>	0.2					1.9
<i>Eurylophella temporalis</i>	30.6	0.2	0.2			0.8
Family Heptageniidae		0.5	0.5	1.0	0.8	
<i>Heptagenia</i> sp.						5.9
<i>Stenacron interpunctatum</i>	0.2	0.9	1.9	3.0	2.3	28.3
<i>Stenonema modestum</i>	73.4	3.9	8.0	10.4	4.7	21.7
Family Neoephemeridae						
<i>Neoephemera youngi</i>	0.2		0.2			

Table 12-17. (cont)

Taxa	Stations					
	12	14	15	16	17	18
Family Oligoneuridae						
<i>Isonychia</i> sp.	0.2	0.6		6.2	0.5	
Family Tricorythidae						
<i>Tricorythodes</i> sp.	0.3	3.4	4.7	0.6		0.5
Ononata						
Anisoptera	0.5		0.2			
Family Aeshnidae						
<i>Boyeria vinosa</i>	0.2		0.7	0.2	0.2	
<i>Nasiaeschna pentacantha</i>	0.2					
Family Corduliidae						
<i>Epicordulia regina</i>		1.2				
<i>Neurocordulia</i> sp.			0.2			
Family Libellulidae						
<i>Erythemis simplicicollis</i>					0.8	
<i>Pachydiplax longipennis</i>					0.6	
Family Macromiidae						
<i>Macromia</i> spp.		0.2			0.2	
Zygoptera	0.2					
Family Calopterygidae						
<i>Hetaerina</i> sp.	0.3					
Family Coenagrionidae			0.2			
<i>Argia</i> sp.	1.0					0.2
<i>Enallagma</i> sp.	1.0		0.2		1.1	
<i>Ischnura</i> sp.					1.4	
Plecoptera						0.5
Family Perlidae	0.6			0.3	0.2	0.2
<i>Acroneuria abnormis</i>		0.3	0.2			
<i>Paragnetina fumosa</i>				0.2		
<i>Perlesta placida</i>	2.2	0.2		0.3		0.5
Family Perlodidae						
<i>Helopicus bogaloosa</i>	0.2	0.2				
<i>Isoperla</i> sp.	0.5					
Family Pteronarcyidae						
<i>Pteronarcys dorsata</i>	0.5					
Family Taeniopterygidae						0.2
<i>Taeniopteryx longicera</i>	2.2					
<i>Taeniopteryx robinae</i>	1.8					
Hemiptera						
Family Corixidae				0.2		
Coleoptera						
Family Elmidae	0.2				0.2	
<i>Ancyronyx variegatus</i>	2.6	0.5	0.2	0.2		0.5
<i>Dubiraphia</i> sp.	0.6					
<i>Macronychus glabratus</i>	20.4	1.2			0.2	
<i>Microcylloepus pusillus</i>	0.2					
<i>Stenelmis</i> sp.	1.6					
Family Gyrinidae						
<i>Dineutes</i> sp.			0.3	0.6		1.3
<i>Gyrinus</i> sp.	1.0					

Table 12-17. (cont)

Taxa	Stations					
	12	14	15	16	17	18
Family Hydrophilidae						
<i>Berosus</i> sp.		0.2				
<i>Hydrobius</i> sp.	0.3					
<i>Parachymus</i> sp.					0.2	
<i>Tropisternus</i> sp.		0.2		0.3		
Megaloptera						
Family Corydalidae						
<i>Corydalus cornutus</i>	1.9	0.2		1.3	0.2	0.3
Trichoptera						
Family Hydropsychidae	0.8	0.6	3.6	1.4		0.3
<i>Cheumatopsyche</i> spp.	357.5	15.5	5.2	4.6	2.9	10.5
<i>Hydropsyche</i> sp.	110.0	147.1	19.0	39.1	2.5	6.1
<i>Macrostemum carolina</i>	255.9	0.2				
Family Hydroptilidae		0.2				
<i>Hydroptila</i> sp.	1.0	1.7			0.2	
<i>Orthotrichia</i> sp.						0.3
<i>Oxyethira</i> sp.	2.7	0.6	3.2	1.0	1.1	0.2
Family Leptoceridae						
<i>Ceraclea</i> sp.					0.3	0.2
<i>Nectopsyche candida</i>	0.3		0.2			
<i>Oecetis</i> sp.	12.6	0.3	0.8	1.6	0.8	4.6
<i>Triaenodes</i> sp.	0.3					
Family Philopotamidae						
<i>Chimarra</i> sp.	100.2	21.9	4.1	13.7	9.9	6.4
Family Polycentropodidae						
<i>Cernotina</i> sp.	0.2					
<i>Cyrnellus</i> sp.		0.2				
<i>Neureclipsis</i> sp.	0.2	14.9	2.2	1.6	0.5	4.5
<i>Polycentropus</i> sp.	0.3					
Family Psychomyiidae						
<i>Lype diversa</i>	0.2	0.2		0.2		
Lepidoptera						
Family Pyralidae						
<i>Neargyractis</i> sp.	0.3					
<i>Paraponyx</i> sp.	0.3					
Diptera						
Family Ceratopogonidae	4.0	3.7	7.4	7.3	4.3	4.3
<i>Ceratopogonidae pupae</i>	0.3				0.2	
Subfamily Forcipomyiinae	0.2	2.6	2.2	2.9	0.8	
<i>Atrichopogon</i> sp.					0.2	
Family Chaoboridae						
<i>Chaoborus punctipennis</i>		0.3				
Family Chironomidae						1033.5
<i>Chironomidae pupae</i>	44.4	40.5	65.2	91.3	46.4	
Subfamily Chironominae						
Tribe Chironomini	54.7	291.1	412.4	554.2	376.3	
<i>Robackia claviger</i>		0.2				

Table 12-17. (cont)

Taxa	Stations					
	12	14	15	16	17	18
Tribe Tanytarsini	392.3	76.4	115.5	136.2	26.8	71.8
Subfamily Diamesinae						
<i>Potthastia</i> sp.		0.2				
Subfamily Orthocladiinae	207.2	74.5	65.9	56.2	19.6	
Subfamily Tanypodinae	36.4	115.0	107.3	80.9	97.0	54.1
Family Empididae	14.0	0.5		0.6	1.1	3.8
Family Simuliidae	3.5					
<i>Simulium</i> sp.	184.7	0.3		0.2	0.3	4.8
Family Tipulidae			0.2			
<i>Tipula</i> sp.	0.2					

Data from Firth et al. 1986 and O'Hop et al. 1986

Table 12-18. Macroinvertebrate taxa found on artificial substrates in Fourmile Branch. (June 1985–September 1987)

Taxon
Class Turbellaria
Phylum Nematoda
Class Polychaeta
<i>Manayunkia speciosa</i>
Class Oligochaeta
Class Hirudinea
Class Gastropoda ^a
Family Ancyliidae
Family Physidae
<i>Physella heterostropha</i>
Family Planorbidae ^a
<i>Gyraulus parvus</i>
<i>Helisoma anceps</i>
<i>Helisoma trivolvis</i>
<i>Menetus dilatatus</i>
Class Pelecypoda ^a
Family Corbiculidae
<i>Corbicula fluminea</i>
Order Hydracarina
Order Amphipoda ^a
Family Talitridae
<i>Hyalella azteca</i>
Order Ephemeroptera ^a
Family Baetidae ^a
<i>Baetis</i>
<i>Callibaetis</i>
<i>Pseudocloeon parvulum</i>
Family Caenidae
<i>Caenis</i>
Family Ephemerellidae ^a
<i>Ephemerella</i>
<i>Eurylophella temporalis</i>
<i>Serratella</i>
Family Heptageniidae ^a
<i>Heptagenia</i>
<i>Stenacron interpunctatum</i>
<i>Stenonema modestum</i>
Family Oligoneuriidae
<i>Isonychia</i>
Family Tricorythidae
<i>Leptohyphes^a</i>
<i>Leptohyphes dolani</i>
<i>Tricorythodes</i>
Order Odonata
Suborder Anisoptera ^a
Family Aeshnidae ^a
<i>Boyeria^a</i>
<i>Boyeria vinosa</i>
Family Corduliidae
<i>Neurocordulia^a</i>

Taxon
<i>Neurocordulia molesta</i>
Family Gomphidae ^a
<i>Hagenius brevistylus</i>
Family Macromiidae
<i>Didymops transversa</i>
<i>Macromia</i>
Suborder Zygoptera ^a
Family Calopterygidae ^a
<i>Calopteryx</i>
<i>Hetaerina</i>
Family Coenagrionidae ^a
<i>Argia</i>
<i>Enallagma</i>
Order Plecoptera ^a
Family Perlidae ^a
<i>Paragnetina fumosa</i>
<i>Paragnetina kansensis</i>
<i>Perlesta</i>
Order Hemiptera
Family Corixidae
Order Coleoptera
Family Chrysomelidae
<i>Pyrrhalta nymphaeae</i>
Family Dytiscidae
<i>Coptotomus</i>
Family Elmidae ^a
<i>Ancyronyx variegatus</i>
<i>Dubiraphia</i>
<i>Macronychus glabratus</i>
<i>Microcylloepus pusillus</i>
<i>Stenelmis</i>
Family Gyrinidae
<i>Dineutus</i>
Family Hydrophilidae
Family Ptilodactylidae
Order Megaloptera
Family Corydalidae ^a
<i>Corydalus cornutus</i>
Order Trichoptera ^a
Family Hydropsychidae ^a
<i>Cheumatopsyche</i>
<i>Hydropsyche</i>
<i>Macrostemum carolina</i>
Family Hydroptilidae ^a
<i>Hydroptila</i>
<i>Oxyethira</i>
Family Leptoceridae ^a
<i>Ceraclea</i>
<i>Nectopsyche</i> ^a
<i>Nectopsyche candida</i>
<i>Oecetis</i>
<i>Trianaodes</i> ^a

Taxon
<i>Trienodes tardus</i>
Family Philopotamidae
<i>Chimarra</i>
Family Polycentropodidae ^a
<i>Cernotina</i>
<i>Neureclipsis</i>
Order Lepidoptera
Family Pyralidae ^a
<i>Neargyractis</i>
<i>Paraponyx</i>
<i>Synclita</i>
Order Diptera ^a
Family Tipulidae ^a
<i>Antocha</i>
<i>Tipula</i>
Family Chaoboridae
<i>Chaoborus punctipennis</i>
Family Simuliidae
<i>Simulium</i>
Family Ceratopogonidae ^a
Subfamily Ceratopogoniinae
Subfamily Forcipomyiinae
Family Chironomidae ^a
Subfamily Tanypodinae
Subfamily Diamesiinae ^a
<i>Potthastia</i>
Subfamily Orthoclaadiinae
Subfamily Chironominae
Tribe Chironomini ^a
<i>Stenochironomus</i>
Tribe Tanytarsini
Family Empididae ^a
<i>Chelifera</i>
<i>Hemerodromia</i>

^aHigher order categories not included in count if lower order taxa were identified.

Fish

Introduction

Classifying Studies

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

Assessment of Thermal Impacts

The second and most extensive phase concentrated on the assessment of impacts caused by the thermal discharges from C Reactor. Fourmile Branch was sampled at various locations, including the ambient temperature section of the stream above C Reactor, the section below C Reactor, and the section that flowed through the Savannah River floodplain swamp (Figure 12-10). These studies focused on distribution and relative abundance, reproduction, and habitat usage.

Assessment of Potential Impacts from Contaminants

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

Figure 12-10. Electrofishing, Fike Net, and Swamp Sampling Stations on Fourmile Branch

Studies Conducted During C Reactor Operations

Fish Movements in Relation to Reactor Operation

Introduction

Fish were observed to enter the lower reaches of Fourmile Branch (i.e., the portion of Fourmile Branch that runs through the SRS Savannah River floodplain swamp) during reactor outages. These movements were studied by Aho et al. (1986) in Fourmile Branch and a similar section of Pen Branch. (See Figure 12-10 on page 12-37.) This work was conducted from September 1983 to December 1985, and involved collections made with fyke nets near the mouths and in the lower swamp reaches of both creeks. The sampling encompassed 3 and 16 outages of C and K Reactors, respectively.

Methods

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

Seasonal Variation

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

Figure 12-11. Variability in the Daily Mean Number of Species and Individuals Entering Fourmile Branch on Different Reactor Cycles, 1983–1985

Reactor Shutdown

Reinvasion of fish into either stream channel was rapid, with individuals captured within 12 hours of the cessation of reactor operations (see Figure 12-11 on page 38). There was no single pulse of upstream movement after the streams returned to ambient water temperatures and reduced discharge rates. Recolonization was variable for the duration of the shutdown (Figure 12-11).

Movement

Fish released following capture and later recaptured showed that several species made movements of 3–5 km within a week of their release. Fish that moved away from the original point of capture also moved downstream, made complex local movements, or shifted lateral position within the stream. Complex local movement was defined as recapture of the same fish at the same net within the same reactor cycle.

Upstream Migration

Within Fourmile Branch, continued upstream migration was limited by a dam located approximately 1 km above the nets. Additionally, a nearby backwater served as a limited refuge area when water temperatures were high (McFarlane 1976). Observations during reactor outages revealed that the dam provides a barrier to the upstream migration of fish independently of reactor operation.

Species Collected

A total of 39 and 29 species of fish were collected from the Fourmile Branch and Pen Branch channels (Aho et al. 1986), respectively. Centrarchids were the most abundant taxa and comprised >30% of the species (see Figure 12-12). Four species [spotted sunfish (*Lepomis punctatus*), lake chubsucker (*Erimyzon sucetta*), golden shiner (*Notemigonus crysoleu-*

Figure 12-12. Overall Percentage Composition of the Fish Assemblage Caught in the Fyke Nets in Fourmile Branch (Source: Aho et al. 1986)

cas), and redbreast sunfish (*Lepomis auritus*)] accounted for more than 50% of the fish entering the stream channels. The common species caught moving into the stream included both juveniles and adults. Cyprinids, principally the coastal shiner (*Notropis petersoni*) and the mosquitofish (*Gambusia affinis*), were frequently observed in the streams during periods of ambient conditions. Their absence reflects a sampling bias of the nets against small fishes regardless of species.

Effects of Reactor Restart

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

Fish Assemblages at Thermal Swamp Sites

Introduction

Aho et al. (1986) also studied the fish assemblage structure within the Savannah River swamp system. Four sites (FMI, FM2, FM3, and FM4) were located in or near the flow path of Fourmile Branch. (See Figure 12-10 on page 12-37.) A total of 11,996 individuals representing 51 species were collected by electrofishing over the course of the study. (Table 12-19 on page 12-41 lists the species collected in Fourmile Branch.) The vast majority of species were categorized as year-round residents. However, two species [hickory shad (*Alosa mediocris*) and striped mullet (*Mugil cephalus*)] were migratory. Centrarchids and cyprinids represented more than 40% of the taxa and individuals.

Faunal Groups

Although the more common species occurred throughout the Savannah River swamp system, a cluster analysis based on relative abundance provided evidence of spatial variation (Figure 12-13 on page 12-41). Eight major faunal groups were formed. The four sites within Fourmile Branch grouped together, although this group also included samples from three additional sites. Temporal variability in assemblage composition was minor compared to spatial differentiation of the groupings. In the majority of cases (>70%), the seasonal censuses from the same site (1-spring, 2-summer, and 3-fall) were found in the same faunal group.

Dominant Species in Faunal Groups

While no faunal group had a unique fish fauna, cross classifying the faunal groups with the dominant fish species (those contributing at least 5% of the numerical size of a faunal group) highlighted basic compositional differences between the different groups. (See Table 12-20 on page 12-42.) Large-bodied species, such as the bowfin, gizzard shad, longnose gar, and largemouth bass, were the dominant species of the depauperate Group A assemblage which included the Fourmile Branch sites. Largemouth bass, brook silversides, longnose gar, and cyprinids were also represented in the suite of common species. For the remaining

Table 12-19. Fish Species Present in 4 Fourmile Branch Study Sites Within the Savannah River Swamp System (taken from Aho et al. 1986)

	Location			
	Fourmile 1	Fourmile 2	Fourmile 3	Fourmile 4
Coastal shiner		x	x	x
Golden shiner	x			
Spotted sucker	x	x		x
Mosquitofish	x			
Brook silversides			x	x
Largemouth bass	x	x	x	x
Spotted sunfish	x			x
Redbreast sunfish		x		
Bluegill		x		
Redear sunfish		x	x	
American eel	x	x		
Longnose gar	x		x	x
Florida gar	x		x	
Bowfin	x		x	x
Chain pickerel	x	x		
Gizzard shad	x	x	x	x
Hickory shad*	x	x		

* Denotes species for which less than 5 individuals were collected.

Figure 12-13. Average Linkage Cluster Analysis of the Fish Assemblage structure from Collections from 12 Sites during 3 Seasons in the Savannah River Swamp System (Source: Aho et al. 1986)

faunal groups, assemblage structure had greater representation of minnows and centrarchids. Groups C through E exhibited a shift in general body plan to an assemblage dominated by small-bodied fish.

Spatial Differentiation

The spatial differentiation in assemblage structure corresponded to two major habitat gradients within the SRSS (Table 12-21 on page 12-43). The first faunal group (A) contrasted a depauperate assemblage against a fauna of greater richness and abundance, illustrating the disturbance caused by elevated water temperatures in the Fourmile Branch region. Areas experiencing high levels of thermal loading had depauperate assemblages dominated by mosquitofish when water temperatures were elevated, but were rapidly reinvaded when ambient temperature conditions returned. The second gradient contrasted habitats with different degrees of canopy closure. Faunal Group B included sites characterized as having a predominantly closed overstory of cypress and tupelo; limited emergent macrophyte growth; and low habitat complexity, open water, and standing tree buttresses being the dominant categories. The number of species was moderate compared to other groups, but abundance was low and dominated by taxa commonly associated with less structured habitats. Open canopy, braided water courses with periodically high flow rates, and high habitat diversity with extensive macrophyte growth and downed timber characterized Faunal Groups C through H, which included sites where the canopy had been lost naturally as a result of prior disturbance regimes. Species associated with structurally complex habitats dominated these groups. Subtle elevations in water temperature at sites from Slave Island (SI2, SI3, and SI4) did not appear to additionally influence assemblage structure for either open or closed canopy groups.

Table 12-20. Two Way Table Comparing Faunal Groups and Fish Species Associations Contributing at least 5% to the Abundance of a Specific Group Within the Savannah River Swamp System. (Source: Aho et al. 1986)

	Faunal Group ^a							
	A	B	C	D	E	F	G	H
mean richness ^b	2.1	12.6	13.5	11.7	18.3	14	15	13
mean abundance	5.9:10.1 (0-11)	11.4:10.8 (8-17)	15.3:11.8 (9-17)	19.8:18.6 (8-16)	32.3:26.4 (13-29)	32.5:39.2	40.8:23.0	44.3:26.9
bowfin	>10%							
longnose gar	>10%							
gizzard shad	>10%	>5%						
brook silversides		>10%	>5%	>10%	>10%	>10%	>10%	>10%
largemouth bass	>5%	>10%		>10%	>5%	>5%		
golden shiner			>5%					>5%
chain pickerel			>10%					
ironcolor shiner		>5%	>10%		>10%		>10%	>10%
coastal shiner		>5%			>10%	>5%	>5%	>5%
lake chubsucker			>5%	>5%	>10%	>5%		
spotted sunfish			>5%		>10%			>5%
pirate perch						>10%		
redbreast sunfish						>5%		
mosquitofish							>10%	

^aFaunal groups can be matched to habitats shown in Figure 12-13.

^bMean species richness is derived from the total number of species from each site-season collection while mean abundance is the mean number of fish per 50-m transect.

Table 12-21. Summary of the Site Characteristics for the Twelve Locations Within the Savannah River Swamp System (Source: Aho et al. 1986)

Site Name	SCI	SC2	SC3	DPI	SII	SI2	SI3	SI4	FM1	FM2	FM3	FM4
Percent shaded	5	0	75	10	50	60	80	30	70	0	0	0
Percent vegetation	2	80	5	70	20	10	5	30	0	0	0	0
Dominant riparian vegetation	Macro-phyte	Macro-phyte	Cypress /tupelo	Macro-phyte	Cypress /tupelo	Cypress /tupelo	Cypress /tupelo	Cypress /tupelo	Tupelo	Dis-turbed*	Dis-turbed	Dis-turbed
Temperature (max. °C)	24.1	26.3	24.2	24.0	23.8	26.9	28.5	31.5	42.3	44.9	43.6	45.4
Temperature condition	Ambi-ent	Ambi-ent	Ambi-ent	Ambi-ent	Ambi-ent	Slightly heated	Slightly heated	Slightly heated	Heated	Heated	Heated	Heated
Maximum depth (m)	1.5	1.2	1.9	1.6	1.0	1.5	1.1	1.5	2.1	1.4	1.6	0.5
Mean current velocity (cm/s)	35	24	22	11	5	18	16	18	55	36	23	47

*No instream macrophytes or overhanging vegetation.

Effects of Canopy Cover

Several factors may have contributed to the contrast in species richness and abundance between open and closed canopy areas. The occurrence of macrophyte growth can affect fish-assemblage dynamics by providing a refuge from predators (Werner and Hall 1979; Laur and Ebling 1983; Werner et al. 1983; Keast 1978). Macrophytes may also influence the availability of food resources by increasing the amount of substrate for secondary productivity of aquatic invertebrates, the dominant prey category for most of the fishes within the SRSS (Benke 1984).

Fish Assemblages at Thermal Stream Sites

Upstream of C Reactor

Paller et al. (1988) electrofished Fourmile Branch above C Reactor (at SRS Road A-7) on six dates. Twenty taxa were identified. Minnows were the most numerically abundant taxon followed by redbreast sunfish, spotted sunfish, and pirate perch (Table 12-22). These taxa were also among the most numerous species in undisturbed upper coastal plain streams of South Carolina as determined by Meffe and Sheldon (1987).

Downstream of C Reactor

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

Paller and Saul (1987) studied fish communities in SRS streams between November 1984 and August 1985. Sampling stations for this study included two sites near Road A and Road A-12.2 where electrofishing was scheduled quarterly. Collection data from that site are summarized in Table 12-23 on page 12-45. The observations from the study by Paller and Saul (1987) indicate that only mosquitofish inhabited the portion of Fourmile Branch below the C Reactor outfall during reactor operation. However, when C Reactor shut down, sunfish migrated into the area according to the findings of Aho et al. (1986) discussed earlier.

Effects of Cool Water

Additional samples in the lower reaches of Fourmile Branch were collected by Paller and Saul (1987). They sampled fish on one occasion (2/21/85) in the Fourmile Branch delta using a backpack electroshocker. Collections were taken from relatively cool backwater areas during a period of reactor operation. Only one specimen, a brook silverside, was captured. Mosquitofish were observed in the cooler portions of the Fourmile Branch delta on numerous occasions when C Reactor was operating. Thus, mosquitofish were undoubtedly year-round residents of portions of the delta

Effects of Reactor Operation

Paller and Saul (1987) electrofished the mouth of Fourmile Branch on 15 occasions (see Table 12-24 on page 45). Eleven taxa were represented. They found that few or no fish were present when C Reactor was operating and water temperatures were elevated, but rapidly reinvaded the area during reactor outages.

Table 12-22. Number of Fish Collected on Six Dates During Electrofishing Collections by ECS at Fourmile Branch Near Road A-7

Taxa	12/21/84	12/31/84	2/28/85	5/17/85	8/8/85	8/9/85	All Dates Combined
minnow spp.	0	2	5	143	57	41	248
redbreast sunfish	30	4	21	18	8	24	105
spotted sunfish	5	5	15	22	4	6	57
pirate perch	16	7	11	5	1	1	41
creek chubsucker	6	11	5	1	1	4	28
dollar sunfish	4	0	1	11	1	1	18
tesselated darter	0	0	8	6	2	0	16
yellow bullhead	5	0	4	3	1	2	15
largemouth bass	1	0	3	2	1	3	10
grass pickerel	5	0	1	0	0	1	7
American eel	1	0	0	2	0	1	4
mosquitofish	3	0	0	0	0	0	3
warmouth	0	0	1	0	1	1	3
madtom	0	2	0	0	0	0	2
redeer sunfish	0	0	0	2	0	0	2
bluegill sunfish	0	0	0	0	0	1	1
blackbanded darter	0	0	0	0	1	0	1
yellow perch	0	0	0	1	0	0	1
flat bullhead	0	0	0	0	1	0	1
bluehead chub	0	0	0	0	0	1	1

Table 12-23. Fish Collected from Fourmile Branch near Road A and Road A-13.2

Date	C-Reactor Status	Taxa	Number Collected
12/3/84	up	mosquitofish	55
3/1/85	up	mosquitofish	25
5/9/85	up	mosquitofish	15
8/19/85	down	mosquitofish	42

Table 12-24. Fish Collected from the Fourmile Branch Delta

Species	1984		1985												
	11/7	12/5	12/14	1/4	1/10	1/17	2/6	2/14	2/21	2/28	3/7	3/14	3/21	4/10	8/19
largemouth bass	5	1	0	1	0	1	0	0	0	0	2	0	1	0	0
bluegill sunfish	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1
channel catfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
redbreast sunfish	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
brook silverside	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bowfin	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0
minnow spp.	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2
spotted sucker	0	0	0	1	0	0	0	0	1	0	0	2	0	0	1
longnose gar	0	0	0	0	1	0	1	2	0	0	0	2	1	0	0
gizzard shad	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1
lake chubsucker	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Ichthyoplankton Distribution

Introduction

Paller and Saul (1987) also collected ichthyoplankton from seven sampling stations on Fourmile Branch during 1984 and 1985. One station (#12) was situated near Road A-7 in the undisturbed headwaters upstream from the confluence with the reactor cooling water effluent. One station was at Road A, approximately 8 km downstream from C Reactor, one at the inflow into the delta, three in the thermal swamp downstream from the delta, and one in the creek mouth. (See Figure 12-10 on page 12-37.) The three thermal swamp stations were grouped together in the following analysis because they had similar habitats and temperatures.

March-July 1984

A total of 206 ichthyoplankters were collected from Fourmile Branch between March 14 and July 31, 1984. Centrarchids were the most abundant taxa, although brook silverside and blueback herring were also well-represented (Table 12-24 on page 12-45).

Effects of Reactor Operation

C Reactor was operating at full power throughout April and May 1984, and operation was intermittent during March. As a result, temperatures at Road A ranged from 33.9 to 40.1°C, and temperatures at the inflow into the delta ranged from 30.1 to 44.8°C during the spring

Table 12-25. Number and Percent Composition of Ichthyoplankton Collected from Fourmile Branch (March 14–July 31, 1984) (Source: Paller 1985)

Taxa	Number	Percent
gizzard and/or threadfin shad	16	7.8
blueback herring	21	10.2
unid. herring or shad	4	1.9
sunfish and/or bass	66	32.0
crappie	5	2.4
yellow perch	1	0.5
darters	2	1.0
minnows	14	6.8
carp	3	1.5
brook silverside	28	13.6
unid. ichthyoplankton ^a	46	22.3
total	206	100.0

^aPrincipally eggs

spawning season of 1984 (Figure 12-14). Ichthyoplankton were absent from these sites with the exception of some brook silverside eggs and unidentifiable eggs collected from the Road A sample site in May 1984. These eggs probably drifted into the channel of Fourmile Branch from cooler side-channel waters (Paller 1985).

Thermal Variation in Swamp

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

February–July 1985

A total of 174 ichthyoplankters were collected from Fourmile Branch between February and July 1985 (Table 12-26 on page 12-48). Unidentified ichthyoplankton (primarily eggs) were most common. Mean densities of ichthyoplankton upstream from C Reactor were generally low (<15/1000 m³), and most of the organisms collected were minnows or centrarchids (Figure 12-14 on page 12-47). Throughout the sampling period, ichthyoplankton were largely absent from the sample station near Road A where water temperatures sometimes exceeded 40°C when C Reactor was operating. Farther downstream in the delta, some

Figure 12-14. Average Ichthyoplankton Density and Water Temperature at Four Sampling Stations along Fourmile Branch

Table 12-26. Number and Percent Composition of Ichthyoplankton Collected from Four-mile Branch (February-July 1985) (Source: Paller et al. 1986a)

	Number	Percent
blueback herring	3	1.7
minnows	14	8.0
carp	7	4.0
mosquitofish	2	1.2
brook silverside	2	1.2
sunfish and/or bass	14	8.0
crappie	3	1.7
darters	6	3.4
unid. ichthyoplankton	123	70.7
total	174	99.9

Figure 12-15. Monthly Mean Water Temperature and Ichthyoplankton Density at Each Sampling Site in Fourmile Branch (February-July 1985)

cooling had occurred, but temperatures still remained near 40°C during much of the sampling period.

Mouth of Fourmile Branch

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

Comparison of 1984 and 1985 Data

Except for the densities at the creek mouth, ichthyoplankton were less abundant in Fourmile Branch during 1985 than during 1984 (Figure 12-16). The differences in the swamp and creek mouth ichthyoplankton densities were probably due to differences in the level of the Savannah River during those years. During the spring of 1984, the swamp was intermittently flooded by cool river water (Paller 1985). Most of the larvae taken from the swamp during 1984 were collected when the swamp was flooded. Conversely, the Savannah River generally remained below flood stage during 1985, and relatively few ichthyoplankton were collected from Fourmile Branch.

Effects of Temperature on Ichthyoplankton

Introduction

Aho et al. (1986) studied larval fish assemblages at nine sampling locations in the SRSS (Figure 12-10 on page 12-37) during 1985. Five stations spanned a wide range of temperatures (temperatures elevated 2-19°C above ambient) along the plumes from Fourmile

Figure 12-16. Total Ichthyoplankton Densities at Fourmile Branch Locations During the 1984 and 1985 Sampling programs (Paller et al. 1986)

Branch and Pen Branch. These were numbered 1-5 from hottest to coolest. The other four stations were at ambient temperatures near the mouth of Steel Creek (Figure 12-10). Each sampling station was an area roughly 50 m in diameter that included both channels and adjacent shallows (except Stations 10 and 12 where there were no distinct channels).

Effect of Reactor Operation

At stations within the thermal plumes, water temperatures changed suddenly when reactors stopped and started. During these reactor cycles, recording thermometers showed temperatures fell to ambient levels (and subsequently rose) at about 1°C/hr at the Fourmile Branch stations. Temperature changes were more gradual at Stations 4 and 5 due to their distances from the main flow from Pen Branch. The most extreme fluctuations among the nonthermal sites occurred at Station 10, a shallow disturbed area that lacked canopy vegetation, where temperatures changed 20°C over a two-week period in February.

January 1985

No larvae were collected in the first week of January at any location, although water temperatures exceeded 15°C in the hottest thermal areas. Densities began to rise at thermal Stations 1 through 3 by the end of January. In the ambient temperature areas, density peaks occurred later in the year.

Densities

The timing of peak ichthyoplankton densities differed by as much as eight weeks between the hottest thermal area and the ambient temperature stations (Figure 12-17). Seasonal patterns were advanced even at Station 5, where temperatures were only about two degrees warmer than in the natural or previously disturbed habitats (Figure 12-17).

Maximum densities occurred two to four weeks earlier in the previously disturbed areas, where canopy trees had been killed, than in the natural areas, although water temperatures were similar (Figure 12-17).

Reproductive Phenology

In the thermal areas, reproductive phenology was disrupted in several respects. Most pronounced was a disruption in the sequence of appearance of larvae of different taxa. Larval cyprinids, golden shiners (*Notemigonus crysoleucas*), brook silversides (*Labidesthes sicculus*), sunfish, and darters were all taken at Stations 1 and 2 by the first week of February, suggesting that many of the normally spring- or summer-spawning species began to reproduce in the thermal areas in early January. Some of these species may have been capable of spawning during the fall and early winter in thermal areas. Water quality values other than temperature appeared similar at all stations. Thus, shifts in reproduction or changes in species composition probably resulted directly or indirectly from differences in temperature, light intensity, or trophic base of the community.

Figure 12-17. Seasonal Changes of Total Ichthyoplankton Density at Each Station

Studies Conducted to Assess F- and H-Area Impacts

Introduction

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

Effects of Seepage Basin Constituents on Fish

The occurrence of elevated levels of several seepage basin constituents in Fourmile Branch water raised concerns about possible impacts to aquatic organisms. Gladden (1988) reviewed the historical data from the upper reaches of Fourmile Branch to determine if outcropping effluent from the seepage basins was adversely affecting the instream communities. He concluded that there was no clear evidence of adverse impacts due to the seepage basin effluent, but believed that the data were insufficient to evaluate possible local effects. To provide more information, a sampling program was designed to assess the abundance, distribution, and tissue contaminant levels of Fourmile Branch fish upstream and downstream from the seepage basins. This program included seven sample stations—six in Fourmile Branch including locations upstream from (Stations 1 and 2) and downstream from (Stations 3-6) the seepage basins, and one in Pen Branch (Station 7). (See Figure 12-10 on page 12-37.) The sample station in Pen Branch was included primarily to serve as a source of uncontaminated fish to establish background levels of potential tissue contaminants. Three 100-m stream segments were electrofished at each sample station.

Sampling Program

Fish assemblage structure differed among sample stations. Station 1 was dominated by pirate perch, redbreast sunfish, and creek chubsuckers (Table 3). Stations 2-4 were dominated by several types of shiners (dusky, yellowfin, or taillight) and sunfishes (dollar, spotted, or redbreast). Stations 5 and 6 were dominated by mosquitofish, redbreast sunfish, spotted sunfish, and yellow bullhead. Number of fish collected per 100 m (CPUE) also differed among stations (Table 3). The lowest CPUE in Fourmile Branch occurred at station 2 (44.7 fish/100 m) and the highest occurred at station 4 (149.7 fish/100 m). However, a comparison of collections at stations 1 and 2 (above the outcropping zone) with stations 3 and 4 (below the outcropping zone) indicated that species number and total (i.e., all species summed) CPUE were higher below the outcropping zone than above (Figure 12-18 on page 12-54, Table 4). On an individual species basis, four species decreased below the outcropping zone while nine increased. These differences were not indicative of adverse impacts due to seepage basin outcropping and were more likely a result of habitat differences among stations.

Table 12-27. Relative abundance (i.e., percent composition) of fish collected at six sample stations in Fourmile Branch and one sample station in the headwaters of Pen Branch. June 1990.

Species	Station number						
	1	2	3	4	5	6	7
American eel	0.0	0.0	0.0	0.2	1.1	0.0	0.0
eastern mudminnow	0.0	0.0	0.0	0.0	0.0	0.0	0.3
redfin pickerel	2.8	3.0	1.6	0.9	1.7	0.0	1.5
bluehead chub	0.0	0.0	1.2	6.0	1.1	0.2	4.3
golden shiner	1.9	0.0	0.0	0.0	0.0	0.0	0.0
ironcolor shiner	0.0	0.0	0.0	0.0	0.0	0.0	0.2
dusky shiner	0.0	22.4	30.5	2.2	8.0	3.9	1.5
yellowfin shiner	0.0	0.0	17.6	41.9	1.1	0.0	72.4
taillight shiner	5.2	0.0	11.3	4.5	0.0	0.0	0.0
coastal shiner	0.0	0.0	0.0	0.7	1.7	0.2	0.0
creek chub	0.0	0.0	0.0	0.0	0.0	0.0	1.5
creek chubsucker	13.7	21.6	3.1	2.2	0.0	0.0	2.3
yellow bullhead	5.2	15.7	1.2	4.9	12.5	12.9	0.0
tadpole madtom	0.0	3.0	3.1	0.0	2.3	0.5	0.0
marginated madtom	0.0	0.0	3.1	0.0	0.0	0.0	0.3
speckled madtom	0.0	0.0	0.0	0.0	0.0	0.0	0.2
pirate perch	36.5	7.5	5.9	2.7	2.3	6.3	4.0
lined topminnow	0.0	0.0	0.0	0.0	0.0	0.0	0.1
mosquitofish	0.5	0.7	2.7	0.4	18.2	39.4	0.3
redbreast sunfish	20.4	3.7	7.0	16.7	28.4	24.6	2.8
dollar sunfish	8.5	9.7	0.0	0.4	0.0	0.0	0.8
spotted sunfish	5.2	12.7	3.1	11.1	16.5	11.9	0.8
largemouth bass	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Savannah darter	0.0	0.0	8.6	1.1	0.0	0.0	0.0
tessellated darter	0.0	0.0	0.0	2.4	0.0	0.0	6.2
blackbanded darter	0.0	0.0	0.0	1.3	5.1	0.0	0.4
Total	99.9	100.0	100.0	99.8	100.0	99.9	99.9
Total number fish	211	134	256	449	176	411	952
Total number species	10	10	14	18	13	9	18

Key to sample station locations-

- 1 Fourmile Branch 1.1 km upstream from Road 4
- 2 Fourmile Branch at Road 4
- 3 Fourmile Branch at Road C
- 4 Fourmile Branch at Road A-7
- 5 Fourmile Branch downstream at Road A
- 6 Fourmile Branch at Cassel's Pond (just upstream of delta/swamp)
- 7 Pen Branch at Road B

Figure 12-18. Mean Electrofishing Catch per Unit Effort at Sample Stations in Fourmile Branch

Changes in Fish Assemblage with Habitat Alterations

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

Fish Communities Comparison with Unimpacted Streams

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

Fish Analysis for RCRA Trace Metals

Fish collected from Fourmile Branch and Pen Branch were analyzed for RCRA trace metals using standard EPA methods. The results of these analyses are reported in Loehle and Paller (1990). Silver, arsenic, beryllium, cadmium, copper, nickel, lead, antimony, and thallium were all either undetectable or had only a few detectable values. Mercury values were all well below the regulatory limit of 1 ug/l. For the total group of fish analyzed, there were no differences among sampling sites for aluminum, chromium, or zinc. Selenium concentrations differed among sites; fish collected near the H-Area and two control sites had the highest concentrations. When the analysis was restricted to sunfishes only, the seepage basin site

Table 12-28. Mean (standard error) electrofishing catch per unit effort (CPUE expressed as number fish per 100 m) at six sample stations in Fourmile Branch and one sample station in the headwaters of Pen Branch. June 1990.

Species	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
American eel	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.7 (0.3)	0.0 (0.0)	0.0 (0.0)
eastern mudminnow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.6)
redfin pickerel	2.0 (1.0)	1.3 (1.3)	1.3 (0.8)	1.3 (0.7)	1.0 (0.6)	0.0 (0.0)	4.7 (1.2)
bluehead chub	0.0 (0.0)	0.0 (0.0)	1.0 (0.6)	9.0 (3.5)	0.7 (0.7)	0.3 (0.3)	13.7 (3.2)
golden shiner	1.3 (0.7)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
ironcolor shiner	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (0.3)
dusky shiner	0.0 (0.0)	10.0 (1.0)	26.0 (15.0)	3.3 (3.3)	4.7 (4.7)	5.3 (3.0)	4.7 (4.2)
yellowfin shiner	0.0 (0.0)	0.0 (0.0)	15.0 (4.5)	62.7 (2.7)	0.7 (0.3)	0.0 (0.0)	229.7 (40.9)
taillight shiner	3.7 (1.9)	0.0 (0.0)	9.7 (0.9)	6.7 (1.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
coastal shiner	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (1.0)	1.0 (1.0)	0.3 (0.3)	0.0 (0.0)
creek chub	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	4.7 (2.2)
creek chubsucker	9.7 (3.3)	9.7 (3.8)	2.7 (1.5)	3.3 (2.4)	0.0 (0.0)	0.0 (0.0)	7.3 (3.5)
yellow bullhead	3.7 (1.2)	7.0 (3.0)	1.0 (0.6)	7.3 (2.3)	7.3 (2.8)	17.7 (5.7)	0.0 (0.0)
tadpole madtom	0.0 (0.0)	1.3 (0.9)	2.7 (1.7)	0.0 (0.0)	1.3 (0.7)	0.7 (0.7)	0.0 (0.0)
marginated madtom	0.0 (0.0)	0.0 (0.0)	2.7 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.0 (0.6)
speckled madtom	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.7 (0.3)
pirate perch	25.7 (13.2)	3.3 (0.7)	5.0 (2.1)	4.0 (0.6)	1.3 (0.7)	8.7 (3.3)	12.7 (4.4)
lined topminnow	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)
mosquitofish	0.3 (0.3)	0.3 (0.3)	2.3 (1.2)	0.7 (0.7)	10.7 (5.4)	54.0 (9.0)	1.0 (0.6)
redbreast sunfish	14.3 (2.8)	1.7 (0.3)	6.0 (1.0)	25.0 (6.7)	16.7 (6.8)	33.7 (18.4)	9.0 (6.5)
dollar sunfish	6.0 (1.5)	4.3 (1.2)	0.0 (0.0)	0.7 (0.7)	0.0 (0.0)	0.0 (0.0)	2.7 (0.9)
spotted sunfish	3.7 (0.9)	5.7 (1.7)	2.7 (1.5)	16.7 (6.4)	9.7 (2.7)	16.3 (5.5)	2.7 (0.7)
largemouth bass	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Savannah darter	0.0 (0.0)	0.0 (0.0)	7.3 (0.9)	1.7 (0.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
tessellated darter	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.7 (1.9)	0.0 (0.0)	0.0 (0.0)	19.7 (6.1)
blackbanded darter	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.0 (1.2)	3.0 (1.2)	0.0 (0.0)	1.3 (0.3)
Total CPUE	70.3 (22.4)	44.7 (1.9)	85.3 (24.3)	149.7 (17.3)	58.7 (13.0)	137.0 (27.2)	317.6 (62.9)
Total species	10	10	14	18	13	9	18

Key to sample station locations

- 1 Fourmile Branch 1.1 km upstream from Road 4
- 2 Fourmile Branch at Road 4
- 3 Fourmile Branch at Road C
- 4 Fourmile Branch at Road A-7
- 5 Fourmile Branch downstream of Road A
- 6 Fourmile Branch at Cassel's Pond (just upstream of delta/swamp)
- 7 Pen Branch at Road B

was shown to be slightly elevated. Among species, yellowfin shiners had higher aluminum and zinc concentrations than sunfishes and bottom fish.

Summary of Studies

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

References

- Aho, J. M., C. S. Anderson, K. B. Floyd, and M. T. Negus. Patterns of Fish Assemblage Structure and Dynamics in Waters of the Savannah River Plant, Comprehensive Cooling Water Study Final Report. SREL-27, Savannah River Ecology Laboratory, Aiken, SC (June 1986).
- Chimney, J. J. and W. R. Cody. Distribution and Abundance of Zooplankton at Selected Locations on the Savannah River and from Tributaries of the Savannah River Plant: December 1984–August 1985. ECS-SR-41. Report prepared by Environmental and Chemical Sciences, Inc. for Savannah River Laboratory, E. I. duPont de Nemours and Company, Aiken, SC (1986).
- Dixon, K. L. and V. A. Rogers. Semi-Annual Sampling of Fourmile Branch and its Seepines in the F and H Areas of SRS: July 1992, WSRC-TR-93-289.
- Firth, P., J. R. O'Hop, B. Coler, and R. A. Green. Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat, Analyses, and the Lower Food Chain Communities. ESC-SR-26, report prepared by Environmental and Chemical Sciences, Inc. for E. I. duPont de Nemours and Company, Aiken, SC (1986).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report, Vol. III, Water Quality. DP-1697, E. I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Hutchinson, G. E. A Treatise on Limnology. Vol. II. Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, New York, NY (1967).
- Lower, M. W. Comprehensive Cooling Water Study Final Report, Volume II, Water Quality. DP-1739-2, E. I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Paller, M. H. A Report of the Ichthyoplankton Sampling Data from the Creeks and Swamps of the Savannah River Plant, March 14, 1984 through July 31, 1984. ECS-SR-16, Prepared by Environmental and Chemical Sciences, Inc. for E. I. duPont de Nemours and Company, Savannah River Plant, Aiken, SC (1985).
- Paller, M. H., and B. M. Saul. 1986. Effects of thermal discharges on the distribution and abundance of adult fishes in the Savannah River and selected tributaries. Annual Report. November 1984–August 1985. ECS-SR-28. Prepared by Environmental and Chemical Sciences, Inc. for E. I. duPont de Nemours and Company. DPST-8. Aiken, SC.
- Paller, M. H., B. M. Saul, and D. W. Hughes. The Distribution of Ichthyoplankton in Thermal and Nonthermal Creeks and Swamps on the Savannah River Plant, February–July 1985. ECS-SR-25, prepared by Environmental and Chemical Sciences, Inc. for E. I. duPont de Nemours and Company, Savannah River Plant, Aiken, SC (1986a).
- Paller, M. H., J. H. Heuer, L. A. Kissick, Steel Creek Fish: L-Lake/Steel Creek Biological Monitoring Program. January 1986–December 1987. ECS-SR-72. Report prepared by Environmental and Chemical Sciences, Inc. for E. I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988).
- Specht, W. L. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. DP-1739-5, E. I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Werner, E. E., J. F. Gilliam, D. J. Hall, and G. G. Mittelbach. "An Experimental Test of the Effects of Predation Risk on Habitat Use in Fish." *Ecology* 64(6):1540–1548 (1983).
- Wetzel, R. G. *Limnology*. 2nd Ed., Saunders College Publ., Philadelphia, PA (1983).

Chapter 13

Pen Branch

Chapter Contents

Drainage Description and Surface Hydrology (page 13-3)

Water Chemistry and Quality (page 13-7)

Algae (page 13-19)

Macrophytes (page 13-21)

Zooplankton (page 13-23)

Macroinvertebrates (page 13-25)

Fish (page 13-39)

References (page 13-45)

Drainage Description and Surface Hydrology

General Description

Pen Branch drains an area of about 55 km² and is approximately 24 km long. The creek follows a southwesterly path, from its headwaters about 3.2 km east of K Area to the Savannah River swamp (Figure 13-1). After entering the swamp, the creek flows parallel to the Savannah River for about 8 km before it enters and mixes with the waters of Steel Creek about 0.4 km from the mouth of Steel Creek on the Savannah River. In its headwaters, Pen Branch is a largely unperturbed blackwater stream, similar to the headwater reaches of Fourmile Branch. Indian Grave Branch is the principal tributary of Pen Branch.

Effluents Contribution

Until K-Reactor shutdown in 1988, Indian Grave Branch received thermal effluent from K Reactor. With K-Reactor discharge, the natural flow of about 0.3 m³/s (10 ft³/s) was increased to about 11.3 m³/s (400 ft³/s). Under the operating conditions of the K-Reactor recirculating cooling tower, the flow in Indian Grave Branch would be approximately 1.6 m³/s (55 ft³/s) of which approximately 1.3 m³/s (45 ft³/s) is blowdown (Paller et al. 1989). K-Reactor cooling water discharges, which originated from the Savannah River, changed the water quality and temperature and flow regimes in Pen Branch (Firth et al. 1986). Currently, the Pen Branch system receives nonthermal effluents (i.e., non process cooling water, ash basin effluent waters, power-house waste water, and sanitary waste water) from K Area and sanitary effluent from the Central Shops Area.

Figure 13-1. Location of Pen Branch on SRS

Delta

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

Flow Measurements

The USGS measures flow at several locations on Pen Branch. Flow statistics of Pen Branch at SRS Road B and at SRS Road A-13.2 (Figure 13-2) are summarized in Table 13-1. Records at SRS Road A-13.2 date back to November 1976 (no records from February 1983 through April 1983). In water-year 1991, the mean flow of Pen Branch at Road A-13.2 was 4.1 m³/s (145 ft³/s). Over the period of record (water-years 1977–1991) at Road A-13.2, the mean flow is 7.7 m³/s (273 ft³/s), the 7-day low flow is 0.62 m³/s (22.0 ft³/s), and the 7Q10 is 0.72 m³/s (25.4 ft³/s). The maximum, minimum, and mean daily flows for the periods of record at the two stations are shown in Figure 13-3 and Figure 13-4.

Figure 13-2. Flow Measurement Sampling Stations for Pen Branch

Table 13-1 Flow Summary for Pen Branch

Station Name	Station Number	Period of Record	Mean		Low		High		7Q10		7-Day Low Flow	
			cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)
at Road B at SRS	021973471	1983-1991	0.22	7.7	0.01	0.2	10.5	372	0.01	0.36	0.01	0.22
at Road A-13.2 at SRS	02197348	1976-1991	7.7	273	0.57	20	21.5	760	0.72	25.4	0.62	22

cms = cubic meters per second

cfs = cubic feet per second

Figure 13-3. Maximum, Mean, and Minimum Flow for Pen Branch at Station 021973471

Figure 13-4. Maximum, Mean, and Minimum Flow for Pen Branch at Station 02197348

Water Chemistry and Quality

Studies and Monitoring

Water-Quality Monitoring

The WSRC Environmental Monitoring Section (EMS) has conducted routine water quality monitoring of the Pen Branch system since 1973. EMS monitors one location on Pen Branch near Road A-17 (Figure 13-5) monthly for physical and biological water quality indicators and quarterly for metals.

The Environmental Monitoring Section also collects an additional sample annually and analyzes it for pesticides, herbicides, and PCBs.

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

Comprehensive Cooling Water Study

Five locations on the Pen Branch system were studied from 1983 to 1985 as part of the Comprehensive Cooling Water Study (CCWS). This study was designed to provide an assessment of present and proposed SRS activities on water quality. The Pen Branch sampling locations, shown in Figure 13-5, include the following:

- Pen Branch at Road B—measured the effects of the effluent from the Central Shops Area
- Indian Grave Branch downstream of K-Reactor Effluent—measured the effects of the

Figure 13-5. Water Chemistry and Quality Sampling Stations for Pen Branch

thermal effluent

- Pen Branch at Road A-13—downstream of mixing of Indian Grave Branch and Pen Branch
- Pen Branch at Road A-17—measured concentrations after release to the Savannah River Swamp
- Pen Branch upstream of Steel Creek confluence—measured thermal effluents and upriver waters during periods of high river water, which overflows into the Savannah River Swamp

The data collected downstream of K-Reactor effluent during the CCWS reflects impacts associated with reactor operations and is not relevant to the current conditions of the stream. However, because limited monitoring data are available for the Pen Branch system, all data will be presented.

Comprehensive results and discussion of CCWS data can be found in the "Comprehensive Cooling Water Study, Volume II: Water Quality" (SREL 1986) or in the "Comprehensive Cooling Water Study, Final Report, Volume II: Water Quality" (Lower 1987).

Priority Pollutants Survey

In 1984 a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral organic compounds in the Pen Branch system. Three stations—near Road C, Road B, and Road A—were established in Pen Branch (Figure 13-5 on page 13-7). The results of this study are documented in the "Comprehensive Cooling Water Study Final Report, Volume II" (Lower 1987). Lower (1987) also reported the results of analyses for pesticides and PCB's in the Pen Branch System.

Field Data (SREL 1986, Lower 1987)

Water Temperature

During reactor operation, mean temperatures in thermal portions of the Pen Branch watershed (33.5°C to 48.1°C) ranged from 18 to 33°C above those of the upstream nonthermal waters (17.4°C) (Table 13-2). The temperatures at the thermal sites fluctuated more widely than those of the nonthermal site due to the reactor cycle. The shutdown of K-Reactor in 1987 resulted in a decrease in temperatures in the Pen Branch System to an average of 22°C.

pH Measurements

The pH values for the thermal sites (mean 7.46) were higher than those of the nonthermal site (mean 6.89), reflecting Savannah River source-water pH levels. The large swampy area upstream of Road A-13 also contributed to the increase in pH relative to nonthermal sites. Over the past five years, the pH near Road A-17 has ranged from 5.7 - 7.9 (Table 13-2).

Physical Characteristics and General Chemistry

Dissolved Oxygen

The dissolved oxygen concentration is inversely related to water temperature, and is reflected in the data obtained during the CCWS. The mean dissolved oxygen concentrations

in the thermal waters were much lower (5.3 to 7.5 mg O₂/l or 87 to 90% saturation) than those at the nonthermal site. Mean dissolved oxygen concentration was 8.12 mg O₂/l at the Pen Branch nonthermal site. Because there has been no thermal input to the Pen Branch system for five years, the mean dissolved oxygen concentration (8.5 mg O₂/l) at Road A-17 has been similar to the concentrations measured at the nonthermal site during the CCWS (Table 13-3 on page 13-10).

Suspended Solids and Turbidity

A wide range of total suspended solids concentrations were measured during the CCWS (mean 3.14 to 13.9 mg/l). At locations with slower water velocities, the total suspended sol-

Table 13-2. Pen Branch Field Data

	Water Temperature (°C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
<i>Pen Branch at Road B (CCWS)^a</i>				
Mean	15.2	6.93	75	48
Range	1.4 - 24.0	5.10 - 9.00	40 - 164	9 - 140
Samples	46	46	28	40
<i>Indian Grave Branch downstream of K-Reactor effluent (CCWS)^a</i>				
Mean	48.1	7.42	100	183
Range	7.6 - 68.0	5.90 - 8.70	31 - 143	45 - 260
Samples	46	46	34	
<i>Pen Branch at Road A-13 (CCWS)^a</i>				
Mean	42.6	7.42	119	124
Range	7.1 - 60.0	5.60 - 8.59	91 - 127	7 - 180
Samples	45	44	28	39
<i>Pen Branch at Road A-17 (CCWS)^a</i>				
Mean	33.5	8.11	29	15
Range	7.90 - 46.3	5.70 - 9.25	23 - 41	-15 - 140
Samples	46	45	21	39
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>				
Mean	22			
Range	7.8 - 56	5.7 - 7.9	NA	NA
Samples	60	60		
<i>Pen Branch Swamp upstream of Steel Creek confluence (CCWS)^a</i>				
Mean	17.4	6.89	120	20
Range	1.0 - 29.0	6.40 - 8.10	21 - 259	5 - 41
Samples	42	45	21	37

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

ids concentrations were lower than at locations with higher water velocities. Data collected from 1987 to 1991 at Road A-17 indicate slightly higher total suspended solids concentrations (mean 7.7 mg/l). Turbidity values measured in Pen Branch during the CCWS and the routine monitoring program displayed the same trend (Table 13-3).

Conductivity

Mean specific conductance increased from 45.6 μ mhos/cm at the nonthermal sites to 73.3 μ mhos/cm at the thermal sites (Table 13-3). This change was linked to the specific conductance of Savannah River source water (Lower 1987). Routine water quality monitoring

Table 13-3. Pen Branch Physical Characteristics and General Chemistry

	Dissolved Oxygen (mg O ₂ /l)	Specific Conductance (μ mhos/cm)	Turbidity (NTU)	Total Suspended Solids (mg/l)
<i>Pen Branch at Road B (CCWS)^a</i>				
Mean	8.12	45.6	10.6	9.63
Range	5.80 - 12.3	28.2 - 75.0	3.10 - 52.2	0.25 - 72.4
Samples	46	38	43	45
<i>Indian Grave Branch downstream of K-Reactor effluent (CCWS)^a</i>				
Mean	5.32	74.6	21.4	10.0
Range	2.70 - 11.5	50.7 - 90.1	7.30 - 61.5	0.25 - 43.2
Samples	45	36	43	45
<i>Pen Branch at Road A-13 (CCWS)^a</i>				
Mean	5.63	73.4	21.3	13.9
Range	3.30 - 11.1	48.9 - 91.4	3.00 - 55.0	1.60 - 145.5
Samples	45	37	42	43
<i>Pen Branch at Road A-17 (CCWS)^a</i>				
Mean	7.53	71.9	14.6	4.63
Range	5.50 - 12.3	47.7 - 98.3	3.80 - 57.4	0.25 - 36.7
Samples	45	38	43	45
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>				
Mean	8.5	69	6.6	7.7
Range	4.2 - 11	13 - 171	1.1 - 54.1	2.0 - 42
Samples	60	60	60	60
<i>Pen Branch Swamp upstream of Steel Creek confluence (CCWS)^a</i>				
Mean	6.65	73.1	5.40	3.14
Range	3.5 - 14.0	46.8 - 95.1	1.30 - 25.5	0.25 - 17.2
Samples	43	35	40	42

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

since the CCWS has measured a wide range of specific conductance (13 to 171 $\mu\text{mhos/cm}$), with a mean of 69 $\mu\text{mhos/cm}$.

Major Anions and Cations

Alkalinity, Chloride, and Sulfate

During the CCWS, mean concentrations of total alkalinity, chloride, and sulfate ranged from 13.8 to 17.9 mg/l, 2.48 to 6.02 mg/l, and 2.53 to 5.26 mg/l, respectively. The maximum total alkalinity, chloride, and sulfate concentrations were measured at the thermal sites and most likely reflected the chemistry of the Savannah River water used to cool the reactor. Mean concentrations of total alkalinity (18.2 mg/l), chloride (7.1 mg/l), and sulfate

Table 13-4. Pen Branch Major Anions

	Alkalinity (mg CaCO_3/l)	Chloride (mg/l)	Sulfate (mg/l)
<i>Pen Branch at Road B (CCWS)^a</i>			
Mean	13.8	2.48	2.53
Range	2.85 - 30.6	1.90 - 3.20	0.25 - 7.67
Samples	45	45	28
<i>Indian Grave Branch downstream of K-Reactor effluent (CCWS)^a</i>			
Mean	17.8	5.86	5.21
Range	11.7 - 22.3	2.70 - 8.40	0.75 - 10.3
Samples	44	46	28
<i>Pen Branch at Road A-13 (CCWS)^a</i>			
Mean	16.8	5.64	5.03
Range	7.40 - 22.0	2.90 - 8.10	0.25 - 9.94
Samples	44	45	26
<i>Pen Branch at Road A-17 (CCWS)^a</i>			
Mean	16.0	6.02	4.97
Range	7.71 - 22.0	2.90 - 8.20	1.96 - 8.02
Samples	44	46	28
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>			
Mean	18.2	7.1	7.4
Range	4 - 25	3.2 - 27	3.0 - 20
Samples	60	60	60
<i>Pen Branch Swamp upstream of Steel Creek confluence (CCWS)^a</i>			
Mean	17.9	5.81	5.26
Range	8.00 - 26.4	2.50 - 9.10	2.07 - 7.94
Samples	42	43	25

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

(7.4 mg/l) from 1987 to 1991 have been slightly higher than the ranges measured during the CCWS (Table 13-4 on page 13-11).

Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, and sodium measured from 1987 to 1991 near Road A-17 have remained similar to those concentrations measured during the CCWS (Table 13-5). It was determined during the CCWS that nearly all of the calcium, magnesium, sodium, and potassium in Pen Branch waters were in the dissolved fraction (SREL 1986). The mean concentrations of calcium and magnesium were slightly higher at the nonthermal site than those at the thermal sites. Sodium and potassium, however, were

Table 13-5. Pen Branch Major Cations (Total)

	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Aluminum (mg/l)	Iron (mg/l)	Manganese (mg/l)
<i>Pen Branch at Road B (CCWS)^a</i>							
Mean	5.27	0.524	1.85	<0.368	0.709	1.23	0.097
Range	0.011 - 10.1	0.001 - 1.29	1.01 - 5.80	<0.368 - 1.22	<0.038 - 3.68	<0.003 - 2.36	<0.0004 - 0.231
Samples	39	39	39	39	39	39	15
<i>Indian Grave Branch downstream of K-Reactor effluent (CCWS)^a</i>							
Mean	3.30	1.32	7.30	1.12	1.09	1.11	0.100
Range	2.67 - 4.37	1.16 - 1.45	3.99 - 10.5	<0.368 - 2.02	0.105 - 2.87	0.035 - 3.22	<0.0004 - 0.291
Samples	39	39	39	39	39	39	16
<i>Pen Branch at Road A-13 (CCWS)^a</i>							
Mean	3.89	1.20	6.46	1.01	1.020	0.999	0.104
Range	2.80 - 13.1	0.485 - 1.45	1.47 - 10.5	<0.368 - 2.08	0.049 - 3.03	0.006 - 2.32	<0.0004 - 0.322
Samples	38	38	38	38	38	38	15
<i>Pen Branch at Road A-17 (CCWS)^a</i>							
Mean	3.14	1.13	7.08	0.960	0.823	0.871	0.089
Range	2.57 - 4.28	0.978 - 1.61	3.15 - 10.9	<0.368 - 1.93	0.182 - 2.30	0.424 - 2.35	<0.0004 - 0.309
Samples	39	39	39	39	39	39	16
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>							
Mean							
Range	2.1 - 5.8	0.78 - 1.40	4.9 - 14.0	NA	0.04 - 1.8	0.03 - 1.3	<0.01 - 0.18
Samples	18	18	19		19	20	18
<i>Pen Branch Swamp upstream of Steel Creek confluence (CCWS)^a</i>							
Mean	3.33	1.24	6.88	0.960	0.350	0.972	0.071
Range	2.65 - 3.96	0.932 - 1.46	2.99 - 12.6	<0.368 - 1.72	0.080 - 1.27	0.019 - 1.79	<0.0004 - 0.140
Samples	36	36	36	36	36	36	15

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

higher at the thermal sites than at the nonthermal sites. Potassium is not measured as part of the routine SRS water quality monitoring program.

Aluminum, Iron, and Manganese

Concentrations of total and dissolved aluminum during the CCWS were higher in the waters of the thermal sites than in those of the nonthermal site (Table 13-5). Approximately 92% of the aluminum was associated with the solid phase at the nonthermal site and 92 to 93% was associated with the solid phase at the thermal sites. Total and dissolved iron concentrations were higher at the nonthermal site than those at the thermal sites. Approximately 83 to 86% of the iron was present in the solid phase. Mean total manganese concentrations ranged from 0.071 to 0.104 mg/l. Roughly 20 to 28% of the manganese was present in the solid phase (SREL 1986). From 1987 to 1991, concentrations of total aluminum, iron, and manganese have been slightly lower than those measured during the CCWS (Table 13-5). The higher concentrations during the CCWS reflected Savannah River source water concentrations.

Nutrients

Phosphorus

All measured forms of phosphorus were higher at the thermal portions of this system than those at the nonthermal site during the CCWS. Whereas, 13% of the phosphorus was present as dissolved orthophosphate at the nonthermal site, 49 to 59% was dissolved orthophosphate at the thermal site. At the nonthermal site 62% of the phosphorus was not orthophosphate, and 27 to 38% of the phosphorus at the thermal sites was not orthophosphate. The speciation and concentrations of phosphorus in the thermal sites reflected, at least partially, the phosphorus speciation and concentrations in the Savannah River (SREL 1986). Only total phosphorus is measured under the routine monitoring program, but concentrations of total phosphorus near Road A-17 were similar to those measured at Road A-17 during the CCWS (Table 13-6 on page 13-14).

Nitrogen

Concentrations of nitrogen species are presented in Table 13-6 on page 13-14. Although the mean concentrations of organic nitrogen were not very different between the thermal and nonthermal waters of this stream, the percentage of nitrogen in the organic form was 73% at the nonthermal waters and only 23 to 26% at the thermal waters (SREL 1986). Organic nitrogen is not measured in Pen Branch as part of the routine monitoring program. During the CCWS, mean ammonia, nitrite, and nitrate concentrations were higher at the thermal sites than the nonthermal site, reflecting the nitrogen species and concentrations in the Savannah River. Over the past five years, concentrations of ammonia and nitrate have remained similar to those concentrations measured during the CCWS. Nitrite has not been measured since the CCWS.

Trace Elements

SREL measured low levels of trace elements during the CCWS. The detection limits reported for the routine monitoring program are higher than the concentrations measured during the CCWS; therefore, only CCWS data is discussed in this section (Table 13-7 on

page 13-15). Mean total arsenic concentrations were similar in the nonthermal waters (1.6 µg/l) and the thermal waters (1.3 to 2.8 µg/l) of Pen Branch. Mean total cadmium concentrations ranged from 0.29 µg/l upstream of the Steel Creek confluence to 0.99 µg/l at Road A-13. Although mean total chromium concentrations were as high as 10.4 µg/l, mean dissolved chromium concentrations were below the detection limit at all sites (SREL 1986). Mean total copper concentrations were approximately 2.1 to 3.2 µg/l. The highest mean concentration of total nickel was found in the near Road A-13 (4.3 µg/l). Mean total zinc concentrations ranged from 4.7 to 6.2 µg/l. Mercury and uranium concentrations were below the detection limit in Pen Branch waters (SREL 1986).

Table 13-6. Pen Branch Nutrients

	Total Phosphorus (mg P/l)	Total Orthophosphate (mg PO ₄ -P/l)	Organic Nitrogen (mg N/l)	Total Kjeldhal Nitrogen (mg N/l)	Ammonia (mg NH ₃ -N/l)	Nitrite (mg NO ₂ /l)	Nitrate (mg NO ₃ -N/l)
<i>Pen Branch at Road B (CCWS)^a</i>							
Mean	0.042	0.017	0.216	0.236	0.039	0.002	0.050
Range	<0.010 - 0.147	0.003 - 0.059	0.012 - 0.860	0.045 - 0.900	0.005 - 0.700	<0.001 - 0.005	0.011 - 0.184
Samples	46	41	45	46	46	44	43
<i>Indian Grave Branch downstream of K-Reactor effluent (CCWS)^a</i>							
Mean	0.114	0.080	0.225	0.298	0.109	0.019	0.288
Range	0.028 - 0.275	0.037 - 0.146	0.015 - 0.680	0.075 - 0.770	0.013 - 0.210	0.005 - 0.041	0.038 - 0.685
Samples	45	41	39	46	46	43	43
<i>Pen Branch at Road A-13 (CCWS)^a</i>							
Mean	0.093	0.071	0.171	0.239	0.075	0.021	0.310
Range	<0.010 - 0.286	0.013 - 0.133	0.010 - 0.829	0.080 - 0.855	0.016 - 0.230	<0.001 - 0.048	0.094 - 0.510
Samples	45	39	44	45	45	42	42
<i>Pen Branch at Road A-17 (CCWS)^a</i>							
Mean	0.103	0.076	0.190	0.221	0.048	0.008	0.228
Range	<0.010 - 0.239	0.005 - 0.144	0.015 - 0.593	0.035 - 0.610	0.005 - 0.250	0.001 - 0.031	0.019 - 0.454
Samples	46	42	43	46	46	44	43
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>							
Mean	0.075				0.055		0.27
Range	0.0 - 0.24	NA	NA	NA	<0.01 - 0.23	NA	0.10 - 0.85
Samples	60				60		60
<i>Pen Branch Swamp upstream of Steel Creek confluence (CCWS)^a</i>							
Mean	0.065	0.045	0.206	0.224	0.027	0.003	0.091
Range	<0.010 - 0.188	0.004 - 0.113	0.019 - 0.624	0.032 - 0.640	0.005 - 0.220	<0.001 - 0.010	<0.001 - 0.378
Samples	43	37	42	43	43	40	39

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Organic Carbon

Total organic carbon concentrations were similar for thermal and nonthermal sites in Pen Branch (Table 13-8). However, the nonthermal site had slightly more organic carbon in the dissolved phase (77%) relative to those of the thermal sites (68 to 69%) (SREL 1986).

Priority Pollutants

Concentrations of all 88 tested volatile, acid, and base/neutral organics were below detection limits in the Pen Branch system. The 1984 study also confirmed the lack of variability between thermal and nonthermal waters (Lower 1987).

Table 13-7. Pen Branch Trace Elements (Total)

	Arsenic (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Lead (mg/l)	Nickel (mg/l)	Zinc (mg/l)
<i>Pen Branch at Road B (CCWS)^a</i>							
Mean	1.6	0.36	6.6	3.0	1.8	2.8	6.1
Range	<0.4 - 6.2	<0.04 - 2.00	<0.4 - 49.0	<0.4 - 14.1	<0.4 - 6.0	<0.4 - 8.7	<0.4 - 23.1
Samples	15	15	15	15	15	15	15
<i>Indian Grave Branch downstream of K-Reactor effluent (CCWS)^a</i>							
Mean	2.6	0.56	10.4	3.0	2.3	3.8	5.8
Range	<0.4 - 10.8	<0.04 - 1.80	<0.4 - 71.0	<0.4 - 9.1	<0.4 - 9.3	<0.4 - 11.0	<0.4 - 25.9
Samples	16	16	16	16	16	16	16
<i>Pen Branch at Road A-13 (CCWS)^a</i>							
Mean	2.8	0.99	10.1	3.0	1.3	4.3	5.7
Range	<0.4 - 10.7	<0.04 - 11.3	<0.4 - 90.0	<0.4 - 6.5	<0.4 - 5.0	<0.4 - 18.0	<0.4 - 27.7
Samples	15	15	15	15	15	15	15
<i>Pen Branch at Road A-17 (CCWS)^a</i>							
Mean	2.3	0.37	7.1	3.2	2.4	3.2	6.2
Range	<0.4 - 8.2	<0.04 - 1.6	<0.4 - 57.0	<0.4 - 7.1	<0.4 - 18.7	<0.4 - 13.0	<0.4 - 21.6
Samples	16	16	16	16	16	16	16
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>							
Mean							
Range	NA	<10 - <20	<10 - <50	<10 - 320	<3 - <50	<10 - 80	<10 - 170
Samples		20	20	20	20	20	20
<i>Pen Branch Swamp upstream of Steel Creek confluence (CCWS)^a</i>							
Mean	1.3	0.29	7.5	2.1	2.0	2.0	4.7
Range	<0.4 - 5.0	<0.04 - 1.42	<0.4 - 65.0	<0.4 - 15.0	<0.4 - 5.4	<0.4 - 7.5	<0.4 - 22.0
Samples	15	15		15		15	15

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987 - 1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 13-8. Pen Branch Major Anions

	Total Organic Carbon (mg/l)	Dissolved Organic Carbon (mg/l)	Particulate Organic Carbon (mg/l)
<i>Pen Branch at Road B (CCWS)^a</i>			
Mean	5.99	5.12	3.40
Range	0.36 - 11.84	2.61 - 9.30	0.24 - 10.7
Samples	25	9	10
<i>Indian Grave Branch downstream from K-Reactor effluent (CCWS)^a</i>			
Mean	6.49	5.04	2.66
Range	2.85 - 12.9	1.16 - 7.25	0.58 - 6.10
Samples	25	9	10
<i>Pen Branch at Road A-13 (CCWS)^a</i>			
Mean	6.82	5.73	3.44
Range	4.40 - 13.2	3.59 - 7.90	0.56 - 11.7
Samples	23	10	9
<i>Pen Branch at Road A-17 (CCWS)^a</i>			
Mean			
Range	NA	NA	NA
Samples			
<i>Pen Branch at Road A-17 (1987 - 1991)^b</i>			
Mean	6.42	5.75	2.43
Range	1.84 - 10.5	3.73 - 8.80	0.45 - 6.12
Samples	25	10	10
<i>Pen Branch upstream of Steel Creek confluence (CCWS)^a</i>			
Mean	6.81	5.48	1.02
Range	2.86 - 13.7	3.62 - 10.1	0.20 - 2.50
Samples	22	11	11

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^a CCWS - Comprehensive Cooling Water Study (SREL 1986).

^b 1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Pesticides, Herbicides, and PCBs

Water samples collected annually as part of the routine monitoring program are analyzed for pesticides, herbicides, and PCBs. None of the analytes have been detected in the Pen Branch system.

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.

Algae

Phytoplankton

Phytoplankton has not been studied in the Pen Branch drainage system. This system is a low-potential impact area for phytoplankton, which contributes insignificantly to the food chain base in this and other shallow streams.

Periphyton

The periphyton community of Pen Branch was included in studies of the ecology of the thermal and nonthermal streams of SRS that were conducted between 1983 and 1985 (Firth et al. 1986, Specht 1987). The analyses of the periphyton communities in these studies was accomplished by taxonomic identifications, chlorophyll analyses, and measurement of ash-free dry weight.

Reactor operations undoubtedly affected periphyton species composition and abundance. Periphyton differed in type between thermal and nonthermal sites. Green algae and diatoms characterized the nonthermal sites, while thick mats of blue-green algae were unevenly distributed at the thermal sites (Specht 1987). Also, variations in periphyton biomass values were higher at the thermal stream sites than at the nonthermal sites. The densely canopied Pen Branch swamp station had a significantly lower periphyton biomass than the Pen Branch delta station. Biomass at the Pen Branch swamp station did not appear to be affected by the status of K Reactor (Firth et al. 1986).

Macrophytes

Introduction

Although rooted aquatic macrophytes are an important component of the structure and function of many aquatic systems, they tend to be less important in flowing waters. These vascular plants provide important stream structure, substrate for periphyton development, cover and substrate for smaller animals, and a source of carbon for the stream system. Macrophytes cannot colonize channels of systems during the large thermal and flow impacts resulting from reactor operations. Since K-Reactor operation ceased in 1988, a certain amount of recolonization of the slower reaches and backwaters of the stream would be expected. However, a period of full flow and low power testing during 1991–1992 may have had a detrimental effect on any macrophyte colonization.

Comprehensive Cooling Water Study

Introduction

The only data dealing with aquatic macrophytes in Pen Branch comes from the Comprehensive Cooling Water Study (CCWS) [Volume IV (Specht 1987)] and was collected from 1983 to 1985. The CCWS data do not represent the current status of aquatic macrophytes in the system because they were collected at only four stations, all of which were impacted by reactor operations. Only one of the sampled stations was in the stream itself, two were in the thermal delta, and one was in the river swamp.

Number of Taxa Collected

The total number of taxa at the thermal stream station and the thermal swamp stations were similar; the stream, however, had no taxa growing in the channel itself. The delta stations had approximately one third of their taxa in the water channels and a similar number (<50%) growing on the flood plain. The channel and flood plain accounted for slightly more than three quarters of the total taxa found in the two delta stations. Little additional information is available from the CCWS except the observation of greater biomass in the thermal delta during the winter of the 1983–1984 sampling and little or no vegetation in the thermal stream and delta channels or the nonthermal swamp during the 1984–1985 sampling period [Volume V (Specht 1987)].

Expectations Since the Cessation of K-Reactor Operations

Normal successional patterns and development of macrophyte beds would be expected to occur in suitable sections of Pen Branch with the cessation of K-Reactor operation. However, ground level data have not been collected on this component of the ecosystem. Analyses of remote sensing data (see Part II—Wetlands Resources) suggest that macrophyte recolonization of the stream and delta have been substantial.

Zooplankton

Chimney and Cody (1986) documented the temporal and spatial characteristics of zooplankton species based on quarterly sampling from December 1984 to August 1985 in Pen Branch. This study evaluated populations with regard to regulatory compliance issues covered by the Clean Water Act (Section 316a). Surface-water grab samples were collected adjacent to macrophyte beds at two stations—the first approximately one-third downstream from the headwaters and a second approximately another third downstream. Because of thermal discharges, mean temperature was greater than 32°C. Species richness consisted of 7 Protozoa, 15 Rotifera, 14 Cladocera, 4 Copepoda, and 1 Ostracoda.

Figure 13-6 indicates that the greatest densities occurred during April 1985. Protozoa and Rotifera comprised more than 80% of the monthly total densities. As with other SRS streams, this result is representative of zooplankton populations, which are warm-water, summer species (Hutchinson 1967).

Figure 13-6. Mean Density of Total Zooplankton in Pen Branch

Macroinvertebrates

Sampling

Comprehensive Cooling Water Study

Macroinvertebrates were sampled monthly at three locations in Pen Branch from November 1983 through September 1984 using Hester-Dendy multiplate samplers, leaf bags, artificial snags, sediment coring and at five locations in Pen Branch from October 1984 through September 1985 (Figure 13-7) using Hester-Dendy multiplate samplers, leaf bags, and drift sampling. Data from 1983 through 1985 were collected as part of the Comprehensive Cooling Water Study (CCWS) when K Reactor was discharging thermal effluent to Pen Branch; these data are representative of the conditions that would exist if K Reactor were to be operated at full power. Details of sampling methodology can be found in Kondratieff and Kondratieff (1984 and 1985) and Firth et al. (1986).

Pen Branch Recovery Study

Subsequent to K-Reactor shutdown in April 1988, the macroinvertebrate community of Pen Branch was sampled with Hester-Dendy multiplate samplers at seven locations in December 1988 and February and May 1989 (Enwright 1989a, 1989b, and 1989c) to document the recovery of the macroinvertebrate community.

Figure 13-7. Macroinvertebrate Sampling Stations for Pen Branch

Results

Introduction

The data presented in this summary are primarily Hester-Dendy multiplate data, since this was the only sampling method used in both the 1984-1985 and 1988-1989 sampling periods. Macroinvertebrate data from the other sampling methods can be found in Kondratieff and Kondratieff (1984 and 1985) and in Firth et al. 1986.

Macroinvertebrate Community of Pen Branch During the Operation of K Reactor

Introduction

From the onset of macroinvertebrate sampling in 1983 until K Reactor shutdown in 1988, Pen Branch was subject to severe thermal stress, with temperatures greater than 60°C recorded at the station closest to the reactor outfall (Station 21). However, during reactor outages, which sometimes lasted for several weeks or longer, stream temperatures were near ambient. Because the multiplate samplers were collected monthly, some collections followed periods of reactor outages when stream temperatures were ambient. Therefore the macroinvertebrate data must be interpreted cautiously to prevent erroneous conclusions.

Nonthermal Areas

Station 20, which is located upstream from all thermal discharges at Road B, was similar to other nonthermal SRS streams during 1984-1985 with respect to density of organisms, biomass, and average number of taxa. Total taxonomic richness (70 taxa, Table 13-9) was higher than all but one of the stations that were sampled during the CCWS. Dominant taxa included orthoclad, tanytarsine, and chironomids; the mayfly *Stenonema modestum*; the beetle *Macronychus glabratus*; and several species of caddisflies (Table 13-3). Macroinvertebrate biomass (ash-free dry weight) was higher at Station 20 (0.187 g/m²) than at the thermally impacted delta stations (0.003 to 0.078 g/m²), but lower than Station 24, which was the mildly impacted swamp station (Table 13-9). At Station 20, large numbers of

Table 13-9. Mean Number of Taxa, Density, and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in Pen Branch (October 1984-September 1985)

Parameter	Station*				
	20	21	22	23	24
Mean number of taxa/sampler	15.2	3.2	6.0	7.1	14.4
Mean density (number/m ²)	695.2	55.6	841.6	2144.9	1620.1
Mean biomass (g AFDW/m ²)	0.187	0.003	0.078	0.070	0.320
Total number taxa collected	70	28	33	38	55
Total number taxa collected all stations combined	92				

Source: Firth et al. (1986)

* Station numbers from CCWS

mayflies (primarily *Stenonema modestum*) and fewer numbers of large predatory stoneflies (*Perlesta*) and dobsonflies (*Corydalus*) made up the majority of the biomass.

Thermally Impacted Delta and Swamp

Number of Taxa Collected

During reactor operation, a total of 51 taxa were collected from the thermally impacted stations in Pen Branch (Table 13-9). Taxonomic richness below the reactor outfall was lowest at the station closest to the reactor outfall (Station 21; 28 taxa) and gradually increased farther downstream to 33 taxa at Station 22 and 38 taxa at Station 23. At Station 24, where temperatures were near ambient, 55 taxa were collected (Table 13-9).

Dominant Species

Table 13-10 presents the relative abundance of major taxonomic groups of macroinvertebrates at each sampling station, while Table 13-14 on page 13-35 contains a complete taxonomic listing for each station. At all of the thermally impacted stations, except Station 23, Diptera was by far the most common insect order collected, ranging from 43.3 to 77.7% of the organisms collected (Table 13-10); Chironominae and Tanytarsini usually predominated at the thermally impacted stations (Table 13-10). Nematode worms were the dominant taxon at Station 23 (71.5%) and were also abundant at the other thermally impacted stations. Nem-

Table 13-10. Percent Abundance of Major Groups of Macroinvertebrate Taxa Collected on Hester-Dendy Multiplate Samplers in Pen Branch During Reactor Operation (October 1984–September 1985)

Taxa	Station				
	2	4	5	23	6
Turbellaria	0.03	0.00	0.00	0.00	0.85
Nematoda	0.42	5.54	24.75	71.47	18.84
Oligochaeta	2.76	7.68	5.99	1.63	4.77
Gastropoda	0.90	2.32	1.33	5.53	5.12
Arachnida	0.17	0.36	0.02	0.01	1.89
Ephemeroptera	14.09	1.96	0.31	4.10	22.49
Odonata	0.46	0.71	0.08	0.07	0.07
Plecoptera	3.06	0.00	0.02	0.00	0.02
Coleoptera	13.35	1.61	0.07	0.03	0.88
Trichoptera	10.87	1.43	0.29	0.11	1.25
Diptera ^a	53.12	77.68	67.11	17.04	43.34
Chironomini	(11.66)	(43.21)	(20.63)	(7.17)	(6.14)
Tanytarsini	(13.89)	(17.68)	(31.29)	(3.46)	(23.30)
Orthocladinae	(17.88)	(11.96)	(3.76)	(0.76)	(5.01)
Tanypodinae	(2.47)	(0.89)	(3.37)	(3.65)	(3.59)
Other	0.77	0.71	0.03	0.01	0.48
Total	100.00	100.00	100.00	100.00	100.00

^a Includes subtaxa in parentheses.

Source: Modified from Firth et al. (1986)

atodes are often an important component of the fauna at thermally stressed sites because of their tolerance for heated water. Oligochaete worms were also commonly collected at all of the stations, with abundances ranging from 1.6 to 7.7% (Table 13-10).

Mayflies were abundant in the swamp at Station 24, accounting for 22.5% of the macroinvertebrates collected. *Stenonema modestum*, *Caenis*, and *Stenocron interpunctatum* were the most common species of mayflies collected at Station 24 (Table 13-13 on page 13-31). Gastropods (primarily *Physella heterostrophia*, *Helisoma trivolvis*, and *Gyrulus parvus*) were abundant at Stations 23 and 24, accounting for 5.5 and 5.1% of the organisms collected. The remaining taxa listed in Table 13-13 (Turbellaria, Arachnida, Odonata, and Plecoptera) each generally accounted for less than 3% of the organisms collected.

Densities

Mean densities of macroinvertebrates on the multiplate samplers ranged from 55.6/m² at the most thermally impacted station (Station 21) to 2144.9/m² in the delta (Station 23; Table 13-9 on page 13-26). The high density at Station 23 was due primarily to large numbers of nematodes (Table 13-13 on page 13-31).

Biomass

Macroinvertebrate biomass (ash-free dry weight) was very low at the thermally impacted stations (0.003 to 0.078 g/m²) and much higher (0.320 g/m²) at Station 24, which was mildly thermal (Table 13-9 on page 13-26). At Station 24, mayflies and gastropods accounted for most of the biomass. Although Station 23 had by far the greatest mean density of organisms (2144.9/m²; Table 13-9), biomass was relatively low at this station (0.033 g/m²) due to a preponderance of small nematodes.

Recovery of Macroinvertebrate Community Subsequent to K-Reactor Shutdown

Introduction

The macroinvertebrate data collected subsequent to K-Reactor shutdown differ from the data collected during reactor operation. They differ in that data were collected for three months in the 1988–1989 program rather than twelve months, and because the level of taxonomic resolution was better in the 1988–1989 study, particularly for chironomids. Any comparisons of species richness or taxonomic composition should take these important differences into consideration.

Number of Taxa Collected

During the sampling conducted during three months in 1988 and 1989, 132 taxa of macroinvertebrates were collected in Pen Branch and Indian Grave Branch (Table 13-14 on page 13-35). Of these taxa, 86 were collected from the portions of the creeks that had been thermally impacted (Table 13-14). It is likely that more taxa would have been collected if sampling had been conducted over the course of an entire year because some species occur seasonally and some rare species are collected infrequently. The total number of taxa collected was highest at Station 1 (58 taxa; Table 13-11). Fewer taxa were collected at the other five stations in Pen Branch, ranging from 48 at Station 5 to 53 at Stations 2 and 6 (Table 13-11). In Indian Grave Branch, substantially fewer taxa were collected (35) (Table 13-11).

Taxa Richness

Taxa richness (mean number of taxa collected per multiplate sampler) ranged from 8.9 at Station 7 to 19.6 at Station 2 (Table 13-11). In general, fewer taxa were collected from the portions of the creek that had been thermally perturbed (Stations 7, 3, 4, and 5, in order of increasing distance from the reactor outfall) than from unperturbed areas of the creek (Stations 1, 2, and 6; Table 13-11). However, in the Pen Branch delta (Station 5) species richness was relatively high (16.1), probably due to the increasing habitat diversity that resulted from recolonization by aquatic macrophytes. These data indicate that although the macroinvertebrate community of Pen Branch had undergone some recovery subsequent to reactor shutdown in April 1988, taxonomic richness was still somewhat depressed and it is likely that the macroinvertebrate community had not completely recovered and was still undergoing succession.

Dominant Species

For all stations combined, chironomid dipterans were by far the most common group of macroinvertebrates on the multiplate samplers, comprising 68.4 to 91.8% of the organisms collected (Table 13-12 on page 13-30). Orthoclad midges were the most abundant chironomids (36.5 to 71.2%) at all but Station 5, where tanytarsine midges were dominant (49.9%; Table 13-12). Non-chironomid dipterans (mostly blackflies or danceflies) were abundant at some stations, comprising 0.4 to 26.6% of the collections. Trichoptera (caddisflies) and Ephemeroptera (mayflies) were also abundant at most stations, accounting for 0.4 to 11.2% and 0 to 8.4%, respectively, of the organisms collected on the multiplate samplers. Plecoptera (stoneflies) and Coleoptera (beetles) were locally abundant at Station 2 (7.8 and 9.3%, respectively), but comprised less than 1% of the macroinvertebrates collected at each of the other stations.

Dominant taxa included several species of orthoclad midges (*Corynoneura* nr. *tarsis*, *Cricotopus* spp., *Orthocladus* spp., and *Tvetenia discoloripes* gr.), chironomini midges (*Microtendipes pedellus*, and *Polypedilum* spp.), tanytarsine midges (*Rheotanytarsus*

Table 13-11. Mean Number of Taxa, Density, and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in Pen Branch and Indian Grave Branch During Ambient Thermal Conditions (December 1988–May 1989) (Source: Enwright 1989a, 1989b, 1989c)

Parameter	Station						
	1	2	3	4	5	6	7
Mean number of taxa/sampler	14.0	19.6	12.9	13.9	16.1	14.3	8.9
Mean density/(number/m ²)	635.7	534.7	692.7	864.0	988.3	610.7	681.7
Mean biomass (g AFDW/m ²)	0.040	0.039	0.044	0.069	0.082	0.030	0.029
Total number of taxa collected	58	53	50	50	48	53	35

distinctissimus and *Tanytarsus* spp.), and blackflies (*Simulium tuberosum* and *S. vittatum*) (Table 13-14 on page 13-35). Other species that were locally abundant at at least one station included the mayflies, *Caenis* sp. and *Stenonema modestum/smithae*; the stonefly, *Perlesta placida*; the caddisflies, *Cheumatopsyche* spp. and *Hydropsyche* spp., the beetle, *Macronychus glabratus*, and danceflies (*Empididae*) (Table 13-14).

Station 7, which is located in Indian Grave Branch just downstream from the reactor outfall, differed from the other stations in that the community was composed almost exclusively of dipterans (99.57%; Table 13-12). Dominant dipterans at this station included the chironomids, *Cricotopus* and *Orthocladius*, blackflies, and empidid danceflies (Table 13-14 on page 13-35). These differences are probably due, at least in part, to differences in substrate composition. Station 7 contains rock rip-rap, which provides stable substrate for attachment by blackflies and other species that prefer rock substrate. However, the conspicuous absence of clinging mayflies, such as *Stenonema*, and the overall low taxonomic richness suggest that Station 7 was still perturbed at the time of sampling.

Densities

Macroinvertebrate densities on the multiplate samplers ranged from 534.7/m² at Station 2 to 988.3/m² at Station 5 (Table 13-11). Densities were variable from month to month (Enwright 1989a, 1989b, 1989c), and no relationship between density and thermal history were apparent.

Table 13-12. Percent Abundance of Major Groups of Macroinvertebrates Collected from Hester-Dendy Multiplate Samplers in Pen Branch and Indian Grave Branch During Ambient Thermal Conditions (December 1988–May 1989) (Source: Enwright 1989a, 1989b, 1989c)

Taxon	Station							Mean
	1	2	3	4	5	6	7	
Annelida	0.00	0.00	0.16	0.04	0.19	0.42	0.00	0.12
Crustacea	0.06	0.00	0.00	0.00	0.00	0.67	0.00	0.09
Mollusca	0.76	0.00	0.05	0.00	0.15	1.09	0.00	0.27
Ephemeroptera	7.36	8.45	1.98	0.62	6.07	1.33	0.00	3.58
Odonata	0.12	0.07	0.00	0.00	0.46	0.12	0.00	0.13
Plecoptera	0.76	7.76	0.05	0.04	0.00	0.00	0.00	0.95
Trichoptera	0.70	1.80	5.03	11.20	10.16	1.09	0.44	5.06
Lepidoptera	0.00	0.00	0.05	0.00	0.04	0.00	0.00	0.01
Megaloptera	0.18	0.00	0.00	0.00	0.04	0.00	0.00	0.03
Coleoptera	0.53	9.28	0.21	0.09	0.08	0.73	0.00	1.22
Diptera - Misc.	0.35	4.22	12.14	13.54	8.14	2.79	26.65	10.07
Diptera - Chironomidae	89.20	68.42	80.32	74.47	74.68	91.75	72.92	78.47
Tanypodinae	2.57	1.73	0.80	0.26	2.56	9.22	0.05	2.31
Orthoclaudiinae	36.54	48.75	71.23	62.08	18.83	55.25	68.17	50.20
Diamesinae	0.00	1.52	0.00	0.00	0.08	0.49	0.05	0.25
Chironomini	33.98	12.47	0.80	6.22	6.26	4.31	0.98	8.74
Tanytarsini	16.11	3.95	7.49	5.91	46.94	22.50	3.65	16.97
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Biomass

Macroinvertebrate biomass was exceptionally low at all stations, ranging from 0.0291 g/m² at Station 7 to 0.0890 g/m² at Station 4 (Table 13-11 on page 13-29). The low biomass was due primarily to the predominance of small chironomids on the multiplate samplers.

Table 13-13. Mean Invertebrate Density/number/m² at Each Station on Pen Branch for Each Taxon Collected on Hester-Dendy Multiplate Samplers (October 1984–September 1985) (Source: Firth et al. 1986)

Taxa	Station				
	2	4	5	23	6
Turbellaria	0.2				13.8
Nematoda	2.9	3.1	208.4	1533.4	305.4
Oligochaeta	19.2	4.3	50.4	34.9	77.3
Hirudinea	0.2			0.2	1.1
Gastropoda	1.7		0.5	0.3	9.0
Family Ancyliidae	3.1			0.2	1.7
<i>Ferrissia rivularis</i>	1.1		0.3	0.2	11.3
<i>Laevapex fuscus</i>					0.3
Family Hydrobiidae					
<i>Amnicola</i>					0.9
<i>Somatogyrus</i> sp.		0.2	0.2		1.6
Family Physidae					
<i>Physella heterostropha</i>	0.2	1.1	10.2	117.9	25.5
Family Planorbidae					0.8
<i>Gyraulus parvus</i>					12.1
<i>Helisoma</i>					0.9
<i>Helisoma trivolvis</i>	0.2				18.3
Family Viviparidae					
<i>Campeloma decisum</i>					0.5
Pelecypoda					
Family Corbiculidae					
<i>Corbicula fluminea</i>	0.8				4.5
Family Sphaeriidae	0.2				
Crustacea					
Isopoda					
<i>Asellus</i>			0.2		1.4
Amphipoda		0.2			
Family Talitridae					
<i>Hyalella azteca</i>	0.2	0.2			0.5
Decapoda					
Family Astacidae					
<i>Procambarus</i>	0.3				
Arachnida					
Hydracarina	1.2	0.2	0.2	0.3	30.7
Insecta					
Ephemeroptera					
Family Baetidae					
<i>Baetis</i>	6.1		0.3	0.2	8.7
<i>Pseudocloeon parvulum</i>				0.2	

Table 13-13. (cont)

Taxa	Station				
	2	4	5	23	6
Family Caenidae					
<i>Caenis</i>	0.5	0.3	1.7	75.3	37.7
Family Ephemerellidae					
<i>Dannella simplex</i>	1.7				
<i>Ephemerella invaria</i>	2.8			11.5	
<i>Eurylophella temporalis</i>	1.6			0.2	0.8
Family Heptageniidae					1.4
<i>Stenacron interpunctatum</i>	0.3	0.2		0.3	36.2
Family Heptageniidae, cont.					
<i>Stenonema modestum</i>	74.5	0.6	0.6	0.3	279.5
Family Neophemeridae					
<i>Neophemera youngi</i>	0.2				
Family Oligoneuriidae					
<i>Isonychia</i>	0.9				
Family Tricorythidae					
<i>Tricorythodes</i>	9.5				0.2
Odonata					
Anisoptera	0.2	0.2	0.2		
Family Aeshnidae					
<i>Boyeria vinosa</i>	0.5				
<i>Nasiaeschna pentacantha</i>	0.5				
Family Libellulidae					
<i>Erythemis simplicicollis</i>				0.3	
<i>Pachydiplax longipennis</i>				0.2	
Zygoptera					
Family Calopterygidae					
<i>Hetaerina</i>	0.2				
Family Coenagrionidae					
<i>Argia</i>	1.2	0.2	0.2		0.5
<i>Enallagma</i>	0.2			0.0	0.5
<i>Ischnura</i>	0.2		0.3		
Plecoptera	0.3		0.2		
Family Perlidae	0.2				
<i>Acroneuria abnormis</i>	0.2				0.2
<i>Paragnetina fumosa</i>	0.5				
<i>Perlesta placida</i>	17.7				0.2
Family Perlodidae					
<i>Helopicus bogaloosa</i>	0.5				
<i>Isoperla</i>	0.8				
Family Pteronarcyidae					
<i>Pteronarcys dorsata</i>	0.3				
Family Taeniopterygidae					
<i>Taeniopteryx longicera</i>	0.6				
<i>Taeniopteryx robiniae</i>	0.2				
Hemiptera					
Family Belostomatidae					
<i>Belostoma</i>				0.2	
Coleoptera					
Family Dryopidae					

Table 13-13. (cont)

Taxa	Station				
	2	4	5	23	6
<i>Helichus</i>	0.3				
Family Elmidae	2.0				
<i>Ancyronyx variegatus</i>	20.3		0.2		0.5
<i>Macronychus glabratus</i>	68.4	0.5	0.2	0.2	10.9
<i>Microcylloepus pusillus</i>	0.3	0.2			
<i>Stenelmis</i>	0.6				0.6
Family Eubriidae					
<i>Ectopria nervosa</i>	0.6				0.2
Family Gyrinidae					
<i>Dineutes</i>	0.3				1.4
Family Gyrinidae, contd					
<i>Gyrinus</i>					0.2
Family Hydrophilidae					
<i>Berosus</i>				0.2	0.2
<i>Enochrus</i> spp.		0.2			
<i>Hydrobius</i>			0.2		
<i>Tropisternus</i>				0.3	
Megaloptera					
Family Corydalidae					0.3
<i>Corydalus cornutus</i>	2.3				
<i>Nigronia</i>	0.2				
Family Sialidae					
<i>Sialis</i>	1.2				
Trichoptera					
Family Brachycentridae					
<i>Brachycentrus</i>	0.9				0.2
Family Hydropsychidae	0.6			0.2	
<i>Cheumatopsyche</i> spp.	29.2	0.3	1.1	1.1	2.8
<i>Hydropsyche</i>	0.5		0.5	0.2	0.5
<i>Macrostemum carolina</i>	0.2				
Family Hydroptilidae					
<i>Orthotrichia</i>			0.2		
<i>Oxyethira</i>	0.2		0.2	0.3	5.1
Family Leptoceridae					
<i>Ceraclea</i>	0.3				
<i>Nectopsyche candida</i>	0.2				
<i>Oecetis</i>	2.3				
Family Limnephilidae					
<i>Pycnopsyche</i>					0.2
Family Philopotamidae					
<i>Chimarra</i>	0.8	0.3			
Family Polycentropodidae					
<i>Ceratotina</i>					1.6
<i>Neureclipsis</i>				0.2	
<i>Phylocentropus</i>					1.1
<i>Polycentropus</i>	0.3		0.2		0.9
Family Psychomyiidae					
<i>Lype diversa</i>	40.2	0.2	0.2	0.3	0.3
Diptera					

Table 13-13. (cont)

Taxa	Station				
	2	4	5	23	6
Family Ceratopogonidae	4.2	0.2	46.6	5.6	38.5
<i>Ceratopogonidae pupae</i>			0.9		
Subfamily Forcipomyiinae	0.2		0.3	0.3	0.2
Family Chaoboridae					
<i>Chaoborus punctipennis</i>		0.2			2.0
Family Chironomidae					
<i>Chironomidae pupae</i>	22.0	1.2	18.2	35.5	44.5
Subfamily Chironominae					
Tribe Chironomini	81.2	24.2	173.7	153.9	99.5
Tribe Tanytarsini	96.7	9.9	263.5	74.2	377.6
Subfamily Diamesinae					
<i>Potthastia</i>	0.2		0.3	0.2	0.2
Subfamily Orthoclaadiinae	124.5	6.7	31.7	16.3	81.2
Subfamily Tanypodinae	17.2	0.5	28.4	78.4	58.2
Family Empididae	20.5	0.3			
Family Ephydriidae			0.5		
Family Simuliidae	0.8				
<i>Simulium</i>	2.0	0.3	0.2	0.6	0.5
Family Stratiomyiidae			0.3	0.3	
<i>Odontomyia</i> sp.				0.2	
Family Tipulidae	0.2				
<i>Hexatoma</i>			0.5		
<i>Tipula</i>	0.2				

Table 13-14 Mean Density (number/m²) of Macroinvertebrates on Hester-Dendy Multiplate Samplers in Pen Branch and Indian Grave Branch During Ambient Thermal Conditions (December 1988–May 1989)

Taxon	Station							Total
	1	2	3	4	5	6	7	
Annelida (worms and leeches)								
<i>Batrachobdella phalera</i>	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.37
Glossiphoniidae	0.00	0.00	0.00	0.00	1.48	0.00	0.00	1.48
<i>Nais communis</i>	0.00	0.00	1.11	0.40	0.00	0.37	0.00	1.88
<i>Placobdella parasitica</i>	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.74
<i>Stylaria lacustris</i>	0.00	0.00	0.00	0.00	0.00	1.48	0.00	1.48
Mollusca (snails and clams)								
<i>Ferrissia henderson</i>	3.33	0.00	0.00	0.00	0.37	0.00	0.00	3.70
<i>Micromenetus dilatatus</i>	0.37	0.00	0.00	0.00	0.00	2.59	0.00	2.96
<i>Physella heterostropha</i>	1.11	0.00	0.37	0.00	0.37	4.07	0.00	5.92
<i>Pseudosuccinea columella</i>	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.74
Crustacea								
<i>Crangonyx obliquus</i>	0.37	0.00	0.00	0.00	0.00	3.70	0.00	4.07
<i>Hyallela azteca</i>	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.37
Ephemeroptera (mayflies)								
<i>Acerpenna pygmaeus</i>	1.85	0.00	0.00	0.00	0.00	0.00	0.00	1.85
<i>Baetis intercalaris</i>	0.00	1.85	0.74	0.40	6.67	0.00	0.00	9.66
<i>Baetis propinquus</i>	0.00	1.11	0.00	0.00	0.00	0.00	0.00	1.11
<i>Caenis</i> sp.	0.00	0.00	2.96	0.40	47.78	2.22	0.00	53.36
<i>Dannella simplex</i>	0.00	1.48	0.00	0.00	0.00	0.00	0.00	1.48
<i>Ephemerella dorothea</i>	0.37	5.19	1.85	0.00	0.00	0.00	0.00	7.41
<i>Ephemerella inconstans</i>	0.00	5.93	0.00	0.00	0.00	0.00	0.00	5.93
<i>Ephemerella rotunda/invaria</i>	0.00	2.22	0.00	0.00	0.00	0.00	0.00	2.22
Ephemerellidae	0.00	0.37	0.00	0.40	0.00	0.00	0.00	0.77
<i>Eurylophella doris</i>	0.00	0.00	0.00	0.00	0.00	1.11	0.00	1.11
<i>Eurylophella</i> nr. <i>temporalis</i>	1.11	0.00	0.00	0.00	0.00	0.00	0.00	1.11
<i>Eurylophella prudentalis</i>	0.00	0.00	0.00	0.00	0.00	1.11	0.00	1.11
<i>Heptagenia flavescens</i>	0.37	0.00	0.00	0.40	0.00	0.00	0.00	0.77
Heptageniidae ^a	0.37	0.00	0.00	0.40	0.00	0.37	0.00	1.14
<i>Leptophlebia</i> sp.	2.59	0.00	0.00	0.00	0.00	0.00	0.00	2.59
<i>Paraleptophlebia</i> sp.	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Stenacron interpunctatum</i>	25.93	0.00	0.00	0.00	1.48	0.00	0.00	27.41
<i>Stenonema integrum</i>	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.74
<i>Stenonema modestum/smithae</i>	13.70	23.70	7.41	3.57	2.96	3.33	0.00	54.67
<i>Tricorythodes</i> sp.	0.00	3.33	0.00	0.00	0.00	0.00	0.00	3.33
Odonata								
<i>Argia tibialis</i>	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Boyeria vinosa</i>	0.00	0.37	0.00	0.00	0.00	0.74	0.00	1.11
<i>Argia translata</i>	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Enallagma</i> sp.	0.00	0.00	0.00	0.00	4.44	0.00	0.00	4.44
Plecoptera (stoneflies)								
<i>Amphinemura delosa</i>	0.00	1.48	0.00	0.00	0.00	0.00	0.00	1.48
<i>Isoperla bilineata</i>	0.00	2.22	0.00	0.00	0.00	0.00	0.00	2.22

Table 13-14. (cont)

Taxon	Station							Total
	1	2	3	4	5	6	7	
<i>Isoperla clio</i>	0.37	1.48	0.00	0.00	0.00	0.00	0.00	1.85
<i>Isoperla</i> nr. <i>nana</i>	1.11	0.00	0.00	0.00	0.00	0.00	0.00	1.11
<i>Perlesta placida</i>	3.33	28.89	0.00	0.40	0.00	0.00	0.00	32.62
Perlidae ^a	0.00	7.41	0.00	0.00	0.00	0.00	0.00	7.41
Perlodidae	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.37
Trichoptera (caddisflies)								
<i>Cernotina spicata</i>	0.00	0.00	0.37	0.00	0.00	0.37	0.00	0.74
<i>Cheumatopsyche</i> spp.	0.37	3.70	5.19	30.56	96.67	3.70	0.79	140.98
<i>Chimarra</i> sp.	0.00	0.00	0.00	14.68	0.37	0.00	0.00	15.05
<i>Hydropsyche elissoma/rossi</i>	0.00	0.00	8.89	28.17	0.00	1.11	1.19	39.36
<i>Hydropsyche</i> nr. <i>incommoda</i>	0.00	0.00	0.74	3.17	0.37	0.00	0.00	4.28
<i>Hydropsyche rossi</i>	0.00	0.00	5.19	18.65	0.74	0.00	0.40	24.98
<i>Hydroptila</i> sp.	0.00	0.00	1.11	0.40	0.00	0.00	0.00	1.51
<i>Lype diversa</i>	4.07	5.93	0.00	0.00	0.00	0.00	0.00	10.00
<i>Macrostemum carolina</i>	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.40
<i>Neureclipsis</i> sp.	0.00	0.00	11.85	2.38	0.00	0.00	0.79	15.02
<i>Oecetis</i> sp.	0.00	0.00	1.11	1.98	0.00	0.37	0.00	3.46
<i>Oxyethira</i> sp.	0.00	0.00	0.00	0.00	0.00	1.11	0.00	1.11
<i>Triaenodes</i> nr. <i>marginata</i>	0.00	0.00	0.37	0.40	0.37	0.00	0.00	1.14
Lepidoptera (moths)								
<i>Parapoynx obscuralis</i>	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.37
Pyralidae	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.37
Megaloptera (hellgrammites)								
<i>Chauliodes pectinicornis</i>	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.37
<i>Nigronia serricornis</i>	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Sialis</i> sp.	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.74
Coleoptera (beetles)								
<i>Ancyronyx variegatus</i>	0.37	1.48	0.37	0.00	0.37	0.00	0.00	2.59
<i>Dineutus</i> sp.	0.00	0.37	0.00	0.40	0.00	0.00	0.00	0.77
<i>Gyrinus</i> sp.	0.00	0.00	0.00	0.00	0.00	2.22	0.00	2.22
<i>Hydroporus</i> sp.	2.22	0.00	0.00	0.00	0.00	0.00	0.00	2.22
<i>Macronychus glabratus</i>	0.37	47.41	1.11	0.00	0.00	2.22	0.00	51.11
<i>Sperchopsis tessellatus</i>	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Stenelmis</i> sp.	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.37
<i>Tropisternus</i> sp.	0.00	0.00	0.00	0.40	0.37	0.00	0.00	0.77
Diptera - Chironomidae (midges)								
Tanypodinae								
<i>Ablabesmyia janta</i>	0.00	0.00	0.00	0.00	0.74	1.48	0.00	2.22
<i>Ablabesmyia mallochi</i>	4.44	1.11	0.37	0.00	10.00	27.78	0.00	43.70
<i>Ablabesmyia</i> sp. ^a	2.22	0.37	0.00	0.00	0.74	0.00	0.00	3.33
<i>Conchapelopia</i> sp.	2.96	7.78	5.19	1.59	12.22	6.67	0.00	36.41
<i>Labrundinia becki</i>	0.37	0.00	0.00	0.00	1.11	0.00	0.00	1.48
<i>Labrundinia</i> nr. <i>neopilosella</i>	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.17
<i>Labrundinia pilosella</i>	0.37	0.00	0.00	0.00	0.00	18.52	0.00	18.89

Table 13-14. (cont)

Taxon	Station							Total
	1	2	3	4	5	6	7	
<i>Nilotanytus fimbriatus</i>	1.48	0.00	0.00	0.00	0.00	0.00	0.40	1.88
<i>Paramerina</i> sp.	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Procladius</i> sp.	0.00	0.00	0.00	0.00	0.00	1.48	0.00	1.48
<i>Zavrelimyia</i> sp.	4.07	0.00	0.00	0.79	0.00	0.00	0.00	4.86
Diptera - Orthocladiinae								
<i>Brillia flavifrons</i>	0.00	9.63	1.48	1.98	0.00	0.00	2.38	15.47
<i>Cardiocladius</i> sp.	0.00	0.00	4.07	0.40	0.00	0.00	13.89	18.36
<i>Corynoneura</i> nr. <i>taris</i>	176.30	17.78	1.48	14.68	57.78	117.04	2.78	387.84
<i>Corynoneura</i> sp.	0.00	3.33	2.22	0.00	0.00	0.17	0.00	5.92
<i>Corynoneura</i> sp. 4	5.19	5.56	0.00	0.00	3.70	0.37	0.00	14.82
<i>Cricotopus bicinctus</i>	0.00	0.37	0.74	0.40	11.85	111.48	0.00	124.84
<i>Cricotopus</i> sp.	0.74	2.59	5.93	2.38	1.11	0.37	200.79	213.91
<i>Cricotopus tremulus</i> gp.	0.00	0.00	0.74	1.19	0.00	0.00	0.00	1.93
<i>Eukiefferiella claripennis</i> gp.	0.00	0.74	18.89	24.60	0.00	0.00	5.16	49.39
<i>Eukiefferiella devonica</i> gp.	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.40
<i>Nanocladius distinctus</i>	0.37	0.00	0.00	0.00	0.00	6.67	0.00	7.04
<i>Nanocladius</i> sp.	0.74	0.00	0.74	0.00	2.22	4.81	0.00	8.51
<i>Orthocladius</i> (<i>Eudactylocladius</i>)	0.00	0.00	4.44	1.59	0.00	0.00	5.95	11.98
<i>Orthocladius curtiseta</i>	0.00	0.00	2.22	0.00	1.85	0.37	38.89	43.33
<i>Orthocladius nigritus</i>	11.11	11.85	76.30	14.29	0.00	0.00	5.16	118.71
<i>Orthocladius</i> nr. <i>oliveri</i>	0.00	2.22	0.00	0.00	0.00	0.00	0.00	2.22
<i>Orthocladius obumbratus</i>	0.00	7.04	0.00	0.40	0.00	0.00	0.00	7.44
<i>Orthocladius</i> sp.	0.37	11.11	110.37	191.27	1.11	0.74	97.22	412.19
<i>Orthocladius</i> sp. a	0.00	0.00	0.00	0.00	1.48	0.00	0.00	1.48
<i>Parakiefferiella</i> sp.	2.22	2.22	8.15	4.37	6.67	31.11	3.97	58.71
<i>Parakiefferiella</i> sp. B	2.96	2.59	5.93	3.97	11.11	9.26	1.19	37.01
<i>Parametriocnemus lundbecki</i>	3.33	44.44	0.74	0.40	0.00	1.85	0.00	50.76
<i>Parametriocnemus</i> sp. C	1.11	2.22	0.00	0.00	0.00	0.00	0.00	3.33
<i>Psectrocladius</i> (<i>Meso.</i>) sp.	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.74
<i>Rheocritcotopus robacki</i>	0.37	23.70	11.85	5.16	9.63	12.96	3.57	67.24
<i>Rheocritcotopus tuberculatus</i>	0.37	1.85	0.00	0.00	0.00	0.00	0.00	2.22
<i>Symposiocladius lignicola</i>	2.22	1.48	3.33	0.79	0.37	0.00	4.37	12.56
<i>Synorthocladius semivirens</i>	0.00	0.00	0.00	0.00	0.00	0.00	4.76	4.76
<i>Thienemanniella fusca</i> gp.	4.44	42.59	0.00	0.40	5.93	7.41	7.54	68.31
<i>Thienemanniella xena</i> gp.	1.85	22.22	8.15	29.76	40.74	31.48	25.79	159.99
<i>Tvetenia discoloripes</i> gp.	0.00	10.74	224.44	260.32	25.19	0.74	72.22	593.65
<i>Tvetenia paucuncula/vitracies</i>	0.00	34.44	0.37	0.00	1.85	0.37	0.79	37.82
<i>Unniella multivirga</i>	18.15	0.00	0.00	0.00	0.00	0.00	0.00	18.15
Diamesinae								
<i>Potthastia longimana</i>	0.00	8.15	0.00	0.00	0.74	2.06	0.40	12.25
Chironomini								
<i>Chironomus</i> sp.	1.11	0.37	0.00	0.00	1.11	0.37	0.00	2.96
<i>Cryptochironomus parafulvus</i>	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.37
<i>Dicrotendipes modestus</i>	0.00	0.00	0.00	0.00	12.22	0.37	0.40	12.99
<i>Microtendipes pedellus</i>	198.52	2.22	0.00	0.00	0.00	0.37	0.00	201.11
<i>Phaenopsectra flavipes</i>	1.85	0.00	1.11	0.00	0.00	0.74	0.00	3.70
<i>Phaenopsectra/Tribelos</i> sp.	6.67	4.44	0.00	0.00	0.00	10.37	0.00	21.48
<i>Polypedilum convictum</i>	0.37	42.22	3.33	32.94	38.15	6.30	1.59	124.90

Table 13-14. (cont)

Taxon	Station							Total
	1	2	3	4	5	6	7	
<i>Polypedilum fallax</i>	2.59	17.04	0.00	2.78	0.00	0.37	1.19	23.97
<i>Polypedilum halterale</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40
<i>Polypedilum illinoiense</i>	0.00	0.37	0.00	0.40	9.26	6.30	2.38	18.71
<i>Polypedilum</i> sp.	0.74	0.00	0.37	0.00	0.00	0.00	0.00	1.11
<i>Polypedilum</i> sp. ^a	3.70	0.00	0.37	19.44	0.00	1.11	0.00	24.62
<i>Stenochironomus</i> sp.	0.00	0.00	0.00	0.40	0.00	0.00	1.19	1.59
Tanytarsini								
<i>Microsetra</i> sp.	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.37
<i>Paratanytarsus</i> sp.	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.37
<i>Rheotanytarsus distinctissimus</i>	1.11	11.11	42.22	48.02	32.96	110.37	26.19	271.00
<i>Tanytarsus glabrescens</i> gp.	0.00	2.59	2.59	0.40	0.37	0.00	0.00	5.95
<i>Tanytarsus</i> sp.	56.67	7.04	6.67	4.76	85.93	19.26	0.40	180.73
<i>Tanytarsus</i> sp. XVI Rutter	34.81	0.00	0.00	0.00	0.00	0.00	0.00	34.81
<i>Tanytarsus</i> sp. XVII Rutter	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.74
<i>Tantarsus</i> sp. ^a	8.52	0.00	0.37	0.00	335.93	7.78	0.00	352.60
Diptera - Misc. (true flies)								
<i>Atrichopogon</i> sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40
<i>Bezzia</i> sp	0.00	0.00	0.00	0.00	0.37	0.74	0.00	1.11
<i>Bezzia</i> sp. 2	0.00	0.00	0.00	0.40	8.89	13.70	0.00	22.99
Empididae	2.22	7.41	10.74	3.57	0.00	0.00	36.90	60.84
<i>Palpomyia</i> sp. 4	0.00	0.00	0.00	0.00	0.00	1.11	0.00	1.11
Sciomyzidae	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40
<i>Simulium dixiense/jonesi</i>	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.37
<i>Simulium tones</i>	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.74
<i>Simulium tuberosum</i>	0.00	14.44	42.96	109.92	37.04	0.37	3.97	208.70
<i>Simulium venustum/verecundum</i>	0.00	0.00	0.00	0.00	16.67	1.11	0.00	17.78
<i>Simulium venustum/vittatum</i>	0.00	0.00	1.48	0.00	14.07	0.00	0.00	15.55
<i>Simulium vittatum</i>	0.00	0.37	28.15	7.54	1.85	0.00	152.38	190.29
<i>Tipula</i> sp. 1	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.40

^a Immature or damaged organisms; probably the same as another taxon.

Source: Data from Enwright (1989a, 1989b, 1989c)

Fish

Introduction

A number of fisheries studies have been conducted in Pen Branch. Apart from an early survey by McFarlane (1983) and later studies by Meffe and Sheldon (1989a, 1989b), these studies have generally been motivated by concern about possible impacts to Pen Branch and its tributary, Indian Grave Branch, as a result of SRS operations. The objective of studies conducted prior to 1988 (Aho et al. 1986, Paller and Saul 1987) were generally to assess the impacts of temperature elevations caused by the discharge of cooling water from K Reactor in Indian Grave Branch and Pen Branch.

In 1988, K Reactor was shut down for maintenance and safety upgrades. The objectives of studies conducted during and after 1988 (Mealing and Paller 1988; Mealing and Heuer 1989a, 1989b, 1989c, and 1989d; and Paller et al. 1992) were to monitor the recovery of the fish community in Indian Grave Branch and Pen Branch and assess possible impacts caused by flow perturbations resulting from tests of the K-Reactor pumping system. Fisheries data collected from the Pen Branch system are summarized in Paller et al. (1989).

Studies Conducted During K-Reactor Operations

Adult Fish

Aho et al. (1986) used multiple-pass electrofishing to sample the fish assemblages in 100 m sample sites located in the headwaters of Pen Branch, a relatively unperturbed reach located above the confluence of Pen Branch and Indian Grave Branch. Samples were also taken from Steel Creek and Meyers Branch. They found that species richness and community structure were generally comparable among streams with the exception of one relatively depauperate sample site in Pen Branch that possessed low habitat diversity (PB1 in Table 13-15 on page 13-40).

Paller and Saul (1987) sampled the midreach of Pen Branch (i.e., the reach between the Indian Grave Branch/Pen Branch confluence and the delta) during 1984 and 1985. Their sampling was restricted to side channels and pools connected to the main channel, because the main channel was too hot to safely electrofish during periods of reactor operation. They found mosquitofish in these relatively cool refugia when the reactor was operating. During outages dollar sunfish and unidentified juvenile sunfish were also collected from these areas, suggesting recolonization by immigrating fish. During periods of reactor operation, fish were presumably absent from the main channel of the midreach because of extremely high temperatures ($>40^{\circ}\text{C}$).

Aho et al. (1986) studied the fish assemblages in Pen Branch just above the delta and a similar section of Fourmile Branch in relation to the operating cycles of K and C Reactors, respectively. Their work involved collections made with fyke nets placed in the stream channels during outage periods to monitor the upstream and downstream movements of fish. Very few fish were collected from the midreach when heated effluents were being released. However, when water temperatures returned to ambient levels during outages, fish

Table 13-15. Distribution and Percent Composition of the Fish Assemblages Collected from Streams on the Savannah River Plant

		Stream Sites								
		PB1	PB2	PB3	SC1	SC2	SC3	MB1	MB2	MB3
<i>Notropis lutipinnis</i>	yellowfin shiner	-	51.7	50.9	53.8	41.1	9.6	59.4	54.7	43.9
<i>Nocomis leptocephalus</i>	bluehead chub	-	9.7	3.0	13.6	13.2	0.2	8.9	8.0	2.0
<i>Hypentelium nigricans</i>	northern hogsucker	-	-	-	11.3	1.7	0.4	0.6	1.0	1.6
<i>Ictalurus nebulosus</i>	brown bullhead	11.7	1.6	0.3	< 0.1	0.1	0.2	0.1	0.1	0.5
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	lake and creek chubsucker	13.0	1.6	1.1	0.9	1.5	0.5	1.6	3.2	1.9
<i>Ictalurus natalis</i>	yellow bullhead	3.2	0.7	0.3	0.1	0.6	0.5	-	0.1	0.8
<i>Ictalurus platycephalus</i>	flat bullhead	-	1.5	0.8	2.0	1.2	0.3	0.1	0.5	0.3
<i>Noturus insignis</i>	marginated madtom	-	1.1	4.2	0.6	0.4	0.2	1.0	2.2	0.1
<i>Noturus leptacanthus</i>	speckled madtom	-	-	4.8	2.6	3.2	2.3	1.7	1.8	3.1
<i>Noturus gyrinus</i>	tadpole madtom	-	0.7	0.7	0.2	1.4	0.4	0.9	0.1	0.3
<i>Lepomis marginatus</i>	dollar sunfish	19.4	0.7	0.1	0.2	1.5	0.5	1.4	0.5	0.1
<i>Lepomis auritus</i>	redbreast sunfish	0.9	1.5	5.4	7.2	2.7	3.8	2.2	4.0	1.9
<i>Lepomis punctatus</i>	spotted sunfish	1.9	4.4	4.4	0.4	5.9	14.6	1.5	2.4	4.9
<i>Micropterus salmoides</i>	largemouth bass	-	0.1	0.5	0.4	0.8	2.5	-	0.2	0.1
<i>Anguilla rostrata</i>	American eel	0.7	1.3	0.4	1.2	1.2	3.8	0.4	0.9	10.9
<i>Aphredoderus sayanus</i>	pirate perch	7.8	11.5	8.8	0.2	6.4	11.2	10.6	8.9	9.3
<i>Gambusia affinis</i>	mosquitofish	-	-	-	0.8	5.0	1.9	-	0.1	0.2
<i>Esox niger</i>	chain pickerel	-	0.3	0.5	-	-	0.4	-	0.2	0.1
<i>Esox americanus</i>	redfin pickerel	12.3	5.9	0.6	0.2	1.7	0.9	1.4	0.6	1.4
<i>Acantharchus pomotis</i>	mud sunfish	27.2	1.5	-	-	-	< 0.1	-	0.2	0.1
<i>Notropis chalybaeus</i>	ironcolor shiner	-	0.1	-	< 0.1	-	0.7	-	< 0.1	0.1
<i>Etheostoma fricksium</i>	Savannah darter	-	3.4	3.5	0.3	0.4	0.3	2.7	1.8	1.1
<i>Percina nigrofasciata</i>	blackbanded darter	-	-	4.4	2.3	2.3	1.9	0.3	0.7	1.3
<i>Fundulus lineolatus</i>	lined topminnow	-	-	0.1	-	-	< 0.1	-	0.1	-
<i>Etheostoma olmstedii</i>	tessellated darter	-	-	4.6	0.2	4.3	8.6	1.4	4.8	8.8
<i>Notropis cummingsae</i>	dusky shiner	1.9	0.5	0.4	0.1	1.2	23.8	3.5	1.9	4.4
<i>Amia calva</i>	bowfin	-	-	0.1	-	-	-	-	-	-
<i>Semotilus atromaculatus</i>	creek chub	-	-	-	0.1	0.3	-	0.2	-	-
<i>Notropis petersoni</i>	coastal shiner	-	-	-	-	1.9	7.2	-	-	-
<i>Lepomis gulosus</i>	warmouth	-	-	0.1	< 0.1	-	0.2	0.1	0.1	-
<i>Enneacanthus gloriosus</i>	bluespotted sunfish	-	-	-	0.1	-	0.1	-	0.1	-
<i>Elassoma zonatum</i>	banded pygmy sunfish	-	-	0.1	-	-	< 0.1	-	-	-
<i>Etheostoma serraferum</i>	sawcreek darter	-	-	-	-	-	0.2	-	-	-
<i>Notropis emiliae</i>	pugnose minnow	-	-	-	-	-	0.2	-	-	-
<i>Perca flavescens</i>	yellow perch	-	-	-	0.2	-	< 0.1	-	0.1	0.1
<i>Notemigonus crysoleucas</i>	golden shiner	-	-	-	0.2	-	-	-	-	-
<i>Centrarchus macropterus</i>	flier	-	-	-	-	-	< 0.1	-	< 0.1	0.1
<i>Chologaster cornuta</i>	swampfish	-	-	-	-	-	0.9	-	-	0.1
<i>Ictalurus brunneus</i>	snail bullhead	-	0.1	-	-	-	-	-	< 0.1	-
<i>Umbra pygmaea</i>	eastern mudminnow	-	-	0.1	-	0.1	0.1	-	< 0.1	0.1
<i>Minytrema melanops</i>	spotted sucker	-	-	-	0.8	-	0.8	-	-	-
<i>Etheostoma fusiforme</i>	swamp darter	-	-	0.1	-	-	0.3	-	-	0.1
<i>Hybopsis rubrifrons</i>	rosyface chub	-	-	-	-	-	< 0.1	-	-	-
<i>Notropis leedsii</i>	bannerfin shiner	-	-	-	-	-	< 0.1	-	-	-
<i>Labidesthes sicculus</i>	brook silverside	-	-	-	-	-	0.2	-	-	-
<i>Enneacanthus chaetodon</i>	blackbanded sunfish	-	-	-	-	-	< 0.1	-	< 0.1	-

Table 13-15. (cont)

		Stream Sites								
		PB1	PB2	PB3	SC1	SC2	SC3	MB1	MB2	MB3
<i>Lepomis macrochirus</i>	bluegill	-	0.1	-	-	-	< 0.1	-	-	-
<i>Fundulus chrysotus</i>	gold topminnow	-	-	-	-	-	-	-	-	0.2
Number of collections		5	8	8	7	7	7	4	8	4
Total number of individuals		309	1519	1809	2531	1174	3415	1579	2823	1501
Mean relative abundance (no /100 m ²)		41.2	87.5	51.7	80.3	47.9	62.3	104.5	70.6	44.2

moved upstream into the creek from the Savannah River swamp. Both juveniles and adults rapidly reinvaded the stream channels; individuals were captured within 12 hours of the cessation of reactor operations. In total, 29 species were collected from the midreach of Pen Branch during reactor outages; the most abundant species were spotted sunfish and lake chubsucker (Figure 13-8). Additional information on this study is presented in Chapter 12—Fourmile Branch.

Delta/Swamp Area

The delta/swamp of Pen Branch included both disturbed, open-canopy areas where water temperatures were elevated to high levels (>40°C in some places), and comparatively undisturbed, closed canopy areas deeper in the swamp where water temperatures remained near ambient even during reactor operation.

Paller and Saul (1987) used backpack electrofishing to sample fish during periods of K-Reactor operation in the highly disturbed open-canopy delta of Pen Branch. Mosquitofish

Figure 13-8. Fish Sampling Stations for Pen Branch

second corresponded to the amount of shading by the cypress/tupelo overstory. (This study is discussed more extensively in Chapter 12—Fourmile Branch).

Larval Fish

While not sampled as extensively as the adult fish, larval fish assemblages in Pen Branch have been studied by Paller et al. (1987) and Aho et al. (1986). Larval fish were collected by Paller et al. (1987) from three sampling stations on Pen Branch during 1984 and 1985 (Paller et al. 1985). One station was located near Road B in the undisturbed headwaters. The second was located at Road A-13.2 (approximately 7.0 km downstream from K Reactor) where water temperatures were well above ambient. The third sample station was located among the braided channels, dead cypress and tupelo, and emergent vegetation in the Pen Branch delta; this station was also highly thermal. A total of 53 fish larvae and eggs were collected from Pen Branch between March and July 1984. Most were collected upstream from K Reactor (primarily minnow and darters). However juvenile mosquitofish and sunfish larvae were collected from the delta and a small number of unidentified eggs were collected from the sampling station near Road A-13.2. The latter probably drifted into the sampling area from relatively cool pools and side channels rather than being produced in the main channel where temperatures often exceeded 40°C. Similar patterns were observed during 1985 (Paller et al. 1987).

Ichthyoplankton

Ichthyoplankton were collected from two sample stations in the Stave Island area of Pen Branch by Aho et al. (1986) as part of a study of the effects of varying temperature elevations on fish reproduction. At least 10 taxa were collected from the Stave Island sample stations; dominant taxa were darters, sunfishes, and minnows. Aho et al. (1986) found that spawning occurred earlier than usual at thermal sample sites, and that spawning was advanced even near Stave Island where temperatures were only one to two degrees warmer than ambient.

Studies Conducted after the Shutdown of K-Reactor

Recolonization of Pen Branch and Indian Grave Branch

Fish recolonized Pen Branch and Indian Grave Branch following the shutdown of K Reactor in April 1988 (Mealing and Paller 1988; Mealing and Heuer 1988, 1989a, 1989b, and 1989c). Sixteen species were collected from the midreaches of Pen Branch (sample station 3) and eleven species were collected from Indian Grave Branch (sample station 7) between November 1988 and January 1989 (Table 13-16). However, the average number of species (4.8) and the average catch per 100-m stream segment (9.3) were low. Samples collected by Paller et al. (1992) (February–May 1991) yielded significantly greater numbers of species (average of 9.9) and numbers of individuals (average of 78.0) demonstrating further recovery of the fish assemblages in the midreach of Pen Branch.

The Pen Branch delta was also recolonized after K-Reactor shutdown. Mealing and Paller (1988) and Mealing and Heuer (1988, 1989a, 1989b, and 1989c) collected 14 species from the delta between November 1988 and January 1989; dominant species included spotted sunfish, coastal shiner, lake chubsucker, mosquitofish, and dollar sunfish (Table 13-16). The relatively shallow water in the delta was probably responsible for the predominance of small

Table 13-16. Percent composition of Electrofishing Collections from Pen Branch During the recent extended outage of K-Reactor. Samples were collected monthly from November 1988–March 1989.

Species	Sample Station Numbers and Locations						
	Upper Reach		Midreach		Delta/Swamp		Indian Grave
	1	2	3	4	5	6	7
longnose gar				3.3		8.9	
bowfin				1.6	0.1		
American eel	0.7	0.2	2.6	0.8		2.3	3.7
eastern mudminnow	4.2	0.1					
redfin pickerel	10.9	0.3			0.1	0.3	
chain pickerel			12.8	2.4		2.6	
bluehead chub	11.9	5.6					
golden shiner			1.3			0.7	3.7
spottail shiner			1.3			2.3	
yellowfin shiner	17.9	73.6					
taillight shiner						0.7	
coastal shiner				11.4	15.8	18.4	18.5
creek chub		1.1					
creek chubsucker	4.2	0.5	2.6	0.8	0.1	1.6	
lake chubsucker	1.8	0.4	14.1	11.4	19.1	7.2	14.8
spotted sucker			6.4			0.3	22.2
silver redhorse			1.3				
yellow bullhead	4.2			0.8	4.3		3.7
flat bullhead		0.3	1.3				
channel catfish				0.8			
tadpole madtom	2.8	1.2					
marginated madtom		0.3					
speckled madtom		1.2					
pirate perch	24.2	5			0.3	0.7	3.7
mosquitofish		0.1			10.9		
lined topminnow	2.1	0.1					
brook silversides			3.8	1.6	0.3	41.8	
Everglades pygmy sunfish						0.3	
bluespotted sunfish					0.1		
mud sunfish	1.1						
redbreast sunfish	2.5	0.5	11.5	6.5	1	1.3	14.8
warmouth			1.3	0.8			
bluegill				0.8		1	
dollar sunfish	1.4			2.4	14.5	0.3	
redeer sunfish			3.8	16.3		1.3	
spotted sunfish	9.8	0.5	1.3	3.3	33.1	1.3	3.7
largemouth bass	0.4	0.2	33.3	35		6.6	
Savannah darter		1.8					3.7
Christmas darter		0.7					
tessalated darter		4.3	1.3		0.1		
sawcheek darter		0.1					
blackbanded darter		1.7					7.4
total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

species in this habitat. Mealing and Paller (1988) and Mealing and Heuer (1988, 1989a, 1989b, and 1989c) also electrofished three transects further downstream near Stave Island in the closed canopy swamp (sample Station 6). They collected 17 species; large fish such as longnose gar and largemouth bass were well represented in deeper channels (Table 13-16). Other relatively abundant species included brook silversides and coastal shiners.

Effects of Artificial Flow Perturbations

During the years following K-Reactor shutdown, high volumes of unheated water were twice pumped into Indian Grave and Pen Branch during tests of the cooling-water pumps. High stream flows can result in the downstream displacement of fishes, and marked reductions in the abundance of species that lack the physical and behavioral adaptations necessary to orient in fast waters (Minckley and Meffe 1987, Bain et al. 1988). Electrofishing samples collected before and after a one-week, nine-fold increase in discharge during January 1989 demonstrated a significant reduction in species number and abundance (Paller et al. 1992). A second period of increased discharge, lasting from February to May 1991, had more limited effects consisting of reductions in shiners, spotted sucker, and largemouth bass. Species number, total fish abundance, and condition did not decline or declined only moderately. Differences between 1989 and 1991 may have been related to the extent of fish-assemblage recovery from previous thermal impacts. In 1989 recovery was in its early stages; many species were represented by only a few transient individuals, and flow-sensitive species comprised a relatively high percentage of the community (Paller et al. 1992).

In summary, fish-assemblage structure varied throughout the Pen Branch system, both as a result of the former influence of K-Reactor discharge and as a result of natural changes in habitat and gradient that accompany the spatial transition along Pen Branch from a small headwater stream to a part of the Savannah River Swamp. When K Reactor operated, water temperature exerted a controlling influence on community structure. Fish were essentially eliminated from Indian Grave Branch and the mid-reaches of Pen Branch, with the exception of a few species in relatively cool refugia off the main channel. Fish began to recolonized formerly thermal areas after K Reactor was shut down and considerable recovery has recently occurred, although habitat degradation resulting from former cooling-water discharges undoubtedly influenced community structure in some areas. In the absence of elevated temperatures, habitat is the primary determinant of community structure with small stream species such as yellowfin shiner and bluehead chub inhabiting the upper reaches; sunfishes, chubsuckers, and largemouth bass predominating in the midreaches; and a typical southeastern swamp community including longnose gar, brook silverside, largemouth bass, coastal shiner, and chain pickerel inhabiting the deep swamp reaches.

References

- Aho, J. M., C. S. Anderson, K. B. Floyd, and M. T. Negus. 1986. Patterns in Fish Assemblage Structure and Dynamics in Waters of the Savannah River Plant. SREL-27 UC-66e. Savannah River Ecology Laboratory. Aiken, SC.
- Arnett, N. W., L. K. Karapatakis, A. R. Mamatey, J. L. Todd. Savannah River Site Environmental Report for 1991. WSRC-TR-92-186, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1992).
- Bain, M. B., J. T. Finn, and H. E. Book. 1988. Stream flow regulation and Fish Community Structure. *Ecology* 69: 382-392.
- Bennett, D. H. and R. W. McFarlane. 1983. The Fishes of the Savannah River Plant: National Environmental Research Park, Report No. SRO-NERP-12. Savannah River Ecology Laboratory. Aiken, SC.
- Chimney, J. J. and W. R. Cody. Distribution and Abundance of Zooplankton at Selected Locations on the Savannah River and from Tributaries of the Savannah River Plant: December 1984-August 1985. ECS-SR-41. Report prepared by Environmental & Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1986).
- Cummins, C. L., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1989, WSRC-IM-90-60, Volume II, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1990).
- Cummins, C. L., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1990, WSRC-IM-91-28, Volume I, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1991).
- Davis, H. A., D. K. Martin, and J. L. Todd. Savannah River Site Environmental Report for 1988. WSRC-RP-89-59-1, Volume II, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1989).
- Enwright Laboratories. Quantitative Macroinvertebrate Survey of Pen Branch and Indian Grave Branch, Sample Retrieval, January 11, 1989. Prepared by Enwright Laboratories for Savannah River Laboratory, Westinghouse Savannah River Site, Aiken, SC. (1989a).
- Enwright Laboratories. Quantitative Macroinvertebrate Survey of Pen Branch and Indian Grave Branch, Sample Retrieval, March 1, 1989. Prepared by Enwright Laboratories for Savannah River Laboratory, Westinghouse Savannah River Site, Aiken, SC. (1989b).
- Enwright Laboratories. Quantitative Macroinvertebrate Survey of Pen Branch and Indian Grave Branch, Sample Retrieval, May 24, 1989. Prepared by Enwright Laboratories for Savannah River Laboratory, Westinghouse Savannah River Site, Aiken, SC. (1989c).
- Firth, P., J. R. O'Hop, B. Coler, and R. A. Green. Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat Analyses and the Lower Food Chain Communities, Volume I. Prepared by Environmental and Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC, DPST-86-797. (1986).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report, Vol. III, Water Quality. DP-1697, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Hutchinson, G. E. A Treatise on Limnology. Vol. II.: Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, New York, NY (1967).
- Industrial Bio-Test Laboratories, Inc. A Baseline/Predictive Environmental Investigation of Lake Wylie, Vol. II. Report prepared for Duke Power Company, Charlotte, NC (1974).

- Kondratieff and Kondratieff 1985 - Kondratieff, P. F. and B. C. Kondratieff. A Lower Food Chain Community Study: Thermal Effects and Post-Thermal Recovery in the Streams and Swamps of the Savannah River Plant, June - September 1984. ECS-SR-19 Prepared by Environmental and Chemical Sciences, Inc. for the Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1985).
- Kondratieff, P. F. and B. C. Kondratieff. A Lower Food Chain Community Study: Thermal Effects and Post-Thermal Recovery in the Streams and Swamps of the Savannah River Plant, November 1983 - May 1984. DPST-85-218, Prepared by Environmental and Chemical Sciences, Inc. for the Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1984).
- Lower, M. W. Comprehensive Cooling Water Study Final Report, Volume II, Water Quality. DP-1739-2, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Mealing, H. G. and J. H. Heuer. 1989. Fish Survey of Pen Branch and Indian Grave Branch, December 1988. ECS-SR-95, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Mealing, H. G. and J. H. Heuer. 1989. Fish Survey of Pen Branch and Indian Grave Branch, February 1989. ECS-SR-97, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Mealing, H. G. and J. H. Heuer. 1989. Fish Survey of Pen Branch and Indian Grave Branch, January 1989. NAI-SR-96, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Mealing, H. G. and J. H. Heuer. 1989. Fish Survey of Pen Branch and Indian Grave Branch, March 1989. NAI-SR-101, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Mealing, H. G. and J. H. Heuer. Fish Survey of Pen Branch and Indian Grave Branch, December 1988. ECS-SR-95, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988).
- Mealing, H. G. and M. H. Paller. 1989. Fish Survey of Pen Branch and Indian Grave Branch, November 1988. ECS-SR-93, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Mealing, H. G. and M. H. Paller. Fish Survey of Pen Branch and Indian Grave Branch, November 1988. ECS-SR-93, report prepared by Normandeau Associates, Inc., Southeastern Regional Office for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1988).
- Meffe, G. K. and A. L. Sheldon. "Post-Defaunation Recovery of Fish Assemblages in Southeastern Blackwater Streams." Manuscript submitted to Ecology.
- Meffe, G. K. and A. L. Sheldon. 1989. "The Influence of Habitat Structure on Fish Assemblage Composition in Southeastern Blackwater Streams." *American Midland Naturalist*: 119(2).
- Mikol, S. C., L. T. Burkhalter, J. L. Todd, and D. K. Martin. U.S. Department of Energy Savannah River Plant Environmental Report for 1987. DPSU-88-30-1, Volume II, E. I. du Pont de Nemours and Company, Savannah River Plant, Aiken, SC (1988).
- Minckley, W. L. and G. K. Meffe. 1987. Flooding in Stream Fish Communities of the Arid Southwest. In W. J. Matthews and D. C. Heins, eds. *Community and Evolutionary Ecology of North American Stream Fishes*. University of Oklahoma Press, Norman OK.

- Paller, M. H. and B. M. Saul. 1987. Effects of Thermal Discharges on the Distribution and Abundance of Adult Fishes in the Savannah River and Selected Tributaries, Annual Report, November 1984 -August 1985, ECS-SR-28, report prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Paller, M. H., E. W. Wilde, W. L. Specht, H. E. Mackey, and N. V. Halverson. 1989. Predictive 316(a) Demonstration for the K-Reactor Cooling System at the Savannah River Plant Following Mitigation with a Recirculating Cooling Tower. DPST-89-349. E. I. du Pont de Nemours & Co. Savannah River Laboratory, Aiken, SC.
- Paller, M. H., E. W. Wilde, W. L. Specht, H. E. Mackey, and N. V. Halverson. 1989. Predictive 316(a) Demonstration for the K-Reactor Cooling System at the Savannah River Plant Following Mitigation with a Recirculating Cooling Tower. DPST-89-349. E. I. du Pont de Nemours and Co. Savannah River Laboratory, Aiken, SC.
- Paller, M. H., S. F. Modica, and E. G. Hofstetter. 1992. Short-term changes in a southeastern coastal plain fish assemblage following artificial increases in streamflow. *Rivers* 3(4): 243-259.
- Patrick and Reimer 1966 - as in Chpt 10
- Specht, W. L. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. DP-1739-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).

Chapter 14

L Lake and Steel Creek

Chapter Contents

Drainage Description and Surface Hydrology (page 14-3)

Water Chemistry and Quality (page 14-9)

Algae (page 14-27)

Macrophytes (page 14-69)

Zooplankton (page 14-77)

Macroinvertebrates (page 14-85)

Fish (page 14-97)

References (page 14-115)

Drainage Description and Surface Hydrology

L Lake

General Description

L Lake was formed by impounding the headwaters of Steel Creek in 1985. L Lake extends about 7000 m along the Steel Creek Valley from the embankment above SC 125 (SRS Road A) to just above SRS Road B (Figure 14-1). The lake width averages about 600 m, reaching a maximum of about 1200 m (DOE 1984). At a normal pool elevation of 58 m, the dam impounds about 31 million m³ of water and covers about 4.185 km² or 418 ha (reported as 1034 acres, nominally 1000 acres) (U.S. Army Corps of Engineers 1987).

Effluent Contribution

As originally constructed, L-Reactor cooling water effluent entered L Lake directly through an effluent canal situated north to south on the north shore of the lake. In 1986, the L-Reactor effluent diversion dike was built to divert the flow from L Reactor into the upper, north-eastern portion of the lake to increase the lake's cooling efficiency. The dike and canal are oriented west to east on the north shore of L Lake, south of SRS Road B (Murdock 1986). The canal formed by the dike is approximately 870 m long and 12 to 15 m wide. The water in the canal is nominally 1.2 m deep at the centerline, with a surface area of about 11,900 m² (DeWitt 1986).

L Lake stratified during the spring and summer due to climatic factors, as is typical of most southeastern lakes and reservoirs. However, stratification occasionally occurred during the

Figure 14-1. Location of L Lake on SRS

winter due to density differences between thermal reactor discharges and underlying lake waters. L Lake received thermal effluent during November 1985–June 1986, December 1986–June 1987 and January 1988–June 1988. Temperatures in excess of 40°C occurred near the L-Reactor outfall during periods of reactor operation. However, the maximum recorded water temperature in Regions 4–8 was approximately 34°C in June 1986. This temperature was approximately 2°C higher than the maximum temperatures in unheated southeastern reservoirs. The highest recorded 24-h mean temperature in Regions 4–8 was 32°C. While the highest temperatures occurred in June, the highest above ambient occurred during the winter and early spring when L Lake waters were elevated as much as 5°C. Littoral zone temperatures exhibited little consistent spatial variation within the study area (Regions 4–8).

L Lake Dam

Description

L-Lake Dam is located approximately 7.2 km above the mouth of Steel Creek and about 0.8 km north of SC Highway 125. The dam consists of a main embankment of rolled fill construction, with a lower embankment (saddledike) extending from the right abutment and a service bridge leading to an intake tower extending from the left abutment. The main embankment is about 670 m long with a 12-m crest width. The top of the embankment is at 27 m. The unpaved emergency spillway has a sill elevation of 60 m. A 60-cm thick concrete cutoff wall is located on the upstream toe of the main dam to minimize seepage under the dam. The saddle dike is about 520 m long with a 12-m crest width. The maximum height of the saddle dike is 3.7 m (U.S. Army Corps of Engineers 1987).

Outlet Structure

The outlet structures for the lake consist of a multigate intake tower, a prefabricated concrete conduit, and a stilling basin located in the valley of the left abutment (U.S. Army Corps of Engineers 1987). Water passes through the intake tower and the conduit and is discharged into the stilling basin before being released to Steel Creek. The discharge intake structure is designed to pass the L-Reactor cooling water flow, the P-Area process water flow, and ambient Steel Creek flow and to serve as the principal means of flood control.

The system of eight gates in the dual wet well tower regulates the reservoir water level. Two gates near the bottom of the lake (lower gates or emergency gates) and two gates 3 m below the normal pool elevation (upper gates) can be opened to let water into the wet wells. These gates are either fully opened or closed. Under normal operating conditions, both lower gates are closed, and both upper gates are open. The lower gates can be opened to release water if the lake level gets too high. The volume of water released from the dam is controlled by the two service gates located at the base of the wet wells. Water flows through both upper gates into the two wet wells and through the service gates into the concrete conduit. Flow through service gates can vary from about 2 m³/sec to 29 m³/sec per gate. Service gates are not operated with an opening of less than about 15 cm to avoid cavitation. To release flows less than 2 m³/sec, such as the minimum flows required during reactor shutdown, two 46-cm-diameter knife gates can be opened. The knife gates can release flows ranging from about 0.3 m³/sec to 2 m³/sec to Steel Creek (Du Pont 1985).

Level and Temperature Monitoring

The reservoir level and the discharge water temperature and volume are electrically monitored by a control system. If the computerized operating system should fail, these data can be visually monitored and the gates manually operated at the dam site (Du Pont 1985).

Steel Creek

General Description

The headwaters of Steel Creek originate near P Reactor (Figure 14-2). The creek flows southwesterly about 3 km before it enters the headwaters of L Lake. The lake is 6.5 km long and relatively narrow, with an area of about 418 ha (1034 acres). Flow from the outfall of L-Lake dam travels about 5 km before entering the SRS Savannah River swamp and then another 3 km before entering the Savannah River. Meyers Branch, the main tributary of Steel Creek, flows approximately 10 km before entering Steel Creek. Meyers Branch is a small blackwater stream that has remained relatively unperturbed by SRS operations. The confluence of Steel Creek and Meyers Branch is located downstream from the L-Lake dam and upstream from SRS Road A. The total area drained by the Steel Creek-Meyers Branch system is about 91 km² (Specht 1987).

Effluents Contribution

In 1954 Steel Creek began receiving thermal effluents from P and L Reactors. By 1961 a total of 24 m³/sec (850 ft³/s) of thermal effluent was being released by both reactors into Steel Creek. From 1961 to 1964 P Reactor partially used the Par Pond recirculating system. In 1964 all P-Reactor effluent was diverted to Par Pond, and in 1968 L Reactor was put on standby. From 1968 until early 1985, Steel Creek was recovering from the impacts of SRS

Figure 14-2. Location of Steel Creek on SRS

operations. In 1981, the Department of Energy initiated activities to restart L Reactor. Based on an environmental assessment of various thermal mitigation alternatives, L Lake was constructed in 1985 along the upper reaches of Steel Creek to receive and cool the heated effluents from L Reactor (restarted in 1985) prior to their release into Steel Creek (Firth et al. 1986). L Reactor was shut down in 1988. Steel Creek has also received nonthermal effluents, including ash basin effluent water, nonprocess cooling water, powerhouse waste water, reactor process effluents, sanitary treatment plant effluents, and vehicle wash waters.

Delta

From 1954 to 1968 when Steel Creek was receiving thermal discharge and increased flow, an extensive delta developed where the creek entered the Savannah River floodplain swamp. The delta is drained by numerous braided channels that eventually coalesce and continue for approximately 1.6 km before entering the Savannah River. Prior to entering the river, the flow from Steel Creek is joined by the flow from Pen Branch and part of the flow from the Fourmile Branch-Beaver Dam Creek system (Specht 1987).

Flow Measurements

The USGS measures flow at several locations on Steel Creek. Flow statistics of Steel Creek at SRS Road A (Figure 14-3) are summarized in Table 14-1. Records for the station at SRS Road A date back to March 1985. Prior to March of 1985, this USGS station was located further downstream at Old Hattiesville Bridge. Flow records at Old Hattiesville Bridge date back to March 1974. In water year 1991, the mean flow of Steel Creek at Road A was 4.7 m³/s (165 ft³/s). Over the period of record (water years 1985–1991) at Road A, the mean flow is 5.2 m³/s (185 ft³/s), the 7-day low flow is 0.33 m³/s (11.6 ft³/s), and the 7Q10 is 0.37 m³/s (12.9 ft³/s). The maximum, minimum, and mean daily flows for the period of record at Road A are shown in Figure 14-4. These statistics do not represent natural flow conditions. Flows in Steel Creek below L Lake are influenced by the flow requirements mandated by the L-Reactor Operation Final Environmental Impact Statement (EIS) (DOE 1984). The 1984 EIS mandates that during reactor outages, flow in Steel Creek at Road A would be maintained at a rate of about 3.0 m³/s (106 ft³/s) during the spring spawning season. During the remainder of the year, flow would be maintained at a rate of about 1.5 m³/s (53 ft³/s) at times of reactor outage.

Table 14-1. Flow Summary for Steel Creek

Station Name	Station Number	Period of Record	Range									
			Mean		Low		High		7Q10		7-Day Low Flow	
			cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)
at Road A at SRS	02197356	1985-1991	5.2	185	0.22	7.7	14.2	500	0.37	12.9	0.33	11.6

Figure 14-3. Flow Measurement Sampling Stations for Steel Creek

Figure 14-4. Maximum, Mean, and Minimum Flow for Steel Creek

Water Chemistry and Quality

L Lake

Water Quality Monitoring

The water quality of L Lake has been monitored on a regular basis since completion of L Lake in 1985 as part of the L Lake/Steel Creek Biological Monitoring Program. This program was designed to meet environmental regulatory requirements associated with the restart of L Reactor, and was driven primarily by Section 316(a) of the Clean Water Act. L Lake is not monitored as part of the routine SRS water quality monitoring program.

L Lake was divided into eight zones based on expected thermal gradients in order to assess the impact of thermal discharge on the L-Lake ecosystem. Water quality sampling was initiated in November 1985 in regions 4-8 (Figure 14-5). The data collected during periods of reactor shut down are more representative of conditions at a later successional stage of L Lake (see Gladden et al. 1989) for a discussion of successional development of lakes.

Kretchmer and Chimney (1992a) report the results of L Lake water quality from November 1985 to December 1991. The following subsections summarize that report.

This discussion emphasizes 1988–1991 after L-Reactor was shut down (no thermal input to the lake), but river water continued to be pumped into the lake.

Figure 14-5. Water Quality Monitoring Stations for L Lake

Field Data

Temperature

Thermal effluent from L Reactor induced periods of temporary thermal stratification in L Lake during the fall and winter of 1985-1987. However, the effect of this phenomenon on water quality appeared to be minimal and the water column quickly returned to isothermal conditions with the cessation of reactor activities. Stratification of the lake during the summer was largely attributed to normal climatic heating and was well established by April of each year. Fall turnover usually began in September or October and was completed by November (Kretchmer and Chimney 1992a).

pH Measurements

From 1988 to 1991, pH values in L Lake varied from 4.9 to 9.4; these measurements were slightly lower than the range of values (5.1 to 10.1) observed from 1985 to 1987. The pH changes in the water column did not appear to be closely related to the establishment or collapse of thermal stratification, but were thought to be more correlated with the intensity of phytoplankton primary productivity.

Physical Characteristics and General Chemistry

Dissolved Oxygen

Changes in dissolved oxygen concentrations throughout the water column from 1985 to 1989 often coincided with the establishment and subsequent collapse of thermal stratification. Oxygen usually decreased in the deeper strata during periods of reactor-induced stratification, but quickly recovered to higher levels when the reactor shut down and the water column remixed. From 1988 to 1991, dissolved oxygen concentrations ranged from <0.1 to 13 mg/l in Region 7. This maximum, measured in 1991, was higher than any value previously reported.

Conductivity

Mean conductivity values in L Lake during 1991 ranged from 45 to 91 $\mu\text{S}/\text{cm}$. These mean values were 10 to 20 $\mu\text{S}/\text{cm}$ lower than in 1990 which in turn were 10 to 20 $\mu\text{S}/\text{cm}$ lower than in previous years. The highest conductivity values were generally recorded at the lake bottom during the fall of each year. No consistent regional differences in water column conductivity were noted for any year.

Suspended Solids and Turbidity

Total suspended solids concentrations ranged from <1 to 20 mg/l from 1988 to 1991. These concentrations were somewhat lower than the concentrations measured in either 1985, 1986, or 1987. The higher concentrations during 1985, 1986, and 1987 may reflect the settling out of high total suspended solids loads in the reactor effluent in the upper regions of L Lake. Turbidity was not measured as part of this study.

Major Cations and Anions

Alkalinity, Chloride, and Sulfate

From 1988 to 1991, alkalinity ranged from 5 to 41 mg CaCO₃/l. This range of individual values were lower than those observed in previous years. Alkalinity values were usually highest in the summer or fall and lowest in the winter. Chloride measurements ranged from 3.2 to 13.8 mg/l and sulfate concentrations ranged from 1 to 10 mg SO₄/l from 1988 to 1991. These chloride and sulfate measurements were similar to those first observed in 1985/86 and 1987.

Calcium, Magnesium, Sodium, and Potassium

Concentrations of total calcium, magnesium, and potassium were similar during all years of the study (Table 14-2). Concentrations of total sodium measured from 1988 to 1991 were slightly higher than those measured in 1985, 1986, and 1987. Ranges of concentrations for sodium during the 1988 to 1991 period were 4.02 to 14.4 mg/l, and during 1985, 1986, and 1987 sodium concentration ranges were 5.92 to 13 mg/l.

Aluminum, Manganese, and Iron

Mean total aluminum concentrations in 1985, 1986, and 1987 were, for the most part, slightly greater than the detection limit of 0.1 mg/l. Means and ranges of individual aluminum values in 1988, 1989, 1990, and 1991 were similar, and generally lower than those in 1985, 1986, and 1987 (Table 14-2).

Total manganese ranged from <0.02 mg/l to 2.0 mg/l from 1988 to 1991. These concentrations were similar to those measured during 1985, 1986, and 1987 with the exception of one measurement at Region 6 (8.46 mg/l). The remaining manganese concentrations ranged from <0.020 to 2.6 mg/l during the 1985-1987 period.

Throughout the years of the study, there was considerable variation in the magnitude of means and ranges of individual concentrations of iron (Table 14-2). However, the iron concentrations were similar during all years of the study.

Nutrients

Phosphorus

L Lake acted as a very effective nutrient sink and retained most of the total phosphorus and ortho-phosphorus imported into it on a concentration basis. L Reactor effluent had mean total phosphorus concentrations, ranging between 60 and 246 µg P/l from 1985 to 1989 (Kretchmer and Chimney 1992a). Concentrations of total phosphorus and ortho-phosphorus measured in L Lake ranged from 0.014 to 0.864 mg/l and from <0.005 to 0.816 mg/l, respectively, during all years of the study (Table 14-2).

Nitrogen

L Lake acted as a very effective nutrient sink and retained most of the nitrite, nitrate, and ammonia imported into it on a concentration basis. However, L Lake usually exported more total Kjeldahl nitrogen than was present in the reactor effluent waters. Concentrations of

Table 14-2. Water Quality Data (range of values) for L Lake (November 1985–December 1991)

Parameter	Temperature (°C)	Dissolved Oxygen (mg/l)	pH	Conductance (µS/cm)	Tot. Diss. Solids (mg/l)	Tot. Sus. Solids (mg/l)	Tot. Org. Carbon (mg/l)
<i>L Lake (1985–1986)</i>							
Region 4*	10.8 - 33.6	0.1 - 10.1	5.6 - 9.5	64 - 133	25 - 91	1 - 41	1 - 13
Region 5	10.9 - 30.2	0.1 - 11.0	5.9 - 9.6	64 - 112	32 - 91	1 - 13	3 - 11
Region 6*	10.9 - 31.1	0.1 - 11.8	5.6 - 9.6	61 - 117	40 - 76	1 - 17	3 - 11
Region 7	10.9 - 32.2	<0.1 - 11.9	5.2 - 9.6	61 - 120	27 - 88	1 - 39	3 - 10
Region 8*	10.7 - 29.8	0.1 - 11.0	5.5 - 9.7	61 - 111	25 - 82	<1 - 13	3 - 12
<i>L Lake (1987–1991)</i>							
Region 4*	6.4 - 32.6	<0.1 - 11.4	4.9 - 9.9	53 - 146	38 - 97	<1 - 11	1 - 13
Region 5	8.5 - 31.0	<0.1 - 12.7	5.4 - 9.9	41 - 122	18 - 90	<1 - 11	<1 - 15
Region 6*	9.5 - 31.4	0.1 - 10.7	6.0 - 10.0	67 - 120	30 - 87	<1 - 20	1 - 9
Region 7	8.5 - 37.1	<0.1 - 13.0	5.3 - 10.1	41 - 143	17 - 95	<1 - 11	<1 - 12
Region 8*	10.2 - 30.8	0.1 - 10.7	5.5 - 10.1	61 - 112	34 - 90	<1 - 11	<1 - 12
Parameter	Diss. Org. Carbon (mg/l)	Tot. Inorg. Carbon (mg/l)	Alkalinity (mg/l)	Ortho- phosphate (mg/l)	Tot. Phosphate (mg/l)	Nitrite (mg/l)	Nitrate (mg/l)
<i>L Lake (1985–1986)</i>							
Region 4*	1 - 11	1 - 21	14.5 - 39.5	<0.005 - 0.654	0.018 - 0.698	<0.001 - 0.036	<0.01 - 0.660
Region 5	2 - 9	1 - 15	12.7 - 50.9	<0.005 - 0.561	0.024 - 0.557	<0.001 - 0.020	<0.01 - 0.276
Region 6*	3 - 9	1 - 13	11.0 - 34.0	<0.005 - 0.489	0.018 - 0.484	<0.001 - 0.022	<0.01 - 0.269
Region 7	3 - 8	1 - 17	14.8 - 34.8	<0.005 - 0.573	0.014 - 0.584	<0.001 - 0.025	<0.01 - 0.758
Region 8*	2 - 8	1 - 12	15.0 - 32.7	<0.005 - 0.413	0.020 - 0.423	<0.001 - 0.022	<0.01 - 0.304
<i>L Lake (1987–1991)</i>							
Region 4*	1 - 16	1 - 19	8 - 41	<0.005 - 0.816	0.025 - 0.864	<0.001 - 0.092	<0.01 - 0.334
Region 5	1 - 17	1 - 15	6 - 35	<0.005 - 0.570	0.026 - 0.572	<0.001 - 0.021	<0.01 - 0.318
Region 6*	1 - 10	2 - 14	9 - 34	<0.005 - 0.520	0.026 - 0.523	<0.001 - 0.019	<0.01 - 0.331
Region 7	<1 - 8	1 - 16	5 - 35	<0.005 - 0.536	0.024 - 0.542	<0.001 - 0.076	<0.01 - 0.369
Region 8*	2 - 10	2 - 10	9 - 33	<0.005 - 0.447	0.025 - 0.447	<0.001 - 0.017	<0.01 - 0.409
Parameter	Ammonia (mg/l)	Tot. Inorg. Nitrogen (mg/l)	Silica (mg/l)	Tot. Aluminum (mg/l)	Diss. Aluminum (mg/l)	Tot. Calcium (mg/l)	Diss. Calcium (mg/l)
<i>L Lake (1985–1986)</i>							
Region 4*	<0.01 - 2.72	<0.01 - 2.73	1.8 - 10.5	<0.1 - 0.42	<0.1 - 0.18	2.12 - 5.09	2.08 - 4.94
Region 5	<0.01 - 2.27	<0.01 - 2.28	1.5 - 10.5	<0.1 - 0.37	<0.1 - 0.17	2.53 - 5.15	2.53 - 4.81
Region 6*	<0.01 - 1.86	0.01 - 1.87	1.0 - 10.4	<0.1 - 0.57	<0.1 - 0.25	2.09 - 5.25	2.08 - 4.78
Region 7	<0.01 - 2.21	0.01 - 2.22	0.6 - 10.4	<0.1 - 0.79	<0.1 - 0.27	1.87 - 5.25	1.76 - 4.79
Region 8*	<0.01 - 1.67	<0.01 - 1.72	0.4 - 10.2	<0.1 - 1.03	<0.1 - 0.94	2.39 - 4.91	2.68 - 4.76
<i>L Lake (1987–1991)</i>							
Region 4*	<0.01 - 2.08	<0.01 - 2.12	3.0 - 9.7	<0.1 - 0.93	<0.1 - 0.17	0.97 - 4.93	0.95 - 5.04
Region 5	<0.01 - 1.74	<0.01 - 1.76	2.9 - 9.5	<0.1 - 0.64	<0.1 - 0.20	0.99 - 4.61	1.01 - 4.58
Region 6*	<0.01 - 1.48	<0.01 - 1.49	2.8 - 9.7	<0.1 - 0.54	<0.1 - 0.20	0.85 - 4.51	0.91 - 4.55
Region 7	<0.01 - 1.70	<0.01 - 1.72	2.9 - 9.7	<0.1 - 0.69	<0.1 - 0.17	1.02 - 4.78	1.05 - 4.65
Region 8*	<0.01 - 1.89	<0.01 - 1.91	2.7 - 10.0	<0.1 - 0.75	<0.1 - 0.20	1.03 - 4.76	0.97 - 4.52

Parameter	Tot. Iron (mg/l)	Diss. Iron (mg/l)	Tot. Magnesium (mg/l)	Diss. Magnesium (mg/l)	Tot. Manganese (mg/l)	Diss. Manganese (mg/l)	Tot. Potassium (mg/l)
<i>L Lake (1985–1986)</i>							
Region 4*	0.052 - 11.60	<0.020 - 11.60	1.04 - 1.69	1.01 - 1.76	<0.02 - 2.60	<0.02 - 2.50	1.10 - 2.06
Region 5	0.101 - 8.94	<0.020 - 8.66	1.20 - 2.00	1.12 - 1.95	<0.02 - 1.88	<0.02 - 1.93	1.17 - 1.96
Region 6*	0.078 - 7.78	<0.020 - 7.30	0.97 - 1.54	1.02 - 1.53	<0.02 - 8.46	<0.02 - 7.80	0.86 - 4.59
Region 7	0.070 - 5.30	<0.020 - 5.51	1.08 - 1.68	1.12 - 1.67	<0.02 - 1.57	<0.02 - 1.53	0.95 - 2.27
Region 8*	0.087 - 6.90	<0.02 - 5.44	1.19 - 1.57	1.18 - 1.58	<0.02 - 1.83	<0.02 - 1.90	1.00 - 4.20
<i>L Lake (1987–1991)</i>							
Region 4*	0.060 - 9.15	<0.020 - 9.51	0.94 - 1.68	0.93 - 1.60	<0.02 - 1.76	<0.02 - 1.83	0.49 - 5.1
Region 5	0.032 - 7.29	<0.020 - 7.01	0.74 - 1.62	0.96 - 1.64	<0.02 - 2.00	<0.02 - 1.53	0.90 - 2.12
Region 6*	0.037 - 5.79	<0.020 - 5.96	0.86 - 1.54	0.94 - 1.55	<0.02 - 1.38	<0.02 - 1.49	0.71 - 2.7
Region 7	0.024 - 5.63	<0.020 - 5.64	0.72 - 1.52	0.97 - 1.65	<0.02 - 2.00	<0.02 - 1.34	0.86 - 2.0
Region 8*	<0.020 - 4.56	<0.020 - 4.58	0.90 - 1.62	0.10 - 1.66	<0.02 - 1.26	<0.02 - 1.26	0.78 - 1.88
Parameter	Diss. Potassium (mg/l)	Tot. Sodium (mg/l)	Diss. Sodium (mg/l)	Chloride (mg/l)	Hydrogen Sulfide (mg/l)	Sulfate (mg/l)	
<i>L Lake (1985–1986)</i>							
Region 4*	1.10 - 1.94	5.92 - 11.19	5.44 - 11.19	6 - 9	<0.1 - 0.3	2 - 6	
Region 5	0.97 - 1.94	7.21 - 13.00	7.19 - 13.30	6 - 13	<0.1 - 0.4	2 - 6	
Region 6*	0.82 - 2.89	6.89 - 12.40	6.81 - 13.40	6 - 9	<0.1 - 0.4	2 - 6	
Region 7	1.05 - 2.15	7.06 - 11.30	6.76 - 11.20	6 - 10	<0.1 - 0.6	2 - 6	
Region 8*	0.94 - 4.55	6.18 - 10.84	6.96 - 11.03	6 - 11	<0.1 - 0.6	2 - 7	
<i>L Lake (1987–1991)</i>							
Region 4*	0.86 - 2.26	8.88 - 14.40	7.28 - 13.80	5.3 - 11.7	<0.1 - 0.1	2 - 10	
Region 5	0.61 - 2.1	4.02 - 14.10	7.38 - 14.10	3.2 - 11.6	<0.1 - 0.3	2 - 10	
Region 6*	0.63 - 2.9	6.90 - 13.80	7.37 - 13.70	5.2 - 11.0	<0.1 - 0.3	1 - 9	
Region 7	0.69 - 2.1	4.10 - 14.20	7.39 - 13.80	4.3 - 11.6	<0.1 - 0.5	2 - 10	
Region 8*	0.83 - 2.1	6.67 - 14.30	7.21 - 14.40	5.1 - 13.8	<0.1 - 0.7	1 - 9	

*Sampling was discontinued in 1990.
Data taken from Chimney (1992)

nitrogen species measured in L Lake ranged as follows: nitrite, <0.001 to 0.092 mg/l; nitrate, <0.001 to 0.660 mg/l; and ammonia, <0.01 to 2.72 mg/l (Table 14-2).

Trace Elements

Trace elements (arsenic, cadmium, chromium, copper, lead, nickel, and zinc) were not measured as part of the L Lake/Steel Creek Biological Monitoring Program.

Organic Carbon

Total organic carbon concentrations were similar throughout all years of the study, with ranges of <1 to 15 mg/l.

Steel Creek

Studies and Monitoring

Water Quality Monitoring

The Environmental Monitoring Section has conducted routine water-quality monitoring of Steel Creek since 1973. One location (Steel Creek at Road A) has been monitored monthly for physical and biological properties and for metals (Figure 14-6). Temperature and dissolved oxygen measurements have also been taken hourly at Steel Creek 4 as part of Consent Order 84-4-W. The Environmental Monitoring Section also collects an additional sample annually and analyzes it for pesticides, herbicides, and PCBs.

All routine water quality monitoring data reported in the following sections can be found in the SRS Environmental Reports, which are published annually.

Comprehensive Cooling Water Study

Nine locations on Steel Creek, Meyers Branch, and the Steel Creek swamp were studied from 1983 to 1985 as part of the Comprehensive Cooling Water Study (CCWS). This study was designed to provide an assessment of present and proposed SRS activities on water quality. Because the CCWS was conducted prior to construction of L Lake, data collected from this study are not representative of conditions in Steel Creek. However, these data are presented in the following subsections for comparison purposes. Lower (1987) should be referenced for a synopsis of CCWS data for Steel Creek.

Figure 14-6. Water Quality Monitoring Stations for Steel Creek

Priority Pollutants Survey

In 1984, a special instream survey of priority pollutants was conducted to determine the levels of volatile, acid, and base/neutral compounds in Steel Creek. Two locations—Steel Creek at Road B and at Road A—were sampled for this study. The results of this study are discussed later in this chapter and documented in Lower (1987).

Chemical Assessment Studies

In 1985, the L Lake/Steel Creek Biological Monitoring Program was initiated to assess various components of the system and identify any changes due to the operation of L Reactor or discharge from L Lake. The study was designed to meet environmental regulatory requirements associated with the restart of L Reactor, and was driven primarily by Section 316(a) of the Clean Water Act. Kretchmer and Chimney (1992b) reports the results of Steel Creek water quality over the six years of the study. A summary of this report is provided later in this chapter.

Field Data

Water Temperature

Water temperatures measured in Steel Creek since construction of L Lake have been similar to pre-construction conditions, with a range of 7.1 to 30°C, and an average of 19°C (Table 14-3).

pH Measurements

The pH of Steel Creek at Road A ranged from 5.6 to 8.3 during the period 1987 to 1991. Similar pHs were measured prior to the construction of L Lake with pH ranges from 6 to 8 (Table 14-3).

Physical Characteristics and General Chemistry

Dissolved Oxygen

Concentrations of dissolved oxygen in Steel Creek at Road A reflect the lack of thermal input to the creek (range 5.0 to 12 mg O₂/l, mean 8.1 mg O₂/l). These concentrations, measured from 1987 to 1991, are similar to concentrations measured during the CCWS (Table 14-4).

Conductivity

From 1987 to 1991, specific conductance in Steel Creek at Road A ranged from 10 to 92 μ Shos/cm (Table 14-4). These measurements are similar to those measured during the CCWS.

Suspended Solids and Turbidity

Mean total suspended solids and turbidity levels in Steel Creek were 4.67 mg/l and 5.60 NTU, respectively, from 1987 to 1991. These levels are within the ranges measured prior to construction of L Lake (Table 14-4).

Table 14-3. Steel Creek - Field Data

	Water Temperature (°C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
<i>Steel Creek at Road B (CCWS)^a</i>				
Mean	18.1	7.07	27	53
Range	4.6 - 27.5	6.20 - 8.30	15 - 57	10 - 115
Samples	46	46	22	41
<i>Steel Creek at Road A-14 (CCWS)^a</i>				
Mean	18.7	7.03	43	55
Range	5.5 - 29.7	6.50 - 8.10	24 - 64	11 - 98
Samples	46	46	19	41
<i>Steel Creek upstream of Meyers Branch (CCWS)^a</i>				
Mean	17.8	7.00	34	50
Range	6.4 - 31.7	6.10 - 8.10	0 - 53	0 - 75
Samples	44	46	35	39
<i>Meyers Branch at Road B-6.2 (CCWS)^a</i>				
Mean	15.5	6.73	49	26
Range	0.6 - 25.2	5.80 - 8.30	35 - 111	5 - 82
Samples	46	46	40	41
<i>Meyers Branch at Road 9 (CCWS)^a</i>				
Mean	15.0	6.90	47	26
Range	0.5 - 22.5	5.90 - 8.30	35 - 99	9 - 55
Samples	46	46	28	41
<i>Meyers Branch upstream of Steel Creek confluence (CCWS)^a</i>				
Mean	16.7	6.93	52	33
Range	0.1 - 25.5	6.00 - 8.30	23 - 90	15 - 70
Samples	44	44	39	40
<i>Steel Creek at Old Hattiesville Bridge (CCWS)^a</i>				
Mean	16.3	7.01	65	40
Range	2.6 - 27.5	6.00 - 8.40	30 - 100	19 - 56
Samples	46	46	40	41
<i>Steel Creek swamp upstream of Pen Branch confluence (CCWS)^a</i>				
Mean	17.6	6.90	121	25
Range	1.0 - 28.0	6.10 - 8.10	32 - 278	3 - 48
Samples	43	44	30	38
<i>Steel Creek upstream of confluence with Savannah River (CCWS)^a</i>				
Mean	17.3	6.93	219	44
Range	0.8 - 27.5	6.40 - 8.10	138 - 504	3 - 112
Samples	46	46	36	38
<i>Steel Creek at Road A (1987-1991)^b</i>				
Mean	19			
Range	7.1 - 30	5.6 - 8.3	NA	NA
Samples	60	60		

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 14-4. Steel Creek - Physical Characteristics and General Chemistry

	Dissolved Oxygen (mg/l)	Specific Conductance (mmhos/cm)	Turbidity (NTU)	Total Suspended Solids (mg/l)
<i>Steel Creek at Road B (CCWS)^a</i>				
Mean	8.33	58.9	76.4	26.0
Range	5.90 - 11.4	22.9 - 78.6	4.6 - 193	0.25 - 345
Samples	46	38	43	45
<i>Steel Creek at Road A-14 (CCWS)^a</i>				
Mean	7.92	67.0	37.5	21.4
Range	4.60 - 11.4	27.2 - 167	2.80 - 200	0.25 - 134
Samples	46	38	43	45
<i>Steel Creek upstream of Meyers Branch (CCWS)^a</i>				
Mean	7.94	68.5	40.9	17.0
Range	4.70 - 11.9	36.4 - 128	8.30 - 283	0.40 - 97.2
Samples	43	36	41	43
<i>Meyers Branch at Road B-6.2 (CCWS)^a</i>				
Mean	7.09	52.7	5.50	6.13
Range	4.20 - 11.6	26.8 - 70.9	1.50 - 35.0	0.25 - 93.2
Samples	44	38	43	45
<i>Meyers Branch at Road 9 (CCWS)^a</i>				
Mean	8.20	43.1	7.00	4.78
Range	5.20 - 12.2	25.0 - 61.0	1.60 - 47.0	0.25 - 31.2
Samples	45	38	43	45
<i>Meyers Branch upstream of Steel Creek confluence (CCWS)^a</i>				
Mean	7.94	48.3	5.60	4.67
Range	5.10 - 12.4	30.4 - 72.4	1.60 - 18.8	0.25 - 17.2
Samples	44	37	42	44
<i>Steel Creek at Old Hattiesville Bridge (CCWS)^a</i>				
Mean	7.42	62.5	26.3	10.8
Range	3.50 - 10.9	34.2 - 117	6.70 - 240	1.20 - 69.2
Samples	45	38	43	45
<i>Steel Creek swamp upstream of Pen Branch confluence (CCWS)^a</i>				
Mean	6.69	68.5	6.10	2.49
Range	3.50 - 13.6	38.4 - 93.4	1.70 - 24.8	0.25 - 7.60
Samples	44	36	43	43
<i>Steel Creek upstream of confluence with Savannah River (CCWS)^a</i>				
Mean	6.73	71.5	7.00	5.18
Range	3.40 - 13.1	46.2 - 91.6	2.50 - 25.3	0.25 - 16.3
Samples	46	38	43	45
<i>Steel Creek at Road A (1987-1991)^b</i>				
Mean	8.1	59	3.7	5.3
Range	5.0 - 12	10 - 92	0.93 - 22	1.0 - 14
Samples	60	60	59	60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Major Anions and Cations

Alkalinity, Chloride, and Sulfate

Alkalinity concentrations in Steel Creek at Road A ranged from 1.0 to 21 mg CaCO₃/l from 1987 to 1991, which was slightly lower than the range of measurements taken during the CCWS (Table 14-5). Chloride and sulfate concentrations measured during the same period were higher than data collected during the CCWS. Mean chloride and sulfate concentrations at Road A from 1987 to 1991 were 6.7 mg/l and 6.9 mg/l, respectively.

Calcium, Magnesium, Sodium, and Potassium

From 1987 to 1991, calcium concentrations ranged from 1.9 to 3.8 mg/l and sodium concentrations ranged from 5.4 to 11.0 mg/l. These concentrations are slightly lower than the concentrations measured during the CCWS (Table 14-6). Magnesium concentrations ranged from 0.89 mg/l to 1.4 mg/l, which is in the range measured during the CCWS. Potassium is not measured as part of the routine water quality monitoring program.

Aluminum, Iron, and Manganese

Concentrations of aluminum, iron, and manganese have been much lower since the construction of L Lake (Table). From 1987 to 1991, aluminum ranged from <0.01 to 0.16 mg/l; iron ranged from <0.02 to 0.26 mg/l; and manganese ranged from <0.01 to 0.17 mg/l.

Nutrients

Phosphorus

Total phosphorus is the only form of phosphorus measured as part of the routine water quality monitoring program. From 1987 to 1991, the mean total phosphorus concentration in Steel Creek at Road A was 0.032 mg P/l, which is similar to the means measured during the CCWS (Table 14-7).

Nitrogen

Organic nitrogen, ammonia, and nitrate are the only forms of nitrogen measured as part of the routine water quality monitoring program in Steel Creek. All forms of nitrogen have been higher in Steel Creek at Road A since the CCWS. The means for these forms of nitrogen were as follows: organic nitrogen, 0.37 mg N/l; ammonia, 0.076 mg N/l; and nitrate 1.00 mg N/l.

Trace Elements

The concentrations of trace elements in Steel Creek at Road A were at or below detection limits for all samples (Table 14-8). Nickel was the only trace element measured above the detection limit, with a maximum concentration of 70 µg/l. Lead and zinc were detected at the detection limits of 30 µg/l and 50 µg/l, respectively.

Organic Carbon

Organic carbon is not measured as part of the routine water quality monitoring program.

Table 14-5. Steel Creek - Major Anions

	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg/l)
<i>Steel Creek at Road B (CCWS)^a</i>			
Mean	14.8	5.16	3.84
Range	0.75 - 20.0	1.90 - 7.40	0.25 - 15.8
Samples	45	46	28
<i>Steel Creek at Road A-14 (CCWS)^a</i>			
Mean	17.1	5.63	4.24
Range	4.75 - 32.7	1.60 - 27.4	0.25 - 11.0
Samples	45	46	28
<i>Steel Creek upstream of Meyers Branch (CCWS)^a</i>			
Mean	17.1	5.33	4.93
Range	6.15 - 26.4	2.30 - 27.4	1.06 - 13.4
Samples	42	44	26
<i>Meyers Branch at Road B-6.2 (CCWS)^a</i>			
Mean	15.0	3.95	1.85
Range	3.25 - 27.8	2.10 - 6.90	0.03 - 8.45
Samples	45	46	27
<i>Meyers Branch at Road 9 (CCWS)^a</i>			
Mean	13.7	2.80	0.91
Range	3.54 - 25.3	1.30 - 4.20	0.13 - 5.61
Samples	45	45	26
<i>Meyers Branch upstream of Steel Creek confluence (CCWS)^a</i>			
Mean	16.9	2.66	0.81
Range	3.75 - 26.9	1.60 - 4.20	0.06 - 5.48
Samples	44	45	25
<i>Steel Creek at Old Hattiesville Bridge (CCWS)^a</i>			
Mean	17.8	4.52	3.65
Range	4.83 - 31.3	2.10 - 14.4	0.25 - 14.7
Samples	44	46	28
<i>Steel Creek upstream of Pen Branch confluence (CCWS)^a</i>			
Mean	18.0	5.21	4.60
Range	10.5 - 24.6	2.20 - 8.10	1.09 - 8.45
Samples	43	44	26
<i>Steel Creek upstream of confluence with Savannah River (CCWS)^a</i>			
Mean	18.4	5.59	5.23
Range	11.8 - 26.2	2.20 - 7.90	1.90 - 8.98
Samples	45	46	28
<i>Steel Creek at Road A (1987-1991)^b</i>			
Mean	15	6.7	6.9
Range	1.0 - 21	1.9 - 9.6	2.0 - 56
Samples	60	60	60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 14-6. Steel Creek - Major Cations (Total)

	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Aluminum (mg/l)	Iron (mg/l)	Manganese (mg/l)
<i>Steel Creek at Road B (CCWS)^a</i>							
Mean	4.13	0.910	4.33	0.700	3.51	1.88	0.141
Range	1.14 - 6.16	0.388 - 1.33	1.82 - 6.33	<0.368 - 1.66	0.201 - 75.1	0.289 - 35.9	<0.0004 - 1.43
Samples	39	39	39	39	39	39	16
<i>Steel Creek at Road A-14 (CCWS)^a</i>							
Mean	4.42	1.01	5.46	0.831	1.80	1.52	0.070
Range	1.64 - 9.07	0.175 - 1.30	1.57 - 23.0	<0.368 - 2.64	0.390 - 9.88	0.712 - 5.04	<0.0004 - 0.141
Samples	39	39	39	39	39	39	16
<i>Steel Creek upstream of Meyers Branch (CCWS)^a</i>							
Mean	4.51	1.03	5.40	0.817	1.85	1.60	0.076
Range	2.62 - 6.72	0.526 - 1.40	1.61 - 15.7	<0.368 - 2.18	0.312 - 14.4	0.448 - 6.24	<0.0004 - 0.210
Samples	37	37	37	37	37	37	16
<i>Meyers Branch at Road B-6.2 (CCWS)^a</i>							
Mean	5.00	0.791	2.94	0.518	0.480	0.979	0.089
Range	1.47 - 8.40	0.336 - 1.41	1.37 - 8.37	<0.368 - 1.38	<0.038 - 3.80	0.198 - 5.89	<0.0004 - 0.294
Samples	39	39	39	39	39	39	15
<i>Meyers Branch at Road 9 (CCWS)^a</i>							
Mean	4.98	0.557	2.05	<0.368	0.460	0.845	0.092
Range	2.58 - 7.26	0.426 - 0.956	1.41 - 4.92	<0.368 - 1.03	0.087 - 1.94	0.248 - 1.73	<0.0004 - 0.430
Samples	38	38	38	38	38	38	16
<i>Meyers Branch upstream of Steel Creek confluence (CCWS)^a</i>							
Mean	6.15	0.572	2.45	<0.368	0.619	0.794	0.082
Range	2.09 - 9.10	0.203 - 1.34	0.558 - 13.7	<0.368 - 1.39	0.070 - 2.40	0.258 - 1.26	<0.0004 - 0.286
Samples	36	36	36	36	36	36	16
<i>Steel Creek at Old Hattiesville Bridge (CCWS)^a</i>							
Mean	5.43	0.878	4.28	0.635	1.45	1.70	0.125
Range	2.69 - 9.55	0.156 - 1.17	1.61 - 11.9	<0.368 - 2.06	0.248 - 19.2	0.577 - 7.83	<0.0004 - 0.293
Samples	39	39	39	39	39	39	16
<i>Steel Creek swamp upstream of Pen Branch confluence (CCWS)^a</i>							
Mean	3.86	1.16	6.15	0.769	0.462	1.54	0.095
Range	2.65 - 5.29	0.786 - 1.61	2.00 - 11.9	<0.368 - 1.69	<0.038 - 2.87	0.316 - 18.2	<0.0004 - 0.182
Samples	37	37	37	37	37	37	17
<i>Steel Creek upstream of confluence with Savannah River (CCWS)^a</i>							
Mean	3.57	1.22	6.47	0.827	0.461	0.976	0.080
Range	2.68 - 4.64	1.02 - 1.49	2.43 - 10.8	<0.368 - 1.69	0.147 - 1.48	0.329 - 1.56	<0.0004 - 0.281
Samples	39	39	39	39	39	39	17
<i>Steel Creek at Road A (1987-1991)^b</i>							
Mean							
Range	1.9 - 3.8	0.89 - 1.4	5.4 - 11.0	NA	<0.01 - 0.16	<0.02 - 0.26	<0.01 - 0.17
Samples	18	18	20		19	20	18

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 14-7. Steel Creek - Nutrients

	Total Phosphorus (mg P/l)	Total Ortho- phosphate (mg PO₄-P/l)	Organic Nitrogen (mg N/l)	Total Kjeldhal Nitrogen (mg N/l)	Ammonia (mg NH₃-N/l)	Nitrite (mg NO₂-N/l)	Nitrate (mg NO₃-N/l)
<i>Steel Creek at Road B (CCWS)^a</i>							
Mean	0.036	0.009	0.211	0.227	0.028	0.003	0.201
Range	<0.010 - 0.391	0.002 - 0.033	0.170 - 0.885	0.012 - 0.900	<0.005 - 0.340	<0.001 - 0.020	0.019 - 0.450
Samples	46	39	45	46	46	44	42
<i>Steel Creek at Road A-14 (CCWS)^a</i>							
Mean	0.067	0.034	0.229	0.252	0.037	0.004	0.207
Range	<0.010 - 0.362	0.005 - 0.123	0.022 - 0.895	0.020 - 0.920	<0.005 - 0.450	<0.001 - 0.013	0.005 - 0.400
Samples	46	40	45	46	46	44	43
<i>Steel Creek upstream of Meyers Branch (CCWS)^a</i>							
Mean	0.062	0.031	0.203	0.218	0.037	0.004	0.207
Range	<0.010 - 0.181	0.003 - 0.201	0.020 - 0.840	0.048 - 0.910	<0.005 - 0.430	<0.001 - 0.012	0.072 - 0.410
Samples	45	39	42	45	43	42	41
<i>Meyers Branch at Road B-6.2 (CCWS)^a</i>							
Mean	0.023	0.007	0.227	0.246	0.028	0.002	0.099
Range	<0.010 - 0.123	<0.001 - 0.024	0.021 - 0.764	0.048 - 0.800	<0.005 - 0.230	<0.001 - 0.005	0.013 - 0.220
Samples	46	41	45	46	46	44	43
<i>Meyers Branch at Road 9 (CCWS)^a</i>							
Mean	0.028	0.006	0.257	0.276	0.026	0.002	0.109
Range	<0.010 - 0.406	<0.001 - 0.013	0.038 - 0.959	0.057 - 1.00	<0.005 - 0.390	<0.001 - 0.010	0.019 - 0.206
Samples	46	41	45	46	46	43	42
<i>Meyers Branch upstream of Steel Creek confluence (CCWS)^a</i>							
Mean	0.022	0.007	0.250	0.251	0.030	0.002	0.092
Range	<0.010 - 0.072	<0.001 - 0.028	0.041 - 0.858	0.010 - 0.870	<0.005 - 0.060	<0.001 - 0.008	0.010 - 0.188
Samples	46	40	43	45	45	43	42
<i>Steel Creek at Old Hattiesville Bridge (CCWS)^a</i>							
Mean	0.056	0.022	0.202	0.224	0.036	0.003	0.146
Range	<0.010 - 0.261	0.003 - 0.062	0.033 - 0.887	0.038 - 0.900	<0.005 - 0.280	<0.001 - 0.010	0.005 - 0.305
Samples	46	41	44	46	46	44	43
<i>Steel Creek swamp upstream of Pen Branch confluence (CCWS)^a</i>							
Mean	0.054	0.036	0.205	0.219	0.027	0.002	0.075
Range	<0.010 - 0.161	0.005 - 0.096	0.039 - 0.543	0.028 - 0.560	0.005 - 0.390	<0.001 - 0.005	0.005 - 0.240
Samples	44	39	43	46	44	42	41
<i>Steel Creek upstream of confluence with Savannah River (CCWS)^a</i>							
Mean	0.057	0.035	0.235	0.250	0.024	0.003	0.075
Range	<0.010 - 0.161	0.005 - 0.077	0.031 - 0.945	0.028 - 0.950	0.005 - 0.210	<0.001 - 0.012	0.003 - 0.228
Samples	44	40	45	46	46	43	42
<i>Steel Creek at Road A (1987-1991)^b</i>							
Mean	0.032		0.37		0.076		1.00
Range	<0.01 - 0.36	NA	<0.1 - 1.9	NA	<0.01 - 0.30	NA	0.02 - 0.39
Samples	60		60		60		60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 14-8. Steel Creek - Trace Elements (Total)

	Arsenic (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Lead (mg/l)	Nickel (mg/l)	Zinc (mg/l)
<i>Steel Creek at Road B (CCWS)^a</i>							
Mean	2.8	0.32	4.9	3.8	2.0	4.6	4.8
Range	<0.4 - 12.0	<0.04 - 1.20	<0.4 - 41.0	<0.4 - 24.0	<0.4 - 9.0	<0.4 - 26.3	<0.4 - 26.1
Samples	16	16	16	16	16	16	16
<i>Steel Creek at Road A-14 (CCWS)^a</i>							
Mean	3.9	0.50	6.2	2.9	1.8	3.7	6.2
Range	<0.4 - 22.1	<0.04 - 5.00	<0.4 - 46.0	<0.4 - 5.2	<0.4 - 9.3	<0.4 - 12.0	<0.4 - 28.8
Samples	16	16	16	16	16	16	16
<i>Steel Creek upstream of Meyers Branch (CCWS)^a</i>							
Mean	2.4	0.50	6.1	2.3	2.2	4.0	12.4
Range	<0.4 - 8.1	<0.04 - 4.50	<0.4 - 46.0	<0.4 - 5.0	<0.4 - 7.3	<0.4 - 14.1	<0.4 - 119
Samples	16	16	16	16	16	16	16
<i>Meyers Branch at Road B-6.2 (CCWS)^a</i>							
Mean	1.7	0.76	8.3	1.9	2.6	2.0	6.0
Range	<0.4 - 6.8	<0.04 - 6.20	<0.4 - 59.0	<0.4 - 4.2	<0.4 - 19.8	<0.4 - 7.0	<0.4 - 30.0
Samples	15	15	15	15	15	15	15
<i>Meyers Branch at Road 9 (CCWS)^a</i>							
Mean	1.3	0.54	6.1	2.7	1.5	2.1	5.1
Range	<0.4 - 16.0	<0.04 - 3.10	<0.4 - 50.0	<0.4 - 12.8	<0.4 - 3.7	<0.4 - 8.4	<0.4 - 23.5
Samples	16	16	16	16	16	16	16
<i>Meyers Branch upstream of Pen Branch confluence (CCWS)^a</i>							
Mean	1.7	0.49	6.9	2.2	1.3	4.7	5.3
Range	<0.4 - 7.8	<0.04 - 2.50	<0.4 - 47.0	<0.4 - 12.8	<0.4 - 5.3	<0.4 - 44.5	<0.4 - 21.6
Samples	16	16	16	16	16	16	16
<i>Steel Creek at Old Hattiesville Bridge (CCWS)^a</i>							
Mean	2.4	0.26	7.8	2.6	1.7	3.9	6.3
Range	<0.4 - 8.2	<0.04 - 1.40	<0.4 - 55.0	<0.4 - 9.5	<0.4 - 7.0	<0.4 - 13.0	<0.4 - 25.8
Samples	16	16	16	16	16	16	16
<i>Steel Creek swamp upstream of Pen Branch confluence (CCWS)^a</i>							
Mean	1.5	0.61	4.0	1.7	1.4	2.0	5.2
Range	<0.4 - 8.9	<0.04 - 5.00	<0.4 - 31.0	<0.4 - 4.2	<0.4 - 3.3	<0.4 - 7.0	<0.4 - 22.0
Samples	17	17	17	17	17	17	17
<i>Steel Creek upstream of confluence with Savannah River (CCWS)^a</i>							
Mean	1.5	0.71	8.8	2.1	2.0	2.3	4.0
Range	<0.4 - 6.4	<0.04 - 7.00	<0.4 - 58.0	<0.4 - 8.1	<0.4 - 7.3	<0.4 - 6.7	<0.4 - 12.4
Samples	17	17	17	17	17	17	17
<i>Steel Creek at Road A (1987-1991)^b</i>							
Mean							
Range	NA	<10	<10 - <50	<10 - 30	<3 - 20	<10 - 70	<10 - 50
Samples		20	20	20	20	20	20

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Priority Pollutants

Lower (1987) reports the results of a special study to determine the levels of volatile, acid, and base/neutral organics in Steel Creek. Concentrations of all 88 tested organics were below detection limits at both the Steel Creek at Road B and at Road A sampling locations.

Pesticides, Herbicides, and PCBs

Water samples are collected annually from Steel Creek at Road A as part of the routine water quality monitoring program and analyzed for pesticides, herbicides, and PCBs. From 1987 to 1991, no analytes were detected in Steel Creek.

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 Assessment Studies

L Lake/Steel Creek Biological Monitoring Program

An extensive water quality monitoring study was initiated after the construction of L Lake. This study was designed to assess various components of the Steel Creek System and identify changes due to the operation of L-Reactor or discharge from L Lake. Thirteen sampling stations were located throughout the Steel Creek corridor, marsh, swamp, and channel (Figure 14-6). The range of values for 34 water quality parameters for Steel Creek from November 1985 to December 1991 can be found in Table 14-10.

Steel Creek water quality during the Steel Creek Biological Monitoring Program was found to be similar to the range of values reported for other regional lotic systems and judged to be typical of southeastern waters in general (Kretchmer and Chimney 1992b).

During parts of the study, downstream gradients were observed between corridor Stations 275 and 290 for temperature, dissolved oxygen, pH total organic and inorganic carbon, ortho- and total phosphorus, nitrite-nitrogen, nitrate-nitrogen, and ammonia-nitrogen, total inorganic nitrogen, silica, total aluminum, total and dissolved iron, total and dissolved sodium, chloride, total and dissolved magnesium, total and dissolved potassium, and total and dissolved calcium. These differences were attributed to natural conditions such as cooling, metabolic activity of stream organisms, or chemical reactions (Kretchmer and Chimney 1992b).

Differences between swamp and marsh stations were noted during at least a portion of the study for temperature, ortho- and total phosphorus, nitrate-nitrogen, total inorganic nitrogen, total and dissolved sodium, and sulfate. However, no consistent differences were evident. Such variation would not be unexpected between stations located in different habitat types (Kretchmer and Chimney 1992b).

Inspection of pre- and post-impoundment data for the years 1985 to 1989 indicated that increases in temperature, conductivity, total phosphorus, nitrate-nitrogen, ammonia-nitrogen, total and dissolved sodium, and chloride, and decreases in pH have occurred relative to pre-impoundment conditions documented during the CCWS. These changes reflected dif-

ferences between water being released from L Lake (dominated by Savannah River water) and the natural drainage of the Steel Creek basin (Kretchmer and Chimney 1992b).

Higher levels were measured at Station 300 for conductivity, total dissolved solids, total inorganic carbon, alkalinity, ammonia-nitrogen, total and dissolved calcium, total iron, total and dissolved magnesium, total and dissolved manganese, and total and dissolved potassium; and lower concentrations at Station 300 for orthophosphate and sulfate during the summers of 1986–1988. Reduced flow velocities due to the abundance of macrophytes were thought to have impeded water exchange with the rest of the swamp and marsh. Water quality differences were much reduced compared to previous years (Kretchmer and Chimney 1992b).

Table 14-9. Water Quality Measurements in Steel Creek (1987–1991)

	Temperature (°C)	Dissolved Oxygen (mg/l)
<i>Quarter 1 (January 1–March 31)</i>		
Hourly Maximum	24	11.2
Hourly Minimum	8.8	7.5
Hourly Average	15	9.3
<i>Quarter 2 (April 1–June 30)</i>		
Hourly Maximum	28	10
Hourly Minimum	14	5.0
Hourly Average	22	7.3
<i>Quarter 3 (July 1–September 30)</i>		
Hourly Maximum	30	8.5
Hourly Minimum	22	3.5
Hourly Average	26	6.1
<i>Quarter 4 (October 1–December 31)</i>		
Hourly Maximum	26	11
Hourly Minimum	9.4	5.5
Hourly Average	17	8.6

Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 14-10. Water Quality Data (range of values) for Steel Creek (November 1985–December 1991)

Parameter	Temperature (°C)	Dissolved Oxygen (mg/l)	pH	Conductance (mS/cm)	Tot. Diss. Solids (mg/l)	Tot. Sus. Solids (mg/l)	Tot. Org. Carbon (mg/l)
<i>Steel Creek (1985–1986)</i>							
Corridor	10.9 - 29.9	4.9 - 11.1	5.4 - 6.2	41 - 97	29 - 74	<1 - 204	4 - 12
Swamp/ delta	7.6 - 27.7	0.6 - 11.4	4.8 - 7.3	22 - 135	7 - 84	4 - 40	3 - 13
<i>Steel Creek (1987–1991)</i>							
Corridor	6.6 - 29.3	4.7 - 13.0	5.3 - 8.5	18 - 126	27 - 83	1 - 59	1 - 8
Swamp/ delta	1.3 - 28.9	1.9 - 12.5	5.0 - 7.7	23 - 114	23 - 91	<1 - 148	1 - 19
Parameter	Diss. Org. Carbon (mg/l)	Tot. Inorg. Carbon (mg/l)	Alkalinity (mg/l)	Ortho- phosphate (mg/l)	Tot. Phosphate (mg/l)	Nitrite (mg/l)	Nitrate (mg/l)
<i>Steel Creek (1985–1986)</i>							
Corridor	4 - 9	2 - 8	6.4 - 23.7	<5 - 87	18 - 343	1 - 20	<10 - 402
Swamp/ delta	3 - 12	1 - 13	1.8 - 50.0	<5 - 51	8 - 154	<1 - 5	<10 - 582
<i>Steel Creek (1987–1991)</i>							
Corridor	2 - 10	2 - 6	9 - 23	<5 - 136	19 - 180	<1 - 82	<10 - 611
Swamp/ delta	1 - 17	2 - 10	7 - 37	5 - 67	19 - 494	1 - 13	<10 - 366

Parameter	Ammonia (mg/l)	Tot. Inorg. Nitrogen (mg/l)	Silica (mg/l)	Tot. Aluminum (mg/l)	Diss. Aluminum (mg/l)	Tot. Calcium (mg/l)	Diss. Calcium (mg/l)
<i>Steel Creek (1985–1986)</i>							
Corridor	11 - 764	27 - 808	3.2 - 10.7	<100 - 991	<100 - 905	2.6 - 4.4	2.8 - 5.8
Swamp/ delta	<10 - 190	21 - 664	1.2 - 13.3	<100 - 1210	<100 - 1270	2.7 - 11.5	2.4 - 11.1
<i>Steel Creek (1987–1991)</i>							
Corridor	<10 - 1080	17 - 1119	0.8 - 9.7	<100 - 1216	<100 - 202	311 - 4.8	1.1 - 4.8
Swamp/ delta	<10 - 157	<10 - 407	0.6 - 19.1	<100 - 449	<100 - 240	2.6 - 7.8	1.9 - 7.8
Parameter	Tot. Iron (mg/l)	Diss. Iron (mg/l)	Tot. Magnesium (mg/l)	Diss. Magnesium (mg/l)	Tot. Manganese (mg/l)	Diss. Manganese (mg/l)	Tot. Potassium (mg/l)
<i>Steel Creek (1985–1986)</i>							
Corridor	0.1 - 3.8	<0.1 - 3.2	0.74 - 1.94	0.70 - 2.01	<20 - 563	<20 - 466	1.06 - 1.98
Swamp/ delta	0.3 - 7.4	0.1 - 0.7	0.64 - 2.66	0.62 - 2.59	<20 - 3590	<20 - 3590	0.45 - 4.12
<i>Steel Creek (1987–1991)</i>							
Corridor	0.1 - 1.2	<0.1 - 1.1	0.77 - 1.40	0.87 - 1.46	<20 - 310	<20 - 311	0.87 - 1.92
Swamp/ delta	0.2 - 4.3	<0.1 - 2.7	0.78 - 1.87	0.84 - 1.83	<20 - 4173	<20 - 4067	0.79 - 4.28
Parameter	Diss. Potassium (mg/l)	Tot. Sodium (mg/l)	Diss. Sodium (mg/l)	Chloride (mg/l)	Hydrogen Sulfide (mg/l)	Sulfate (mg/l)	
<i>Steel Creek (1985–1986)</i>							
Corridor	1.00 - 1.94	4.0 - 13.1	3.7 - 12.1	7 - 8	<0.1	3 - 11	
Swamp/ delta	0.38 - 3.35	6.0 - 14.6	6.0 - 14.8	6 - 10	<0.1	1 - 12	
<i>Steel Creek (1987–1991)</i>							
Corridor	0.24 - 1.96	4.1 - 13.5	6.9 - 13.6	4.0 - 11	<0.1	1 - 9	
Swamp/ delta	0.54 - 4.45	5.1 - 13.1	5.4 - 13.3	3 - 12	<0.1	1 - 12	

Data taken from Kretchmer and Chimney (1992b)

Algae

L Lake

Phytoplankton

Studies in L Lake

Phytoplankton were sampled monthly in L Lake from 1986 through 1991. Regions 4 through 8 were sampled during 1986-1989, while only Regions 5 and 8 were sampled in 1990-1991 (Figure 14-7). This sampling was conducted to determine species composition and abundance expressed as densities of organisms, biovolumes, chlorophyll *a*, dry weight, and ash-free dry weight. Primary productivity of the phytoplankton was also measured. Detailed methods and results can be found in Carson (1992). Data from 1986-1987 have been previously summarized in compliance documents (Gladden et al. 1988 and Wike et al. 1989) and the data for 1986-1989 were more recently summarized in a technical report by Bowers (1991).

Phytoplankton Establishment After the Construction of L Lake

The phytoplankton communities of newly created reservoirs are frequently unstable for the first few years and this disequilibrium phase may have been confounded in L Lake by the sporadic operation of L Reactor at decreasing power levels during 1986-1988 (Figure 14-8). For example, substantial blooms of the nuisance blue green alga *Microcystic aeruginosa* during the first two years of the lake's existence (Figure 14-9, Gladden et al. 1988) appeared

Figure 14-7. Algae Sampling Stations for L Lake

to be related to the pumping of heated, relatively nutrient-rich cooling water (derived from the Savannah River) into L Lake. This nutrient enrichment resulted in phosphorus concentrations that were among the highest recorded in southeastern lakes (Carson 1992).

Extremely high chlorophyll *a* and primary productivity levels were also observed concurrently with peak reactor operation during the spring of 1986.

Current Status of L Lake Phytoplankton

With the cessation of reactor operations in 1988, and the natural aging process, the phytoplankton community of L Lake demonstrated a stabilizing trend and was much more typical of other lakes of the region in 1990 and 1991. Annual trends for species richness, primary productivity, chlorophyll *a* relative abundance of major algal groups and total phytoplankton density, are shown in Figure 14-10 through Figure 14-13, respectively. Comprehensive species lists from the six-year study appear in Table 14-11 and Table 14-12.

Periphyton

Studies in L Lake

Periphyton sampling was conducted monthly in Regions 4-8 of L Lake (Figure 14-7) from 1986 through 1989 using periphytometers and sediment cores. Periphyton parameters that were studied included taxonomy and abundance of organisms expressed in terms of densities and biovolumes, dry mass and ash-free dry mass, chlorophyll *a*, and primary productivity. Detailed methods and results can be found in Chimney et al. (1990). Data from 1986-1987 have been previously summarized in compliance documents by Gladden et al. (1988) and Wike et al. (1989).

L Reactor Impacts

Impacts on the periphyton community of L Lake resulting from L Reactor operations were not apparent. There were no consistent regional relationships between periphyton grown on artificial substrates and although the periphyton in sediment cores varied regionally in terms of species composition, there was no gradient among regions indicative of varying degrees of thermal pollution.

Quantities of total periphyton (Figure 14-14) and primary productivity (Figure 14-15) indicated a trend involving less fluctuation and reduced peaks in the attached algae with reservoir aging (and the reduction/termination of L Reactor operations). However, chlorophyll *a* dry weight values did not show any discernible pattern over the four-year study period (Figure 14-16 & Figure 14-17). Densities and biovolumes of blue-green algae (Figure 14-18 & Figure 14-19) showed a tendency toward reduced temporal and spatial variation and a general reduction in biomass. The relative abundance of blue-green algae was substantially lower in 1988 and 1989 compared to 1986 and 1987 (Chimney et al. 1990). Both reservoir aging and reductions in thermal and nutrient additions to the reservoir resulting from the reduction and subsequent cessation of reactor operations are likely to have contributed to the diminishing quantities of blue-green algae observed over the four-year study period.

Lists of the important periphyton taxa identified during the study period appear in Table 14-13 through Table 14-16.

Figure 14-8. L-Lake Reactor and Monitoring History

Figure 14-9. Mean Phytoplankton Biovolume in the Pelagic Zone of Regions 4-8 in L Lake (January 1986-December 1987) (Source: Gladden et al. 1988)

Figure 14-10. Mean Algae Species Richness ($\pm$ SD) in L Lake

Figure 14-11. Mean Integrated Primary Productivity ($\pm$ SD) in L Lake

Figure 14-12. Mean Integrated Chlorophyll a ($\pm$ SD) in the Mixed Layer of L Lake

Figure 14-13. Percent Abundance of Blue-Greens, Greens, and Diatoms in L Lake

Table 14-11. Phytoplankton Taxa Collected from L-Lake Pelagic Zone Sampling Stations.
January 1986–December 1989.

Taxon	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8
Division Bacillariophyta					
<i>Achnanthes exigua</i>			X	X	
<i>Achnanthes lanceolata</i> var. <i>apiculata</i>	X	X			
<i>Achnanthes minutissima</i>	X	X	X	X	X
<i>Asterionella formosa</i>				X	X
<i>Attheya zachariasii</i>	X	X	X	X	X
<i>Capartogramma crucicula</i>	X				
<i>Cyclostephanos tholiformis</i>	X	X	X	X	X
<i>Cyclotella atomus</i>	X	X	X	X	X
<i>Cyclotella meneghiniana</i>	X	X	X	X	X
<i>Cyclotella pseudostelligera</i>	X	X	X	X	X
<i>Cyclotella stelligera</i>	X	X	X	X	X
<i>Cymbella minuta</i>	X				X
<i>Cymbella tumida</i>	X				
<i>Eunotia pectinalis</i>		X			
<i>Eunotia zasuminensis</i>		X			
<i>Fragilaria crotonensis</i>		X	X	X	X
<i>Fragilaria virescens</i>					X
<i>Gomphonema parvulum</i>	X	X	X	X	X
<i>Gyrosigma acuminatum</i>				X	
<i>Gyrosigma spencerii</i>	X	X	X	X	X
<i>Melosira ambigua</i>	X	X	X	X	X
<i>Melosira distans</i>	X	X	X	X	X
<i>Melosira granulata</i>	X	X	X	X	X
<i>Melosira granulata</i> var. <i>angustissima</i>	X	X	X	X	X
<i>Melosira varians</i>	X	X	X	X	X
<i>Navicula capitata</i>		X			
<i>Navicula confervacea</i>	X	X	X	X	X
<i>Navicula cryptocephala</i>	X	X	X	X	X
<i>Navicula cuspidata</i>	X				
<i>Navicula decussis</i>	X	X	X	X	X
<i>Navicula luzonensis</i>			X		
<i>Navicula minima</i>	X	X			
<i>Navicula rhynchocephala</i> var. <i>germainii</i>		X			
<i>Navicula</i> spp.	X	X	X		X
<i>Nitzschia acicularis</i>	X	X	X	X	X
<i>Nitzschia agnita</i>	X	X	X	X	X
<i>Nitzschia amphibia</i>	X		X	X	X
<i>Nitzschia capitellata</i>	X				
<i>Nitzschia fonticola</i>	X	X	X	X	X
<i>Nitzschia gracilis</i>	X	X	X	X	X
<i>Nitzschia holsetica</i>	X	X	X	X	X
<i>Nitzschia intermedia</i>		X			
<i>Nitzschia palea</i>	X	X	X	X	X
<i>Nitzschia paleacea</i>	X	X	X	X	X
<i>Nitzschia</i> spp.		X	X		
<i>Pinnularia</i> spp.				X	
<i>Pinnularia viridis</i>					X
<i>Rhizosolenia eriensis</i>	X	X	X	X	X

Taxon	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8
<i>Rhizosolenia longiseta</i>	X	X	X	X	X
<i>Skeletonema potamos</i>	X	X	X	X	X
<i>Stephanodiscus</i> sp. 2	X	X	X	X	X
<i>Surirella robusta</i>	X	X		X	X
<i>Synedra delicatissima</i>	X		X	X	X
<i>Synedra parasitica</i>		X			
<i>Synedra planktonica</i>	X	X	X	X	X
<i>Synedra rumpens</i>	X	X	X	X	X
<i>Synedra tenera</i>	X	X	X	X	X
<i>Synedra ulna</i>	X	X	X	X	X
<i>Synedra ulna</i> var. <i>oxyrhynchus</i>	X				
Division Chlorophyta					
<i>Actinastrum hantzschii</i>	X	X	X	X	X
<i>Ankistrodesmus falcatus</i>	X	X	X	X	X
<i>Ankistrodesmus spiralis</i>	X	X	X	X	X
<i>Arthrodesmus octocornis</i>			X		
<i>Carteria</i> sp. 1				X	
<i>Carteria</i> spp.	X	X	X	X	X
<i>Chaetophora elegans</i>					X
<i>Characium</i> spp.	X	X	X	X	X
<i>Chlamydomonas</i> spp. < 5 µ	X	X	X	X	X
<i>Chlamydomonas</i> spp. 5 - 9.9 µ	X	X	X	X	X
<i>Chlamydomonas</i> spp. 10 - 15 µ	X	X	X	X	X
<i>Chlamydomonas</i> spp. > 15 µ	X	X	X	X	X
chlorobacteria < 2 µ		X			
chloroflagellate spp. < 5 µ	X	X	X	X	X
chloroflagellate spp. 5 - 9.9 µ	X	X	X	X	X
<i>Closteriopsis longissima</i>	X				X
<i>Closterium aciculare</i>	X	X	X		X
<i>Closterium acutum</i>	X	X	X	X	X
<i>Closterium cornu</i>	X		X		
<i>Closterium gracile</i>	X	X	X	X	X
<i>Closterium moniliferum</i>	X				
<i>Closterium parvulum</i>	X				
coccoid Chlorophyta spp. < 5 µ	X	X	X	X	X
coccoid Chlorophyta spp. 5 - 9.9 µ	X	X	X	X	X
coccoid Chlorophyta spp. 10 - 15 µ					X
<i>Coelastrum microporum</i>	X	X	X	X	X
<i>Coelastrum reticulatum</i>	X	X	X	X	X
<i>Coelastrum sphaericum</i>	X	X	X	X	X
<i>Coronastrum aestivale</i>	X	X	X	X	X
<i>Cosmarium botrytis</i>			X		
<i>Cosmarium contractum</i>	X	X	X	X	X
<i>Cosmarium depressum</i>	X	X	X	X	X
<i>Cosmarium granatum</i>				X	
<i>Cosmarium regnellii</i>		X			
<i>Cosmarium reniforme</i>					X
<i>Cosmarium tenue</i>	X	X	X	X	X
<i>Crucigenia cruciata</i>	X	X	X	X	X
<i>Crucigenia quadrata</i>	X	X	X	X	X

Taxon	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8
<i>Crucigenia tetrapedia</i>	X	X	X	X	X
<i>Desmidium swartzii</i>			X		
<i>Dictyosphaerium ehrenbergianum</i>	X	X	X		
<i>Dictyosphaerium pulchellum</i>	X	X	X	X	X
<i>Didymocystis fina</i>	X	X	X	X	X
<i>Elakatothrix viridis</i>	X	X	X	X	X
<i>Euastrum binale</i>	X	X	X	X	X
<i>Eudorina elegans</i>			X		
<i>Franceia ovalis</i>	X	X	X	X	X
<i>Gloeocystis planctonica</i>	X	X	X	X	X
<i>Golenkinia radiata</i>	X	X	X	X	X
<i>Gonium pectorale</i>	X	X	X	X	X
<i>Keratococcus raphidioides</i>	X	X	X	X	X
<i>Kirchneriella lunaris</i>	X	X	X	X	X
<i>Kirchneriella obesa</i>	X	X	X		X
<i>Lagerheimia citrifomis</i>			X	X	X
<i>Lagerheimia genevensis</i>	X	X	X	X	X
<i>Lagerheimia subsalsa</i>	X	X	X	X	X
<i>Leptosira mediciniana</i>			X		
<i>Micractinium pusillum</i>	X	X	X	X	X
<i>Monoraphidium circinale</i>	X	X	X	X	X
<i>Monoraphidium</i> sp. 1	X	X	X	X	X
<i>Mougeotia</i> spp.		X	X	X	X
<i>Oedogonium</i> spp. 1g	X	X	X	X	X
<i>Oocystis parva</i>	X	X	X	X	X
<i>Oocystis pusilla</i>	X	X	X	X	X
<i>Pandorina charkowiensis</i>	X	X	X	X	X
<i>Pandorina morum</i>	X	X	X	X	X
<i>Pediastrum duplex</i>	X	X	X	X	X
<i>Pediastrum tetras</i>	X	X	X	X	X
<i>Pleurotaenium ehrenbergii</i>		X			
<i>Polyedriopsis spinulosa</i>	X	X	X	X	X
<i>Scenedesmus acuminatus</i>	X	X	X	X	X
<i>Scenedesmus acutus</i>	X	X	X	X	X
<i>Scenedesmus bernardii</i>	X				
<i>Scenedesmus bicaudatus</i>	X	X	X	X	X
<i>Scenedesmus brasiliensis</i>	X	X	X	X	X
<i>Scenedesmus brevispina</i>	X				
<i>Scenedesmus denticulatus</i>	X	X	X	X	X
<i>Scenedesmus dimorphus</i>	X	X	X	X	X
<i>Scenedesmus ecornis</i>	X	X	X	X	X
<i>Scenedesmus opoliensis</i>	X	X	X	X	X
<i>Scenedesmus perforatus</i>	X				
<i>Scenedesmus producto-capitatus</i>	X	X	X	X	X
<i>Scenedesmus quadricauda</i>	X	X	X	X	X
<i>Scenedesmus</i> sp.				X	
<i>Scenedesmus spinosus</i>	X	X	X	X	X
<i>Schroederia setigera</i>	X	X	X	X	X
<i>Selenastrum minutum</i>	X	X	X	X	X
<i>Selenastrum westii</i>	X	X	X	X	X

Taxa	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8
<i>Spermatozoopsis exultans</i>	X	X	X	X	X
<i>Sphaerocystis Schroeteri</i>	X	X	X	X	X
<i>Spirogyra</i> spp.					X
<i>Staurastrum alternans</i>		X			
<i>Staurastrum chaetoceras</i>	X	X	X	X	X
<i>Staurastrum cingulum</i>	X	X	X	X	X
<i>Staurastrum excavatum</i>	X	X	X	X	X
<i>Staurastrum gracile</i>	X	X	X	X	
<i>Staurastrum hexacerum</i>					X
<i>Staurastrum leptocladum</i>	X	X	X	X	X
<i>Tetraedron caudatum</i>	X	X	X	X	X
<i>Tetraedron gracile</i>	X	X	X	X	X
<i>Tetraedron minimum</i>	X	X	X	X	X
<i>Tetraedron</i> sp.			X		X
<i>Tetraedron trigonum</i>	X	X	X	X	X
<i>Tetrastrum heteracanthum</i>	X	X	X	X	X
<i>Tetrastrum staurogeniaeforme</i>	X	X	X	X	X
<i>Treubaria setigerum</i>	X	X	X	X	X
<i>Treubaria triappendiculata</i>	X	X	X	X	X
<i>Ulothrix tenerrima</i>	X	X	X		
Division Chrysophyta					
<i>Chromulina</i> spp. < 5 µ	X	X	X	X	X
<i>Chromulina</i> spp. 5 - 9.9 µ	X	X	X	X	X
chrysoflagellate spp. < 5 µ	X	X	X	X	X
chrysoflagellate spp. 5 - 9.9 µ	X	X	X	X	X
chrysophyte unidentified sp. 2	X	X	X	X	X
<i>Chrysosphaerella longispina</i>		X			
coccoid Chrysophyta spp. < 5 µ	X	X	X	X	X
coccoid Chrysophyta spp. 5 - 9.9 µ	X	X	X	X	X
coccoid Chrysophyta spp. 10 - 15 µ	X	X	X	X	
<i>Dinobryon divergens</i>		X	X	X	X
<i>Dinobryon</i> sp. 1	X	X	X	X	
<i>Mallomonas caudata</i>	X	X	X	X	X
<i>Mallomonas pseudocoronata</i>	X	X		X	
<i>Mallomonas</i> sp. 3	X		X	X	
<i>Mallomonas</i> spp.	X				
<i>Mallomonas tonsurata</i>	X	X	X	X	X
<i>Microglenea cordiformis</i>	X	X	X	X	X
<i>Ochromonas</i> spp. < 5 µ	X		X		
<i>Ophiocytium capitatum</i>		X			
<i>Paraphysomonas</i> spp.			X	X	X
<i>Salpingoeca</i> spp.	X	X	X	X	X
<i>Synura uvella</i>	X	X	X	X	X
Division Cryptophyta					
<i>Cryptomonas erosa</i>	X	X	X	X	X
<i>Cryptomonas marsonii</i>	X	X	X	X	X
<i>Cryptomonas rostratiformis</i>	X	X	X	X	X
<i>Rhodomonas minuta</i>	X	X	X	X	X
<i>Rhodomonas minuta</i> var. <i>nannoplanc-tonica</i>	X	X	X	X	X
Division Cyanophyta					

Taxon	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8
<i>Anabaena planctonica</i>	X	X	X	X	X
<i>Anabaena spiroides</i>	X	X	X	X	X
<i>Anabaena</i> spp.	X	X	X	X	X
<i>Anabaena subcylindrica</i>	X	X	X	X	X
<i>Anabaena visconsinense</i>	X		X		
<i>Anabaenopsis raciborskii</i>	X	X	X	X	X
<i>Anabaenopsis</i> sp. 1	X	X	X	X	X
<i>Aphanizomenon flos-aquae</i>	X	X	X	X	X
<i>Aphanocapsa elachista</i>			X	X	X
<i>Aphanothece nidulans</i>	X	X	X	X	X
<i>Aphanothece saxicola</i>		X	X		X
<i>Chroococcus lacustris</i>		X	X	X	X
<i>Chroococcus minutus</i>	X	X	X	X	X
<i>Chroococcus</i> sp. 1		X	X		
coccoid Cyanophyta spp. < 5 µ	X	X	X	X	X
coccoid Cyanophyta spp. 5 - 9.9 µ	X	X	X	X	X
<i>Coelosphaerium naegelianum</i>	X	X	X	X	X
<i>Coelosphaerium pallidum</i>	X	X	X	X	X
<i>Dactylococcopsis</i> sp. 1	X	X	X	X	X
<i>Lyngbya limnetica</i>	X	X	X	X	X
<i>Lyngbya</i> sp. 1	X	X	X		
<i>Lyngbya</i> spp.		X		X	
<i>Lyngbya subtilis</i>		X		X	
<i>Mastigocladus laminosus</i>	X	X	X	X	X
<i>Merismopedia glauca</i>				X	
<i>Merismopedia minima</i>	X	X	X	X	X
<i>Merismopedia tenuissima</i>	X	X	X	X	X
<i>Microcystis aeruginosa</i>	X	X	X	X	X
<i>Microcystis incerta</i>	X	X	X	X	X
<i>Oscillatoria acutissima</i>	X	X	X	X	X
<i>Oscillatoria amphibia</i>	X	X	X	X	X
<i>Oscillatoria anguina</i>		X			
<i>Oscillatoria angustissima</i>	X	X	X	X	X
<i>Oscillatoria geminata</i>	X	X	X	X	X
<i>Oscillatoria limnetica</i>	X	X	X	X	X
<i>Oscillatoria limosa</i>	X				
<i>Oscillatoria ornata</i>	X	X	X	X	X
<i>Oscillatoria</i> sp. 1	X		X	X	
<i>Oscillatoria</i> spp.	X	X	X	X	X
<i>Oscillatoria subtilissima</i>		X	X	X	X
<i>Oscillatoria tenuis</i>	X	X	X		X
<i>Phormidium molle</i>	X				
<i>Phormidium</i> sp. 1	X	X	X	X	X
<i>Phormidium</i> spp.	X	X	X	X	X
<i>Rhabdoderma</i> sp. 1		X	X	X	X
<i>Rhabdoderma</i> sp. 2	X	X	X	X	X
<i>Schizothrix</i> sp. 1	X	X	X	X	X
<i>Schizothrix</i> spp.	X	X	X	X	X
Division Euglenophyta					
<i>Euglena acus</i>	X	X	X	X	

Taxon	Reg 4	Reg 5	Reg 6	Reg 7	Reg 8
<i>Euglena minuta</i>	X	X	X	X	X
<i>Euglena</i> spp.	X	X	X	X	X
<i>Phacus longicauda</i>			X		
<i>Phacus monilata</i>	X	X	X	X	X
<i>Phacus</i> spp.	X	X	X	X	X
<i>Trachelomonas hispida</i>	X	X	X	X	X
<i>Trachelomonas stokesiana</i>	X	X	X		
<i>Trachelomonas volvocina</i>	X	X	X	X	X
Division Pyrrhophyta					
<i>Ceratium hirundinella</i>	X	X	X	X	X
<i>Gymnodinium ordinatum</i>	X	X	X	X	X
<i>Gymnodinium</i> sp. 1	X	X	X	X	X
<i>Gymnodinium</i> spp.	X	X	X	X	X
<i>Peridinium inconspicuum</i>	X	X	X	X	X
<i>Peridinium</i> sp.	X	X			X
<i>Peridinium</i> sp. 1	X	X	X	X	X
<i>Peridinium volzii</i>	X		X		

Table 14-12. Phytoplankton collected from Regions 5 and 7 in L Lake and in Par Pond, January–December 1990 and 1991.

Taxon	1991 L Lake Region 5	1991 L Lake Region 7	1991 Par Pond Region 1	1990 L Lake Region 5	1990 L Lake Region 7	1990 Par Pond Region 1
Bacillariophyta						
<i>Achnanthes minutissima</i>	X	X	X	X	X	X
<i>Asterionella formosa</i>	X	X	X	X	X	X
<i>Attheya zachariasii</i>	X	X	X	X	X	X
<i>Cyclostephanos tholiformis</i>	X	X	X	X	X	X
<i>Cyclotella atomus</i>	X	X	X			
<i>Cyclotella pseudostelligera</i>	X	X	X	X	X	X
<i>Cyclotella stelligera</i>	X	X	X	X	X	X
<i>Eunotia zasuminensis</i>	X	X	X	X	X	X
<i>Fragilaria capucina</i>					X	
<i>Fragilaria crotonensis</i>	X	X	X			X
<i>Gomphonema parvulum</i>					X	
<i>Melosira ambigua</i>	X	X	X	X	X	X
<i>Melosira distans</i>	X	X	X	X	X	X
<i>Melosira distans</i> var. <i>tenella</i>	X	X	X			
<i>Melosira granulata</i>	X	X	X	X	X	X
<i>Melosira herzogii</i>					X	
<i>Melosira varians</i>	X	X		X	X	X
<i>Navicula cryptocephala</i>	X	X	X	X	X	
<i>Navicula decussis</i>		X				
<i>Nitzschia acicularis</i>	X	X	X	X	X	X
<i>Nitzschia agnita</i>	X	X	X	X	X	
<i>Nitzschia holsetica</i>	X	X	X	X	X	X
<i>Rhizosolenia eriensis</i>	X	X	X	X	X	X
<i>Rhizosolenia longiseta</i>		X				
<i>Skeletonema potamos</i>	X	X				
<i>Stephanodiscus</i> sp. 2		X		X	X	
<i>Synedra delicatissima</i>	X	X	X	X	X	X
<i>Synedra planktonica</i>	X	X	X	X	X	X
<i>Synedra rumpens</i>	X	X	X	X	X	X
<i>Synedra</i> sp. 1	X	X	X			
<i>Synedra</i> spp.	X	X	X			
<i>Synedra tenera</i>	X	X	X	X	X	X
<i>Synedra ulna</i>	X	X	X	X	X	X
<i>Tabellaria fenestrata</i>	X	X	X			
Chlorophyta						
<i>Actinastrum hantzschii</i>	X	X			X	
<i>Ankistrodesmus falcatus</i>	X	X	X	X	X	X
<i>Ankistrodesmus spiralis</i>	X	X	X	X	X	X
<i>Arthrodesmus bifidus</i> var. <i>latidivergens</i>	X					
<i>Carteria</i> spp.		X				
<i>Characium</i> spp.	X	X	X			
<i>Chlamydomonas</i> spp. 10 - 15 µ	X	X			X	
<i>Chlamydomonas</i> spp. 5 - 9.9 µ	X	X	X	X	X	X
<i>Chlamydomonas</i> spp. < 5 µ	X	X	X	X	X	X
<i>Chlamydomonas</i> spp. > 15 µ	X	X				
chloroflagellate spp. 5 - 9.9 µ	X	X	X	X	X	
chloroflagellate spp. < 5 µ	X	X	X	X	X	

Taxon	1991 L Lake Region 5	1991 L Lake Region 7	1991 Par Pond Region 1	1990 L Lake Region 5	1990 L Lake Region 7	1990 Par Pond Region 1
<i>Chlorogonium</i> sp.		X		X	X	
<i>Closteriopsis</i> sp.			X			
<i>Closterium acutum</i>	X	X	X	X	X	X
<i>Closterium gracile</i>	X		X	X	X	X
<i>Closterium kutzingii</i>			X			
Coccoloid chlorophyta spp. 10 - 15 µ	X					
Coccoloid chlorophyta spp. 5 - 9.9 µ	X	X	X	X	X	X
Coccoloid chlorophyta spp. < 5 µ	X	X	X	X	X	X
coccoloid chlorophyte colony #1	X					
<i>Coelastrum microporum</i>	X	X	X	X	X	X
<i>Cosmarium corbula</i>		X				
<i>Cosmarium regnesi</i> var. <i>montanum</i>	X	X	X	X	X	
<i>Cosmarium tenue</i>	X	X	X	X	X	X
<i>Crucigenia crucifera</i>	X	X	X	X	X	X
<i>Crucigenia quadrata</i>	X					
<i>Crucigenia tetrapedia</i>	X	X	X	X	X	X
<i>Dictyosphaerium ehrenbergianum</i>	X					
<i>Dictyosphaerium pulchellum</i>	X	X	X	X	X	X
<i>Didymocystis fina</i>	X	X	X	X	X	X
<i>Elakatothrix gelatinosa</i>			X			
<i>Elakatothrix viridis</i>	X	X	X	X	X	X
<i>Euastrum binale</i>	X	X	X	X	X	X
<i>Eudorina elegans</i>	X				X	
<i>Franceia ovalis</i>	X	X	X	X	X	X
<i>Gloeocystis planctonica</i>	X	X	X			X
<i>Golenkinia radiata</i>	X	X	X	X	X	X
<i>Gonium pectorale</i>	X	X		X	X	
<i>Keratococcus raphidioides</i>	X	X		X	X	
<i>Kirchneriella lunaris</i>	X	X	X	X	X	X
<i>Kirchneriella microscopia</i>				X	X	X
<i>Kirchneriella obesa</i>				X		
<i>Lagerheimia citriformis</i>	X					
<i>Lagerheimia genevensis</i>	X	X	X	X	X	X
<i>Lagerheimia subsalsa</i>				X	X	
<i>Micractinium pusillum</i>	X	X	X	X	X	X
<i>Monoraphidium circinale</i>	X	X	X	X	X	
<i>Monoraphidium</i> sp. 1		X				
<i>Mougeotia</i> spp.	X	X	X	X	X	X
<i>Oedogonium</i> spp. lg			X			
<i>Oocystis parva</i>	X	X	X	X	X	X
<i>Oocystis pusilla</i>	X	X	X	X	X	X
<i>Pandorina charkowiensis</i>	X	X		X	X	X
<i>Pandorina morum</i>				X	X	
<i>Pediastrum biradiatum longecornutum</i>		X				
<i>Pediastrum duplex</i>	X			X	X	X
<i>Pediastrum tetras</i>	X	X	X	X	X	X
<i>Quadrigula closterioides</i>	X	X	X			X
<i>Scenedesmus acuminatus</i>	X	X	X	X	X	X

Taxon	1991 L Lake Region 5	1991 L Lake Region 7	1991 Par Pond Region 1	1990 L Lake Region 5	1990 L Lake Region 7	1990 Par Pond Region 1
<i>Scenedesmus bicaudatus</i>	X	X	X	X	X	
<i>Scenedesmus denticulatus</i>	X	X	X	X	X	X
<i>Scenedesmus ecornis</i>	X	X	X	X	X	X
<i>Scenedesmus opoliensis</i>	X	X	X	X	X	
<i>Scenedesmus quadricauda</i>	X	X	X	X	X	X
<i>Scenedesmus</i> sp.	X		X			X
<i>Scenedesmus spinosus</i>	X	X	X	X	X	X
<i>Schroederia setigera</i>	X			X		
<i>Selenastrum minutum</i>	X	X	X	X	X	X
<i>Spermatozoopsis exultans</i>	X	X	X	X	X	X
<i>Sphaerocystis schroeteri</i>	X	X	X	X	X	X
<i>Spondylosium papillosum</i>	X	X	X			
<i>Staurastrum anatinum</i>			X			
<i>Staurastrum chaetoceras</i>	X	X	X	X	X	X
<i>Staurastrum cingulum</i>			X			X
<i>Staurastrum cuspidatum</i>	X	X	X		X	X
<i>Staurastrum excavatum</i>		X				
<i>Staurastrum gracile</i>	X	X				X
<i>Staurastrum laeve</i>						X
<i>Staurastrum leptocladum</i>			X			
<i>Staurastrum pentacerum</i>			X			
<i>Staurastrum smithii</i>	X	X	X	X	X	X
<i>Staurastrum</i> sp. 1			X			X
<i>Staurastrum</i> sp. 2	X	X	X			
<i>Tetraedron caudatum</i>	X	X	X	X	X	X
<i>Tetraedron gracile</i>	X	X	X	X	X	
<i>Tetraedron minimum</i>	X	X	X	X	X	X
<i>Tetrastrum heteracanthum</i>	X	X		X	X	
<i>Treubaria setigerum</i>	X	X	X	X	X	X
<i>Treubaria triappendiculata</i>	X	X	X	X	X	
<i>Westella botryoides</i>					X	
<i>Westella</i> sp. 1			X			
Cyanophyta						
<i>Anabaena spiroides</i>				X	X	X
<i>Anabaena</i> spp.	X	X	X	X	X	X
<i>Anabaenopsis raciborskii</i>	X	X	X	X	X	X
<i>Anabaenopsis</i> sp. 1	X	X		X	X	X
<i>Aphanothece saxicola</i>				X	X	X
<i>Aphanothece</i> sp. 1	X	X	X	X	X	X
<i>Chroococcus dispersus</i> var. <i>minor</i>	X	X				
<i>Chroococcus minimus</i>	X	X		X	X	X
<i>Chroococcus minutus</i>	X			X		
<i>Chroococcus</i> sp. 1	X	X	X			
coccoid cyanophyta spp. < 5 µ	X	X	X	X	X	X
<i>Coelosphaerium kuetzingianum</i>			X			
<i>Coelosphaerium naegelianum</i>	X					
<i>Coelosphaerium pallidum</i>		X				
<i>Dactylococcopsis</i> sp. 1	X	X	X	X	X	X

Taxon	1991 L Lake Region 5	1991 L Lake Region 7	1991 Par Pond Region 1	1990 L Lake Region 5	1990 L Lake Region 7	1990 Par Pond Region 1
<i>Lyngbya limnetica</i>	X	X	X	X	X	X
<i>Mastigocladus laminosus</i>				X	X	X
<i>Merismopedia minima</i>			X	X	X	
<i>Merismopedia tenuissima</i>	X	X	X		X	
<i>Microcystis aeruginosa</i>		X				
<i>Microcystis incerta</i>	X	X	X	X	X	X
<i>Oscillatoria limnetica</i>	X	X	X	X	X	X
<i>Oscillatoria tenuis</i>			X			X
<i>Phormidium frigidum</i>				X	X	
<i>Raphidiopsis curvata</i>		X		X		
<i>Synechococcus elongatus</i>	X	X	X			
Cryptophyta						
<i>Cryptomonas erosa</i>	X	X	X	X	X	X
<i>Cryptomonas marsonii</i>	X	X	X	X	X	X
<i>Cryptomonas rostratiformis</i>	X	X	X	X	X	X
<i>Rhodomonas minuta</i>	X	X	X	X	X	X
Chrysophyta						
chrysoflagellate spp. 10 - 15 µ	X	X		X	X	X
chrysoflagellate spp. 5 - 9.9 µ	X	X	X	X	X	X
chrysoflagellate spp. < 5 µ	X	X	X	X	X	X
coccoid chrysophyta spp. 10 - 15 µ	X					
coccoid chrysophyta spp. 5 - 9.9 µ	X	X	X	X	X	X
coccoid chrysophyta spp. < 5 µ	X	X	X	X	X	X
<i>Dinobryon bavaricum</i>	X	X	X	X	X	
<i>Dinobryon divergens</i>	X	X	X	X	X	X
<i>Mallomonas akrokomos</i>		X	X			
<i>Mallomonas caudata</i>	X	X	X	X	X	X
<i>Mallomonas crassiquama</i>	X	X	X			
<i>Mallomonas</i> spp.	X	X				
<i>Mallomonas tonsurata</i>	X	X	X	X	X	X
<i>Microglena cordiformis</i>	X	X	X	X	X	X
<i>Ophiocytium capitatum</i>			X			
<i>Synura</i> sp. 1	X	X	X			
<i>Synura uvella</i>	X	X	X	X	X	X
Pyrrophyta						
<i>Ceratium hirundinella</i>	X	X	X	X	X	X
<i>Gymnodinium ordinatum</i>	X	X	X	X	X	X
<i>Gymnodinium</i> spp.	X	X	X	X	X	X
<i>Peridinium cinctum</i>			X			
<i>Peridinium inconspicuum</i>	X	X	X	X	X	X
<i>Peridinium</i> sp. 1	X	X	X	X	X	
<i>Peridinium umbonatum</i>		X				
<i>Peridinium wisconsinense</i>	X	X	X			X

Taxon	1991 L Lake Region 5	1991 L Lake Region 7	1991 Par Pond Region 1	1990 L Lake Region 5	1990 L Lake Region 7	1990 Par Pond Region 1
Euglenophyta						
<i>Euglena</i> spp.	X	X	X	X	X	X
<i>Phacus longicauda</i>	X	X	X			
<i>Phacus monilata</i>	X	X	X	X	X	X
Euglenophyta						
<i>Phacus</i> spp.			X	X	X	X
<i>Trachelomonas hispida</i>	X	X	X	X	X	X
<i>Trachelomonas volvocina</i>	X	X	X	X	X	X
Phytoflagellates						
Rhodophyta

Figure 14-14. Mean Total Periphyton Densities (organisms/mm²) on Periphytometer Slides from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Figure 14-15. Mean Periphyton Primary Productivity Per Hour (mg C/m²/h) from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Figure 14-16. Mean Periphyton Primary Productivity Per Unit of Light ($\text{mg C/m}^2/\text{E}$) from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Figure 14-17. Mean Periphyton Chlorophyll *a* ($\text{mg C/m}^2/\text{h}$) in sediment Cores from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Figure 14-18. Mean Periphyton Dry Mass ($\text{mg C/m}^2/\text{E}$) on Periphytometer Slides from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Figure 14-19. Mean densities of Cyanophyta (organisms/mm^2) on Periphytometer Slides from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Figure 14-20. Mean Biovolumes of Cyanophyta ($\mu\text{m}^3 \times 10^3/\text{mm}^2$) from L-Lake Littoral Sampling Stations in Regions 4–8 (January 1986–December 1989)

Table 14-13. Numerically Important Periphyton Taxa in Sediment Cores from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989.

Year	Division ^a	Taxon	No. samples in which important
1986	Baci	<i>Navicula decussis</i>	44
	Baci	<i>Melosira granulata</i>	36
	Baci	<i>Navicula cryptocephala</i>	32
	Cyan	<i>Microcystis aeruginosa</i>	27
	Chlo	<i>Scenedesmus denticulatus</i>	17
	Chlo	<i>Scenedesmus dimorphus</i>	15
	Baci	<i>Navicula lateropunctata</i>	13
	Baci	<i>Synedra rumpens</i>	12
	Baci	<i>Nitzschia amphibia</i>	10
	Baci	<i>Achnanthes minutissima</i>	8
	Chlo	<i>Ankistrodesmus spiralis</i>	8
	Baci	<i>Achnanthes exigua</i>	6
	Baci	<i>Nitzschia paleacea</i>	5
1987	Baci	<i>Navicula decussis</i>	53
	Baci	<i>Melosira granulata</i>	36
	Cyan	<i>Microcystis aeruginosa</i>	36
	Chlo	<i>Scenedesmus denticulatus</i>	32
	Baci	<i>Navicula cryptocephala</i>	19
	Cyan	coccoid Cyanophyta spp. <5 μ	18
	Chlo	<i>Ankistrodesmus spiralis</i>	17
	Baci	<i>Achnanthes lanceolata</i> var. <i>apiculata</i>	7
	Chlo	<i>Scenedesmus dimorphus</i>	6
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 μ	5

Year	Division ^a	Taxon	No. samples in which important
1988	Cyan	<i>Lyngbya subtilis</i>	5
	Cyan	<i>Microcystis incerta</i>	5
	Baci	<i>Navicula decussis</i>	54
	Chlo	<i>Scenedesmus denticulatus</i>	38
	Baci	<i>Achnanthes exigua</i>	35
	Baci	<i>Achnanthes lanceolata</i>	29
	Chlo	<i>Ankistrodesmus spiralis</i>	25
	Cyan	<i>Microcystis aeruginosa</i>	22
	Baci	<i>Achnanthes lanceolata</i> var. <i>apiculata</i>	20
	Baci	<i>Navicula cryptocephala</i>	18
	Chlo	<i>Scenedesmus dimorphus</i>	14
	Baci	<i>Fragilaria virescens</i>	10
	Baci	<i>Navicula minima</i>	9
	Baci	<i>Melosira granulata</i>	8
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	7
	Chlo	<i>Scenedesmus quadricauda</i>	7
	Baci	<i>Achnanthes minutissima</i>	7
	Cyan	<i>Microcystis incerta</i>	7
	Baci	<i>Fragilaria construens</i>	6
	Cyan	<i>Merismopedia glauca</i>	5
1989	Baci	<i>Navicula decussis</i>	45
	Baci	<i>Achnanthes exigua</i>	36
	Chlo	<i>Scenedesmus denticulatus</i>	30
	Chlo	<i>Scenedesmus dimorphus</i>	30
	Cyan	<i>Microcystis aeruginosa</i>	29
	Cyan	<i>Microcystis incerta</i>	21
	Baci	<i>Achnanthes lanceolata</i>	20
	Baci	<i>Fragilaria construens</i>	20
	Chlo	<i>Ankistrodesmus spiralis</i>	17
	Baci	<i>Navicula minima</i>	16
	Chlo	coccoid Chlorophyta spp. < 5 µ	13
	Baci	<i>Fragilaria pinnata</i>	12
	Baci	<i>Navicula cryptocephala</i>	9
	Baci	<i>Synedra rumpens</i>	7
	Baci	<i>Achnanthes minutissima</i>	6
	Cyan	coccoid Cyanophyta spp. <5 µ	6
	Cyan	<i>Merismopedia glauca</i>	6

^aBaci = Bacillariophyta; Chlo = Chlorophyta; Cyan = Cyanophyta

Table 14-14. Volumetrically Important Periphyton Taxa in Sediment Cores from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989.

Year	Division ^a	Taxon	No. samples in which important
1986	Baci	<i>Melosira granulata</i>	49
	Baci	<i>Navicula decussis</i>	43
	Baci	<i>Melosira varians</i>	27
	Baci	<i>Navicula cryptocephala</i>	25
	Cyan	<i>Microcystis aeruginosa</i>	15
	Baci	<i>Navicula lateropunctata</i>	14
	Baci	<i>Nitzschia amphibia</i>	9
	Baci	<i>Navicula cuspidata</i>	6
	Baci	<i>Navicula viridula</i>	6
	Baci	<i>Navicula capitata</i>	5
	Chlo	<i>Oedogonium</i> spp. large	5
	Baci	<i>Pinnularia acrosphaeria</i>	5
1987	Baci	<i>Melosira granulata</i>	55
	Baci	<i>Navicula decussis</i>	51
	Baci	<i>Achnanthes lanceolata</i> var. <i>apiculata</i>	27
	Baci	<i>Melosira varians</i>	18
	Baci	<i>Navicula cryptocephala</i>	14
	Cyan	<i>Microcystis aeruginosa</i>	14
	Baci	<i>Navicula viridula</i>	12
	Chlo	<i>Scenedesmus denticulatus</i>	11
	Baci	<i>Nitzschia amphibia</i>	5
	Baci	<i>Nitzschia gracilis</i>	5
1988	Baci	<i>Navicula decussis</i>	57
	Baci	<i>Achnanthes lanceolata</i> var. <i>apiculata</i>	50
	Baci	<i>Melosira granulata</i>	
	Baci	<i>Melosira varians</i>	24
	Baci	<i>Achnanthes lanceolata</i>	21
	Baci	<i>Achnanthes exigua</i>	13
	Baci	<i>Navicula cryptocephala</i>	13
	Baci	<i>Epithemia adnata</i>	14
	Baci	<i>Fragilaria virescens</i>	11
	Baci	<i>Nitzschia amphibia</i>	6
	Chlo	<i>Scenedesmus denticulatus</i>	5
	Baci	<i>Navicula viridula</i>	5
	Baci	<i>Rhopaidoia gibba</i>	5
1989	Baci	<i>Navicula decussis</i>	56
	Baci	<i>Melosira varians</i>	35
	Baci	<i>Achnanthes lanceolata</i> var. <i>apiculata</i>	25
	Baci	<i>Achnanthes lanceolata</i>	24
	Baci	<i>Achnanthes exigua</i>	21
	Baci	<i>Fragilaria construens</i>	15
	Cyan	<i>Microcystis aeruginosa</i>	15
	Chlo	<i>Scenedesmus denticulatus</i>	14
	Baci	<i>Navicula cryptocephala</i>	13
	Baci	<i>Epithemia adnata</i>	10
	Baci	<i>Cymbella tumida</i>	5

^aBaci = Bacillariophyta; Chlo = Chlorophyta; Cyan = Cyanophyta

Table 14-15. Numerically Important Periphyton Taxa on Periphytometer Slides from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989.

Year	Division ^a	Taxon	No. samples in which important
1986	Baci	<i>Achnanthes minutissima</i>	37
	Chlo	<i>Chaetophora elegans</i>	28
	Baci	<i>Synedra rumpens</i>	24
	Baci	<i>Gomphonema parvulum</i>	18
	Chlo	<i>Characium</i> spp.	11
	Cyan	<i>Chamaesiphon minimus</i>	10
	Cyan	coccoid Cyanophyta spp. < 5 µ	10
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	8
	Cyan	<i>Lyngbya subtilis</i>	7
	Baci	<i>Melosira varians</i>	7
	Chlo	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	6
	Cyan	<i>Phormidium</i> sp. 1	6
	Cyan	<i>Phormidium</i> spp.	6
	Baci	<i>Navicula decussis</i>	5
	Cyan	<i>Rhabdoderma sigmoidea</i>	5
1987	Baci	<i>Achnanthes minutissima</i>	51
	Cyan	<i>Lyngbya subtilis</i>	33
	Cyan	coccoid Cyanophyta spp. 5 - 9.9 µ	22
	Chlo	<i>Chaetophora elegans</i>	16
	Baci	<i>Navicula decussis</i>	16
	Baci	<i>Synedra rumpens</i>	10
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	9
	Cyan	coccoid Cyanophyta spp. < 5 µ	8
	Chlo	<i>Oedogonium</i> spp. sm	8
	Baci	<i>Gomphonema gracile</i>	6
	Baci	<i>Achnanthes exigua</i>	5
	Chlo	<i>Characium</i> spp.	5
	Chlo	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	5
	Baci	<i>Gomphonema parvulum</i>	5
	Chlo	<i>Scenedesmus denticulatus</i>	5
1988	Baci	<i>Achnanthes minutissima</i>	59
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	33
	Cyan	<i>Lyngbya subtilis</i>	33
	Baci	<i>Navicula decussis</i>	13
	Cyan	<i>Microcystis incerta</i>	12
	Baci	<i>Achnanthes exigua</i>	10
	Baci	<i>Navicula minima</i>	10
	Chlo	<i>Characium</i> spp.	10
	Chlo	<i>Scenedesmus denticulatus</i>	9
	Cyan	<i>Calothrix</i> sp 1	8
	Baci	<i>Gomphonema gracile</i>	7
	Chlo	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	7
	Chlo	<i>Chaetophora elegans</i>	6
	Cyan	coccoid Cyanophyta spp. 5 - 9.9 µ	6
	Baci	<i>Nitzschia paleacea</i>	5
	Baci	<i>Synedra rumpens</i>	5
1989	Baci	<i>Achnanthes minutissima</i>	60

Year	Division ^a	Taxon	No. samples in which Important
	Chlo	coccoid Chlorophyta spp. < 5 µ	24
	Baci	<i>Synedra rumpens</i>	23
	Cyan	<i>Lyngbya subtilis</i>	22
	Baci	<i>Gomphonema parvulum</i>	14
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	12
	Chlo	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	11
	Chlo	<i>Oedogonium</i> spp. sm	10
	Baci	<i>Gomphonema gracile</i>	9
	Chlo	<i>Scenedesmus denticulatus</i>	8
	Cyan	coccoid Cyanophyta spp. < 5 µ	7
	Baci	<i>Cocconeis placentual</i>	5

^aBaci = Bacillariophyta; Chlo = Chlorophyta; Cyan = Cyanophyta

Table 14-16. Volumetrically Important Periphyton Taxa on Periphytometer Slides from L-Lake Littoral Zone Sampling Stations, Regions 4–8. January 1986–December 1989.

Year	Division ^a	Taxon	No. Samples in Which Important
1986	Baci	<i>Achnanthes minutissima</i>	33
	Chlo	<i>Chaetophora elegans</i>	29
	Baci	<i>Gomphonema parvulum</i>	28
	Chlo	<i>Oedogonium</i> spp. Lg	22
	Baci	<i>Synedra rumpens</i>	20
	Baci	<i>Synedra ulna</i>	18
	Baci	<i>Melosira varians</i>	17
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	16
	Baci	<i>Gomphonema gracile</i>	12
	Cyan	<i>Chomosiphon minimus</i>	9
	Baci	<i>Melosira granulata</i>	8
	Baci	<i>Gomphonema subclavatum</i>	7
	Baci	<i>Navicula cryptocephala</i>	7
	Cyan	coccoid Cyanophyta spp. < 5 µ	6
	Baci	<i>Gomphonema rhombicum</i>	5
	Chlo	<i>Spirogyra</i> spp	5
1987	Baci	<i>Cymbella tumida</i>	37
	Baci	<i>Achnanthes minutissima</i>	31
	Baci	<i>Gomphonema gracile</i>	22
	Baci	<i>Melosira varians</i>	17
	Cyan	coccoid Cyanophyta spp. 5 - 9.9 µ	17
	Baci	<i>Navicula decussis</i>	10
	Chlo	<i>Chaetophora elegans</i>	15
	Baci	<i>Gomphonema subclavatum</i>	14
	Chlo	<i>Spirogyra</i> spp sm	12
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	10

Year	Division ^a	Taxon	No. Samples in Which Important
	Baci	<i>Epithemia adnata</i>	9
	Baci	<i>Synedra ulna</i>	8
	Baci	<i>Synedra rumpens</i>	7
	Baci	<i>Synedra tenera</i>	7
	Baci	<i>Gomphonema truncatum</i>	6
	Baci	<i>Melosira granulata</i>	6
	Chlo	<i>Oedogonium</i> spp. sm	6
	Chlo	<i>Spirogyra</i> spp Lg	6
	Baci	<i>Gomphonema parvulum</i>	5
	Chlo	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	5
	Cyan	<i>Lyngbya subtilis</i>	5
1988	Baci	<i>Achnanthes minutissima</i>	29
	Baci	<i>Cymbella tumida</i>	24
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	18
	Baci	<i>Melosira varians</i>	18
	Baci	<i>Navicula decussis</i>	10
	Baci	<i>Epithemia adnata</i>	13
	Chlo	<i>Spirogyra</i> spp Lg	13
	Baci	<i>Gomphonema parvulum</i>	11
	Baci	<i>Achnanthes exigua</i>	10
	Baci	<i>Gomphonema gracile</i>	9
	Baci	<i>Cocconeis placentula</i>	8
	Chlo	<i>Scenedesmus denticulatus</i>	8
	Chlo	<i>Chaetophora elegans</i>	6
	Chlo	<i>Oedogonium</i> spp. Lg	5
	Baci	<i>Nitzschia paleacea</i>	5
1989	Baci	<i>Achnanthes minutissima</i>	36
	Baci	<i>Gomphonema parvulum</i>	25
	Chlo	<i>Spirogyra</i> spp Lg	23
	Baci	<i>Melosira varians</i>	21
	Baci	<i>Cymbella tumida</i>	17
	Baci	<i>Gomphonema truncatum</i>	16
	Baci	<i>Gomphonema gracile</i>	15
	Baci	<i>Cocconeis placentula</i>	
	Chlo	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	10
	Chlo	coccoid Chlorophyta spp. 5 - 9.9 µ	
	Baci	<i>Synedra rumpens</i>	9
	Baci	<i>Epithemia adnata</i>	6
	Chlo	<i>Oedogonium</i> spp. Lg	6
	Baci	<i>Synedra ulna</i>	5

^aBaci = Bacillariophyta; Chlo = Chlorophyta; Cyan = Cyanophyta

Steel Creek

Phytoplankton

Primary producers in Steel Creek consist of macrophytes and periphyton. Phytoplankton are believed to contribute insignificantly to the food base, as is typically the case in shallow stream systems (Wetzel 1983) and, therefore, were not included in biological monitoring programs.

Periphyton

Studies in Steel Creek

The abundance and community structure of periphyton assemblages in the Steel Creek system were studied from 1986-1991 as part of an extensive biological monitoring program initiated to assess the ecological impacts of L-Reactor operations. Sampling locations are shown in Figure 14-21. Detailed methods and results can be found in reports by Hooker (1990) and Toole and Duyn (1992). Data from 1986-1987 have been previously summarized in compliance documents by Gladden et. al. (1988) and Wike et. al. (1989).

Biomass Quantities

Periphyton biomass values, measured as organisms per millimeter of glass slide surface, did not reveal consistent seasonal patterns Figure 14-22 through Figure 14-25. The highest quantities were obtained from the corridor stations with successively lower quantities in the marsh, channel, and swamp locations, respectively. The largest quantities reported from the study were from the upper corridor during reactor operations (1986-1988). Periphyton biomass values measured as chlorophyll *a* and ash free dry weight were also generally higher in the corridor than at the other sampling locations throughout the study (Table 14-17 and Table 14-18).

Figure 14-21. Periphyton Sampling Stations for Steel Creek

Taxa Identified

Diatoms were the dominant algal group in most samples from all stations and dates. (Table 14-19). One notable exception was at Station 275 in the upper corridor of the creek where blue-green algae comprised 80.1% of the total periphyton during 1987 (Table 14-19). Major species of periphyton from the Steel Creek System are listed in Table 14-20.

Figure 14-22. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Corridor Stations (January 1986–December 1989)

Figure 14-23. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Marsh Stations (January 1986–December 1989)

Figure 14-24. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Swamp Stations (January 1986–December 1989)

Figure 14-25. Seasonal Total Algal Counts (no./mm²) on Glass Slides Incubated at Steel Creek Channel Stations (January 1986–December 1989)

Table 14-17. Annual Means for Periphyton Chlorophyll a Content (mg/m²) Accumulated on Glass Slides Incubated in Steel Creek and Meyer's Branch. Minimum and Maximum Values are Presented in Appendix Table 1. January 1986–December 1991.

Location	Station	1986 ^a		1987 ^a		1988 ^a		1989 ^a		1990		1991	
		Mean	SE ^b	Mean	SE ^b	Mean	SE ^b	Mean	SE ^b	Mean	SE ^b	Mean	SE ^b
Corridor	275	7.76	(.74)	13.59	(2.60)	12.62	(1.08)	10.91	(1.12)	-	-	-	-
	280	7.60	(1.07)	3.75	(0.60)	4.61	(0.87)	10.60	(1.34)	-	-	-	-
	285	10.73	(1.02)	15.92	(1.46)	17.40	(2.38)	14.04	(0.99)	-	-	-	-
	290	8.41	(0.70)	12.37	(1.76)	15.62	(1.82)	9.72	(0.83)	17.61	(0.68)	11.92	(2.11)
Marsh	300	5.99	(0.65)	5.95	(1.01)	7.95	(1.32)	4.41	(0.67)	-	-	-	-
	310	6.43	(0.97)	10.15	(1.65)	7.16	(1.70)	6.19	(0.61)	-	-	-	-
	320	6.23	(1.02)	6.38	(1.23)	10.29	(2.01)	5.41	(0.78)	-	-	-	-
	330	7.53	(0.85)	10.47	(1.78)	5.67	(0.81)	3.65	(0.74)	8.04	(1.52)	4.70	(1.09)
Swamp	340	2.44	(0.65)	2.73	(0.68)	1.12	(0.12)	3.18	(0.56)	-	-	-	-
	350	2.57	(0.90)	2.86	(0.93)	0.85	(0.31)	1.26	(0.38)	4.08	(1.18)	0.95	(0.30)
Channel	360	2.44	(0.68)	3.06	(0.54)	3.56	(0.63)	2.43	(0.65)	-	-	-	-
	370	8.00	(0.93)	5.38	(1.51)	8.49	(1.02)	4.18	(0.88)	5.30	(1.61)	0.96	(0.32)
Meyer's Branch	400	2.50	(0.54)	1.01	(0.35)	1.06	(0.35)	1.14	(0.34)	-	-	-	-

^a Summary statistics for 1986-1989 were recalculated for comparison with 1990 and 1991 results by using data only from the four months that corresponded to the 1990 and 1991 quarterly sampling months.

^b Standard error

Table 14-18. Annual Means for Periphyton Ash-free Dry Mass (g/m²) Accumulated on Glass Slides Incubated in Steel Creek and Meyer's Branch. Minimum and Maximum Values are Presented in Appendix Table 2. January 1986–December 1991.

Location	Station	1986 ^a		1987 ^a		1988 ^a		1989 ^a		1990		1991	
		Mean	SE ^b	Mean	SE ^b	Mean	SE ^b	Mean	SE ^b	Mean	SE ^b	Mean	SE ^b
Corridor	275	6.79	(1.51)	5.84	(0.94)	35.52	(7.33)	6.57	(1.04)	-	-	-	-
	280	3.13	(0.38)	1.70	(0.32)	1.49	(0.14)	1.38	(0.17)	-	-	-	-
	285	4.09	(0.52)	3.42	(0.50)	2.18	(0.22)	2.22	(0.22)	-	-	-	-
	290	1.95	(0.28)	1.73	(0.17)	2.07	(0.16)	2.03	(0.12)	2.29	(0.23)	2.53	(0.19)
Marsh	300	1.62	(0.27)	0.96	(0.18)	1.27	(0.12)	1.05	(0.13)	-	-	-	-
	310	1.06	(0.22)	1.20	(0.12)	0.85	(0.13)	1.02	(0.08)	-	-	-	-
	320	0.73	(0.12)	1.00	(0.12)	1.13	(0.18)	0.87	(0.13)	-	-	-	-
	330	1.44	(0.23)	0.79	(0.09)	0.94	(0.09)	0.68	(0.10)	1.47	(0.14)	1.63	(0.28)
Swamp	340	0.63	(0.05)	0.53	(0.07)	0.27	(0.02)	0.51	(0.06)	-	-	-	-
	350	0.58	(0.09)	0.49	(0.08)	0.26	(0.03)	0.34	(0.05)	0.60	(0.06)	1.11	(0.45)
Channel	360	0.50	(0.05)	0.30	(0.04)	0.44	(0.05)	0.28	(0.04)	-	-	-	-
	370	0.96	(0.33)	0.38	(0.07)	0.72	(0.09)	0.66	(0.10)	0.90	(0.12)	0.58	(0.24)
Meyer's Branch	400	1.16	(0.18)	1.03	(0.18)	0.70	(0.09)	0.62	(0.06)	-	-	-	-

^a Summary statistics for 1986-1989 were recalculated for comparison with 1990 and 1991 results by using data only from the four months that corresponded to the 1990 and 1991 quarterly sampling months.

^b Standard error.

Table 14-19. Periphyton Community Composition on Glassss Slides Incubated in Steel Creek and Meyer's Branch. Relative Abundance of Major Algal Divisions. January 1986–December 1991.

Station	Division ^a	Relative Abundance (%)					
		1986	1987	1988	1989	1990	1991
275	Bacillariophyta	69.3	16.1	42.6	48.1	-	-
	Chlorophyta	17.9	3.7	40.4	40.4	-	-
	Cyanophyta	12.8	80.1	16.8	11.5	-	-
280	Bacillariophyta	71.8	54.2	79.9	37.4	-	-
	Chlorophyta	18.4	6.7	9.9	28.6	-	-
	Cyanophyta	9.8	39.1	10.2	33.7	-	-
285	Bacillariophyta	81.8	85.4	94.8	80.8	-	-
	Chlorophyta	5.8	1.8	1.2	1.8	-	-
	Cyanophyta	12.4	12.8	3.9	17.3	-	-
290	Bacillariophyta	28.6	82.2	87.1	84.7	80.1	70.8
	Chlorophyta	62.9	13.9	11.8	12.0	18.7	26.7
	Cyanophyta	8.4	3.8	1.1	3.3	1.2	2.5
300	Bacillariophyta	43.4	60.8	32.2	52.4	-	-

Station	Division ^a	Relative Abundance (%)					
		1986	1987	1988	1989	1990	1991
310	Chlorophyta	49.9	29.0	65.4	42.1	-	-
	Cyanophyta	6.4	10.1	2.3	5.3	-	-
	Bacillariophyta	23.0	61.6	36.5	30.3	-	-
320	Chlorophyta	72.0	30.8	59.9	54.4	-	-
	Cyanophyta	5.0	7.3	3.5	15.2	-	-
	Bacillariophyta	33.4	50.7	55.4	24.1	-	-
330	Chlorophyta	56.1	33.4	36.8	69.6	-	-
	Cyanophyta	10.4	15.7	7.8	6.3	-	-
	Bacillariophyta	58.4	80.7	36.3	24.3	34.9	59.2
340	Chlorophyta	27.8	16.0	57.1	41.4	53.6	-
	Cyanophyta	13.7	3.2	6.5	34.2	10.4	2.5
	Bacillariophyta	23.9	28.3	63.3	47.1	-	-
350	Chlorophyta	69.3	42.1	30.9	43.5	-	-
	Cyanophyta	6.5	29.3	3.0	9.2	-	-
	Bacillariophyta	76.9	52.4	61.1	34.5	60.2	65.5
360	Chlorophyta	14.2	30.6	24.7	16.3	37.8	28.4
	Cyanophyta	8.7	16.7	12.8	49.2	2.0	5.8
	Bacillariophyta	81.1	87.1	71.3	76.0	-	-
370	Chlorophyta	14.9	8.9	4.0	10.6	-	-
	Cyanophyta	4.0	3.9	24.3	13.3	-	-
	Bacillariophyta	40.8	72.1	74.1	64.9	42.6	82.5
400	Chlorophyta	58.0	15.2	18.5	14.2	53.4	15.3
	Cyanophyta	1.1	12.4	7.4	20.8	3.9	1.6
	Bacillariophyta	78.3	89.3	89.5	91.1	-	-
400	Chlorophyta	3.2	7.2	1.6	2.3	-	-
	Cyanophyta	18.5	3.2	8.9	6.4	-	-
	Bacillariophyta	78.3	89.3	89.5	91.1	-	-

^aBacillariophyta - diatoms

Chlorophyta - green algae

Cyanophyta - blue-green algae

Table 14-20. Seasonal Common Taxa (> 5% Abundance Listed in Order of Importance) of Periphytic Algae Growing on Glass Slides. January 1986–December 1989.

Station	Season	Common Taxa			
		1986	1987	1988	1989
275	W	<i>Gomphonema parvulum</i> <i>Gomphonema gracile</i>	<i>Gomphonema Parvulum</i> <i>Synedra rumpens</i>	<i>Skeletonema potamos</i> <i>Synedra rumpens</i> coccoid Cyanophyta spp. < 5 µ <i>Ankistrodesmus spiralis</i>	<i>Gomphonema parvulum</i> <i>Achnanthes minutissima</i> <i>Synedra rumpens</i> <i>Chlamydomonas</i> spp. 5 - 9.9 µ
	Sp	<i>Gomphonema parvulum</i>	coccoid Cyanophyta spp. < 5 µ	<i>Microcystis aeruginosa</i>	<i>Achnanthes minutissima</i>
		coccoid Cyanophyta spp. < 5 µ	<i>Microcystis aeruginosa</i>	<i>Nitzschia fonticola</i>	<i>Leptosira medicinana</i>
				coccoid Chlorophyta spp. 5 - 9.9 µ <i>Nitzschia paleacea</i> <i>Cocconeis placentula</i>	<i>Gomphonema parvulum</i>
	Su	<i>Achnanthes minutissima</i>	<i>Achnanthes minutissima</i>	<i>Navicula mensuilus</i> <i>upsaliensis</i>	coccoid Chlorophyta spp. < 5 µ
		coccoid Chlorophyta spp. 5 - 9.9 µ <i>Characium</i> spp.	<i>Phormidium</i> spp.	<i>Coelochaetae</i> spp.	coccoid Cyanophyta spp. < 5 µ
				<i>Navicula confervacea</i>	coccoid Chlorophyta spp. 5 - 9.9 µ
				coccoid Chlorophyta spp. 5 - 9.9 µ <i>Monoraphidium circinale</i> <i>Scenedesmus denticulatus</i>	<i>Chaetophora elegans</i>
					<i>Lyngbya subtilis</i>
	F	<i>Ankistrodesmus spiralis</i>	<i>Gomphonema parvulum</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Microcystis incerta</i>
		<i>Melosira granulata</i>	<i>Synedra rumpens</i>	<i>Monoraphidium circinale</i>	<i>Nitzschia paleacea</i>
		<i>Synedra rumpens</i>	<i>Lyngbya subtilis</i>	<i>Scenedesmus denticulatus</i>	<i>Navicula cryptocephala</i>
		coccoid Cyanophyta spp. < 5 µ <i>Navicula cryptocephala</i> <i>Scenedesmus dimorphus</i>	<i>Nitzschia paleacea</i> <i>Ankistrodesmus spiralis</i> <i>Gomphonema gracile</i>	<i>Navicula menisculus</i> <i>Scenedesmus quadicauda</i>	coccoid Chlorophyta spp. < 5 µ <i>Navicula decussis</i> coccoid Chlorophyta 5 - 9.9 µ
280	W	<i>Gomphonema parvulum</i> <i>Gomphonema gracile</i>	<i>Gomphonema parvulum</i> <i>Synedra rumpens</i>	<i>Gomphonema parvulum</i> <i>Synedra rumpens</i> <i>Navicula minima</i>	<i>Gomphonema parvulum</i> <i>Synedra rumpens</i> <i>Cocconeis placentula</i> <i>Melosira varians</i>
	Sp	<i>Gomphonema parvulum</i>	coccoid Cyanophyta spp. < 5 µ	<i>Microcystis incerta</i>	<i>Microcystis incerta</i>
		<i>Chaetophora elegans</i>	<i>Cocconeis placentula</i>	<i>Nitzschia fonticola</i>	<i>Cyclotella</i> <i>pseudostelligera</i>
		<i>Gomphonema subclavatum</i>		<i>Nitzschia paleacea</i>	coccoid Cyanophyta spp. < 5 µ
		<i>Navicula minima</i>		<i>Cyclotella meneghiniana</i>	<i>Nitzschia fonticola</i>

Station	Season	Common Taxa			
		1986	1987	1988	1989
		coccoid Cyanophyta spp. < 5 µ			<i>Scenedesmus quadricauda</i> <i>Scenedesmus denticulatus</i>
280	Su	<i>Cocconeis placentula</i> <i>Synedra rumpens</i> <i>Navicula minima</i> coccoid Cyanophyta spp. < 5 µ	<i>Navicula cryptocephala</i> <i>Navicula minima</i> <i>Achnanthes exigua</i> <i>Eunotia pectinalis</i> <i>Merismopedia minima</i> <i>Scenedesmus dimorphus</i> <i>Scenedesmus denticulatus</i>	<i>Microcystis incerta</i> <i>Navicula minima</i> <i>Achnanthes minutissima</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Lyngbya subtilis</i> <i>Eunotia pectinalis</i>	coccoid Cyanophyta spp. < 5 µ coccoid Chlorophyta spp. < 5 µ <i>Cocconeis fluviatilis</i> <i>Eunotia pectinalis</i> <i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i>
	F	<i>Melosira granulata</i> <i>Navicula cryptocephala</i> <i>Ankistrodesmus spiralis</i> <i>Chaetophora elegans</i> coccoid Cyanophyta spp. < 5 µ	<i>Gomphonema parvulum</i> <i>Nitzschia palea</i> <i>Achnanthes minutissima</i>	<i>Navicula menisculus</i> <i>Microcystis incerta</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Scenedesmus quadricauda</i> <i>Navicula decussis</i>	<i>Pseudoulvella americana</i> <i>Cocconeis fluviatilis</i> <i>Eunotia pectinalis</i> coccoid Chlorophyta spp. < 5 µ
285	W	<i>Gomphonema parvulum</i> <i>Gomphonema gracile</i> <i>Nitzschia agnita</i> <i>Navicula minima</i> <i>Cyclotella pseudostelligera</i> <i>Nitzschia kutzingiana</i>	<i>Gomphonema parvulum</i> <i>Synedra rumpens</i>	<i>Gomphonema parvulum</i> <i>Navicula minima</i> <i>Synedra rumpens</i> <i>Melosira varians</i> <i>Achnanthes lanceolata</i>	<i>Gomphonema parvulum</i> <i>Navicula minima</i>
	Sp	<i>Gomphonema parvulum</i> <i>Gomphonema subclavatum</i> <i>Phormidium</i> spp. coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema rhombicum</i>	<i>Gomphonema parvulum</i> <i>Cymbella minuta</i> <i>Microcystis incerta</i> <i>Ulothrix subtilissima</i> coccoid Cyanophyta spp. < 5 µ <i>Lyngbya subtilis</i>	<i>Achnanthes lanceolata</i> <i>Cocconeis fluviatilis</i>	coccoid Cyanophyta spp. 5 - 9.9 µ <i>Achnanthes lanceolata</i> <i>Cocconeis placentula</i>
	Su	coccoid Cyanophyta spp. < 5 µ <i>Eunotia pectinalis</i> <i>Navicula menisculus</i>	<i>Eunotia pectinalis</i> <i>Cocconeis fluviatilis</i>	<i>Eunotia pectinalis</i> <i>Cocconeis fluviatilis</i> <i>Cocconeis placentula</i> <i>Oscillatoria limosa</i>	<i>Eunotia pectinalis</i> coccoid Cyanophyta spp. < 5 µ <i>Cocconeis fluviatilis</i>
285	F	<i>Navicula cryptocephala</i>	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>

		Common Taxa			
Station	Season	1986	1987	1988	1989
		<i>Melosira granulata</i> <i>Microcystis aeruginosa</i> coccoid Cyanophyta spp. < 5 µ <i>Ankistrodesmus spiralis</i> <i>Lyngbya subtilis</i>	<i>Achnanthes lanceolata</i>	<i>Navicula minima</i> <i>Achnanthes lanceolata</i>	
290	W	<i>Gomphonema parvulum</i> <i>Chaetophora elegans</i>	<i>Gomphonema parvulum</i> <i>Synedra rumpens</i> <i>Melosira varians</i> <i>Melosira granulata</i> <i>Navicula cryptocephala</i>	<i>Achnanthes lanceolata</i> <i>Cocconeis placentula</i> <i>Navicula minima</i>	<i>Gomphonema parvulum</i> <i>Melosira varians</i> <i>Navicula cryptocephala</i>
	Sp	<i>Chaetophora elegans</i> coccoid Chlorophyta spp. 5 - 9.9 µ coccoid Cyanophyta spp. <5 µ <i>Cocconeis diminuta</i> <i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i> <i>Achnanthes minutissima</i> <i>Cocconeis placentula</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Characium</i> spp.	coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema parvulum</i> <i>Characium</i> spp. <i>Achnanthes lanceolata</i> <i>Pseudoulvella americana</i> <i>Cocconeis fluviatilis</i> <i>Cocconeis placentula</i>	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> coccoid Chlorophyta spp. <5 µ <i>Cocconeis placentula</i>
	Su	<i>Eunotia pectinalis</i> <i>Navicula minima</i> coccoid Cyanophyta spp. < 5 µ <i>Cocconeis diminuta</i>	<i>Navicula minima</i> <i>Eunotia pectinalis</i> <i>Achnanthes exigua</i>	<i>Achnanthes lanceolata</i> <i>Navicula minima</i> <i>Cocconeis fluviatilis</i> <i>Eunotia pectinalis</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. < 5 µ <i>Pseudoulvella americana</i> coccoid Cyanophyta spp. < 5 µ <i>Achnanthes lanceolata</i>
	F	<i>Pseudoulvella americana</i> <i>Melosira granulata</i> <i>Eunotia pectinalis</i>	<i>Gomphonema parvulum</i> <i>Navicula cryptocephala</i> <i>Synedra tenera</i>	<i>Achnanthes lanceolata</i> <i>Navicula decussis</i> <i>Gomphonema parvulum</i> <i>Navicula minima</i> <i>Nitzschia paleacea</i>	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> <i>Navicula decussis</i> <i>Navicula cryptocephala</i>
300	W	<i>Chaetophora elegans</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema parvulum</i> <i>Skeletonema potamus</i> <i>Characium</i> spp. <i>Palmella</i> spp.	<i>Pseudoulvella americana</i>	<i>Pseudoulvella americana</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Chaetophora elegans</i> <i>Achnanthes lanceolata</i> <i>Characium</i> spp. <i>Gomphonema parvulum</i>	<i>Gomphonema subclavatum</i> <i>Synedra rumpens</i> coccoid Chlorophyta spp. < 5 µ
	Sp	<i>Gomphonema parvulum</i>	<i>Chaetophora elegans</i>	<i>Chaetophora elegans</i>	coccoid Chlorophyta spp. <5 µ

		Common Taxa			
Station	Season	1986	1987	1988	1989
		<i>Chaetophora elegans</i>	<i>Achnanthes minutissima</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Characium</i> spp.
		<i>Achnanthes minutissima</i> <i>Characium</i> spp.	<i>Gomphonema parvulum</i> <i>Cocconeis placentula</i>	<i>Gomphonema parvulum</i>	<i>Microcystis incerta</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema parvulum</i>
		coccoid Chlorophyta spp. 5 - 9.9 µ <i>Phormidium</i> spp.	coccoid Cyanophyta spp. <5 µ coccoid Chlorophyta spp. 5 - 9.9 µ		<i>Oedogonium</i> spp. SM
Su		<i>Oedogonium</i> spp. large	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Characium</i> spp.	coccoid Chlorophyta spp. <5 µ
		coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Navicula</i> spp.	<i>Chaetophora elegans</i>	<i>Navicula minima</i>
		<i>Oscillatoria princeps</i> coccoid Cyanophyta spp. <5 µ	<i>Navicula cryptocephala</i> <i>Navicula minima</i> <i>Gomphonema parvulum</i> <i>Ulothrix subtilisma</i> <i>Oedogonium</i> spp. small <i>Chaetophora elegans</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Microcystis incerta</i> coccoid Cyanophyta spp. <5 µ <i>Gomphonema parvulum</i>
F		<i>Ulothrix subtilisma</i> <i>Oedogonium</i> spp. small	<i>Synedra rumpens</i> <i>Nitzschia palea</i>	<i>Eunotia pectinalis</i> coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i>
		coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Synedra tenera</i> <i>Ulothrix subtilisma</i> <i>Gomphonema parvulum</i> <i>Oscillatoria geminata</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Microcystis incerta</i>	<i>Characium</i> spp. <i>Navicula minima</i> <i>Gomphonema parvulum</i> <i>Nitzschia paleacea</i> <i>Navicula menisculus</i>	<i>Oedogonium</i> spp. SM coccoid Chlorophyta spp. <5 µ coccoid Chlorophyta spp. 5 - 9.9 µ
310	W	<i>Gomphonema parvulum</i>	<i>Chaetophora elegans</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Gomphonema parvulum</i>
		<i>Eunotia pectinalis</i>	<i>Gomphonema parvulum</i>	<i>Chaetophora elegans</i>	coccoid Chlorophyta spp. <5 µ
		<i>Gomphonema gracile</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Achnanthes lanceolata</i>	<i>Achnanthes lanceolata</i>
		<i>Fragilaria vaucheriae</i>	<i>Ulothrix subtilisma</i>	<i>Cocconeis placentula</i> <i>Pseudoulvella americana</i>	coccoid Chlorophyta spp. 5 - 9.9 µ <i>Navicula minima</i>
Sp		<i>Chaetophora elegans</i>	<i>Chaetophora elegans</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Characium</i> spp.
		<i>Characium</i> spp.	<i>Cocconeis placentula</i>	<i>Navicula minima</i>	coccoid Chlorophyta spp. <5 µ
		<i>Achnanthes minutissima</i>	coccoid Cyanophyta spp. <5 µ	<i>Gomphonema parvulum</i>	<i>Pseudoulvella americana</i>

		Common Taxa			
Station	Season	1986	1987	1988	1989
		coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Gomphonema parvulum</i> <i>Achnanthes minutissima</i>	<i>Characium</i> spp.	coccoid Cyanophyta spp. <5 µ <i>Eunotia pectinalis</i>
	Su	<i>Characium</i> spp. <i>Gomphonema parvulum</i> coccoid Cyanophyta spp. <5 µ <i>Lyngbya subtilis</i> <i>Eunotia pectinalis</i>	<i>Characium</i> spp. <i>Navicula minima</i> <i>Achnanthes lanceolata</i> <i>Chaetophora elegans</i> <i>Eunotia pectinalis</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema parvulum</i>	<i>Lyngboya</i> spp. <i>Schizothrix</i> spp. coccoid Chlorophyta spp. 5 - 9.9 µ	coccoid Cyanophyta spp. <5 µ <i>Leptosira medicinana</i> <i>Gomphonema parvulum</i> coccoid Chlorophyta spp. <5 µ <i>Navicula minima</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Characium</i> spp.
	F	coccoid Chlorophyta spp. 5 - 9.9 µ <i>Navicula cryptocephala</i> <i>Gomphonema parvulum</i> <i>Achnanthes lanceolata</i> <i>Chaetophora elegans</i> <i>Nitzschia kutzingiana</i>	<i>Gomphonema parvulum</i> <i>Navicula minima</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Nitzschia palea</i> <i>Achnanthes lanceolata</i> <i>Synedra tenera</i> <i>Characium</i> spp.	Not sampled	coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema parvulum</i> coccoid Chlorophyta spp. <5 µ <i>Navicula minima</i> <i>Navicula cryptocephala</i> <i>Eunotia pectinalis</i> <i>Cymbella minuta</i>
320	W	<i>Chaetophora elegans</i> <i>Eunotia pectinalis</i> <i>Pseudoulvella americana</i>	<i>Chaetophora elegans</i>	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> <i>Pseudoulvella americana</i>	<i>Synedra rumpens</i> <i>Ulothrix subtilis</i> <i>Oedogonium</i> spp. LG coccoid Chlorophyta spp. <5 µ coccoid Chlorophyta spp. 5 - 9.9 µ
	Sp	<i>Chaetophora elegans</i> <i>Cocconeis placentula</i> <i>Gomphonema parvulum</i> <i>Characium</i> spp.	coccoid Cyanophyta spp. <5 µ <i>Achnanthes lanceolata</i> <i>Melosira varians</i> <i>Navicula minima</i>	Not sampled	coccoid Chlorophyta spp. <5 µ coccoid Cyanophyta spp. <5 µ coccoid Chlorophyta spp. 5 - 9.9 µ <i>Leptosira mediciana</i> <i>Gomphonema parvulum</i>
	Su	<i>Anabaena subcylindrica</i> <i>Characium</i> spp. <i>Navicula meniscus</i> <i>Lyngbya subtilis</i>	coccoid Chlorophyta spp. 5 - 9.9 µ <i>Microcystis incerta</i> <i>Characium</i> spp. <i>Navicula minima</i>	<i>Characium</i> spp. <i>Chaetophora elegans</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Microcystis incerta</i>	coccoid Chlorophyta spp. <5 µ <i>Achnanthes lanceolata</i> <i>Ankistrodesmus spiralis</i> <i>Navicula minima</i>

		Common Taxa			
Station	Season	1986	1987	1988	1989
		coccoid Cyanophyta spp. <5 µ	<i>Gomphonema parvulum</i>	<i>Navicula minima</i>	<i>Pseudoulvella americana</i>
		coccoid Chlorophyta spp. 5 - 9.9 µ		<i>Achnanthes lanceolata</i>	<i>Microcystis incerta</i> <i>Characium</i> spp.
	F	<i>Gomphonema parvulum</i> <i>Navicula cryptocephala</i>	<i>Melosira varians</i> <i>Achnanthes lanceolata</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. 5 - 9.9 µ	Not sampled
		coccoid Chlorophyta spp. 5 - 9.9 µ <i>Lyngbya subtilis</i> <i>Oscillatoria geminata</i> <i>Characium</i> spp. Cyanophyta colony 1	<i>Gomphonema parvulum</i> <i>Synedra tenera</i>	<i>Navicula minima</i> <i>Chaetophora elegans</i> <i>Nitzschia paleacea</i> <i>Lyngbya subtilis</i>	
330	W	<i>Gomphonema parvulum</i> <i>Cocconeis placentula</i> <i>Achnanthes lanceolata</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Chaetophora elegans</i> <i>Synedra rumpens</i> <i>Pseudoulvella americana</i>	<i>Chlamydomonas</i> spp. 5 - 9.9 µ <i>Gomphonema parvulum</i> <i>Achnanthes lanceolata</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. <5 µ <i>Achnanthes lanceolata</i> coccoid Chlorophyta spp. <5 µ <i>Chlamydomonas</i> spp. 5 - 9.9 µ
	Sp	<i>Achnanthes minutissima</i> <i>Chaetophora elegans</i> <i>Characium</i> spp. <i>Gomphonema parvulum</i> <i>Phormidium</i> spp. <i>Coelosphaerium pallidum</i>	<i>Chaetophora elegans</i> <i>Cocconeis placentula</i> coccoid Cyanophyta spp. <5 µ <i>Achnanthes minutissima</i> <i>Achnanthes lanceolata</i> <i>Eunotia pectinalis</i> <i>Gomphonema parvulum</i>	<i>Chaetophora elegans</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Gomphonema parvulum</i> coccoid Cyanophyta spp. 5 - 9.9 µ <i>Navicula cryptocephala</i>	coccoid Cyanophyta spp. <5 µ <i>Leptosira mediana</i> <i>Pseudoulvella americana</i> <i>Characium</i> spp.
	Su	<i>Eunotia pectinalis</i> coccoid Cyanophyta spp. <5 µ <i>Chaetophora elegans</i> <i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> <i>Navicula minima</i>	<i>Pseudoulvella americana</i> <i>Characium</i> spp. coccoid Chlorophyta spp. 5 - 9.9 µ <i>Achnanthes lanceolata</i> <i>Navicula minima</i> <i>Gomphonema parvulum</i>	<i>Characium</i> spp. <i>Achnanthes lanceolata</i> coccoid Chlorophyta spp. 5 - 9.9 µ <i>Navicula minima</i>	<i>Microcystis incerta</i> <i>Navicula minima</i> <i>Gomphonema parvulum</i> <i>Pseudoulvella americana</i> coccoid Cyanophyta spp. <5 µ <i>Achnanthes lanceolata</i>
	F	<i>Gomphonema parvulum</i> <i>Achnanthes lanceolata</i>	<i>Gomphonema parvulum</i> <i>Synedra rumpens</i>	<i>Gomphonema parvulum</i> <i>Achnanthes lanceolata</i>	coccoid Chlorophyta spp. 5 - 9.9 µ coccoid Chlorophyta spp. <5 µ

		Common Taxa			
Station	Season	1986	1987	1988	1989
		coccoid Chlorophyta spp. 5 - 9.9 μ <i>Pseudoulevella americana</i> <i>Navicula minima</i> <i>Nitzschia kutzingiana</i> <i>Eunotia pectinalis</i> <i>Navicula cryptocephala</i>			<i>Gomphonema parvulum</i> <i>Navicula cryptocephala</i> <i>Eunotia pectinalis</i> <i>Navicula minima</i> <i>Oedogonium</i> spp. SM
340	W	<i>Pseudoulevella americana</i> <i>Eunotia pectinalis</i> <i>Chaetophora elegans</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. 5 - 9.9 μ coccoid Chlorophyta colony 1	<i>Achnanthes lanceolata</i> <i>Pseudoulevella americana</i>	<i>Pseudoulevella americana</i> coccoid Chlorophyta spp. <5 μ <i>Achnanthes lanceolata</i> coccoid Chlorophyta spp. 5 - 9.9 μ <i>Cocconeis placentula</i>
	Sp	<i>Chaetophora elegans</i> <i>Gomphonema parvulum</i> <i>Achnanthes minutissima</i> coccoid Chlorophyta spp. 5 - 9.9 μ <i>Cocconeis placentula</i> <i>Characium</i> spp.	Cyanophyta colony 2	<i>Navicula cryptocephala</i> <i>Navicula minima</i> coccoid Chlorophyta spp. 5 - 9.9 μ <i>Nitzschia paleacea</i> <i>Characium</i> spp.	<i>Achnanthes lanceolata</i> coccoid Chlorophyta spp. <5 μ <i>Leptosira medicinana</i> <i>Gomphonema parvulum</i> <i>Characium</i> spp. <i>Microcystis incerta</i>
	Su	<i>Navicula minima</i> coccoid Cyanophyta spp. <5 μ <i>Gomphonema parvulum</i> <i>Characium</i> spp. <i>Achnanthes hungarica</i> <i>Achnanthes lanceolata</i>	<i>Navicula minima</i> <i>Gomphonema parvulum</i> <i>Navicula cryptocephala</i> coccoid Chlorophyta spp. 5 - 9.9 μ	<i>Navicula minima</i> coccoid Chlorophyta spp. 5 - 9.9 μ <i>Gomphonema parvulum</i> <i>Nitzschia paleacea</i> <i>Lyngbya subtilis</i> <i>Navicula</i> spp.	coccoid Chlorophyta spp. <5 μ <i>Navicula minima</i> <i>Gomphonema parvulum</i> <i>Characium</i> spp. coccoid Chlorophyta spp. 5 - 9.9 μ <i>Eunotia pectinalis</i> <i>Nitzschia amphibia</i>
	F	<i>Lyngbya subtilis</i> <i>Navicula minima</i> coccoid Chlorophyta spp. < 5 μ <i>Oedogonium</i> spp. sm <i>Gomphonema parvulum</i> <i>Oscillatoria geminata</i> <i>Navicula cryptocephala</i>	coccoid Chlorophyta spp. 5 - 9.9 μ <i>Ulothrix subtilisma</i> <i>Gomphonema parvulum</i> <i>Nitzschia gracilis</i> <i>Nitzschia palea</i>	coccoid Chlorophyta spp. 5 - 9.9 μ <i>Nitzschia paleacea</i> <i>Gomphonema parvulum</i> <i>Cryptomonas erosa</i> <i>Navicula minima</i>	coccoid Chlorophyta spp. 5 - 9.9 μ coccoid Chlorophyta spp. <5 μ coccoid Cyanophyta spp. <1 μ <i>Ulothrix subtilisma</i> <i>Navicula minima</i> <i>Nitzschia paleacea</i> <i>Eunotia pectinalis</i>
350	W	<i>Gomphonema parvulum</i>	<i>Pseudoulevella americana</i>	<i>Achnanthes lanceolata</i>	coccoid Chlorophyta spp. <5 μ

		Common Taxa			
Station	Season	1986	1987	1988	1989
		<i>Chaetophora elegans</i>	<i>Gomphonema parvulum</i>	<i>Pseudourella americana</i>	coccoid Chlorophyta spp. 5 - 9.9 µ
		<i>Fragilaria vaucheriae</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Achnanthes lanceolata</i>
		<i>Achnanthes lanceolata</i> coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Ulothrix subtilisma</i> <i>Characium</i> spp.		<i>Cocconeis placentula</i>
350	Sp	<i>Achnanthes lanceolata</i>	<i>Achnanthes lanceolata</i>	<i>Navicula minima</i>	coccoid Cyanophyta spp. <5 µ
		<i>Gomphonema parvulum</i>	Cyanophyta colony 2	<i>Navicula cryptocephala</i>	<i>Achnanthes lanceolata</i>
		<i>Chaetophora elegans</i>	<i>Gomphonema parvulum</i>	<i>Nitzschia amphibia</i>	<i>Leptosira medicinana</i>
		<i>Cocconeis placentula</i>	coccoid Cyanophyta spp. < 5 µ	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Characium</i> spp.
		coccoid Cyanophyta spp. < 5 µ	<i>Navicula seminulum</i>	<i>Characium</i> spp.	
		<i>Eunotia pectinalis</i>	<i>Eunotia pectinalis</i> <i>Chaetophora elegans</i>	<i>Achnanthes lanceolata</i>	
	Su	<i>Achnanthes lanceolata</i>	<i>Achnanthes lanceolata</i>	<i>Microcystis incerta</i>	coccoid Cyanophyta spp. <1 µ
		<i>Chaetophora elegans</i>	<i>Eunotia pectinalis</i>	<i>Lyngbya subtilis</i>	
		<i>Gomphonema parvulum</i>	<i>Achnanthes hungarica</i>	Chaetophoraceae (uniden- tified)	
		<i>Navicula minima</i>	<i>Navicula cryptocephala</i>	<i>Achnanthes lanceolata</i>	
		<i>Achnanthes hungarica</i>	<i>Gomphonema parvulum</i>	<i>Eunotia pectinalis</i>	
	F	<i>Lyngbya subtilis</i>	<i>Gomphonema parvulum</i>	<i>Microcystis incerta</i>	coccoid Cyanophyta spp. <1 µ
		<i>Gomphonema parvulum</i>	coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Gomphonema parvulum</i>	coccoid Chlorophyta spp. <5 µ
		<i>Schizothrix</i> spp.	<i>Nitzschia gracilis</i>	<i>Achnanthes lanceolata</i>	coccoid Chlorophyta spp. 5 - 9.9 µ
		<i>Achnanthes lanceolata</i>		<i>Navicula minima</i>	<i>Gomphonema parvulum</i>
360	W	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>
		<i>Nitzschia gracilis</i>	<i>Pseudourella americana</i>	<i>Navicula minima</i>	<i>Achnanthes lanceolata</i>
		<i>Nitzschia kutzingiana</i>	<i>Chlamydomonas</i> spp. 5 - 9.9 µ	<i>Cocconeis placentula</i>	
		<i>Fragilaria vaucheriae</i>	coccoid Chlorophyta spp. 5 - 9.9 µ		
		<i>Chaetophora elegans</i>	<i>Cocconeis placentula</i>		
		coccoid Chlorophyta spp. 5 - 9.9 µ			
		<i>Achnanthes lanceolata</i>			
	Sp	<i>Gomphonema parvulum</i>	<i>Cocconeis placentula</i>	<i>Achnanthes lanceolata</i>	coccoid Cyanophyta spp. <5 µ
		<i>Achnanthes lanceolata</i>	coccoid Cyanophyta spp. < 5 µ	<i>Gomphonema parvulum</i>	<i>Achnanthes lanceolata</i>

		Common Taxa			
Station	Season	1986	1987	1988	1989
		<i>cocconeis placentula</i> <i>Achnanthes minutissima</i>	<i>Eunotia pectinalis</i> <i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i>	<i>Eunotia pectinalis</i> <i>Cocconeis placentula</i> <i>Microcystis aeruginosa</i>	<i>Microcystis incerta</i> <i>Eunotia pectinalis</i>
360	Su	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> <i>Navicula minima</i> <i>Lyngbya subtilis</i> <i>Characium</i> spp.	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> <i>Eunotia pectinalis</i> <i>Pseudouvella americana</i> <i>Navicula cryptocephala</i> <i>Navicula minima</i> <i>Achnanthes hungarica</i> <i>Lyngbya subtilis</i> Coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Chroococcus minor</i> <i>Achnanthes lanceolata</i>	coccoid Chlorophyta spp. <5 µ <i>Schizothrix</i> spp. coccoid Cyanophyta spp. <5 µ <i>Navicula minima</i> <i>Gomphonema parvulum</i>
	F	<i>Gomphonema parvulum</i> <i>Achnanthes lanceolata</i>	<i>Gomphonema parvulum</i> <i>Synedra tenera</i>	<i>Gomphonema parvulum</i> <i>Achnanthes lanceolata</i> <i>Navicula menisculus</i> <i>Eunotia pectinalis</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. <5 µ coccoid Chlorophyta spp. 5 - 9.9 µ <i>Achnanthes lanceolata</i> <i>Navicula minima</i> <i>Navicula cryptocephala</i>
370	W	<i>Gomphonema parvulum</i> <i>Fragilaria vaucheriae</i> <i>Eunotia pectinalis</i>	<i>Gomphonema parvulum</i> coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Navicula minima</i> <i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i> <i>Achnanthes minutissima</i> <i>Chaetophora elegans</i> coccoid Chlorophyta spp. 5 - 9.9 µ
	Sp	<i>Cocconeis placentula</i> <i>Achnanthes lanceolata</i> <i>Eunotia pectinalis</i> <i>Chaetophora elegans</i>	<i>Gomphonema parvulum</i> coccoid Cyanophyta spp. < 5 µ <i>Lyngbya subtilis</i> <i>Chaetophora elegans</i>	<i>Achnanthes lanceolata</i> <i>Chaetophora elegans</i> <i>Cocconeis placentula</i> coccoid Chlorophyta spp. 5 - 9.9µ <i>Microcystis incerta</i> <i>Eunotia pectinalis</i>	coccoid Cyanophyta spp. <5 µ <i>Cocconeis placentula</i> <i>Achnanthes lanceolata</i> <i>Leptostira medicinana</i> <i>Eunotia pectinalis</i>
	Su	<i>Chaetophora elegans</i> <i>Achnanthes lanceolata</i>	<i>Achnanthes lanceolata</i> <i>Chaetophora elegans</i> <i>Gomphonema parvulum</i> coccoid Chlorophyta spp. 5 - 9.9 µ	<i>Achnanthes lanceolata</i> <i>Gomphonema parvulum</i> Chaetophoraceae (uniden- tified) <i>Cocconeis fluviatilis</i>	coccoid Cyanophyta spp. <1 µ coccoid Cyanophyta spp. < 5 µ <i>Microcystis incerta</i>

Station	Season	Common Taxa			
		1986	1987	1988	1989
			<i>Cocconeis fluvialis</i>	<i>Microcystis incerta</i>	
370	F	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>	<i>Achnanthes lanceolata</i>	coccoid Cyanophyta spp. <1 µ
		<i>Achnanthes lanceolata</i>	<i>Synedra tenera</i>	<i>Gomphonema parvulum</i>	coccoid Chlorophyta spp. <5 µ
			<i>Nitzschia gracilis</i> <i>Nitzschia palea</i>	<i>Nitzschia paleacea</i> <i>Eunotia pectinalis</i>	<i>Schizothrix</i> spp.
400	W	<i>Gomphonema parvulum</i>	<i>Gomphonema parvulum</i>	<i>Achnanthes reimeri</i>	<i>Gomphonema parvulum</i>
		<i>Achnanthes minutissima</i>	<i>Achnanthes minutissima</i>	<i>Achnanthes minutissima</i>	<i>Achnanthes minutissima</i>
		<i>Eunotia pectinalis</i>	<i>Achnanthes reimeri</i>	<i>Synedra rumpens</i>	<i>Achnanthes reimeri</i>
		<i>Meridion circulare</i>	<i>Eunotia pectinalis</i>	<i>Gomphonema parvulum</i>	
		<i>Cocconeis placentula</i>	<i>Synedra rumpens</i>		
		<i>Cymbella minuta</i>			
	Sp	<i>Schizothrix</i> spp.	<i>Schizothrix</i> spp.	<i>Microcystis incerta</i>	<i>Schizothrix</i> spp.
		<i>Cocconeis placentula</i>	<i>Gomphonema parvulum</i>	<i>Achnanthes lanceolata</i>	<i>Achnanthes lanceolata</i>
		<i>Gomphonema parvulum</i>	<i>Achnanthes minutissima</i>	<i>Chamaesiphon minutus</i>	<i>Eunotia pectinalis</i>
		<i>Navicula capitata</i>		<i>Chaetophora elegans</i>	coccoid Chlorophyta spp. <5 µ
		<i>Achnanthes minutissima</i>		<i>Cocconeis placentula</i>	<i>Characium</i> spp.
		<i>Oscillatoria subtilissima</i>		<i>Microcystis aeruginosa</i>	<i>Navicula cryptocephala</i>
				<i>Aphanothece saxicola</i>	
				<i>Schizothrix</i> spp.	
	Su	<i>Lyngbya subtilis</i>	<i>Lyngbya subtilis</i>	<i>Lyngbya subtilis</i>	coccoid Cyanophyta spp. <1 µ
		<i>Achnanthes minutissima</i>	coccoid Cyanophyta spp. < 5 µ	<i>Microcystis incerta</i>	<i>Schizothrix</i> spp.
		<i>Navicula minima</i>	<i>Navicula minima</i>	<i>Schizothrix</i> spp.	<i>Microcystis incerta</i>
		<i>Nitzschia kutzingiana</i>	<i>Achnanthes minutissima</i>	<i>Navicula cryptocephala</i>	coccoid Cyanophyta spp. <5 µ
	F	<i>Lyngbya subtilis</i>	<i>Gomphonema parvulum</i>	<i>Oscillatoria angustissima</i>	<i>Schizothrix</i> spp.
		<i>Oscillatoria geminata</i>	<i>Achnanthes minutissima</i>		coccoid Cyanophyta spp. <1 µ
		<i>Melosira granulata</i>	<i>Eunotia pectinalis</i>		coccoid Chlorophyta spp. <5 µ
		<i>Schizothrix</i> spp.			

Macrophytes

L Lake

L Lake aquatic macrophytes are not covered in this section; refer to Chapter 7—Wetlands of L Lake.

Steel Creek

Comprehensive Cooling Water Study

Between the shutdown of L Reactor in 1968 and the construction of L Lake in 1984–1985, Steel Creek went through successional recovery from the impacts of high flows and temperatures caused by previous L Reactor discharges. Steel Creek was sampled thoroughly during the Comprehensive Cooling Water Study (CCWS) where four channel, one delta, and two swamp stations were sampled quarterly during 1984–1985. Two stations on Meyers Branch, an unimpacted tributary of Steel Creek, were also sampled as a control.

Summary data from the CCWS for Steel Creek and Meyers Branch can be found in Table 14-21 through Table 14-26. Species diversity appears to be similar between the post-thermal and reference streams, but there may be differences between the two swamp stations (Table 14-21). Further data (Table 14-22 and Table 4-23) indicate these differences are real, this is probably attributable to the fact that Station 33 is in the delta and principally open canopy while Station 35 is in the closed canopy area of the swamp. The data in Table 14-24 and Table 14-25 demonstrate clear similarities between three of the four (26, 27, 29) stream corridor site macrophyte populations and those of the reference stream (39, 40). These are all closed canopy portions of the stream. Station 28 is more similar to the delta and swamp stations, principally because it is an open-canopy area. Diversity of plant community is similar for the delta and swamp stations (33, 34, 35) (Table 14-25), but greater area, volume, biomass, and percent cover at station 33 (Table 14-24) can be attributed to its open canopy as opposed to the closed canopy in the other swamp stations.

Table 14-21. Number of Macrophyte Taxa at 4 Steel Creek and 2 Meyers Branch Sampling Stations (November 1983–May 1984) (Source: Gladden et al. 1985)

	Post-thermal Stream		Post-thermal Swamp		Reference Stream	
	26	28	33	35	39	40
total no. taxa	28	32	22	32	35	26
taxa growing in stream channel	1	2	9	12	6	2
taxa growing on floodplain	0	18	11	18	0	17
taxa growing in other riparian areas	27	12	2	2	29	7
channel + floodplain taxa	1	20	20	30	6	19

Table 14-22. Macrophyte Standing Crop (g AFDW/m²)* at Steel Creek Swamp 1983-1984 Stations During Winter, Spring, and Summer 1984. Mean, Standard Deviations (s), Coefficient of Variation (CV), and Number of Samples (n) are Given for Samples Collected January–September 1984. (Source: Kondratieff and Kondratieff 1985a, 1985b)

	33 SCS-n	35 SCS-n
<i>Winter</i>		
Mean	5.02	3.21
s	2.75	3.41
CV	19.93	106.03
n	32	41
<i>Spring</i>		
Mean	115.60	31.27
s	69.16	23.13
CV	59.83	73.97
n	75	50
<i>Summer</i>		
Mean	43.82	7.32
s	12.9	6.79
CV	29.5	92.7
n	68	94

Abbreviations are listed in Table V-3.2.

Table 4-23. Biomass (g/m²) and Percent of Total Biomass Contributed by Macrophyte Genera Collected at Steel Creek Stations 33 and 35 During Winter, Spring, and Summer Sampling (November 1983–May 1984) (Source: Kondratieff and Kondratieff 1985a)

Season	Genus	Biomass (g/m ²)		% of Total Biomass	
		Station 33	Station 35	Station 33	Station 35
Winter	<i>Hydrocotyle</i>	1.46	0.43	28.95	12.87
	<i>Ceratophyllum</i>	2.17	0.72	42.90	21.34
	<i>Myriophyllum</i>	1.42	0.31	28.14	9.41
	<i>Nuphar</i>	0.00	1.09	0.00	32.48
	<i>Vallisneria</i>	0.00	0.62	0.00	18.49
	<i>Callitriche</i>	0.00	0.16	0.00	4.80
	<i>Potamogeton</i>	0.00	0.00	0.00	0.00
Spring	<i>Hydrocotyle</i>	4.38	2.97	3.84	9.54
	<i>Ceratophyllum</i>	62.35	2.47	54.71	7.95
	<i>Myriophyllum</i>	4.06	0.27	3.56	0.87
	<i>Nuphar</i>	0.00	3.01	0.00	9.67
	<i>Vallisneria</i>	6.32	0.78	5.54	2.50
	<i>Callitriche</i>	27.81	20.50	24.41	65.87
	<i>Potamogeton</i>	9.03	1.12	7.93	3.58
Summer	<i>Hydrocotyle</i>	0.67	0.24	1.56	3.03
	<i>Ceratophyllum</i>	36.71	7.36	85.66	93.68
	<i>Myriophyllum</i>	1.35	0.20	3.16	2.50
	<i>Nuphar</i>	0.00	0.03	0.00	0.38
	<i>Vallisneria</i>	4.11	0.02	9.59	0.27

Table 14-24. Annual Mean N, and Standard Deviation (s) are Presented for the Following Vegetation Parameters on a per m² Basis at Each Mapped 1984-1985 Station: Aquatic Vascular Plant (AVP) Area (m²/m²); AVP Volume (m³/m²); AVP Biomass (g/m²) and AVP Percent Cover (October 1984–September 1985) (Source: Firth et al. 1986)

Station	Location/ Thermal Regime	AVP Area		AVP Volume		AVP Biomass		Percent Cover		N
		Mean	s	Mean	s	Mean	s	s		
26	SC	0.0019	0.0049	-	-	-	-	-	0.4960	16
27	SC	0.0001	0.0004	-	-	-	-	-	0.0367	9
28	SC	0.0423	0.0675	0.0010	0.0015	16.75	28.83	4.226	6.736	16
29	SC	0.0002	0.0004	<0.0001	<0.0001	0.0855	0.1949	0.0202	0.0430	12
33	SCD	0.3958	0.1434	0.1807	0.1349	82.18	48.70	39.61	14.17	20
34	SCS	0.2786	0.2968	0.1196	0.1666	84.01	113.4	29.87	29.85	20
35	SCS	0.2331	0.3229	0.0832	0.1267	59.62	78.83	23.32	32.31	20
39	MB	0.0001	0.0002	<0.0001	<0.0001	0.0002	0.0007	0.0054	0.0167	20
40	MB	0.0009	0.0030	0.0002	0.0005	0.0111	0.0331	0.0916	0.2998	20

Table 14-25. The Annual Mean, Number of Reaches Mapped During Year (N) and Standard Deviation (s) are Given for the Following Plant Taxa Parameters: Area (m²/m²); Volume (m³/m²); Biomass (g/m²); Percent Cover (percent of mapped area covered by species in question) (October 1984–September 1985) (Source: Firth et al. 1986)

Species	Area		Volume		Biomass		Percent Cover		N
	Mean	s	Mean	s	Mean	s	Mean	s	
Station 26 (SC-n)									
MISC	0.0019	0.0049	-		-	-	0.1848	0.4960	16
Station 27 (SC-n)									
MISC	0.0001	0.0004	-		-	-	0.0122	0.0367	9
Station 28 (SC-n)									
ALT	0.0012	0.0041	0.0001	0.0004	0.2847	0.9330	0.1235	0.4130	16
BA	0.0001	0.0002	<0.0001	<0.0001	0.0010	0.0041	0.0063	0.0250	16
LUD	0.0001	0.0004	0.0001	0.0003	0.0334	0.1335	0.0102	0.0408	16
MISC	0.0003	0.0012	-	-	-	-	0.0308	0.1233	16
MYR	0.0063	0.0108	0.0008	0.0012	0.9620	2.258	0.4261	0.6815	16
POL	0.0341	0.0631	-	-	15.30	28.33	3.406	6.304	16
POT	0.0002	0.0008	<0.0001	0.0001	0.0240	0.0930	0.0230	0.0806	16
Station 29 (SC-n)									
MISC	<0.0001	0.0001	-	-	-	-	0.0016	0.0055	12
POL	0.0002	0.0004	-	-	0.0837	0.1957	0.0186	0.0434	12
Station 33 (SCD-n)									
AZ	0.0010	0.0038	0	0	0.1706	0.6763	0.0955	0.3785	20
CAL	0.0065	0.0139	0.0025	0.0073	1.306	3.769	0.8090	1.576	20
CER	0.0965	0.0561	0.0502	0.0295	62.24	38.38	9.649	5.611	20
HLA	0.0014	0.0050	-	-	0.3548	2.669	0.1445	0.4958	20
HY	0.0023	0.0057	0.0007	0.0021	0.9281	2.669	0.2296	0.5698	20
LEM	0.0028	0.0074	-	-	0.0858	0.1419	0.2802	0.7396	20
MYR	0.0248	0.0407	0.0132	0.0232	8.941	14.06	2.346	4.093	20
POL	0.0011	0.0030	-	-	0.4941	1.334	0.1103	0.2971	20
VAL	0.2594	0.1572	0.1140	0.1201	7.665	8.016	0.1103	0.2971	20

Species	Area		Volume		Biomass		Percent Cover		N
	Mean	s	Mean	s	Mean	s	Mean	s	
Station 34 (SCS-n)									
CAL	0.1391	0.2398	0.0726	0.1287	37.50	66.99	13.91	23.98	20
CER	0.0329	0.0396	0.0133	0.0187	16.73	23.14	3.287	3.956	20
HY	0.0002	0.0010	0.0001	0.0005	0.1478	0.6430	0.0234	0.0980	20
LEM	0.0092	0.0273	-	-	0.2646	0.5258	0.9217	2.732	20
MYR	0.0111	0.0314	0.0031	0.0087	2.921	8.884	3.112	10.08	20
NU	0.0167	0.0269	0.0056	0.0103	0.1712	0.3243	1.668	2.692	20
POT	0.0607	0.0728	0.0214	0.0384	25.85	47.13	6.073	7.278	20
VAL	0.0087	0.0243	0.0034	0.0094	0.2251	0.6058	0.8746	2.433	20
Station 35 (SCS-n)									
AZ	0.0002	0.0007	-	-	0.0278	0.1241	0.0155	0.0693	20
CAL	0.1682	0.3223	0.0575	0.1214	29.81	62.93	16.82	32.24	20
CER	0.0381	0.0453	0.0185	0.0260	23.02	34.41	3.804	4.535	20
EG	0.0049	0.0083	0.0020	0.0041	1.846	3.428	0.4878	0.8311	20
HY	0.0006	0.0013	0.0001	0.0001	0.2961	1.147	0.0583	0.1255	20
LEM	0.0056	0.0108	-	-	0.2057	0.5313	0.5594	1.077	20
MISC	0.0001	0.0002	-	-	-	-	0.0056	0.0218	20
MYR	0.0013	0.0028	0.0006	0.0017	0.5947	1.748	0.1256	0.2772	20
NU	0.0040	0.0095	0.0010	0.0029	0.0048	0.1343	0.4016	0.9544	20
POT	0.0089	0.0161	0.0031	0.0054	3.750	6.615	0.8943	1.608	20
VAL	0.0014	0.0032	0.0004	0.0012	0.0268	0.0764	0.1445	0.3255	20
Station 39 (MB-n)									
MISC	<0.0001	0.0001	-	-	-	-	0.0030	0.0134	20
VAL	<0.0001	0.0001	<0.0001	-0.0001	0.0002	0.0007	0.0024	0.0107	20
Station 40 (MB-n)									
NU	0.0001	0.0003	<0.0001	0.0001	0.0003	0.0014	0.0076	0.0338	20
Station 40 (MB-n) Cont.									
VAL	0.0008	0.0030	0.0002	0.0005	0.0108	0.0332	0.0840	0.3002	20

List of species abbreviations:

ALT	<i>Alternanthera philoxeroides</i>
AZ	<i>Azolla caroliniana</i>
BA	<i>Bacopa</i> sp.
CAL	<i>Callitriche heterophylla</i>
CER	<i>Ceratophyllum demersum</i>
EG	<i>Egeria densa</i>
HLA	<i>Hydrolea quadrivalvis</i>
HY	<i>Hydrocotyle ranunculoides</i>
LEM	<i>Lemna</i> spp. (and occasional <i>Spirodela fronds</i>)
LUD	<i>Ludwigia</i> sp.
MISC	Unidentified
HYR	<i>Hyriophyllum spicatum</i>
NU	<i>Nuphas luteum</i>
POL	<i>Polygonum</i> spp.
POT	<i>Potamogeton pusillus</i>
VAL	<i>Vallisneria americana</i> (and/or <i>Sparangium</i> sp.)

L-Lake/Steel Creek Biological Monitoring Program

The L-Lake/Steel Creek Biological Monitoring Program sampled 13 stations quarterly from 1986 through 1989 and 4 of those stations semi-annually in 1990 and 1991 as part of the *habitat formers analysis* (Toole and Westbury 1992). The following excerpts from Toole and Westbury (1992) serve as a summary of the information collected during this extensive monitoring program.

The percentage of the mapped reaches covered by aquatic macrophytes in summers of 1985 through 1991 are presented in Table 14-26. Summary statistics for 1991 macrophyte percent cover are in Table 14-27.

The greatest amount of vegetative cover was at Stations 330 and 350 in all years (Table 14-26). Percent cover was greater at Station 330 than Station 350 from 1985–1989; however, the opposite was true in 1990 and 1991. The smallest percent cover was at Station 290 in all years, with the exceptions of 1990 and 1991 when it was smaller at Station 370. At Station 350 in 1990 and 1991, the percent cover was greater than 100% because of multiple layers of vegetation. The lack of boat traffic and stream flow through Station 350 in 1990 and 1991 may have contributed to the increase in macrophyte cover at this station. Macrophyte cover doubled at Station 330 and increased nine-fold at Station 350 between 1985 and 1990. Percent macrophyte cover continued to increase at Station 350 in 1991 but decreased slightly at Station 330 that year. Macrophyte cover was greatly reduced at Station 350 soon after the sampling date in 1991 when much of the vegetation (especially *Lemna* and *Azolla*) was washed away by increased flow due to flooding on the Savannah River. At Station 370, macrophyte cover decreased from 20.1 to 0.2% between 1986 and 1990 then increased to 0.9% in 1991. At Station 290 macrophyte percent cover varied from 0.0 to 0.3% from 1985–1988, but then increased from 1988 to 1991 when it reached 7.1%. Macrophyte cover

Table 14-26. Mean Total Vegetation (%) Cover at Selected Steel Creek Stations During Summer Quarter. Summary Statistics for 1991 are in Appendix Table 12. July–September 1985–1991.

Location	Station	Mean Percent Cover ^a (%)						
		1985	1986	1987	1988	1989	1990	1991
Corridor	290	<0.1	0.0	0.3	0.0	4.6	4.5	7.1
Marsh	330	32.6	67.9	55.5	58.4	67.1	71.5	63.1
Swamp	350	15.2	24.3	22.6	58.0	37.4	136.5	142.9
Channel	370	^b	20.1	11.6	17.7	15.5	0.2	0.9

^aMean percent cover = total percent of each mapped channel covered by all taxa of aquatic macrophytes.

^bStation not sampled for this parameter in 1985.

Table 14-27. Summary Statistics for Total Vegetation Percent Cover at Selected Steel Creek Stations in Summer 1991.

Station	Mean	N	STDERR	Min	Max
290	7.1	2	4.3	2.8	11.4
330	63.1	2	6.9	56.2	70.0
350	142.9	2	17.6	125.3	160.5
370	0.9	2	0.8	0.0	1.7

has increased overall at Stations 290, 330, and 350 since the shutdown of L-Reactor in 1988, perhaps due to the reduction in stream flow.

The plant taxa that comprised $\geq 1.0\%$ of the total mapped area in summers of 1985 through 1991 are listed in Table 14-28. All taxa and summary statistics for 1991 data are presented in Table 14-29. Plant taxa having $\geq 1.0\%$ are referred to as common taxa in this report.

Data presented in Hooker (1990) indicate that channel structures were slightly affected by increased discharges from L Lake. At Station 290 macrophyte percent cover remained very close to zero until 1989, when it increased to 4.6% and remained at 4.5% in 1990 (Table 14-26). In 1991 macrophyte percent cover rose to 7.1%.

Table 14-28. Mean Percent Cover (%) of Common Aquatic Macrophyte Taxa ($\geq 1.0\%$ cover) at Selected Steel Creek Stations. Summary Statistics for 1991 are in Appendix Table 13. July–September 1985–1991.

Location	Station	Taxa	Mean Percent Cover ^a (%)						
			1985	1986	1987	1988	1989	1990	1991
Corridor	290	<i>Alternanthera</i>	d	b	d	b		1.4	
		<i>Leersia</i>					1.9	1.0	
		<i>Ceratophyllum</i>							4.9
		<i>Murdannia</i>							1.3
Marsh	330	<i>Alternanthera</i>				2.1			
		<i>Ceratophyllum</i>	15.9	19.0	23.4	19.7	12.1	20.2	12.0
		<i>Egeria</i>			8.3	25.4	46.7	50.3	50.8
		<i>Callitriche</i>	2.8						
		<i>Lemna</i>	1.0		3.8				
		<i>Hydrocotyle</i>				2.7			
		<i>Murdannia</i>				1.0			
		<i>Myriophyllum</i>	1.2	1.8					
		<i>Polygonum</i>				2.0	5.5		
		<i>Paspalum</i>		6.4					
		<i>Potamogeton</i>		1.6	1.1				
		<i>Sparganium</i>		37.1	18.0	5.0	2.2		
		<i>Vallisneria</i> ^c	10.8						
		<i>Ceratophyllum</i>	8.2	3.1		1.0		1.0	
		<i>Egeria</i>	1.8	18.4	18.6	43.9	24.2	82.6	94.8
Swamp	350	<i>Hydrocotyle</i>				1.7			
		<i>Lemna</i>	1.9	1.9	1.0	3.9	1.0	34.7	8.7
		<i>Potamogeton</i>	2.5						
		<i>Riccia</i>						9.7	
		<i>Sparganium</i>				7.4	11.5	8.5	1.4
		<i>Azolla</i>							38.1
		<i>Ceratophyllum</i>	c	5.8	5.3	3.3			
		<i>Egeria</i>		13.4	5.3	13.9	8.4		
Channel	370	<i>Murdannia</i>					4.2		

^aMean percent cover - [sum of surface area of taxon (m²) per mapped area of reach (m²)] x 100.

^bNo plant taxa recorded at station.

^cStation not sampled for these parameters in 1985.

^dNo individual taxon had $\geq 1\%$ cover.

^e*Vallisneria* was identified in 1985 but not found in subsequent years. May have been *Sparganium* misidentified as *Vallisneria* in 1985.

Total vegetation percent cover in the Steel Creek Corridor stations from 1985–1989 ranged from 0.0 to 7.9% (Hooker 1990). There was a marked increase in total vegetation since L-Reactor was placed on standby in 1988. The decreased stream flow in years following the L-Reactor shutdown may have provided opportunity for plants to attach themselves to channel structures. *Leersia* was common in the channel at Station 290 in 1989 and 1990. *Alternanthera* was common at this station in 1990 only. *Ceratophyllum* and *Murdannia* replaced *Leersia* and *Alternanthera* as the common macrophytes in 1991.

Vallisneria and *Ceratophyllum* were reported to be the two most common macrophytes in the channel at Station 330 in 1985. The *Vallisneria* may have been *Sparganium* misidentified. In 1986 and 1987, *Sparganium* and *Ceratophyllum* were the most common macrophytes, while *Egeria* had the highest percent cover in 1988–1991. The aquatic plant community, as measured by percent cover at this site in 1989, was comparable to that documented in 1988. However, as *Egeria* coverage increased, diversity of plant taxa in the channel at Station 330 decreased during 1989. By 1990 and 1991 *Egeria* and *Ceratophyllum* were the only taxa with greater than 1.0% cover.

Table 14-29. Summary statistics for percent cover (%) of aquatic macrophyte taxa which have been common at selected Steel Creek stations in summer 1991.

Station	Species	Mean	N	STDERR	MIN	MAX
290	<i>Alternanthera philoxeroides</i>	0.285	2	0.121	0.165	0.406
290	<i>Ceratophyllum demersum</i>	4.888	2	3.777	1.110	8.665
290	<i>Egeria densa</i>	0.114	2	0.114	0.000	0.227
290	<i>Elodea canadensis</i>	0.070	2	0.070	0.000	0.139
290	<i>Leersia</i> spp.	0.035	2	0.035	0.000	0.070
290	<i>Ludwigia leptocarpa</i>	0.022	2	0.022	0.000	0.044
290	<i>Micranthemum umbrosum</i>	0.131	2	0.006	0.125	0.136
290	<i>Mikania cordifolia</i>	0.003	2	0.003	0.000	0.007
290	<i>Murdania keisak</i>	1.313	2	0.209	1.104	1.523
290	<i>Myriophyllum aquaticum</i>	0.143	2	0.136	0.007	0.279
290	<i>Polygonum sagittatum</i>	0.005	2	0.005	0.000	0.010
290	<i>Sacciolepis striata</i>	0.093	2	0.046	0.047	0.139
330	<i>Ceratophyllum demersum</i>	11.930	2	3.622	8.307	15.552
330	<i>Egeria densa</i>	50.852	2	2.959	47.893	53.810
330	<i>Polygonum</i> spp.	0.311	2	0.311	0.000	0.622
350	<i>Azolla caroliniana</i>	37.894	2	14.994	22.901	52.888
350	<i>Egeria densa</i>	94.809	2	5.191	89.618	100.000
350	<i>Lemna</i> spp.	8.728	2	1.272	7.457	10.000
350	<i>Murdania keisak</i>	0.086	2	0.086	0.000	0.172
350	<i>Sparganium americanum</i>	1.374	2	1.374	0.000	2.748
370	<i>Egeria densa</i>	0.689	2	0.679	0.011	1.368
370	<i>Hibiscus</i> spp.	0.000	2	0.000	0.000	0.000
370	<i>Lemna</i> spp.	0.171	2	0.171	0.000	0.342

Large increases in the total macrophyte percent cover at the swamp station (350) occurred between 1987 and 1988, but due to higher water levels in 1989, mean cover decreased at the site between 1988 and 1989. The channel became wider and more shallow in 1990, and macrophyte cover was nearly four times greater in 1990 than in 1989. The percent cover of *Egeria* increased substantially from 1986 through 1988 in the main channel throughout the area, but decreased between 1988 and 1989. However, between 1989 and 1991, the percent cover of *Egeria* almost quadrupled.

Overall changes noted in the swamp between 1986 and 1987 (the same time period that L-Reactor was in operation) are probably a result of natural variability and dependence on hydrology, with no major trends appearing. However, a dramatic increase in percent cover of aquatic macrophytes occurred between 1989 and 1990. A more moderate increase in vegetation percent cover occurred between 1990 and 1991.

Macrophyte cover increased at Station 370 in 1988. In 1989, macrophyte cover decreased in response to higher water levels in the downstream channel and was limited to the more shallow channel edges. In 1990 and 1991 macrophytes were nearly absent from Station 370.

Macrophyte communities in marsh channels appear to have withstood the effects of variable discharge (late 1985 through spring 1988) with no major detrimental effects noted in this study. However, several factors make it difficult to extrapolate the measurements of macrophyte communities to other comparable marsh/swamp systems. These are: (1) measurements for this study are confined to open, deep water channels and, therefore, do not take into account the vast zones of emergent vegetation in the marsh adjacent to the channel; (2) measurements were made only once a year in two 25-m reaches per station; (3) in areas with braided channels, wood and vegetation occurring in locations other than the mapped channel were not documented; and (4) other casual factors that influence macrophyte development and flooding tolerance were beyond the scope of work for this study.

An earlier study (Gladden et al. 1985) on the Steel Creek system documented recovery of marsh plant communities in the deep water areas such as those monitored in this project. They noted that *Ceratophyllum demersum* and *Myriophyllum* were common submergents, while the emergent, *Polygonum lapathifolium* and *Murdannia*, colonized low-flow areas. More shallow areas supported *Sagittaria* and *Rhynchospora*, among other taxa.

In the present study, several taxa were common in deep water marsh channels that were not listed as common in the earlier study (Gladden et al. 1985). Plant succession during the years since that study led the way for different taxa to become established and even dominate the channels. Most notable is the establishment of *Egeria* in lower marsh and swamp channels and that it eventually dominated some channels to the extent of displacing other taxa. *Egeria* is an exotic submersed, perennial monocot that, by virtue of its competitive superiority, displaces native species (Godfrey and Wooten 1979). There was a great increase in 1990 percent cover of macrophyte vegetation at swamp Station 350 resulting from a multiple-layer plant community consisting of a layer of floating *Lemna* and a layer of submergent *Egeria*. In 1991, a large amount of *Azolla* was mixed with the *Lemna*. This phenomenon probably resulted from reduced flow and boat traffic through the study area. Other taxa that have become established in marsh/swamp deep water areas include *Sparganium americanum*, *Hydrocotyle*, and *Callitriche*. *Myriophyllum* was seldom common in the lower marsh and swamp channels in the last few years of this study.

Zooplankton

L Lake

Taylor et al. (1992) described zooplankton succession in L Lake for the first three years of the basin's existence. During 1986 and 1987 larger macrozooplankters, *Daphnia parvula*, *Daphnia retrocurva*, *Diaphanosoma brachyurum*, *Diaptomus pallidus*, and *Diaptomus dorsalis*, were dominant species. *Bosmina longirostris*, the smallest of the cladocerans, was most abundant during 1988. During the third year of the study, loricate rotifers (*Keratella* spp., *Polyarthra* spp., and *Kellicottia bostoniensis*), *Synchaeta stylata*, and *Conochilus unicornis* dominated the zooplankton assemblage. Size-selective predation by the threadfin shad (*Dorosoma petenense*) was responsible for this shift in community structure.

L-Lake total macrozooplankton, mainly zooplankton crustacea (cladocerans, copepods and total microzooplankton, Rotifera and the Protozoa, reached their greatest abundance during the summers of 1988 and 1989 (Fig. LL-Zoo. 1). Numerically, the protozoans dominated zooplankton communities in L Lake. However, copepod and cladoceran densities reveal the striking effect of size-selective predation in L Lake (Fig. LL-Zoo. 2). During 1986 and 1987 when planktivorous densities of the threadfin shad were low, these larger more visually vulnerable species existed in the lake. However as threadfin shad, a voracious consumer of these animals (Drenner and McComas 1980; Drenner et al. 1984; Prophet and Frey 1987) increased, they began to literally drive their preferred prey to extinction in the lake. By 1990 copepod and cladoceran were nonexistent in the open waters of L Lake.

At the species level, these temporary extinctions were even more apparent (Fig. LL-Zoo. 3). Only *Paracyclops* and *Diaphanosoma* were remaining at detectable densities in the plank-

Figure 14-26. Zooplankton in L Lake

Figure 14-27. Zooplankton in L Lake

Figure 14-28. Zooplankton in L Lake

ton and for plausible reasons. *Diaphanosoma* is a large and easily seen by a planktivorous fish, but this inshore littoral species rarely is located offshore where the threadfin shad hunts. Thus its behavioral pattern significantly reduces the animal's mortality to a pelagic predator. *Paracyclops* is the smallest of these macrozooplankters and is not as easily detected by the shad. In summary, the zooplankton size structure of L Lake reflected intense planktivorous predation during the last 4 years. No large species can be collected in the open waters. Threadfin shad must now switch to smaller prey which require more time and energy per unit of searching time to meet metabolic needs. This may explain shad decreases during 1990 and 1991.

Yet another factor in macrozooplankton abundance is the phantom midge, *Chaoborus punctipennis* (Havens 1990). Haven (1990) has also noted that during periods of high *Chaoborus* abundance, preferred prey such as soft-bodied rotifers and small cladocerans disappear, while loricated rotifers and larger cladocerans coexist with the predator.

In L Lake the relative abundance of *Chaoborus* reached its maximum concentrations during the summer and fall months of 1987, 1989, 1990, and 1991. Protozoans, due to their very small size, are not thought to be important prey. Densities of protozoans appeared positively correlated to *Chaoborus*. Rotifera densities declined in L Lake after 1989, but were not correlated to midge abundance maxima. Cladocerans also declined in L Lake after 1988. However, this pattern does suggest that *Chaoborus* may be preying extensively on small species. Note that maximum abundances of *Chaoborus* do co-occur with cladoceran densities during 1987 and 1988 and with a slight time-lag during 1989. Copepod densities, like those of cladocerans declined after 1988, more likely due to fish predation.

Steel Creek

Introduction

Chimney and Cody (1986) comparatively examined the zooplankton community in several SRS stream systems (including Steel Creek) prior to the construction of L Lake. Bowers (1991) sampled zooplankton at seven locations (Figure StC-Zoo. 1) of the Steel Creek system from 1986 to 1989 following the construction of L Lake.

Early Effects of L Lake on Steel Creek Zooplankton

During 1985 Rotifera and Cladocera constituted over 75% of the total number of zooplankton species in the Steel Creek swamp/delta. By 1986 the number of species had decreased by about 50% for rotifers, cladocerans, and copepods. By 1987 the rotifera had increased to 29 species, five more than in 1985. Based only on the number of species, the impoundment of Steel Creek during 1984 and 1985 and the subsequent beginning of L-Lake discharge significantly affected the number of zooplankton taxa in the Steel Creek swamp and delta regions during 1985 and 1986, but recovery of taxa richness for all groups, but cladocerans, had occurred by 1987.

The littoral rotifers dominated the community during 1985 and suffered severe losses during 1986 following impoundment. Those littoral rotifers were replaced by planktonic rotifers from L Lake during 1986, while in 1987, littoral rotifer species returned. Many of the original littoral cladoceran species were lost by 1986 only to be replaced by a single cladoceran, *Chydorus brevilabris*, and several new species of copepods. By 1987, the Steel

Creek swamp and delta region appeared to be reaching a new, steady-state post-impoundment community structure. However, successional changes were probably not complete in this habitat and the community is expected to continue to change. The disappearance of limnetic zooplankton is common to reaches of streams located below reservoirs throughout the United States. Ward's (1975) study on the South Platte River below a large reservoir is a good example. Relative abundances of cladocerans, copepods, and rotifers decreased 79%, 91%, and 61%, respectively, over an 8.5 km stretch downstream from the reservoir.

Effect of L Lake Releases on Steel Creek Zooplankton

The abundance, diversity, and turnover of zooplankton populations in Steel Creek reflect zooplankton community composition and population densities in L Lake and flow rates from the L-Lake dam. Whether L Reactor was operational or not, zooplankton are continually introduced into the corridor region of Steel Creek, above the delta and swamp region. When L Reactor was restarted, populations of limnetic zooplankton are introduced into the corridor region of Steel Creek at an accelerated rate.

Zooplankton Taxa Found in Steel Creek

A comprehensive list of taxa identified from monthly zooplankton collections in Steel Creek at corridor and swamp and delta stations during 1984 and 1985 is given in Chimney and Cody 1986. These taxa represented three broad taxonomic categories including: the phylum Rotifera (33 taxa), and within the phylum Arthropoda, the order Cladocera (16 taxa), and the subclass Copepoda (9 taxa).

The most recent sampling has monitored zooplankton populations in Steel Creek and L Lake from 1986 through 1989. Stations in Steel Creek were averaged over the corridor (stations 275, 280, and 290) and swamp-delta (stations 310, 330, 350, and 370) regions from 1986 to 1989 (see Fig. StC-Zoo. 1 for locations).

Figure 14-29. Zooplankton Sampling Stations in Steel Creek

Species Densities

Cladoceran densities reached their greatest concentrations during the months of May and June for 1986, 1987, and 1988 (Fig. StC-Zoo. 2). Thereafter densities remained very low. Cladoceran densities in the corridor region most likely reflect populations originating from L Lake which significantly decreased after 1988 due to threadfin shad predation. Copepod populations also suffered to a much lesser degree from fish predation in L Lake (Fig. StC-Zoo. 3). However, copepod densities remained greater than 5/L throughout the study period. Greatest densities were observed during May 1986, May 1987, September 1987, and during the winter months of 1988. Variation between years and within each season was considerable due to natural variations and sampling. Rotifer densities also followed this pattern with no pronounced seasonal cycle that is often observed in lakes (Fig. StC-Zoo. 4). These patterns reflect two features of the lower Steel Creek. Zooplankton in L Lake are continually being washed into the corridor region, especially when flow rates ($>11 \text{ m}^3/\text{sec}$) were great due to L-Reactor operations. Furthermore, thermal loading into L Lake altered species composition and thus seasonal population cycles.

Seasonal Variations

Most of the zooplankton originating in L Lake are consumed by stream predators before reaching the delta and swamp regions. Significant populations only occur in very slow flowing sections. They do not play a significant role in community metabolism. Cladoceran populations were sporadic throughout the study period at very low densities without any marked seasonal trend (Fig. StC-Zoo. 5). Copepod densities also did not follow any seasonal pattern having their greatest abundances at several times in any given year (Fig. StC-Zoo. 6). Rotifer populations had their greatest densities during the months of February through April 1987, a period when all zooplankton groups were abundant (Fig. StC-Zoo. 6).

Figure 14-30. Zooplankton in Steel Creek

Figure 14-31. Zooplankton in Steel Creek

Figure 14-32. Zooplankton in Steel Creek

Figure 14-33. Zooplankton in Steel Creek

Figure 14-34. Zooplankton in Steel Creek

Macroinvertebrates

L Lake

Sampling Locations and Methods

316(a) Demonstration

From January 1986 through December 1989, macroinvertebrates were collected in Regions 4 through 8 of L Lake (Figure 14-35). Meroplankton was sampled monthly at night using vertical plankton tows. The benthic littoral community was sampled monthly at two depths (2 m and 4 m) using a ponar grab sampler. Emerging adult insects were collected during one week of every month from floating emergence traps placed in each region. In addition, littoral habitats were sampled quarterly in each region using a D-frame dip net.

Beginning in January 1990, the overall level of effort for the macroinvertebrate sampling program was reduced. All macroinvertebrate sampling was limited to Regions 5 and 7. Meroplankton and insect emergence were sampled monthly. Ponar samples were collected quarterly at 1 m, 2 m, and 4 m depths. Qualitative dip net sampling was continued on a quarterly basis in Regions 5 and 7. Details of sampling methods can be found in Lauritsen (1990) and Trapp (1992).

Figure 14-35. Macroinvertebrate Sampling Stations for L Lake

Results

Meroplankton

Like most lakes, the meroplankton community of L Lake was always overwhelmingly dominated by the phantom midge (*Chaoborus punctipennis*), which comprised 94.3 to 99.9% of the organisms collected annually in the meroplankton samples. Other macroinvertebrate taxa that were commonly collected in the plankton nets included the oligochaetes *Stylaria lacustris*, *Nais behningi*, and *Nais variabilis*; the amphipod *Hyalella azteca*; and several genera of chironomids (Trapp 1992). Meroplankton densities during the six-year period ranged from 17,168.6 organisms/1000 m³ in Region 8 in 1986 to 206,486.4 organisms/1000 m³ in Region 4 in 1987 (Table 14-30). Meroplankton densities at all stations were lowest in 1986 and highest in 1987 (Table 14-30). Meroplankton biomass followed a similar temporal pattern, with low biomass in 1986, followed by high biomass in 1987 as the lake community became more established. During the six-year period, mean annual meroplankton biomass ranged from 1.630 g/1000 m³ at Region 8 in 1986 to 15.371 g/1000 m³ in Region 5 in 1987 (Table 14-31). Meroplankton density and biomass were generally lowest in Region 8.

Benthic Macroinvertebrates

Dominant Taxa and Taxa Richness

The littoral benthic macroinvertebrate community of L Lake was numerically dominated by oligochaetes including *Lumbriculus variegatus*, *Limnodrilus hoffmeisteri*, *Nais communis*, and *Aulodrilus* sp.; turbellarians; the amphipod *Hyalella azteca*; and several genera of chironomids, including *Chironomus*, *Dicrotendipes*, and *Ablabesmyia*. In most regions, the

Table 14-30. Meroplankton Densities (Number/1000 m³) in L Lake, 1986–1991

Year	Region				
	4	5	6	7	8
1986	26,727.7	29,377.5	20,985.3	24,008.8	17,168.6
1987	206,486.4	181,274.3	157,701.5	137,218.2	112,996.5
1988	87,700.1	72,417.6	58,342.9	47,005.7	36,152.8
1989	130,247.6	124,361.5	106,123.7	96,569.3	78,433.8
1990	-	86,318.5	-	107,487.1	-
1991	-	82,206.0	-	97,921.6	-

Table 14-31. Meroplankton Biomass (g/1000 m³) in L Lake, 1986–1991

Year	Region				
	4	5	6	7	8
1986	2.024	2.567	2.009	2.024	1.630
1987	14.072	15.371	12.941	12.279	10.741
1988	5.807	3.869	4.034	2.443	2.553
1989	5.758	5.237	4.656	4.516	4.658
1990	-	4.930	-	7.115	-
1991	-	3.862	-	7.467	-

fewest number of taxa were collected during the first year of sampling (9.3 to 11.6 taxa) when the littoral community was first becoming established and the largest number were collected in 1989 (14.4 to 17.3 taxa; Table 14-32). Taxa richness in 1990 and 1991 was somewhat lower than in 1989 (Table 14-33). In general, taxa richness varied considerably with depth, between sampling stations within the same region, among regions and among seasons (Trapp 1992). However, no consistent pattern was discernible for any of these parameters.

Densities

Benthic densities were also lowest in 1986, ranging from 3955.5 to 4471.6 organisms/m² (Table 14-33). The density of organisms in most regions peaked in 1988 or 1989, with densities of approximately 10,000 to 12,000 organisms/m² occurring in all regions except Region 8, where the maximum mean annual density was 8948.1 organisms/m². Densities in 1991 were substantially lower for both Regions 5 and 7, averaging less than 7000 organisms/m². The density patterns exhibited in L Lake are typical of that reported for many new reservoirs, with densities peaking in the third or fourth year, and then declining somewhat as the ecosystem approaches equilibrium.

Biomass

Benthic biomass followed a similar trend, with very low biomass (<1 g/m²), reported for all regions during 1986, followed by a gradual increase in 1987 and 1988 (Table 14-34). Biomass in most regions peaked in 1989 or 1990, with standing crops as high as 17.182 g/m² reported. Biomass in 1991 was somewhat lower than in the previous two years. Biomass in

Table 14-32. Monthly Mean Number of Macroinvertebrate Taxa Collected from Ponar Dredge Samples in L Lake, 1986–1991

Year	Region				
	4	5	6	7	8
1986	11.6	10.4	12.2	10.1	9.3
1987	11.8	11.1	11.5	10.3	10.2
1988	15.3	14.7	14.0	12.9	11.8
1989	17.3	16.3	17.3	16.1	14.4
1990	-	15.1	-	15.7	-
1991	-	13.0	-	14.1	-

Table 14-33. Benthic Macroinvertebrate Density (No./m²) in L Lake, 1986–1991

Year	Region				
	4	5	6	7	8
1986	4091.9	4072.8	4471.6	3955.5	3955.8
1987	8066.4	8676.3	8481.9	8503.2	7672.5
1988	10,773.1	11,029.6	11,694.1	11,017.4	8948.1
1989	10,933.1	9897.5	11,762.3	10,671.4	7617.4
1990	-	10,601.6	-	11,713.1	-
1991	-	6586.2	-	6966.7	-

Table 14-34. Benthic Macroinvertebrate Biomass (g/m²) in L Lake, 1986–1991

Year	Region				
	4	5	6	7	8
1986	0.768	0.907	0.764	0.755	0.749
1987	1.307	1.421	1.248	1.449	1.255
1988	1.322	4.227	2.790	3.177	2.074
1989	17.182	13.554	6.829	5.180	2.094
1990	-	16.424	-	11.520	-
1991	-	10.142	-	4.183	-

Region 8 was always substantially lower than in the other regions, ranging from 0.749 to 2.094 g/m². Benthic habitat in Region 8 was poorer than that of the other regions of the lake, primarily due to the presence of large areas of hard-packed clay, which provided a poor substrate for most species of macroinvertebrates. The biomass patterns exhibited in L Lake is typical of that reported for many new reservoirs, with biomass peaking in the third or fourth year, and then declining somewhat as the ecosystem approaches equilibrium.

Emergence Traps

Emergence traps were used in L Lake to document successful reproduction of aquatic insects in the reservoir and to collect taxa that might be missed by other sampling methods. The majority of the insects collected from the emergence traps were chironomids. The most prevalent taxa included *Glyptotendipes* spp., *Procladius sublettei*, *Cricotopus* sp., *Nanocladius* sp., *Ablabesmyia* sp., *Labrundinia* spp., *Tanytarsus* spp., and *Cladotanytarsus viridiventris* (Lauritsen 1990; Trapp 1992). Other dipterans caught in the traps included *Chaoborus punctipennis*, Ephydriidae and Cetatopogonidae. Mayflies and caddisflies were also collected in low numbers (Lauritsen 1990). As expected, emergence rates were typically highest during the spring and summer months (Trapp 1992). Annual mean emergence rates during the six year period ranged from 0.62 insects/m²/day in Region 5 in 1991 to 36.47 insects/m²/day in Region 4 in 1988. Emergence rates were fairly comparable in 1986 through 1989, but were much lower in 1990 and 1991 (Trapp 1992).

Steel Creek

Sampling Locations and Methods

Comprehensive Cooling Water Study

Macroinvertebrates were collected at 11 stations in Steel Creek and two stations in Meyers Branch in 1983-1985 as part of the CCWS (Figure 14-36). CCWS data will not be discussed here, since the data collected subsequent to impoundment of Steel Creek are more representative of present conditions. A summary of the CCWS macroinvertebrate data for Steel Creek can be found in Specht (1987).

316(a) Demonstration

From January 1986 through December 1991, macroinvertebrates were collected at up to 12 stations throughout the Steel Creek corridor, marsh/swamp, and lower channel regions and at one station in the Meyers Branch tributary of Steel Creek.

In 1986 through 1989 macroinvertebrates were sampled monthly with Hester-Dendy multi-plate samplers at each of the 13 sampling stations. Macroinvertebrate drift and insect emergence were sampled monthly at seven stations. Macroinvertebrates were collected from natural substrates, including snags, macrophytes and sediment cores semiannually at seven stations and qualitative sampling of natural substrates was conducted semiannually at 13 stations (Lauritsen and Hosey 1990).

In 1990 and 1991 the overall level of effort for macroinvertebrate sampling was reduced. All sampling was restricted to four stations. Hester-Dendy samples, drift, and qualitative dip net samples were collected quarterly at each of the four stations. Natural substrates were sampled semiannually. Emergence continued to be sampled on a monthly basis, but beginning in June 1990, a different type of emergence trap was used (Trapp and Hosey 1992). Due to the changes in sampling frequency for most parameters, data from 1990-1991 are not directly comparable to the 1986-1989 data. However, for summary purposes, annual means for the data for all six years will be presented.

Results

Introduction

Steel Creek and Meyers Branch both support diverse and productive macroinvertebrate communities. Macroinvertebrate taxa richness, densities and biomass in Steel Creek were

Figure 14-36. Macroinvertebrate Sampling Stations for Steel Creek

generally similar to what has been observed in reference streams at the Savannah River Site, as well as in other southeastern streams. The macroinvertebrate community in the stream corridor downstream from L Lake is strongly influenced by seston inputs from the reservoir. The corridor stations contain high densities and biomass of filter-feeding organisms. The macroinvertebrate communities of the delta and lower creek channel appeared to be little affected by the impoundment of Steel Creek, although *Chaoborus* and other lentic species were collected at times, particularly in the drift samples.

Taxa Richness

Taxa richness (mean number of macroinvertebrate taxa per station) on Hester-Dendy multiple samplers ranged from 35 to 103 (Table 14-35). In general, taxa richness was lowest just downstream from L Lake (Stations 275 and 280) and at stream channel Station 360. Taxa richness in Meyers Branch, on the average, was a little higher than at most stations in Steel Creek.

Dominant Taxa

Dominant groups of taxa in Steel Creek and Meyers Branch included dipterans (13.0 to 94.2%), caddisflies (1.0 to 46.5%), oligochaetes (0.3 to 36.9%) and mayflies (20.1 to 21.5%; Table 14-36). Gastropods (snails), isopods, and amphipods were also locally abundant in the delta.

From 1986 to 1992, the relative abundance of dipterans decreased at most stations, while the relative abundance of oligochaetes, caddisflies and mayflies increased (Lauritsen and Hosey 1990, Trapp and Hosey 1992).

Although species composition differed somewhat among stations and among years, the most common taxa collected on the multiplate samplers in the Steel Creek corridor included filter-feeding organisms such as *Simulium* (blackflies), tanytarsine and orthoclad chironomids, and net-spinning caddisflies such as *Cheumatopsyche* and *Hydropsyche*. In the delta, amphipods (*Hyalella azteca* and *Gammarus fasciatus*), oligochaetes, caddisflies (*Cheumatopsyche* and *Oxythira*), isopods (*Caecidotea*), gastropods (*Amnicola*, *Physella*, *Menetus*, and limpets), the mayflies *Baetis*, *Eurylophella*, and *Stenonema* and the chironomid groups Tanypodinae, Orthoclaadiinae, Chironomini, and Tanytarsini were most abundant. Dominant taxa at the channel stations included oligochaetes, the mayfly, *Stenonema*, and orthoclad and tanytarsine chironomids.

Densities

The mean annual density of organisms collected from the multiplate samplers ranged from 294.7 organisms/m² at delta Station 330 in 1990 to 41,080.3 organisms/m² at corridor Station 275 in 1988 (Table 14-37). Macroinvertebrate densities just downstream from the L-Lake dam at Station 275 were always much higher than at the other stations, due to the presence of numerous filter-feeding organisms that fed on the seston inputs flowing into the stream from L Lake. In general, macroinvertebrate densities were higher in the upper stream corridor than in the delta. In the stream channel downstream from the delta, densities were always lower at Station 360 than near the creek mouth (Station 370). In Meyers Branch, macroinvertebrate densities were usually fairly similar to densities in the Steel Creek delta (Table 14-39). Although macroinvertebrate densities at all stations varied considerably among years, no distinct temporal trends were observed during the six-year study (Table 14-39).

Standing Crop

Macroinvertebrate standing crop on the multiplate samplers, as measured by ash-free dry mass/m², ranged from 0.001 g/m² at Station 370 in 1990 to 8.220 g/m² at Station 275 in 1988 (Table 14-38). In general, standing crop followed the same patterns as density, with the highest biomass usually found at stations in the stream corridor just downstream from the L-Lake dam. No distinct temporal trends were observed.

Drift

Densities

Mean annual densities of macroinvertebrate drift in Steel Creek ranged from 1653.6 organisms/1000 m³ at Station 310 in 1991 to 35,880.7 organisms/1000 m³ at this same station in 1990 (Table 14-39). Very high drift densities were reported at delta Stations 330 and 350 during the spring of 1990. No obvious reason for the high drift densities was reported. Drift could not be collected at these two stations during the spring of 1991 due to low water levels (Trapp and Hosey 1992).

Dominant Species

Dominant taxa collected in the drift included oligochaetes; hydroptilid caddisflies (*Oxyethira* and *Hydroptila*); the mayflies *Baetis*, *Caenis*, and *Stenonema*; the amphipod, *Hyalella azteca*; water mites; blackflies (*Simulium*); the phantom midge, *Chaoborus punctipennis*; and the chironomids *Rheotanytarsus*, *Cricotopus* and *Orthocladius*. The taxonomic composition of the drift varied greatly on a seasonal basis.

Table 14-35. Mean Number of Macroinvertebrate Taxa/Station Collected from Hester-Dendy Multiplate Samplers in Steel Creek and Meyer's Branch, 1986-1991

Station	Year					
	1986	1987	1988	1989	1990	1991
<i>Corridor</i>						
275	38	35	39	52	36	-
280	41	48	52	53	-	-
285	49	47	61	51	-	-
290	54	59	57	56	70	103
<i>Delta</i>						
300	55	49	63	49	-	-
310	53	46	57	48	-	-
320	54	54	57	51	-	-
330	54	60	48	57	69	87
340	50	55	64	69	-	-
350	51	51	60	67	57	82
<i>Channel</i>						
360	36	36	56	45	-	-
370	41	52	60	60	76	60
<i>Meyer's Branch</i>						
400	56	62	60	54	-	-

Table 14-36. Relative Abundance of Macroinvertebrate Groups in Steel Creek, 1986-1991

Year	Station												
	275	280	285	290	400	300	310	320	330	340	350	360	370
<i>Oligochaeta</i>													
1986	1.4	4.1	6.5	1.2	0.3	27.1	5.6	5.0	6.8	3.9	1.4	0.5	0.3
1987	4.1	6.8	2.8	1.2	3.2	7.6	5.6	18.1	6.5	8.1	6.7	0.6	1.1
1988	1.8	1.8	1.4	1.4	0.4	7.3	3.1	13.3	4.2	7.0	7.0	3.4	0.6
1989	4.4	2.5	2.4	2.3	1.2	36.9	10.0	22.2	14.3	18.0	9.2	7.9	6.1
1990	5.6	-	-	2.3	-	-	-	-	6.7	-	7.1	-	10.2
1991	-	-	-	4.8	-	-	-	-	4.7	-	4.8	-	7.5
<i>Nematoda</i>													
1986	<0.1	0.1	0.2	0.4	0.2	0.1	0.5	0.7	0.9	0.3	0.4	0.3	<0.1
1987	<0.1	0.1	0.4	0.5	1.0	1.3	1.3	1.4	0.7	0.3	0.4	0.6	0.2

Year	Station												
	275	280	285	290	400	300	310	320	330	340	350	360	370
1988	<0.1	<0.1	0.2	0.1	0.2	0.5	0.5	2.9	0.3	1.5	0.7	0.2	<0.1
1989	<0.1	0.1	0.2	0.3	0.4	1.2	0.6	1.1	0.8	0.9	0.5	0.3	0.5
1990	0.4	-	-	1.7	-	-	-	-	1.3	-	8.0	-	5.3
1991	-	-	-	4.6	-	-	-	-	1.9	-	7.3	-	1.1
<i>Platyhelminthes</i>													
1986	<0.1	<0.1	0.6	<0.1	<0.1	<0.1	0.9	1.7	0.5	1.7	0.3	0.1	<0.1
1987	<0.1	0.1	<0.1	0.1	<0.1	3.3	2.0	4.5	1.1	4.0	2.0	0.1	0.5
1988	0.3	0.3	0.1	<0.1	<0.1	2.1	0.4	2.3	0.6	0.8	1.2	0.4	0.5
1989	1.0	0.1	<0.1	0.2	0.1	1.3	0.6	2.8	0.7	2.1	2.2	0.3	<0.1
1990	5.6	-	-	0.0	-	-	-	-	0.0	-	2.8	-	2.1
1991	-	-	-	0.0	-	-	-	-	13.0	-	3.6	-	0.0
<i>Hirundinea</i>													
1986	<0.1	0.0	<0.1	<0.1	0.0	1.3	0.2	0.3	0.2	0.8	<0.1	0.1	<0.1
1987	<0.1	<0.1	<0.1	<0.1	<0.1	2.3	0.2	0.6	0.4	0.3	0.1	0.6	0.2
1988	<0.1	<0.1	0.1	<0.1	<0.1	0.5	0.4	2.9	0.2	2.2	1.4	<0.1	<0.1
1989	<0.1	<0.1	<0.1	<0.1	0.0	0.7	0.2	0.3	0.2	0.4	0.2	0.2	12.6
1990	0.4	-	-	3.2	-	-	-	-	2.7	-	1.7	-	0.0
1991	-	-	-	0.0	-	-	-	-	1.4	-	2.5	-	0.0
<i>Gastropoda</i>													
1986	0.1	0.2	0.8	0.6	1.3	14.3	6.8	8.8	3.5	17.6	2.2	0.9	0.1
1987	1.4	0.3	0.7	0.5	1.6	14.6	8.2	12.8	12.8	11.2	4.1	0.3	0.7
1988	0.5	0.3	1.2	0.4	1.9	7.6	5.4	10.3	2.9	20.1	3.4	1.0	0.7
1989	1.6	0.3	0.4	0.2	2.6	2.4	3.1	24.4	2.0	6.5	3.2	0.5	2.1
1990	1.0	-	-	4.7	-	-	-	-	11.8	-	11.4	-	17.9
1991	-	-	-	2.3	-	-	-	-	8.0	-	13.6	-	3.8
<i>Decapoda</i>													
1986	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1	<0.1	0.0	0.0	<0.1	0.0	0.0
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	0.0	0.0	0.0
1988	0.0	0.0	0.0	0.0	<0.1	<0.1	0.4	0.1	0.1	0.1	0.2	0.3	<0.1
1989	<0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	<0.1	<0.1	0.0	0.2
1990	0.0	-	-	0.0	-	-	-	-	1.9	-	0.0	-	0.0
1991	-	-	-	0.4	-	-	-	-	1.5	-	1.0	-	1.1
<i>Isopoda</i>													
1986	0.0	0.0	<0.1	<0.1	0.0	8.8	4.8	2.2	0.5	0.0	<0.1	<0.1	<0.1
1987	0.0	<0.1	<0.1	<0.1	0.0	6.0	2.5	4.3	1.2	0.1	0.3	0.1	<0.1
1988	0.0	<0.1	<0.1	<0.1	<0.1	8.9	1.5	<0.1	0.9	0.1	0.1	0.2	<0.1
1989	0.0	0.0	<0.1	<0.1	0.0	0.5	0.3	<0.1	0.4	0.0	<0.1	0.1	<0.1
1990	0.0	-	-	0.0	-	-	-	-	11.9	-	1.0	-	2.3
1991	-	-	-	0.2	-	-	-	-	23.7	-	4.6	-	1.5
<i>Amphipoda</i>													
1986	<0.1	<0.1	<0.1	0.1	0.1	1.2	13.4	14.4	12.9	2.2	7.1	3.2	0.8
1987	<0.1	0.0	0.0	<0.1	0.1	7.3	12.1	4.1	7.4	1.1	5.6	2.8	2.5

Year	Station												
	275	280	285	290	400	300	310	320	330	340	350	360	370
1988	0.0	<0.1	<0.1	<0.1	0.2	13.8	15.3	0.8	16.3	1.1	6.4	12.8	4.3
1989	<0.1	<0.1	<0.1	<0.1	0.3	1.8	12.7	1.3	6.4	1.0	8.6	4.5	3.1
1990	0.8	-	-	0.0	-	-	-	-	16.0	-	13.0	-	12.7
1991	-	-	-	1.0	-	-	-	-	11.0	-	6.4	-	5.1
<i>Hydracarina</i>													
1986	<0.1	0.3	1.5	1.8	0.3	0.1	0.5	0.2	0.9	0.4	0.5	0.2	0.2
1987	<0.1	0.6	0.8	2.0	0.7	0.2	0.4	1.2	0.7	0.5	0.5	1.1	0.4
1988	<0.1	0.4	0.5	0.6	0.3	0.8	0.7	0.7	1.3	0.8	0.6	0.9	0.2
1989	0.2	0.2	0.4	0.8	0.4	1.9	1.7	0.3	1.4	0.8	0.8	1.6	1.1
1990	0.4	-	-	6.3	-	-	-	-	9.3	-	2.8	-	3.5
1991	-	-	-	13.8	-	-	-	-	8.1	-	6.4	-	8.1
<i>Collembola</i>													
1986	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	0.0	0.0	0.0	0.0
1987	0.0	<0.1	0.0	0.0	0.0	0.0	0.1	<0.1	0.1	0.0	<0.1	0.1	0.0
1988	0.0	0.0	0.0	0.0	0.0	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	<0.1
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1	0.0	<0.1	0.0
1990	0.0	-	-	3.3	-	-	-	-	3.5	-	0.0	-	1.4
1991	-	-	-	0.2	-	-	-	-	1.6	-	0.8	-	0.0
<i>Ephemeroptera</i>													
1986	<0.1	0.7	3.5	4.2	6.2	0.7	6.1	3.3	12.0	7.4	6.9	7.4	2.7
1987	<0.1	0.6	1.9	5.1	14.2	2.8	7.7	2.5	11.1	16.3	8.4	15.3	10.3
1988	0.1	2.9	6.3	6.9	15.0	6.5	7.3	3.6	21.1	9.5	7.2	14.8	7.6
1989	0.6	5.0	8.9	4.8	9.7	2.6	5.5	3.8	7.2	7.3	7.4	21.5	13.6
1990	0.4	-	-	14.8	-	-	-	-	4.0	-	6.9	-	10.2
1991	-	-	-	8.1	-	-	-	-	3.8	-	7.8	-	9.6
<i>Plecoptera</i>													
1986	0.0	<0.1	0.1	0.4	1.3	<0.1	0.0	0.0	<0.1	0.0	0.0	0.0	<0.1
1987	0.0	<0.1	<0.1	0.3	2.9	0.0	0.0	0.0	0.0	<0.1	<0.1	0.0	0.1
1988	0.0	0.1	0.3	0.6	3.8	<0.1	0.0	0.0	<0.1	0.1	<0.1	<0.1	<0.1
1989	<0.1	0.1	0.4	0.4	4.3	<0.1	0.1	0.1	<0.1	0.1	<0.1	0.1	0.1
1990	0.0	-	-	2.4	-	-	-	-	1.6	-	0.0	-	1.4
1991	-	-	-	3.3	-	-	-	-	0.7	-	0.0	-	2.2
<i>Coleoptera</i>													
1986	<0.1	0.2	0.7	0.2	2.3	0.2	0.6	0.1	0.4	0.6	0.9	0.5	0.3
1987	<0.1	0.3	0.6	0.2	4.5	0.1	0.2	<0.1	0.3	0.4	1.1	0.9	1.2
1988	<0.1	0.1	0.4	0.1	2.7	0.3	0.1	0.1	0.4	0.8	1.1	1.3	0.9
1989	<0.1	<0.1	0.5	0.3	2.9	0.4	0.1	0.2	0.1	0.7	1.1	1.1	1.4
1990	0.0	-	-	4.8	-	-	-	-	0.4	-	1.9	-	5.3
1991	-	-	-	8.3	-	-	-	-	2.2	-	3.0	-	3.4
<i>Trichoptera</i>													
1986	13.5	22.1	6.6	16.2	6.4	1.2	9.3	2.1	6.5	2.6	2.8	9.4	4.3
1987	2.3	13.9	3.5	16.5	8.6	1.0	1.8	2.1	6.8	1.5	2.3	8.7	11.0
1988	3.0	36.0	7.6	17.7	9.1	3.1	3.1	3.8	7.0	3.1	3.2	10.8	6.8

Year	Station												
	275	280	285	290	400	300	310	320	330	340	350	360	370
1989	20.2	46.5	19.0	29.9	7.8	6.7	10.4	2.1	8.6	4.6	8.5	5.9	5.3
1990	21.0	-	-	21.9	-	-	-	-	5.9	-	5.9	-	7.5
1991	-	-	-	9.0	-	-	-	-	2.7	-	4.5	-	20.9
<i>Odonata</i>													
1986	<0.1	0.0	0.0	<0.1	<0.1	0.8	0.8	1.2	1.5	0.7	0.5	0.1	<0.1
1987	<0.1	<0.1	0.0	<0.1	0.1	1.4	0.7	0.3	0.6	0.6	0.3	0.0	0.0
1988	<0.1	<0.1	<0.1	<0.1	<0.1	1.9	0.7	0.2	0.5	1.1	0.9	0.3	0.2
1989	0.4	-	-	2.1	-	-	-	-	1.3	-	5.2	-	1.0
1990	-	-	-	0.4	-	-	-	-	1.8	-	5.3	-	0.0
1991													
<i>Diptera</i>													
1986	84.9	72.2	79.2	74.7	81.2	44.0	50.2	59.7	53.1	61.8	76.7	76.7	91.2
1987	91.9	76.2	88.9	73.4	62.5	51.9	56.9	47.9	49.8	55.5	68.1	68.9	71.1
1988	94.2	57.7	81.4	72.0	65.7	45.9	60.7	57.4	44.1	51.0	66.3	53.2	77.7
1989	71.5	44.7	67.3	60.5	69.5	42.3	54.1	40.3	57.4	56.6	57.1	55.2	53.2
1990	63.6	-	-	25.5	-	-	-	-	16.6	-	30.3	-	15.8
1991	-	-	-	41.6	-	-	-	-	13.0	-	27.4	-	35.1

Table 14-37. Mean Annual Macroinvertebrate Densities (No./m²) on Hester-Dendy Multiplate Samplers in Steel Creek and Meyer's Branch, 1986–1991

Station	Year					
	1986	1987	1988	1989	1990	1991
<i>Corridor</i>						
275	15,078.1	8258.5	41,080.3	12,456.5	-	-
280	6688.8	5853.8	5206.5	5680.5	-	-
285	3400.4	2347.5	3788.8	2518.5	-	-
290	3113.6	3635.6	4376.6	3849.8	6535.8	4277.9
<i>Delta</i>						
300	1138.7	732.5	794.7	631.8	-	-
310	864.5	770.3	892.5	595.3	-	-
320	1751.4	1548.7	870.5	577.6	-	-
330	889.7	1202.4	688.7	1023.8	294.7	695.5
340	1086.7	1032.9	754.3	1125.9	-	-
350	1176.9	880.5	748.1	1042.7	586.6	722.5
<i>Channel</i>						
360	486.0	414.2	631.4	410.8	-	-
370	2996.3	995.1	1815.2	635.5	611.7	1141.1
<i>Meyer's Branch</i>						
400	1472.7	837.4	818.7	557.9	-	-

Table 14-38. Mean Annual Macroinvertebrate Biomass (g/m²) on Hester-Dendy Multi-plate Samplers in Steel Creek and Meyer's Branch, 1986–1991

Station	Year					
	1986	1987	1988	1989	1990	1991
<i>Corridor</i>						
275	4.634	1.217	8.220	3.575	-	-
280	1.428	1.033	1.750	2.404	-	-
285	0.370	0.336	0.611	1.178	-	-
290	0.335	0.356	0.518	0.493	0.254	0.613
<i>Delta</i>						
300	0.184	0.107	0.123	0.069	-	-
310	0.407	0.156	0.338	0.287	-	-
320	0.551	0.204	0.367	0.768	-	-
330	0.197	0.220	0.284	0.374	0.097	0.529
340	0.204	0.145	0.106	0.310	-	-
350	0.126	0.128	0.185	0.271	0.015	0.008
<i>Channel</i>						
360	0.323	0.103	0.315	0.351	-	-
370	0.494	0.289	0.388	0.202	0.001	0.170
<i>Meyer's Branch</i>						
400	0.152	0.110	0.146	0.197	-	-

Table 14-39. Mean Annual Density (No./1000 m³) of Macroinvertebrate Drift in Steel Creek and Meyer's Branch, 1986–1991

Station	Year					
	1986	1987	1988	1989	1990	1991
<i>Corridor</i>						
275	1976.9	4684.7	3712.9	3704.9	-	-
280	4976.1	5363.4	5187.4	1995.2	-	-
290	3426.2	6422.3	2772.6	1807.1	2606.9	4184.6
<i>Delta</i>						
310	4741.0	4639.6	3793.0	2908.2	-	-
330	2669.4	6216.8	2083.5	4361.8	35,880.7	1653.6
350	3417.9	3016.7	1980.3	1895.5	26,613.3	3076.4
<i>Channel</i>						
370	2696.3	2974.3	2100.0	1758.1	8111.2	4718.3

Fish

L Lake

Introduction

The fish community in L Lake was extensively sampled from January 1986 to December 1989; this sampling began approximately two months after the lake was filled in November 1985. Somewhat less-extensive sampling continued from January 1990 through December 1992. Both adult and larval fish assemblages were sampled. The extensive sampling program on L Lake provided an unusually complete database documenting the development of the fish community and the relationship between the fish community and other trophic levels. Most of the following discussion is based on research reported in Paller et al. (1992).

Discussion

Sampling Methods

The lower end of L Lake was divided longitudinally into five sampling regions (Regions 4–8) (Figure 14-37). Throughout these regions 20 electrofishing sample stations were distributed during January 1986–December 1989; this number was reduced to 8 during January 1990–December 1992. Each sample station consisted of a 100 m transect parallel to the shoreline following the 1-m depth contour. Electrofishing samples were also collected from many of the artificial reefs in Regions 4–8 (Figure 14-37). Electrofishing was conducted at night on a monthly basis from January 1986 to December 1990 and quarterly thereafter.

Figure 14-37. Fish Sampling Stations for L Lake

Ichthyoplankton were collected with paired 0.5-m diameter, 0.505 mm mesh plankton nets during darkness. During January 1986–December 1989 collections were made weekly during February–July and biweekly during the remaining months. During January 1990–December 1992 collections were made weekly from February–August. Temperature, dissolved oxygen concentration, pH, and conductivity were routinely measured *in situ* at the same times and locations where fish samples were collected (Paller et al. 1992) for more information on fisheries sampling methodologies).

Hydroacoustic methods were used to document the abundance of pelagic fishes. This technology was particularly useful in monitoring threadfin shad abundance (see Paller et al. 1988 for further details).

Artificial Stocking Program

L Lake was stocked with approximately 40,000 juvenile (20–30 mm) bluegill in the fall of 1985 and approximately 4000 juvenile largemouth bass in the spring of 1986.

Physical and Chemical Conditions in L Lake

L Lake stratified during the spring and summer due to climatic factors, as is typical of most southeastern lakes and reservoirs. However, stratification occasionally occurred during the winter due to density differences between thermal reactor discharges and underlying lake waters. L Lake received thermal effluent during November 1985–June 1986, December 1986–June 1987 and January 1988–June 1988. Temperatures in excess of 40°C occurred near the L-Reactor outfall during periods of reactor operation. However, the maximum recorded water temperature in Regions 4–8 was approximately 34°C in June 1986. This temperature was approximately 2°C higher than the maximum temperatures in unheated southeastern reservoirs. The highest recorded 24-h mean temperature in Regions 4–8 was 32°C. While the highest temperatures occurred in June, the highest above ambient occurred during the winter and early spring when L Lake waters were elevated as much as 5°C. Littoral zone temperatures exhibited little consistent spatial variation within the study area (Regions 4–8).

When L Lake stratified, hypolimnetic waters became anoxic; however, the epilimnion remained oxygenated throughout this study. The lowest 24-h mean dissolved oxygen concentration in the littoral and epilimnetic waters of L Lake was approximately 5 mg/l and the minimum recorded concentration was approximately 3 mg/l. None of the other 36 water-quality variables monitored in the littoral zone of L Lake reached levels detrimental to warm-water fishes.

Species that Failed to Colonize L Lake

Most of the 28 species of fish present in the reach of Steel Creek that was impounded to create L Lake failed to colonize L Lake. At least seven of the species that failed to colonize L Lake are known to prefer sites with relatively fast flowing water; they are tessellated darter (*Etheostoma olmstedi*), blackbanded darter (*Percina nigrofasciata*), Savannah darter (*Etheostoma fricksium*), bluehead chub (*Nocomis leptoccephalus*), speckled madtom (*Noturus leptacanthus*), northern hogsucker (*Hypentilium nigricans*), and yellowfin shiner (*Notropis lutipinnis*) (Meffe and Sheldon 1988). Other species that did not colonize L Lake from Steel Creek may have had other types of habitat requirements that were not met in L Lake.

For example, chain pickerel (*Esox niger*), redbfin pickerel (*Esox americanus*), and eastern mudminnow (*Umbra pygmaea*) require aquatic vegetation for successful reproduction (Laerm and Freeman 1986), and spotted sucker (*Minytrema melanops*) generally require riffle areas. Neither habitat was present in L Lake when initial colonization was occurring. None of the preceding species were collected from L Lake in more than trace numbers; they may have avoided L Lake because of unsuitable habitat or entered L Lake but failed to successfully reproduce. Thus, the first stage of colonization was controlled by the habitat requirements of the species that occupied Steel Creek prior to impoundment.

Successful early colonists of L Lake

Early Colonists

Only eight species of fish found in Steel Creek before it was impounded entered L Lake in substantial numbers: mosquitofish (*Gambusia affinis*), brook silverside (*Labidesthes sicculus*), coastal shiner (*Notropis petersoni*), golden shiner (*Notemigonus chrysoleucas*), creek chubsucker (*Erimyzon oblongus*), dollar sunfish (*Lepomis marginatus*), redbreast sunfish and spotted sunfish (*Lepomis punctatus*) (Table 14-40). These eight species can be divided into three groups—those that did not reproduce in L Lake, those that reproduced but did not persist, and those that persisted.

Table 14-40. Electrofishing Catch Rates Over Time in L Lake. Only Dominant Taxa and Catch Rates ≥ 0.1 Fish/Minute are Shown.

Species	1986						1987						1988						Number fish
	Jan Feb	Mar Apr	May Jun	Jul Aug	Sept Oct	Nov Dec	Jan Feb	Mar Apr	May Jun	Jul Aug	Sept Oct	Nov Dec	Jan Feb	Mar Apr	May Jun	Jul Aug	Sept Oct	Nov Dec	
mosquitofish	2.0	0.1	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	922
creek chubsucker	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	68
brook silverside	0.3	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	158
coastal shiner	1.5	1.0	1.2	0.5	0.6	0.2	0.3	-	-	-	-	-	-	-	-	-	-	-	1905
golden shiner	0.9	0.3	1.0	0.2	0.1	0.2	0.2	0.1	-	-	-	-	-	-	-	-	-	-	1025
dollar sunfish	0.3	0.3	0.2	0.2	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	456
spotted sunfish	0.6	0.2	0.5	0.3	0.3	0.1	0.5	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	-	-	926
redbreast sunfish	3.4	0.8	1.7	4.9	8.9	6.8	3.9	4.5	7.3	7.0	7.1	7.1	6.0	7.0	5.8	4.2	5.6	5.3	26737
bluegill	0.1	-	0.1	32.2	52.0	44.7	23.4	11.2	22.7	14.7	12.0	19.8	16.9	11.0	6.6	5.6	8.3	13.1	79105
largemouth bass	-	-	0.3	0.5	0.6	1.1	0.5	0.9	0.9	1.1	1.5	1.2	0.9	0.8	0.6	0.8	0.9	0.8	3512
warmouth	-	-	-	-	-	-	-	-	0.1	0.1	0.1	0.1	-	0.1	0.1	0.1	0.1	0.2	274
flat bullhead	-	-	-	-	-	0.1	0.1	0.1	-	-	0.1	0.1	0.1	0.4	-	0.1	0.1	0.1	283
gizzard shad	-	-	-	-	-	-	-	-	-	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.1	377
threadfin shad	-	-	-	-	-	-	-	-	0.1	0.4	9.8	2.4	0.4	1.5	4.7	13.5	13.5	3.7	13399

Species that Did Not Reproduce in L Lake

The creek chubsucker and brook silverside, although collected from L lake as adults, probably did not reproduce based on an inability to collect larvae or juveniles of either species. These species quickly decreased in abundance after L Lake was filled and were virtually absent from the electrofishing catches by March 1986 and May 1986, respectively (Table 14-40).

Species that Reproduced but Did Not Persist in L Lake

Mosquitofish, golden shiner, coastal shiner, dollar sunfish and spotted sunfish were able to reproduce but did not persist in L Lake or declined to very low numbers over time (Table 14-40). Large schools of mosquitofish were observed swimming along the shoreline of L lake as it was filling in late 1985. Electrofishing catches for this species were relatively high in January 1986 but decreased in February and March (Figure 14-38). Catch rates again increased in April and May 1986 as fish that spawned in the spring (Figure 14-39) were recruited into the population. In June, however, numbers of mosquitofish declined precipitously leading to the disappearance of this species from L Lake by late 1986.

Coastal shiner and golden shiner were comparatively abundant in L Lake during January through May 1986 (Table 14-40, Figure 14-38) and successfully reproduced during this period as indicated by the collection of larvae (Figure 14-39). These larvae could not have drifted into L Lake from Steel Creek because Regions 4–8 of L Lake were separated from Steel Creek by a thermal barrier ($>40^{\circ}\text{C}$) created by the discharge of reactor effluent at the upper end of L Lake. In spite of their ability to reproduce, numbers of coastal shiner and golden shiner decreased sharply after May 1986 and both species disappeared from L Lake by mid 1987.

Dollar sunfish and spotted sunfish were relatively abundant during early 1986 but subsequently decreased in abundance (Table 14-40, Figure 14-38). Dollar sunfish persisted until mid-1987 and spotted sunfish persisted in very small numbers through the end of the study. Spotted sunfish and dollar sunfish were able to reproduce in L Lake, as indicated by the collection of relatively small individuals (under 80 mm) after June 1986 (juveniles collected prior to this may have been spawned in Steel Creek while L Lake was filling).

Species that Persisted in L Lake

Of the eight species that initially dominated the L Lake fish community, only redbreast sunfish increased in number. Unlike the aforementioned species, redbreast sunfish were recruited in large numbers in the summer of 1986 causing the electrofishing catch rate for this species to double or triple from spring levels (Table 14-40, Figure 14-40). Recruitment was also observed in 1987 and 1988. By 1988, this species supported a stable population with substantial numbers of individuals of all sizes from juvenile through adult.

Decline of the early colonists

Five species of fish established reproducing populations and initially dominated the L Lake fish community but later declined as related above. It is unlikely that this decline was caused by harsh abiotic conditions since critical water-quality variables, including dissolved oxygen concentration and temperature, did not reach levels in the littoral and epilimnetic portions of Regions 4-8 likely to be lethal to the early colonists.

Figure 14-38. Mean Electrofishing Catch Rates (Logarithmically Transformed) of Five Species of Fish that Colonized L Lake, But Then Declined (January 1986–December 1988)

Figure 14-39. Mean Fish Densities (no./1000 m³) in Regions 4-8 of L Lake During 1986 as Indicated by Plankton Net Tows

Figure 14-40. Mean Electrofishing Catch Rates (Logarithmically Transformed) of Three Species of Fish that Persisted After Entering L Lake (January 1986-December 1988)

The decline of most of the species that initially colonized L Lake coincided with the establishment and increase in number of other species of fish. Catch per unit effort of largemouth bass increased substantially beginning in April 1986 as fish stocked earlier in the spring and those spawned in L Lake early in 1986 grew to catchable size (Table 14-40, Figure 14-40). This increase in largemouth bass abundance began just before the abrupt decline of several of the initial colonists, and the monthly average electrofishing catch rate of largemouth bass was inversely correlated with the monthly average catch rates of the early colonists that later declined (i.e., dollar sunfish, spotted sunfish, coastal shiner, mosquitofish, and golden shiner summed) (Pearson $r=-0.78$, $P\leq 0.05$).

Bluegill catch per unit effort increased greatly in August 1986 due to the recruitment of large numbers of juvenile fish (Figure 14-40). The juvenile bluegill collected during the summer of 1986 were the progeny of fish stocked into L Lake in November 1985 and of the small numbers of bluegill that may have been present before stocking. Other species that became established in L Lake during 1987 and 1988 were threadfin shad (*Dorosoma petenense*), gizzard shad (*Dorosoma cepedianum*), warmouth (*Lepomis gulosus*), and flat bullhead (*Ictalurus platycephalus*) (Table 14-30). Larvae of some of these fish may have been transported to L Lake in unheated water pumped to the reservoir from the Savannah River during summer reactor outages.

By 1988 the initial fish fauna of Regions 4–8 of L Lake, with the exception of redbreast sunfish, had been replaced by later arriving species (Table 14-30). The only events that closely coincided with the decline of the unsuccessful early colonists were relatively sudden increases in the size of largemouth bass, bluegill, and redbreast sunfish populations. This concurrence of events coupled with an absence of negative changes in the abiotic environment indicates that interactions between the early colonists and the rapidly expanding species were responsible for the community changes observed during 1986.

Fish Assemblages Upstream from Regions 4–8

High temperatures ($>40^{\circ}\text{C}$) precluded the survival of fish above Regions 4–8 during periods of reactor operation. However, during the extended summer reactor outages, which lasted approximately six months, temperatures decreased to ambient levels permitting fish from Regions 4–8 to invade the upper portion of L Lake. When L Reactor was restarted in the fall, large numbers of these fish were killed by elevated temperatures (Paller et al. 1988). There was no indication, however, that these fish killed affected community structures in the lower portion (Regions 4–8) of L Lake.

Recent Status of the L Lake Fish Community

Largemouth bass, bluegill, redbreast sunfish, and threadfin shad have dominated the L Lake fish community since 1987. The most important trends in the fish community in recent years involve changes in the abundances of these species and interactions between the dominant fish species and lower trophic levels, particularly zooplankton. The latter have been documented by Taylor et al. (1992) who described zooplankton succession in L Lake during the three years following impoundment. During 1986 and 1987 larger macrozooplankton dominated the zooplankton assemblage. However, during 1988, *Bosmina longirostris*, the smallest of the cladocerans, was the most abundant macrozooplankton, and loricat rotifers dominated the zooplankton assemblage. Size selective predation by threadfin shad was implicated in this shift in community structure.

Several of the dominant fish taxa in L Lake have declined in abundance from previous levels. After reaching peak population densities in 1988, threadfin shad densities have declined to relatively low levels (Figure 14-41). Bluegill and redbreast sunfish numbers have also declined from earlier levels (Figure 14-41). Decreases in bluegill and redbreast sunfish numbers were associated with changes in condition (a measure of weight in relation to length) and size distribution (Sayers and Mealing 1992). There are several possible reasons for these changes, including predatory and competitive interactions and changes in the primary productivity of L Lake.

Steel Creek

Introduction

The fish assemblages of Steel Creek were first studied in 1976 (McFarlane 1976). However, extensive sampling began in 1983 and continued through 1985 (Paller et al. 1984, 1985, and 1986). These studies emphasized ichthyoplankton but also included limited sampling of adult and juvenile fish. Their objective was to assess the importance of spawning habitats in Steel Creek that could be damaged by the planned restart of L Reactor in late 1985.

Fisheries studies were intensified during 1986–1991 to document the effects of thermal effluents released from L Reactor on the fish assemblages of L Lake and Steel Creek. These comparatively extensive studies included both juvenile/adult and ichthyoplankton sample stations located throughout Steel Creek. The following discussion of fisheries studies in Steel Creek has been divided into two sections, pre L-Reactor restart and post L-Reactor restart.

Figure 14-41. Mean Annual Catch Per Unit Effort from Electrofishing Transects in L Lake

Studies Conducted Prior to the Restart of L-Reactor

Thermal effluent from L-Reactor was discharged directly into Steel Creek during 1954–1968, resulting in the destruction of the cypress-tupelo canopy in portions of the Steel Creek swamp and the stream corridor upstream from the swamp (Gladden et al. 1985). Loss of vegetational cover and high reactor flows also caused erosion in the stream corridor and the deposition of sediments where Steel Creek entered the Savannah River swamp. Areas of open canopy swamp previously impacted by high temperatures and sediment deposition came to support a marsh habitat characterized by an abundance of submerged and emergent macrophytes and woody plants such as willow and buttonbush.

McFarlane (1976) studied the fish assemblages in Steel Creek during to determine if it had recovered from previous thermal discharges from L-Reactor. He reported that recovery was “almost complete” based on comparisons of species richness between Steel Creek and nearby unimpacted streams.

Sampling efforts in Steel Creek during 1983–1985 were part of the Comprehensive Cooling Water Study, which evaluated the impacts of SRS operations on spawning activity and ichthyoplankton distribution at a number of sites on SRS and in the Savannah River. Special emphasis was placed on Steel Creek because of concerns that it would be negatively impacted by the restart of L Reactor after approximately 17 years of non-operation (with the exception of a brief operational period in the mid-1970s). Ichthyoplankton sampling was originally confined to the mouth of Steel Creek to document the contribution of Steel Creek to the ichthyoplankton assemblages of the Savannah River but was later expanded to include a number of sample sites in the swamp, marsh, and channel habitats located upstream from the stream mouth. Samples were also taken from the Savannah River and a number of other Savannah River tributaries to develop a basis for assessing the relative importance of Steel Creek compared with other spawning sites. Ichthyoplankton were collected with paired 0.505 mm mesh nets during daylight hours on a weekly basis from February through July. Sampling effort was approximately equal among years.

Ichthyoplankton composition in Steel Creek near its confluence with the Savannah River varied among years. Larval minnows (Cyprinidae), larval yellow perch (*Perca fluvescens*), larval sunfish/bass (Centrarchidae), and blueback herring (*Alosa estivalis*) were the most abundant taxa in 1983 (Table 14-41). Species composition was fairly similar in 1984 except that darters replaced yellow perch. However, species composition changed in 1985 when American shad, blueback herring, and darters were the dominant species and minnows and sunfishes were comparatively rare (Paller et al. 1984, 1985, and 1986).

In spite of this variability, Steel Creek was consistently one of the most productive Savannah River tributaries in terms of its contribution to the river ichthyoplankton assemblage. This contribution was assessed by determining the number of ichthyoplankton transported from creek to river (Paller et al. 1984, 1985, and 1986). In 1983 Steel Creek ranked ninth among the 33 tributaries under study (Table 14-41). This number included all the major tributaries between river mile 29.6 and 187.1. The only creeks with greater transport were located in lower reaches of the river. A similar pattern was observed during 1984 except that only three creeks transported more ichthyoplankton into the Savannah River than Steel Creek. In 1985 more ichthyoplankton were transported to the Savannah River from Steel Creek than from any other tributary under study. The numbers of ichthyoplankton transported from all creeks was much lower during 1985 than during 1984 or 1983, possibly due

to decreased creek discharges (79% lower during 1985 than 1984) or decreased spawning resulting from comparatively low water levels.

Ichthyoplankton transported from Steel Creek raised Savannah River ichthyoplankton levels by an estimated 10% in 1983, 12.8% in 1984, and 2% in 1985 (Paller et al. 1984, 1985, and 1986). All creeks made minimal contributions in 1985. While creek-to-river transport varied among years, Steel Creek consistently demonstrated high transport in relation to the other creeks in the mid-reaches of the Savannah River. Steel Creek also typically produced more American shad and blueback herring eggs and larvae than most of the other creeks. Relatively high ichthyoplankton transport from Steel Creek during three years with dissimilar hydrological patterns indicated that Steel Creek was an important spawning area compared with other Savannah River tributaries.

Early indications of the importance of Steel Creek as a spawning area led to further interest in locating and assessing the spawning and nursery areas in Steel Creek. Fifteen ichthyoplankton sample stations were established throughout Steel Creek (Paller et al. 1986); most were concentrated in the lower reaches of the creek which consisted of three main habitats: creek mouth, a channel connecting the creek mouth to the marsh/swamp, and the marsh/swamp. The marsh/swamp consisted of open canopy marsh habitats where previous discharges from L-Reactor killed the cypress-tupelo canopy and closed canopy cypress-tupelo swamp. Aquatic macrophytes were abundant in the open canopy areas.

Sampling was conducted weekly from February through July during 1984 and 1985 (Paller 1985, Paller et al. 1986). Spawning generally began in March, peaked in April and May, then declined through June and July. In 1984 ichthyoplankton densities were approximately comparable in the swamp/marsh and creek mouth; densities further upstream in Steel Creek were relatively low (Figure 14-41). In 1985 densities were highest in the creek mouth but also fairly high in the creek channel and at several locations upstream from the swamp/marsh. However, species composition differed among habitats with American shad, blueback herring, and darters predominating in the creek mouth and channel and minnows and darters predominating further upstream. These data indicated the importance of the creek mouth and creek channel habitats as spawning areas for anadromous fish.

Most of the ichthyoplankton sampling efforts in Steel Creek concentrated on assessing and comparing ichthyoplankton distribution among macrohabitats (i.e., creek mouth, marsh, swamp, upper creek). However, efforts were also made to assess the distribution of ichthyoplankton among microhabitats in portions of the Steel Creek marsh/swamp (Paller 1987). Three microhabitats (macrophyte beds, open channels, and macrophyte bed/open channel interface) were sampled by pumping water through a 0.505 mm mesh net with a trash pump. Samples were taken during day and night. The results demonstrated very high abundances of a number of taxa (suckers, minnows, pirate perch, and sunfishes) within the macrophyte beds indicating the importance of this habitat as a spawning or nursery area (Table 14-42). Larvae were seldom found in the open channels except at night. Larvae drifting in the open channels probably originated in the macrophyte beds and were invariably young. Many were undoubtedly transported out of Steel Creek into the Savannah River.

Aho et al. (1986) sampled adult/juvenile fishes by electrofishing in Steel Creek and two other streams to assess the persistence and stability of the fish assemblages in these streams. Steel Creek had slightly higher species richness and diversity than the other streams (Table 14-43). Species richness was highest in the lower reaches of all streams. While limited tem-

poral variability occurred at all sites, there were no consistent differences in degree of variability between sites on Steel Creek or between Steel Creek and the other streams under study.

Aho et al. (1986) also electrofished 12 sample sites in the Savannah River swamp system, three of which were in the Steel Creek marsh/swamp. Number of species and fish density were highest in the Steel Creek marsh where habitat diversity, structural complexity, and productivity were high as a result of abundant macrophyte growth and other factors related to the progression of secondary succession. Sites in the Steel Creek marsh were dominated by small-bodied species such as minnows and brook silversides while larger species were more common in closed canopy areas with less macrophyte growth. While the fish assemblages in the Steel Creek marsh/swamp varied temporally and annually, assemblage stability and persistence of species was generally high with most species repeatedly found over census periods and the rank order of species abundance remaining relatively constant over time.

Studies Conducted Following the Restart of L Reactor

The ecological importance of the lower reaches of Steel Creek led to the decision to build a cooling reservoir that would reduce the temperature of L-Reactor cooling water to environmentally acceptable levels. After the restart of L-Reactor in late 1985, the emphasis of fisheries studies in Steel Creek was on assessing possible impacts caused by the presence of L Lake and the operation of L Reactor. These studies initially included 14 sample stations located throughout Steel Creek, although this number was reduced to four in 1991. Adult/juvenile fish and ichthyoplankton were collected at each sample station.

There was a major change in reactor operations during the 1986–1992 study period that affected environmental conditions in Steel Creek. L-Reactor was operated from 1986 to mid-1988 resulting in the discharge of large volumes of water to Steel Creek. However, L Reactor was not operated following July 1988. The shutdown of L-Reactor coupled, in some instances, with decreases in natural runoff due to low rainfall resulted in greatly diminished reservoir releases to Steel Creek. Resulting instream changes included diminished depths, current velocities, and habitat volumes.

The Steel Creek sample stations represented a variety of habitats; these were categorized as corridor (the stream reach between the L Lake dam and the marsh/swamp), marsh (the open canopy area in the marsh/swamp), swamp (the closed canopy area in the marsh/swamp) and channel (the stream channel between the marsh/swamp and creek mouth) (Paller et al. 1987). Differences in habitat led to marked differences in species composition among sample sites. In addition, the impacts of reactor operation differed markedly among sites.

Marsh sample stations supported a diverse fauna of primarily small species such as minnows (particularly coastal shiner) sunfishes, and pirate perch (Table 14-44). Other species of importance were bullheads, chubsuckers, and largemouth bass. Closed canopy swamp stations supported fewer small fishes and more large fishes such as largemouth bass and chain pickerel (Table 14-45). Fish assemblages in the Steel Creek marsh/swamp showed little immediate change following the restart of L Reactor. Exceptions were a possible decrease in the abundance of brook silverside and an increase in the abundance of redbreast sunfish and bluegill. The latter species probably emigrated into the marsh from L Lake where it was found in large numbers. By 1988 it was probable that a reproducing population

of bluegill had become established in the Steel Creek marsh/swamp, although there was no sign that this species displaced indigenous swamp species (Heuer and Kissick 1989). Reductions in flow and depth associated with the shutdown of L Reactor in 1988 were associated with reductions in species richness and the abundance of some taxa, but this could have partly resulted from reduced sampling effort due to program changes and the inaccessibility of some sample stations (Sayers and Mealing 1992).

The greatest impacts of the L-Reactor restart occurred in the stream corridor. High densities of larvae and, in some cases, juveniles of species common in L Lake were observed immediately below the L Lake dam. This influx of L Lake species (in water discharged from L Lake) led to the temporary establishment of bluegill in the stream corridor and possibly permanent establishment of this species in the marsh/swamp as discussed. Other species observed to enter Steel Creek from L Lake were redbreast sunfish and gizzard shad (Heuer and Kissick 1989). While bluegill temporarily attained high numbers at several locations in the corridor and in Meyers Branch, a tributary of Steel Creek, they decreased over time and had no apparent effects on the stream's indigenous fish fauna. Meffe (1991) concluded that the failure of bluegill to establish permanent populations in Meyers Branch was the result of unfavorable habitat and the maintenance of natural flow regimes in this stream.

Additional impacts on the corridor fish assemblage resulted from large increases in current velocity and habitat volume due to the discharge of water from L Lake into Steel Creek. Pre-post comparisons indicated a decrease in species typical of small streams such as darters and some types of minnows (Paller et al. 1987). Species richness declined over time due to the loss of these species and the L-Lake species that colonized the corridor from L Lake as described above (Heuer and Kissick 1989). Fish assemblage structure continued to change following the shut-down of L-Reactor, with sunfishes and largemouth bass composing a larger proportion of the catch than in previous years. Fish abundance also appeared to decline, possibly reflecting lower habitat availability due to reduced flows (Sayers and Mealing 1992).

The channel below the marsh swamp initially experienced increased flows as a result of the discharge of L-Reactor effluent. However, pre-post comparisons demonstrated little measurable effect on fish assemblage structure (Paller et al. 1987). The ichthyofauna of the channel remained dominated by largemouth bass, longnose gar, catfish, spotted sucker, and minnows (Table 14-46), and ichthyoplankton collections demonstrated continued use of the channel as a spawning area by the anadromous American shad and blueback herring. Flow reductions following the shutdown of L-Reactor were associated with a shift in dominance to largemouth bass and minnows and a reduction in species richness (Sayers and Mealing 1992). The latter could be the result of reduced habitat availability, but it also coincided with a reduction in sampling effort that could have resulted in the collection of fewer species.

Table 14-41. Relative Abundance of Ichthyoplankton in Steel Creek, 1983–1985 (Paller et al. 1985).

Species	1983	1984	1985
unidentifiable clupeid		1.1	1.6
blueback herring	14.5	6.9	27.2
American shad	3.2	2.2	33.2
gizzard or threadfin shad		0.5	
pickerel			
minnow	25.0	37.8	4.0
carp			
unidentifiable sucker	1.0	0.8	0.4
spotted sucker	0.5		1.2
catfish or bullhead			
pirate perch	4.7	0.1	
topminnow			
pickerel	0.3	0.1	
brook silverside	1.8	0.9	0.4
striped bass			
unidentifiable sunfish	3.8	9.8	3.6
sunfish (<i>Lepomis</i>)	16.3	17.5	1.2
crappie	2.3	3.1	
largemouth bass		0.2	
darter	3.1	17.7	12.0
yellow perch	22.1	0.2	2.0
unidentifiable larvae or eggs	1.7	1.1	13.2
total percent	100.0	100.0	100.0
total larvae and eggs	621	871	250
number ichthyoplankton transported to river x 10 ⁶	77	53	5
mean discharge (m ³ /sec)	26	16	9

Table 14-42. Fish Collected During the Night in Open Channel, Channel/Weed Bed Interface and Weed Bed Habitats.
February–July 1985.

Species	Open Channel				Channel/Weed Bed Interface				Weed Bed				A
	E ^a	P	L	J	E	P	L	J	E	P	L	J	
pickerel	0	0	0	0	0	0	0	0	0	0	0	1	1
unidentified minnow	0	0	19	0	0	1	23	0	2	6	265	0	0
chubsucker	0	0	3	0	0	1	6	0	0	0	312	0	0
madtom	0	0	1	0	0	0	0	1	0	0	0	1	2
swampfish	0	0	0	0	0	0	0	0	0	0	1	5	5
pirate perch	0	0	2	0	0	0	2	0	0	0	21	60	3
topminnow	0	0	0	0	0	0	0	0	0	0	5	1	0
mosquitofish	0	0	0	0	0	0	0	0	0	0	2	4	25
brook silverside	0	0	2	0	0	0	0	0	0	0	40	0	0
sunfish and/or bass	0	0	8	0	1	0	27	0	1	1	417	20	0
sunfish (<i>Lepomis</i> spp.)	0	0	32	0	0	0	46	0	0	0	100	0	0
sunfish (<i>Elassoma</i> spp.)	0	0	0	0	0	0	0	0	0	0	14	13	1
crappie	0	0	0	0	0	0	0	0	0	0	4	0	0
darer (<i>Etheostoma</i> sp.)	0	3	4	0	1	6	13	0	2	2	22	0	0
unidentifiable taxa	0	2	63	0	12	0	52	0	6	4	492	0	0
total ichthyoplankton	0	5	134	0	14	8	169	1	11	13	1695	105	37

Program STA99 was used to compute the data presented in this table.

^aFish life stage: E = egg; P = prolarvae (yolk sac larvae); L = larvae; J = juvenile; and A = adult.

Table 14-43. Distribution and Percent Composition of the Fish Assemblages Collected from Streams on the Savannah River Plant

		Stream Sites								
		PB1	PB2	PB3	SC1	SC2	SC3	MB1	MB2	MB3
<i>Notropis lutipinnis</i>	yellowfin shiner	-	51.7	50.9	53.8	41.1	9.6	59.4	54.7	43.9
<i>Nocomis leptocephalus</i>	bluehead chub	-	9.7	3.0	13.6	13.2	0.2	8.9	8.0	2.0
<i>Hypentilium nigricans</i>	northern hogsucker	-	-	-	11.3	1.7	0.4	0.6	1.0	1.6
<i>Ictalurus nebulosus</i>	brown bullhead	11.7	1.6	0.3	< 0.1	0.1	0.2	0.1	0.1	0.5
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	lake and creek chubsucker	13.0	1.6	1.1	0.9	1.5	0.5	1.6	3.2	1.9
<i>Ictalurus natalis</i>	yellow bullhead	3.2	0.7	0.3	0.1	0.6	0.5	-	0.1	0.8
<i>Ictalurus platycephalus</i>	flat bullhead	-	1.5	0.8	2.0	1.2	0.3	0.1	0.5	0.3
<i>Noturus insignis</i>	marginated madtom	-	1.1	4.2	0.6	0.4	0.2	1.0	2.2	0.1
<i>Noturus leptacanthus</i>	speckled madtom	-	-	4.8	2.6	3.2	2.3	1.7	1.8	3.1
<i>Noturus gyrinus</i>	tadpole madtom	-	0.7	0.7	0.2	1.4	0.4	0.9	0.1	0.3
<i>Lepomis marginatus</i>	dollar sunfish	19.4	0.7	0.1	0.2	1.5	0.5	1.4	0.5	0.1
<i>Lepomis auritus</i>	redbreast sunfish	0.9	1.5	5.4	7.2	2.7	3.8	2.2	4.0	1.9
<i>Lepomis punctatus</i>	spotted sunfish	1.9	4.4	4.4	0.4	5.9	1.6	1.5	2.4	4.9
<i>Micropterus salmoides</i>	largemouth bass	-	0.1	0.5	0.4	0.8	2.5	-	0.2	0.1
<i>Anguilla rostrata</i>	American eel	0.7	1.3	0.4	1.2	1.2	3.8	0.4	0.9	10.9
<i>Aphredoderus sayanus</i>	pirate perch	7.8	11.5	8.8	0.2	6.4	11.2	10.6	8.9	9.3
<i>Gambusia affinis</i>	mosquitofish	-	-	-	0.8	5.0	1.9	-	0.1	0.2
<i>Esox niger</i>	chain pickerel	-	0.3	0.5	-	-	0.4	-	0.2	0.1
<i>Esox americanus</i>	redfin pickerel	12.3	5.9	0.6	0.2	1.7	0.9	1.4	0.6	1.4
<i>Acaniharchus pomotis</i>	mud sunfish	27.2	1.5	-	-	-	< 0.1	-	0.2	0.1
<i>Notropis chalybaeus</i>	ironcolor shiner	-	0.1	-	< 0.1	-	0.7	-	< 0.1	0.1
<i>Etheostoma fricksium</i>	Savannah darter	-	3.4	3.5	0.3	0.4	0.3	2.7	1.8	1.1
<i>Percina nigrofasciata</i>	blackbanded darter	-	-	4.4	2.3	2.3	1.9	0.3	0.7	1.3
<i>Fundulus lineolatus</i>	lined topminnow	-	-	0.1	-	-	< 0.1	-	0.1	-
<i>Etheostoma olmstedii</i>	tessellated darter	-	-	4.6	0.2	4.3	8.6	1.4	4.8	8.8
<i>Notropis cummingsae</i>	dusky shiner	1.9	0.5	0.4	0.1	1.2	23.8	3.5	1.9	4.4
<i>Amia calva</i>	bowfin	-	-	0.1	-	-	-	-	-	-
<i>Semotilus atromaculatus</i>	creek chub	-	-	-	0.1	0.3	-	0.2	-	-
<i>Notropis petersoni</i>	coastal shiner	-	-	-	-	1.9	7.2	-	-	-
<i>Lepomis gulosus</i>	warmouth	-	-	0.1	< 0.1	-	0.2	0.1	0.1	-
<i>Enneacanthus gloriosus</i>	bluespotted sunfish	-	-	-	0.1	-	0.1	-	0.1	-
<i>Elassoma zonatum</i>	banded pygmy sunfish	-	-	0.1	-	-	< 0.1	-	-	-
<i>Etheostoma serriferum</i>	sawcreek darter	-	-	-	-	-	0.2	-	-	-
<i>Notropis emiliae</i>	pugnose minnow	-	-	-	-	-	0.2	-	-	-
<i>Perca flavescens</i>	yellow perch	-	-	-	0.2	-	< 0.1	-	0.1	0.1
<i>Notemigonus crysoleucas</i>	golden shiner	-	-	-	0.2	-	-	-	-	-
<i>Centrarchus macropterus</i>	flier	-	-	-	-	-	< 0.1	-	< 0.1	0.1
<i>Chologaster cornuta</i>	swampfish	-	-	-	-	-	0.9	-	-	0.1
<i>Ictalurus brunneus</i>	snail bullhead	-	0.1	-	-	-	-	-	< 0.1	-
<i>Umbra pygmaea</i>	eastern mudminnow	-	-	0.1	-	0.1	0.1	-	< 0.1	0.1
<i>Minytrema melanops</i>	spotted sucker	-	-	-	0.8	-	0.8	-	-	-

		Stream Sites								
		PB1	PB2	PB3	SC1	SC2	SC3	MB1	MB2	MB3
<i>Etheostoma fusiforme</i>	swamp darter	-	-	0.1	-	-	0.3	-	-	0.1
<i>Hybopsis rubrifrons</i>	rosyface chub	-	-	-	-	-	< 0.1	-	-	-
<i>Notropis leedsi</i>	bannerfin shiner	-	-	-	-	-	< 0.1	-	-	-
<i>Labidesthes sicculus</i>	brook silverside	-	-	-	-	-	0.2	-	-	-
<i>Enneacanthus chaetodon</i>	blackbanded sunfish	-	-	-	-	-	< 0.1	-	< 0.1	-
<i>Lepomis macrochirus</i>	bluegill	-	0.1	-	-	-	< 0.1	-	-	-
<i>Fundulus chrysotus</i>	gold topminnow	-	-	-	-	-	-	-	-	0.2
Number of collections		5	8	8	7	7	7	4	8	4
Total number of individuals		309	1519	1809	2531	1174	3415	1579	2823	1501
Mean relative abundance (no /100 m ²)		41.2	87.5	51.7	80.3	47.9	62.3	104.5	70.6	44.2

Table 14-44. Mean Electrofishing Catch Per Unit Effort (CPUE; No./100 m) and Relative Abundance (% Composition) of Common Species in an Open-Canopy Marsh Habitat in the Steel Creek Swamp. Samples were collected from between the islands before and after the impoundment of L Lake and restart of L-Reactor. 1983–1988.

Taxa	Before						After					
	1983 ^a		1984 ^a		1985 ^a		1986		1987		1988	
	CPUE	%	CPUE	%	CPUE	%	CPUE	%	CPUE	%	CPUE	%
longnose gar	-	-	-	-	-	-	0.17	1.1	0.07	0.3	0.07	0.3
bowfin	0.36	1.5	0.59	1.3	0.72	1.8	0.54	3.4	0.35	1.5	1.05	4.7
American eel	0.10	0.4	0.12	0.3	1.66	4.1	0.16	1.1	0.07	0.3	0.22	1.0
redfin pickerel	0.39	1.7	0.68	1.5	0.22	0.5	0.01	0.1	0.14	0.6	0.44	2.0
chain pickerel	-	-	-	-	-	-	0.39	2.5	0.28	1.2	0.71	3.2
golden shiner	1.50	6.4	1.80	4.0	1.01	2.5	0.44	2.8	1.03	4.4	1.73	7.7
minnow	12.34	52.4	24.22	54.1	10.80	26.4	3.66	23.2	13.83	58.7	3.76	16.7
chubsucker	1.05	4.5	3.02	6.8	2.72	6.7	1.61	10.2	1.11	4.7	2.12	9.4
spotted sucker	0.59	2.5	0.69	1.5	0.67	1.6	0.72	4.6	0.89	3.8	0.63	2.8
pirate perch	0.44	1.9	2.02	4.5	1.96	4.8	0.31	2.0	0.33	1.4	1.05	4.7
mosquitofish	0.78	3.3	0.67	1.5	0.11	0.3	0.62	3.9	0.47	2.0	0.05	0.2
brook silverside	2.11	9.0	4.50	10.0	5.85	14.3	0.38	2.4	0.17	0.7	0.03	0.1
redbreast sunfish	-	-	-	-	-	-	0.32	2.0	0.15	0.6	0.25	1.1
bluegill	-	-	-	-	-	-	0.27	1.7	0.72	3.1	0.97	4.3
spotted sunfish	1.80	7.6	3.08	6.9	10.50	25.7	2.00	12.7	1.29	5.5	4.34	19.3
largemouth bass	2.11	9.0	3.35	7.5	4.71	11.5	3.43	21.8	1.90	8.1	3.00	13.4
blackbanded darter	-	-	-	-	-	-	0.24	1.5	0.24	1.0	0.59	2.6
other	-	-	-	-	-	-	0.44	3.1	0.53	2.1	1.44	6.4
total ^b	23.57	100.2	44.74	99.9	40.93	100.2	15.71	100.0	23.57	100.0	22.46	99.9

^a From Aho et al. 1986.

^b Deviations between arithmetic sum of the column and the indicated total for CPUE and the differences from 100.0 for percent composition are due to rounding.

Table 14-45. Mean Electrofishing Catch Per Unit Effort (CPUE; No./100 m) and Relative Abundance (% Composition) of Common Species in a Closed-Canopy Swamp Habitat in the Steel Creek Swamp before and after the impoundment of L Lake and restart of L-Reactor. 1983–1988.

Taxa	Before						After					
	1983 ^a		1984 ^a		1985 ^a		1986		1987		1988	
	CPUE	%	CPUE	%	CPUE	%	CPUE	%	CPUE	%	CPUE	%
longnose gar	0.42	4.3	0.94	4.7	2.29	15.1	0.25	2.7	0.21	2.8	0.65	4.9
Florida gar	-	-	-	-	-	-	-	-	-	-	0.56	4.2
bowfin	0.47	4.8	1.36	6.8	0.39	2.6	0.42	4.5	0.19	2.6	0.31	2.3
American eel	0.14	1.4	0.36	1.8	-	-	0.20	2.1	0.07	0.9	-	-
bizzard shad	0.08	0.8	0.44	2.2	0.28	1.8	0.06	0.6	0.07	0.9	-	-
redfin pickerel	-	-	-	-	-	-	-	-	-	-	-	-
chain pickerel	-	-	-	-	-	-	0.25	2.7	0.21	2.8	0.60	4.5
golden shiner	0.06	0.6	1.11	5.6	0.50	3.3	0.57	6.1	0.31	4.1	0.21	1.6
minnow	1.75	17.9	6.66	33.3	4.34	28.7	2.03	21.5	2.47	33.3	3.32	25.1
chubsucker	0.14	1.4	0.25	1.2	0.17	1.1	0.35	3.7	0.35	4.7	0.79	6.0
spotted sucker	0.73	7.5	1.42	7.1	1.95	12.9	1.24	13.2	0.65	8.8	1.46	11.0
pirate perch	-	-	0.34	1.7	0.28	1.8	0.15	1.6	0.11	1.5	0.15	1.1
lined topminnow	-	-	-	-	-	-	0.01	0.1	-	-	-	-
mosquitofish	0.11	1.1	0.11	0.6	-	-	0.01	0.1	0.18	2.4	-	-
brook silverside	3.84	39.3	2.74	13.7	2.06	13.6	0.39	4.1	0.31	4.1	0.06	0.4
redbreast sunfish	0.08	0.8	0.22	1.1	0.06	0.4	0.06	0.6	0.01	0.2	0.08	0.6
bluegill	-	-	-	-	-	-	0.01	0.1	0.08	1.1	0.10	0.8
redeer sunfish	-	-	-	-	-	-	0.17	1.8	-	-	0.24	1.8
spotted sunfish	0.28	2.9	0.59	3.0	0.72	4.8	0.32	3.4	0.36	4.9	0.64	4.8
largemouth bass	1.00	10.2	1.23	6.2	1.05	6.9	1.63	17.3	1.03	13.9	2.12	16.0
yellow perch	0.50	5.1	1.27	6.4	0.66	4.4	0.94	10.0	0.49	6.6	1.24	9.4
blackbanded darter	0.06	0.6	0.39	2.0	0.28	1.8	0.10	1.1	0.11	1.5	0.22	1.7
striped mullet	0.11	1.1	0.56	2.8	0.11	0.7	0.01	0.1	-	-	-	-
other	-	-	-	-	-	-	0.25	2.5	0.17	2.4	0.50	3.8
total ^b	9.77	99.8	19.99	100.2	15.14	99.9	9.42	99.9	7.42	99.5	13.24	100.0

^a Adapted from Aho et al. 1986.

^b Deviations between arithmetic sum of the column and the indicated total for CPUE and the differences from 100.0 for percent composition are due to rounding.

Table 14-46. Mean Electrofishing Catch Per Unit Effort (CPUE; No./100 m) at a Sample Station in the Mouth of Steel Creek Before (1983, 1984, and 1985) and after (1986, 1987, and 1988) the Impoundment of L Lake and Restart of L-Reactor. 1983–1988.

Taxa	1983 ^a	1984 ^b	1985 ^c	1986	1987	1988
longnose gar	-	-	-	0.06	-	0.06
Florida gar	-	0.08	-	-	0.03	-
bowfin	0.63	0.33	0.22	0.22	0.08	0.56
American eel	-	-	-	0.03	0.06	0.11
herring/shad	-	-	-	0.17	-	-
blueback herring	-	-	-	0.03	-	-
American shad	-	-	-	0.06	0.11	0.17
gizzard shad	0.13	-	-	0.11	0.03	-
eastern mudminnow	-	-	-	-	0.03	-
redfin pickerel	-	0.83	-	0.14	-	-
chain pickerel	-	0.08	0.11	0.28	0.11	0.14
minnow	-	-	0.44	2.14	5.44	3.22
creek chubsucker	-	-	-	0.06	-	-
northern hogsucker	-	-	-	-	0.03	0.03
spotted sucker	0.75	0.17	0.11	0.36	0.42	0.56
silver redhorse	0.13	-	-	-	-	0.08
snail bullhead	-	-	0.11	-	-	0.06
brown bullhead	-	-	-	0.03	-	-
flat bullhead	-	-	-	0.06	-	0.14
channel catfish	0.13	-	0.11	-	0.06	0.08
madtom	-	-	-	0.03	-	0.44
pirate perch	0.13	-	0.11	0.19	0.08	-
Atlantic needlefish	-	-	-	0.03	-	0.03
mosquitofish	-	-	-	0.06	-	-
brook silverside	0.25	0.08	0.11	0.61	0.72	0.44
mud sunfish	-	-	-	-	0.03	-
bluespotted sunfish	-	-	0.11	0.14	0.03	-
redbreast sunfish	0.50	0.17	1.22	0.56	0.36	0.42
warmouth	-	-	0.11	0.06	-	-
bluegill	0.25	-	-	0.03	0.78	0.06
dollar sunfish	-	-	-	0.03	-	0.03
redeer sunfish	0.13	-	-	0.03	-	0.08
spotted sunfish	2.00	0.33	1.44	1.14	0.44	0.19
largemouth bass	1.25	0.33	0.44	0.67	0.47	0.17
black crappie	-	-	-	0.06	-	-
darter	-	-	-	0.06	-	-
tessellated darter	-	-	-	0.19	0.03	0.03
yellow perch	0.38	0.08	0.22	0.06	0.06	0.03
blackbanded darter	-	-	0.11	0.19	0.17	0.28
striped mullet	-	-	-	-	0.14	0.25
other	-	0.08	0.33	-	0.03	0.11
total ^d	6.66	2.56	5.30	7.83	9.72	7.75

^aPaller et al. 1984.

^bPaller and Osteen 1985.

^cPaller and Saul 1986.

^dAny deviations between arithmetic sum of the column and the indicated total for CPUE are due to rounding error.

References

- Sayers, R. E., Jr., and H. G. Mealing. 1992. Steel Creek fish: L-Lake/Steel Creek biological monitoring program, January 1986 - December 1991. Normandeau Associates, Inc., Aiken, SC. NAI-SR-145.
- Heuer, J. H., and L. A. Kissick. 1989. Steel Creek fish: L-Lake/Steel Creek biological monitoring program, January 1986 - December 1988. Normandeau Associates, Inc., Aiken, SC. NAI-SR-87.
- Paller, M. H., J. H. Heuer, H. G. Mealing, and D. W. Hughes. 1987. Steel Creek fish: L-Lake/Steel Creek biological monitoring program, January - December 1986. Environmental and Chemical Sciences, Inc., Aiken, SC. ECS-SR-***.
- Paller, M. H., B. M. Saul, and D. W. Hughes. 1986. The distribution of ichthyoplankton in thermal and non-thermal creeks and swamps on the Savannah River Plant. February-July 1985. Environmental and Chemical Sciences, Inc., Aiken, SC. ECS-SR-25.
- Paller, M. H. 1985. A report on the ichthyoplankton sampling data from the creeks and swamps of the Savannah River Plant. March 14, 1984 through July 31, 1984. Environmental and Chemical Sciences, Inc., Aiken, SC. ECS-SR-16.
- Paller, M. H. 1987. Distribution of larval fish between open channels and macrophyte beds in a southeastern floodplain swamp. *Journal of Freshwater Ecology* 4: 191-200.
- Meffe, G. K. 1991. Failed invasion of a southeastern blackwater stream by bluegills: implications for conservation of native communities. *Transactions of the American Fisheries Society* 120:333-338.
- Aho, J. M., C. S. Anderson, K. B. Floyd, M. T. Negus, and M. R. Meador. 1986. Patterns of fish assemblage structure and dynamics in waters of the Savannah River Plant. Savannah River Ecology Laboratory. Aiken, SC. SREL-27, UC-66e.
- Paller, M. H., J. O'Hara, V. Osteen. 1985. Annual report on the Savannah River aquatic ecology program. September 1983 - August 1984. Vol. II. Ichthyoplankton. ECS-SR-18. Environmental and Chemical Sciences, Inc., Aiken, S.C. 177 pp.
- Paller, M. H., B. M. Saul, and D. V. Osteen. 1986. Distribution and abundance of ichthyoplankton in the mid-reaches of the Savannah River and selected tributaries. ECS-SR-27. Environmental & Chemical Sciences, Inc. Aiken, SC. 363 pp.
- Paller, M. H., J. O'Hara, V. Osteen, W. Specht and H. Kania. 1984. Annual report on the Savannah River aquatic ecology program. September 1982 - August 1983, Vol. I. ECS-SR-8. Environmental and Chemical Sciences, Inc., Aiken, S.C. 243 pp.
- Paller, M. H., J. B. Gladden, and J. H. Heuer. 1992. Development of the fish community in a new South Carolina reservoir. *Am Midl. Nat.* 128:95-114.
- Taylor, B. E., A. E. DeBiase, and D. L. Mahoney. 1993. manuscript submitted. Zooplankton community development in a new cooling reservoir.
- Anderson, K. B., E. F. Benfield, and A. L. Buikema Jr. 1977. Zooplankton of a swamp water ecosystem. *Hydrobiologia* 55:177-185.
- Bowers, J. A. 1991. The limnology of L Lake: Results of the L-Lake monitoring program 1986-1989 (U). WSRC-92-RP-1244, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC 29808-0001.
- Chimney and Cody 1986 database code: A322555
- Goodard, K. A. and W. F. McDiffett. 1983. Rotifer distribution, abundance and community structure in four habitats of a freshwater marsh. *J. Freshwat. Ecol.* 2:199-211.
- Hutchinson, G. E. 1967. A treatise on limnology. Vol. II, Wiley and Sons, London.
- Ward, J. V. 1975. Downstream fate of zooplankton from a hypolimn.
- References
- DeMott, W. R. and F. Moxter. 1991. Foraging on cyanobacteria by copepods: Responses to chemical defenses and resource abundance. *Ecology* 72:1820-1834.

- Drenner, R. W., and S. R. McComas. 1980. The roles of zooplankton escape ability and fish size selectivity in the selective feeding and impact of planktivorous fish. pp. 587-593 In *Evolution and ecology of zooplankton communities*. W. C. Kerfoot (ed.). Amer. Soc. Limnol. Oceanogr. Spec. Symp. 3. New England Press, Hanover, NH.
- Drenner, R. W., J. R. Mummert, F. deNoyelles, Jr., and D. Kettle. 1984. Selective particle ingestion by a filter-feeding fish and its impact on phytoplankton community structure. *Limnol. Oceanogr.* 29:941-948.
- Federenko, A. Y. 1975. Feeding characteristics and predation impact of *Chaoborus* (Diptera, Chaoboridae) larvae in a small lake. *Limnol. Oceanogr.* 20:250-259.
- Fedorenko, A. Y. 1973. Predation interactions between zooplankton and two species of *Chaoborus* (Diptera, Chaoboridae) in a small coastal lake. M. S. Thesis, Univ. British Columbia. 123p.
- Fulton, III, R. S., and H. W. Paerl. 1987. Toxic and inhibitory effects of the blue-green alga *Microcystis aeruginosa* on herbivorous zooplankton. *J. Plankton Res.* 9:837-855.
- Hanazato, T., and M. Yasuno. 1987. Evaluation of *Microcystis* as food for zooplankton in a eutrophic lake. *Hydrobiologia* 144:251-259.
- Haven, K. E. 1990. *Chaoborus* predation and zooplankton community structure in a rotifer-dominated lake. *Hydrobiologia* 198:215-226.
- Hodson, R. E. 1987. Microbial processes in L Lake. Seminar presented at E. I. du Pont de Nemours & Co., Savannah River Laboratory, Environmental Sciences Division, Aiken, SC. Contribution from Institute of Ecology and Department of Microbiology, University of Georgia, Athens, Georgia 30602.
- Horridge, G. A. 1966. Some recently discovered underwater vibration receptors in invertebrates, p. 395-405. In H. Barnes (ed.), *Some contemporary studies in marine science*. Allen and Unwin.
- Jarvis, A. C., R. C. Hart, and S. Combrink. 1987. Cladoceran filtration rate. *J. Plank. Res.* 10:115-132.
- Lampert, W. 1982. Further studies on the inhibitory effect of the toxic blue-green *Microcystis aeruginosa* on the filtering rate of zooplankton. *Arch. Hydrobiol.* 95:207-220.
- Lewis, W. M. 1977. Feeding selectivity of a tropical *Chaoborus* population. *Freshwater Biol.* 7:311-325.
- Lewis, W. M. 1977. Feeding selectivity of a tropical *Chaoborus* population. *Freshwater Biol.* 7:311-325.
- Nizan, S., C. Dimentman, and M. Shilo. 1986. Acute toxic effects of the cyanobacterium *Microcystis aeruginosa* on *Daphnia magna*. *Limnol. Oceanogr.* 31:497-502.
- Parma, S. 1971. *Chaoborus flavicans* (Meigen) (Diptera, Chaoboridae): An autecological study. Ph. D. thesis, Groningen. 128 p.
- Pastorok, R. A. 1978. Predation by *Chaoborus* larvae and its impact on the zooplankton community. Ph. D. thesis, Univ. Washington, Seattle. 238p.
- Pastorok, R. A. 1980. Selection of prey by *Chaoborus* larvae: A review and new evidence for behavioral flexibility. pp. 538-554, In W. C. Kerfoot. (ed.) *Evolution and ecology of zooplankton communities*. Spec. Symp. Vol. 3, Univ. Press of New England, Hanover, NH.
- Pollard, J. E. 1976. The life cycle and trophic relationships of *Chaoborus nyblaei* in a small coastal pond. M. A. thesis, Humboldt State Univ. 66p.
- Porter, K. G., M. L. Pace, and J. F. Battey. 1979. Ciliate protozoans as a link in freshwater planktonic food chains. *Nature* 227:563-564.
- Prophet, C. W., and J. K. Frey. 1987. Capture of *Diaptomus siciloides* and *Diaptomus pallidus* by suction and gizzard shad (*Dorosoma cepedianum*). *J. Freshwater Biol.* 4:253-258.
- Swuste, H. F. J., R. Cremer, and S. Parma. 1973. Selective predation by larvae of *Chaoborus flavicans* (Meigen) (Diptera, Chaoboridae). *Int. Ver. Theor. Angew. Limnol. Verh.* 18:1559-1563.

- Taylor, B. E., A. E. DeBiase, and D. L. Mahoney. 1993. manuscript submitted. Zooplankton community development in a new cooling reservoir.
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. R. Specht, and E. W. Wilde. 1985. *Comprehensive Cooling Water Study Annual Report, Volume V, Wetland Plant Communities, Savannah River Plant*. DP-1697-5. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Godfrey, R. K. and J. W. Wooten. 1979. *Aquatic and Wetland Plants of Southeastern U.S. - Monocotyledons*. University of GA Press. Athens, GA.
- Hooker, K. L. 1990. Steel Creek Habitat Formers: Channel Mapping. L-Lake/Steel Creek Biological Monitoring Program. January 1986–1989. NAI-SR-118. Prepared by NAI for Westinghouse Savannah River Company. Aiken, SC.
- Peter, C. and H. M. Westbury. 1990. Steel Creek Habitat Formers: Floodplain Habitat. L-Lake/Steel Creek Biological Monitoring Program. January 1986–December 1989. NAI-SR-119. Prepared by NAI for Westinghouse Savannah River Company. Aiken, SC.
- DOE (U.S. Department of Energy). Final Environmental Impact Statement, L-Reactor Operation, Savannah River Plant, Volume II. DOE/EIS-0108, Savannah River Operations Office, Aiken, SC. (1984).

Chapter 15

Lower Three Runs and Par Pond

Chapter Contents

Drainage Description and Surface Hydrology (page 15-3)

Water Chemistry and Quality (page 15-9)

Algae (page 15-23)

Macrophytes (page 15-37)

Zooplankton (page 15-39)

Macroinvertebrates (page 15-45)

Fish (page 15-63)

References (page 15-83)

Drainage Description and Surface Hydrology

Par Pond

General Description

Par Pond is a 1012-ha reactor cooling reservoir built to augment the cooling requirements for both P and R reactors (Figure 15-1). It was created in 1958 by constructing an earthen dam (Cold Dam) on Lower Three Runs and was formed along the course of Poplar Branch, Joyce Branch, and the upper reach of the Lower Three Runs drainage system (Wilde and Tilly 1985).

Effluents 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 Arm via the pre-cooler 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 pond through a series of canals and pre-cooler ponds, including Pond C (Figure 15-1). In July 1964, R-Reactor operations were suspended and the reactor was placed on standby. Thereafter, Par Pond received thermal effluent from P Reactor only, and Pond B has not received any effluent cooling water.

Figure 15-1. Location of Par Pond on SRS

Recirculation of Water to P Area

A pumphouse located on the south arm (Intake Arm) of Par Pond 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 15-1). Flow from the Par Pond pumphouse to P Reactor averaged $9.8 \text{ m}^3/\text{s}$ ($346 \text{ ft}^3/\text{s}$) 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 , and was released through a series of precooling 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 below the surface of Par Pond, and the effluent flowed upward, forming a thermal plume as it mixed with cooler water and 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 to $1.3 \text{ m}^3/\text{s}$ when the reactor was operating (Wilde 1985). Between 1980 and 1985, the amount of makeup water pumped from the Savannah River averaged $1.1 \text{ m}^3/\text{s}$ (Wilde 1985). Other than the addition of Savannah River makeup water, and the overflow and seepage to Lower Three Runs via the Cold Dam, Par Pond has operated as a closed loop system.

Flow Patterns

Flow patterns for Par Pond are influenced by weather, drainage basin morphometry, and pumping rates associated with reactor operations (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 by reactor operations to 68 days from 1962 to 1977 (Tilly 1981) and to 108.8 days from January 1984 to June 1985 (Chimney et al. 1985).

Meteorological Factors

The major meteorological factors that affect the structure and function of the reservoir ecosystem are air temperature, solar insolation, relative humidity (and saturation deficit), wind speed and direction, and precipitation (Wilde and Tilly 1985). The morphometry of Par Pond has been influenced by 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. In contrast, the North Arm is more riverine and shallow (Wilde and Tilly 1985).

Drawdown of Par Pond

An inspection of the Par Pond dam in March of 1991 led to the discovery of a depression on the downstream face. Although further investigations found no impending potential for dam failure, the pond level was drawn down to minimize the potential for failure. The pond level was drawn down to the 181-foot level, compared with normal elevation of 200 feet above mean sea level (Arnett et al. 1992).

Lower Three Runs

General Description

Lower Three Runs is a large blackwater creek draining about 460 km², with a 1012 ha (2500 acres) mainstream impoundment (Par Pond, see page 15-3 for a detailed description) on its headwaters (Figure 15-2). From the Par Pond dam, Lower Three Runs flows about 39 km before it enters the Savannah River. The SRS boundary includes the narrow strip of land between the dam and the river, including the floodplain. Several other ponds were constructed in the headwaters above Par Pond to improve cooling of the reactor effluent. Pond B, the largest, has an area of about 73 ha (180 acres).

Effluents Contribution

Before construction of Par Pond, effluent cooling water from R Reactor (about 5.66 m³/sec) was discharged through Joyce Branch to Lower Three Runs. In 1964 R Reactor was shut down, and all P-Reactor cooling water was diverted from Steel Creek to Par Pond. P Reactor was shut down in 1988. Historically, SRS operations caused large discharge fluctuations just downstream from the dam at Par Pond, but groundwater and tributary inputs were sufficient to dampen these fluctuations farther downstream (Firth et al. 1986).

Flow Measurements

The USGS measures flow at several locations on Lower Three Runs. Flow statistics of Lower Three Runs near Snelling (Patterson Mill) and below Par Pond (Figure 15-3) are summarized in Table 15-1 on page 15-6. Records for the most downstream station (Lower Three Runs near Snelling) date back to March 1974. In water year 1991, the mean flow of Lower Three Runs at Patterson Mill was 1.8 m³/s (65 ft³/s). Over the period of record (water years 1974-1991) at Patterson Mill, the mean flow is 2.4 m³/s (85 ft³/s), the 7-day low flow

Figure 15-2. Location of Lower Three Runs on SRS

is 0.43 m³/s (15.1 ft³/s), and the 7Q10 is 0.44 m³/s (15.6 ft³/s). The maximum, minimum, and mean daily flows for the periods of record at the two stations are shown in Figure 15-4 and Figure 15-5.

Table 15-1. Flow Summary for Lower Three Runs

Station Name	Station Number	Period of Record	Mean		Range		High		7Q10		7-Day Low Flow	
			cms ^a	(cfs) ^a	Low		cms	(cfs)	cms	(cfs)	cms	(cfs)
below Par Pond at SRS	02197380	1974-1982, 1987-1991	1.0	36.5	0.02	0.6	6.2	220	0.03	1.2	0.03	0.9
near Snelling (Patterson Mill)	02197400	1974-1991	2.4	85	0.37	13	21.0	743	0.44	15.6	0.43	15.1

^a Cubic meters per second

^b Cubic feet per second

Map No.	Station Name
01	below Par Pond at SRS
02	near Snelling (Patterson Mill)

Figure 15-3. Flow Sampling Stations on Lower Three Runs

Figure 15-4. Maximum, Mean, and Minimum Flows for Upper Three Runs at Station 02197380

Figure 15-5. Maximum, Mean, and Minimum Flows for Upper Three Runs at Station 02197400

Water Chemistry and Quality

Par Pond

Studies and Monitoring

Water Quality Monitoring

The routine water quality monitoring program does not include any sampling within Par Pond, except for annual pesticide, herbicide, and PCB monitoring. Wilde (1985) summarizes water chemistry data from three primary sources (Chimney et al. 1985; SREL 1986; and Tilly 1981) for Par Pond between 1972 and 1985. Gladden et al. (1985) also summarizes Par Pond water quality data prior to the CCWS. There is no water quality data available following the Par Pond drawdown.

Comprehensive Cooling Water Study

The Comprehensive Cooling Water Study (CCWS), conducted from 1983 to 1985, water quality was designed to assess the impacts associated with current and proposed SRS activities. The following two sampling locations were sampled on Par Pond (Figure 15-6):

- Par Pond in western arm near pumphouse intake—reflects the “cold” section of Par Pond
- Par Pond “bubble-up” between Pond C and middle arm of Par Pond—the hot dam overflow from Pond C that accepts reactor cooling water effluents from P Reactor following travel through a series of pre-cooler ponds

Figure 15-6. Location Map of Par Pond

Comprehensive results and discussion of CCWS data can be found in the "Comprehensive Cooling Water Study, Volume II: Water Quality" (SREL 1986) or in the "Comprehensive Cooling Water Study, Final Report, Volume II: Water Quality" (Lower 1987).

The CCWS data presented 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 1992 investigated the L Lake / Steel Creek System. One sampling location, near the Cold Dam, was chosen on Par Pond for use in data comparison (Figure 15-6 on page 15-9). The L Lake/Steel Creek data reflect post-reactor operation conditions.

The 1990–1991 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).

Field Data

Water Temperature

The mean water temperature at sampling locations in Par Pond ranged from 21.5 to 31.0°C during the CCWS (Table 15-2). The mean water temperature of Par Pond during the L Lake/Steel Creek Program (1990–1991) was 18.12°C (Table 15-3 on page 15-12). 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 15-2). The L Lake/Steel Creek Program of 1990–1991 has shown a decrease in the mean pH (6.33) since P-Reactor shutdown (Table 15-3 on page 15-12).

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 O₂/l (Table 15-4 on page 15-13). Dissolved oxygen averaged 81 to 92% saturation in Par Pond (SREL 1986). The mean dissolved oxygen concentration during the L Lake/Steel Creek Program was 6.01 mg O₂/l (Table 15-3 on page 15-12).

Conductivity

A much smaller range of specific conductance values was exhibited in Par Pond than in Lower Three Runs. During the CCWS, values in Par Pond ranged from 55.2 to 77.0 µmhos/cm (mean range, 62.9 to 66.4 µmhos/cm). The range of conductivity values measured during the L Lake/Steel Creek Biological Monitoring Program was 46 to 126 µmhos/cm (mean, 70 µmhos/cm). Conductivity data are presented in Table 15-4 on page 15-13 and Table 15-3 on page 15-12.

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 15-4 on page 15-13). The mean suspended solids concentration in Par Pond during the L Lake/Steel Creek Biological Monitoring Program was 2.02 mg/l (Table 15-3 on page 15-12). The low suspended solids concentrations are indicative of the low velocities in Par Pond. In Par Pond, the mean turbidity ranged from 2.8 to 3.4 NTU during the CCWS.

Table 15-2. Lower Three Runs/Par Pond Field Data

	Water Temperature (°C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
Par Pond in western arm near pumphouse intake (CCWS) ^a				
Mean	21.5	7.32		
Range	5.3 - 33.0	6.14 - 8.83	NA	NA
Samples	46	45		
Par Pond "bubble-up" between Pond C and middle arm of Par Pond (CCWS) ^a				
Mean	31.0	7.33		
Range	14.8 - 43.0	6.75 - 8.23	NA	NA
Samples	46	46		
Lower Three Runs at Road B (CCWS) ^a				
Mean	19.3	6.94	41	34
Range	7.0 - 31.0	5.50 - 8.80 ¹	21 - 89	4 - 120
Samples	46	46	28	38
Lower Three Runs at Patterson Mill (CCWS) ^a				
Mean	16.2	7.17	69	19
Range	1.5 - 25.0	5.90 - 8.50	48 - 117	4 - 60
Samples	46	46	30	39
Lower Three Runs at Patterson Mill (1987–1991) ^b				
Mean	18			
Range	7.7 - 29	5.9 - 7.4	NA	NA
Samples	60	60		
Lower Three Runs at US Highway 125 (CCWS) ^a				
Mean	16.0	7.17	222	11
Range	1.5 - 24.7	6.10 - 8.40	195 - 283	2 - 50
Samples	60	46	19	39

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Major Anions and Cations

Alkalinity, Chloride, and Sulfate

Alkalinity, chloride, and sulfate concentrations are presented in Table 15-5 on page 15-14 and Table 15-3. 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 to 15.6 mg CaCO₃/l). Mean chloride concentrations in Par Pond during both the CCWS and the L Lake/Steel Creek Program have 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 to 5.12 mg/l).

Table 15-3. Lake/Steel Creek Biological Monitoring Program (November 1985–December 1991)
(Source: Kretchmer and Chimney 1992)

Par Pond Near Cold Dam					
	Water Temperature (°C)	pH	Dissolved Oxygen (mg/l)	Specific Conductance (µmhos/cm)	Total Suspended Solids (mg/l)
Mean	18.1	6.33	6.01	70.0	2.02
Range	8.5 - 31	5.54 - 7.25	0.02 - 11.6	46 - 126	0 - 10
Samples	96	84	96	96	96
	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg/l)	Tot. Calcium (mg/l)	Tot. Magnesium (mg/l)
Mean	14.6	5.73	4.62	3.42	0.84
Range	6.73 - 40.3	3.52 - 8.0	3.6 - 7.8	2.44 - 4.72	0.593 - 1.04
Samples	96	28	28	28	28
	Tot. Sodium (mg/l)	Tot. Potassium (mg/l)	Tot. Aluminum (mg/l)	Tot. Iron (mg/l)	Tot. Manganese (mg/l)
Mean	6.15	1.04	0.032	0.517	0.251
Range	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
	Tot. Phosphorus (mg/l)	O-Phosphate (mg/l)	Tot. Kjeldhal Nitrogen (mg/l)	Ammonia (mg N/l)	Nitrite (mg N/l)
Mean	0.032	0.007	0.302	0.046	0.003
Range	0.008 - 0.28	0 - 0.238	0 - 1.03	0 - 0.891	0 - 0.026
Samples	1000	999	1000	1000	1000
	Nitrate (mg N/l)				
Mean	0.073				
Range	0 - 0.385				
Samples	999				

Calcium, Magnesium, Sodium, and Potassium

Table 15-6 on page 15-15 summarizes calcium, magnesium, sodium, and potassium concentrations found in Par Pond during the CCWS and the L Lake/Steel Creek Biological Monitoring Program. Monitoring at the two sampling locations in the CCWS (near pump-house intake and at “bubble up” between Pond C and middle arm of Par Pond) resulted in almost identical results. At its only sampling location (near the Cold Dam), the L Lake/Steel Creek Biological Monitoring Program produced concentrations similar to those of the CCWS.

Table 15-4. Lower Three Runs/Par Pond - Physical Characteristics and General Chemistry

	Dissolved Oxygen (mg/l)	Specific Conductance (mmhos/cm)	Turbidity (NTU)	Total Suspended Solids (mg/l)
Par Pond in western 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
Lower Three Runs at Road B (CCWS) ^a				
Mean	7.06	74.1	6.1	4.11
Range	2.40 - 10.2	56.9 - 134.8	1.2 - 37.0	0.25 - 28.4
Samples	46	38	43	44
Lower Three Runs at Patterson Mill (CCWS) ^a				
Mean	7.51	86.3	3.5	5.40
Range	5.20 - 11.9	46.6 - 125.4	1.1 - 13.5	0.25 - 69.2
Samples	46	38	43	44
Lower Three Runs at Patterson Mill (1987–1991) ^b				
Mean	8.0	75	2.8	4.9
Range	5.8 - 11	13 - 140	0.94 - 38	1 - 34
Samples	60	60	60	60
Lower Three Runs at US Highway 125 (CCWS) ^a				
Mean	7.30	82.5	6.3	4.43
Range	4.60 - 13.0	38.9 - 119.2	1.4 - 50.0	0.25 - 27.2
Samples	46	38	43	45

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Aluminum, Iron, and Manganese

The total concentrations of aluminum, iron, and manganese measured during the CCWS and the L Lake/Steel Creek Program are summarized in Table 15-6. Similar to Lower Three Runs, total aluminum concentrations measured in Par Pond have decreased since the CCWS.

Table 15-5. Lower Three Runs/Par Pond - Major Anions

	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg/l)
Par Pond in western 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
Lower Three Runs at Road B (CCWS) ^a			
Mean	21.8	6.17	3.51
Range	12.1 - 63.7	4.90 - 7.40	0.25 - 7.20
Samples	45	45	28
Lower Three Runs at Patterson Mill (CCWS) ^a			
Mean	35.1	3.82	1.85
Range	9.76 - 61.2	2.30 - 5.90	0.04 - 5.75
Samples	45	45	26
Lower Three Runs at Patterson Mill (1987–1991) ^b			
Mean	31	5.0	4.5
Range	14 - 60	1.7 - 8.4	0.05 - 12
Samples	60	60	60
Lower Three Runs at US Highway 125 (CCWS) ^a			
Mean	33.6	3.71	0.78
Range	11.9 - 53.6	2.40 - 6.20	0.20 - 3.34
Samples	45	45	26

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 15-6. Lower Three Runs/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 western arm 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	3.017 - 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
Lower Three Runs at Road B (CCWS)^a							
Mean	5.87	1.06	5.24	0.657	0.255	1.54	0.209
Range	3.22 - 19.2	0.901 - 1.29	3.67 - 7.77	<0.368 - 1.69	<0.038 - 1.50	0.265 - 8.40	<0.0004 - 0.760
Samples	39	39	39	39	39	39	16
Lower Three Runs at Patterson Mill (CCWS)^a							
Mean	11.9	0.800	3.01	0.440	0.380	0.509	0.069
Range	5.20 - 20.9	0.593 - 1.07	1.33 - 5.34	<0.368 - 1.17	0.044 - 1.53	0.181 - 1.59	<0.0004 - 0.188
Samples	39	39	39	39	39	39	16
Lower Three Runs at Patterson Mill (1987–1991)^b							
Mean							
Range	6.6 - 17	0.67 - 1.0	3.1 - 7.8	NA	<0.01 - 0.18	<0.01 - 0.52	<0.01 - 0.07
Samples	18	18	20		19	20	18
Lower Three Runs at US Highway 125 (CCWS)^a							
Mean	11.0	0.781	2.82	1.32	0.454	0.713	0.100
Range	3.65 - 16.6	0.506 - 1.29	1.60 - 9.68	<0.368 - 3.70	0.073 - 1.77	0.283 - 2.66	<0.0004 - 0.309
Samples	39	39	39	39	39	39	16

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

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). Concentrations of total phosphorus and total ortho-phosphate measured during the CCWS and the L Lake/Steel Creek Program are summarized in Table 15-7. 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 P/l and mean total orthophosphate ranged from 0.005 to 0.007 mg P/l.

Table 15-7. Lower Three Runs/Par Pond - Nutrients

	Total Phosphorus (mg P/l)	Total Ortho- phosphate (mg PO₄-P/l)	Organic Nitrogen (mg N/l)	Total Kjeldhal Nitrogen (mg N/l)	Ammonia (mg NH₃-N/l)	Nitrite (mg NO₂-N/l)	Nitrate (mg NO₃-N/l)
Par Pond in western 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
Lower Three Runs at Road B (CCWS)^a							
Mean	0.045	0.018	0.200	0.264	0.086	0.003	0.041
Range	<0.010 - 0.174	<0.001 - 0.118	0.010 - 0.864	0.050 - 0.900	0.012 - 0.620	<0.001 - 0.010	<0.001 - 0.157
Samples	46	41	43	46	46	42	43
Lower Three Runs at Patterson Mill (CCWS)^a							
Mean	0.037	0.019	0.255	0.275	0.029	0.003	0.090
Range	<0.010 - 0.093	0.003 - 0.042	0.031 - 0.938	0.044 - 0.900	<0.005 - 0.220	<0.001 - 0.005	0.019 - 0.191
Samples	46	41	45	46	46	43	42
Lower Three Runs at Patterson Mill (1987–1991)^b							
Mean	0.029				0.072		0.10
Range	0.01 - 0.16	NA	NA	NA	<0.01 - 1.4	NA	<0.02 - 1.1
Samples	60				60		60
Lower Three Runs at US Highway 125 (CCWS)^a							
Mean	0.053	0.024	0.225	0.257	0.040	0.004	0.124
Range	<0.010 - 0.229	0.005 - 0.039	0.018 - 0.929	0.052 - 0.980	<0.005 - 0.245	<0.001 - 0.035	0.021 - 0.257
Samples	46	41	45	46	46	43	42

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Nitrogen

Table 15-7 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 Kjeldhal nitrogen, ammonia, and nitrate.

Trace Elements

Table 15-8 on page 15-18 summarizes trace element concentrations measured in Par Pond during the CCWS. Trace elements were not analyzed during the L Lake/Steel Creek Biological Monitoring Program. Low level detection limits were used in the CCWS. 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 western arm near the pumphouse intake. The highest concentration of lead (1.3 µg/l) was found at both locations.

Organic Carbon

Mean concentrations of total organic carbon in Par Pond waters ranged from 5.7 to 6.2 mg C/l. These concentrations are comparable to the mean upriver total organic carbon concentrations of 6.1 mg C/l (Lower 1987).

Pesticides, Herbicides, and PCBs

The Environmental Monitoring Section collects a sample annually from the Par Pond pumphouse and analyzes it for pesticides, herbicides, and PCBs. From 1987 to 1991, concentrations in Par Pond have been below analytical detection limits.

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

Lower Three Runs

Studies and Monitoring

Water-Quality Monitoring

The Environmental Monitoring Section has routinely monitored the water quality of Lower Three Runs since 1973. Monitoring of Lower Three Runs has occurred at various locations (below Par Pond and at Patterson Mill) over the period of record. Since 1982, the routine monitoring program has included only the Patterson Mill station (Figure 15-7 on page 15-19). The Patterson Mill location is currently sampled monthly for physical and biological parameters and quarterly for metals. Additional samples are collected annually and analyzed for pesticides and PCBs. All routine water quality data reported in the following sections can be found in the SRS environmental reports, which are published annually.

Comprehensive Cooling Water Study

The Comprehensive Cooling Water Study, conducted from 1983 to 1985, included the following sampling locations for Lower Three Runs (Figure 15-7):

- Lower Three Runs at Road B - consists of Par Pond effluents only
- Lower Three Runs at Patterson Mill - reflects Par Pond effluents and natural runoff waters from Lower Three Runs tributaries
- Lower Three Runs at US Highway 125 - combines cumulative effects of natural runoff from entire Lower Three Runs watershed, just above confluence with the Savannah River

Table 15-8. Lower Three Runs/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 western 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
Lower Three Runs at Road B (CCWS) ^a							
Mean	2.4	0.67	7.3	3.0	1.5	6.8	9.7
Range	<0.4 - 10.5	<0.04 - 4.70	<0.4 - 47.0	<0.4 - 5.5	<0.4 - 4.3	<0.4 - 59.9	<0.4 - 60.0
Samples	16	16	16	16	16	16	16
Lower Three Runs at Patterson Mill (CCWS) ^a							
Mean	1.6	0.37	7.0	2.5	1.2	8.1	5.8
Range	<0.4 - 6.8	<0.04 - 2.30	<0.4 - 56.0	<0.4 - 5.5	<0.4 - 4.7	<0.4 - 61.3	<0.4 - 30.0
Samples	16	16	16	16	16	16	16
Lower Three Runs at Patterson Mill (1987–1991) ^b							
Mean							
Range	NA	<10	<10 - <50	<10 - 16	<3 - <100	<10 - 60	<10 - 20
Samples		20	20	20	20	19	20
Lower Three Runs at US Highway 125 (CCWS) ^a							
Mean	2.0	0.45	4.6	2.5	1.4	3.0	4.8
Range	<0.4 - 7.8	<0.04 - 3.1	<0.4 - 30.0	<0.4 - 5.2	<0.4 - 5.7	<0.4 - 8.2	<0.4 - 21.5
Samples	15	16	16	16	16	16	16

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Comprehensive results and discussion of CCWS data can be found in SREL (1986) and Lower (1987). Gladden et al. (1985) summarize LTR water quality data prior to CCWS. The CCWS data presented in the following sections reflects impacts associated with reactor operation.

Priority Pollutant Study

In 1984 a special study was conducted to determine the levels of volatile, acid, and basic/neutral organic compounds in Lower Three Runs. One location of LTR, near Road B, was sampled for this study. The results of this special study are discussed in the sections that follow and are reported in Lower (1987).

Monitoring Data

The CCWS and the routine monitoring program show similar water quality analysis results for Lower Three Runs. Because Lower Three Runs has not received direct thermal discharge since 1958, its water quality and chemistry have remained relatively constant.

Field Data

Water Temperature

The mean water temperature at sampling locations in Lower Three Runs ranged from 16.0 to 19.3°C during the CCWS and routine monitoring program (Table 15-2 on page 15-11). These temperatures reflect the blackwater nature of this stream. Historic monitoring data indicated slight thermal effects from stream-water samples collected just downstream of Par Pond at Road B. Temperatures at this location averaged 2°C higher than other nonthermal or post-thermal surface waters at SRS (Gladden et al. 1985).

Figure 15-7. Water Chemistry and Quality Sampling Stations for Lower Three Runs

pH Measurements

During the CCWS, the pH of Lower Three Runs bordered on neutral, with means ranging from 6.94 just below Par Pond to 7.17 at both Patterson Mill and Highway 125 near the confluence of Lower Three Runs and the Savannah River. The pH ranged from 5.9 to 7.4 during routine monitoring (Table 15-2 on page 15-11).

Physical Characteristics and General Chemistry

Dissolved Oxygen

The mean dissolved oxygen concentrations in Lower Three Runs during the CCWS ranged from 7.06 to 7.51 mg O₂/l. From 1987 to 1991, the mean dissolved oxygen concentrations increased to 8.0 mg O₂/l at the Patterson Mill location (Table 15-4 on page 15-13). The low mean dissolved oxygen value of 7.06 mg O₂/l measured during the CCWS can be attributed to the higher water temperatures found during the CCWS at the sampling location just below Par Pond.

Conductivity

Specific conductance values ranged from 38.9 to 134.8 µmhos/cm (mean range, 74.1 to 86.3 µmhos/cm) in Lower Three Runs during the CCWS. From 1987–1991, specific conductance at Patterson Mill has averaged 75 µmhos/cm with a range of 13 to 140 µmhos/cm (Table 15-4 on page 15-13).

Suspended Solids and Turbidity

Mean turbidity values in Lower Three Runs ranged from 2.8 to 6.3 NTU during the CCWS and routine monitoring. The lowest average (2.8 NTU) was recorded during routine monitoring (1987–1991).

The concentration of suspended solids in Lower Three Runs has not changed substantially since the CCWS (Table 15-5 on page 15-14). Mean concentrations ranged from 4.11 to 5.40 mg/l during the CCWS. Routine monitoring has produced a suspended solids mean concentration of 4.9 mg/l.

Major Anions and Cations

Alkalinity, Chloride, and Sulfate

Concentrations of alkalinity, chloride, and sulfate are presented in Table X. The mean total alkalinity in Lower Three Runs during the CCWS ranged from 21.8 mg CaCO₃/l at the Cold Dam to 35.1 mg CaCO₃/l at Patterson Mill. Routine monitoring from 1987 to 1991 has shown a similar mean value at Patterson Mill (31 mg CaCO₃/l). Generally, alkalinity concentrations increased with distance downstream and reflected the alkaline nature of local groundwaters entering Lower Three Runs (Siple 1967; SREL 1986). Furthermore, the presence of calcareous deposits underlying portions of the Lower Three Runs streambed (Langley and Marter 1973) likely contributes to the increased alkalinity of the stream water (Gladden et al. 1985).

Mean chloride values were higher in Lower Three Runs at Road B (6.17 mg/l) than downstream at Highway 125 (3.71 mg/l). This is consistent with the higher values measured in Par Pond during the CCWS and the L Lake/Steel Creek Biological Monitoring Study (mean range: 5.73 to 6.28 mg/l) (Krotchener and Chimney 1992). Mean sulfate concentrations have followed this same trend. During the CCWS, mean sulfate concentrations ranged from 0.78 mg/l at the downstream station to 3.51 mg/l at the Cold Dam. From 1987 to 1991, the mean sulfate concentration has increased to 4.5 mg/l at Patterson Mill.

Calcium, Magnesium, Sodium, and Potassium

The calcium, magnesium, sodium, and potassium concentrations (total) measured in Lower Three Runs during the 1990–1991 L Lake/Steel Creek Biological Monitoring Study are similar to the concentrations measured during the CCWS (Table 15-6 on page 15-15). Potassium concentrations are not measured during routine monitoring, but were often below the detection limit (0.368 mg/l) during the CCWS.

Aluminum, Iron, and Manganese

During the CCWS, mean total aluminum concentrations ranged from 0.255 to 0.454 mg/l. Mean total iron concentrations ranged from 0.509 to 1.54 mg/l and mean total manganese concentrations ranged from 0.069 to 0.209 mg/l. Both iron and manganese concentrations were highest just downstream of Par Pond. Insufficient data prevented the calculation of mean concentrations for the period of routine monitoring. However, the measurement ranges show that the concentrations of aluminum, iron, and manganese have all decreased since the CCWS (Table 15-6 on page 15-15).

Nutrients

Phosphorus

All measured forms of phosphorus generally indicate that Lower Three Runs is phosphorus deficient relative to the waters of the Savannah River (Lower 1987). Mean total phosphorus concentrations ranged from 0.037 to 0.053 mg P/l during the CCWS (Table 15-7 on page 15-16). The mean total phosphorus concentration during routine monitoring has decreased to 0.029 mg P/l. Mean total orthophosphate concentrations ranged from 0.018 to 0.024 mg PO₄-P/l during the CCWS. Orthophosphate is not measured as part of the routine monitoring program.

Nitrogen

During the CCWS, mean concentrations for organic nitrogen and total Kjeldhal nitrogen (TKN) ranged from 0.200 to 0.255 mg N/l and 0.257 to 0.275 mg N/l respectively (Table 15-7 on page 15-16). Mean ammonia concentrations ranged from 0.029 to 0.086 mg N/l. Mean nitrite concentrations ranged from 0.003 to 0.004 mg N/l and mean nitrate concentrations ranged from 0.041 to 0.124 mg N/l. Concentrations measured during the routine monitoring program for ammonia and nitrate also fell within these ranges. Organic nitrogen, TKN, and nitrite are not measured as part of the routine monitoring program.

Trace Elements

Table 15-8 on page 15-18 summarizes trace element concentrations measured in Lower Three Runs. Low level concentrations of trace element were measured during the CCWS. The detection limits used in the routine monitoring program are higher than those used in the CCWS. As is generally the case with SRS thermal, non-thermal, and post-thermal waters, very low trace element concentrations, reflecting Savannah River concentrations, were found in Lower Three Runs (Lower 1987).

Organic Carbon

In Lower Three Runs, mean total organic carbon concentrations measured during the CCWS increased from 5.4 mg C/l downstream of the Par Pond overflow to 8.2 mg C/l at the Highway 125 crossing. This latter mean concentration was the highest found in all waters of onsite streams (SREL 1986).

Priority Pollutants

Concentrations of all 88 volatile, acid, and base/neutral organic compounds tested in Lower Three Runs at Road B never exceeded the lower limit of detection. The results of this study are documented in Lower (1987).

Pesticides, Herbicides, and PCBs

The Environmental Monitoring section collects a sample annually from Lower Three Runs and analyzes it for pesticides, herbicides, and PCBs. From 1987 to 1991, concentrations in Lower Three Runs have been below analytical detection limits.

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

Algae

Par Pond

Phytoplankton

Studies in the Par Pond System

The phytoplankton community of Par Pond was quantitatively analyzed monthly from January 1984 through June 1985 (Chimney et al. 1985). Several less comprehensive studies of the phytoplankton in the Par Pond system were conducted before 1984. These earlier studies were summarized by Wilde and Tilly (1985). Phytoplankton studies of Par Pond since 1985 are described in Chapter 18—Regional Lakes.

Taxonomic Groups Found In Par Pond

In the 1984–1985 study (Chimney et al. 1985), 337 phytoplankton taxa representing all of the major taxonomic groups characteristic of North American freshwaters (Smith 1950; Prescott 1962; Whitford and Schumacher 1984) were collected from Par Pond (Table 15-9 on page 15-25). Principal taxonomic groups listed in descending order of overall numerical importance (organisms per ml) were Bacillariophyta (diatoms), Chrysophyta (yellow-brown algae), Cryptophyta (cryptomonads), Chlorophyta (green algae), and Cyanophyta (blue-green algae). The Chlorophyta contained the largest number of species observed (152) with Bacillariophyta containing the second largest number of species (69) (Chimney et al. 1985).

Differences in Par Pond Locations

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 photosynthetic 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 stations elsewhere in Par Pond.

Effect of Reactor Operation

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). It was concluded that the addition of heat from reactor operations increases productivity and has no significant adverse impact on the phytoplankton community of Par Pond (Wilde 1985).

Changes in Community Structure, 1965-1985

The species identified in the 1984–1985 study by Chimney et al. (1985) included most (128) of the 169 phytoplankters identified in a 1978 study by Wilde (1983) (Table 15-9). 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 reported for 1978 by Wilde (1983). 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 under reactor operating conditions.

Community Comparison with Other Regional Lakes

Comparisons of Par Pond phytoplankton community with those of other regional lakes is discussed in Chapter 18—Regional Lakes.

Periphyton

Several studies of periphyton attached to glass slides placed at various locations in Par Pond were conducted by Tilly (Wilde and Tilly 1985). A species list containing the principal taxa observed in these studies appears in Table 15-10 on page 15-33. 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 station. 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 stations elsewhere in the pond.

Lower Three Runs

The algae of Lower Three Runs have not been studied with the exception of two stations that were sampled for periphyton as part of the Comprehensive Cooling Water Study conducted during 1984–1985. Periphyton biomass during this study reportedly was similar to that of Upper Three Runs (Specht 1987).

Table 15-9. Phytoplankton Taxa Collected from Par Pond During Monthly Sampling in 1984-1985 and Quarterly Sampling in 1978

Taxa	1984-1985 ^a	1978 ^b
Bacillariophyta		
<i>Achnanthes linearis</i>	x	x
<i>A. minutissima</i>	x	x
<i>Achnanthes</i> sp.	x	
<i>Asterionella formosa</i>	x	x
<i>Atthea zachariasii</i>	x	x
<i>Caloneis bacillum</i>	x	
<i>C. ventricosa</i>	x	
<i>Caloneis</i> sp.		x
<i>Cyclotella stelligera</i>	x	x
<i>Cyclotella</i> sp.	x	x
<i>Cymbella lunata</i>	x	
<i>C. minuta</i>	x	x
<i>Diploneis elliptica</i>	x	
<i>Eunotia curvata</i>	x	
<i>E. dioden</i>	x	
<i>E. flexuosa</i>	x	
<i>E. pectinalis</i>	x	x
<i>E. zazumensis</i>	x	
<i>Eunotia</i> sp.	x	
<i>Fragilaria capucina</i>	x	
<i>F. crotonensis</i>	x	x
<i>F. vaucheriae</i>	x	
<i>Fragilaria</i> sp.	x	
<i>Frustrulla rhomboides</i>	x	x
<i>Gomphonema acuminatum</i>	x	
<i>G. clevei</i>	x	
<i>G. gracile</i>	x	x
<i>G. parvulum</i>	x	x
<i>Gyrosigma acuminatum</i>	x	
<i>Gyrosigma</i> sp.	x	
<i>Melosira ambigua</i>	x	x
<i>M. distans</i>	x	
<i>M. distans</i> v. <i>tenella</i>	x	
<i>M. herzogii</i>	x	
<i>M. granulata</i>	x	x
<i>M. granulata</i> v. <i>angustissima</i>	x	x
<i>M. italica</i>	x	
<i>M. varians</i>	x	
<i>Navicula capitata</i>	x	
<i>N. cryptocephala</i>	x	
<i>N. elginensis</i>	x	
<i>N. hustedtii</i>		x
<i>N. minima</i>	x	
<i>N. pupula</i>	x	
<i>N. radiosa</i>	x	
<i>N. radiosa</i> v. <i>tenella</i>	x	
<i>Navicula</i> sp.	x	x
<i>Nitzschia acicularis</i>	x	x

Table 15-9. (cont)

Taxa	1984-1985 ^a	1978 ^b
<i>N. amphibia</i>	x	x
<i>N. dissipata</i>		x
<i>N. holsetica</i>	x	x
<i>N. intermedia</i>	x	
<i>N. palea</i>	x	x
<i>N. sigmoidea</i>	x	
<i>Pinnularia biceps</i>	x	
<i>P. major</i>	x	
<i>Rhizosolenia eriensis</i>	x	x
<i>Rhizosolenia</i> sp.		x
<i>Stauroneis phoenicenteson</i>	x	
<i>Stauroneis</i> sp.		x
<i>Surirella linearis</i>	x	
<i>S. robusta</i>	x	
<i>Surirella</i> sp.	x	
<i>Synedra delicatissima</i>	x	x
<i>S. parasilica</i>	x	
<i>S. planktonica</i>	x	x
<i>S. radians</i>	x	
<i>S. rumpens</i>	x	x
<i>S. tenera</i>	x	
<i>S. ulna</i>	x	x
<i>S. vaucheriae</i>		x
<i>Synedra</i> sp.	x	
<i>Tabellaria flocculosa</i>	x	
<i>T. fenestrata</i>		x
Chlorophyta		
<i>Actinastrum hantzschii</i>		x
<i>Ankistrodesmus convolutus</i>		
<i>A. falcatus</i>		x
<i>A. falcatus</i> v. <i>mirabilis</i>		x
<i>A. spiralis</i>	x	x
<i>Arthrodesmus maximum</i>	x	
<i>A. octocornus</i>	x	
<i>A. validus</i>	x	
<i>Arthrodesmus</i> sp. 1	x	x
<i>Arthrodesmus</i> sp. 2	x	
<i>Botryococcus braunii</i>		x
<i>Carteria dissecta</i>	x	
<i>C. globosa</i>	x	
<i>Carteria</i> sp. 1	x	x
<i>Characium ambiguum</i>	x	
<i>Characium</i> sp. 1	x	
<i>Chlamydomonas</i> sp. 1	x	x
<i>Chlamydomonas</i> sp. 2	x	
<i>Chlorogonium</i> sp.	x	
<i>Closteriopsis longissima</i>	x	x
<i>Closteriopsis</i> sp.	x	
<i>Closterium abruptum</i>	x	
<i>C. acerosum</i>	x	

Table 15-9. (cont)

Taxa	1984–1985 ^a	1978 ^b
<i>C. acutum</i>	x	
<i>C. aciculare</i>	x	
<i>C. diana</i>	x	
<i>C. gracile</i>	x	
<i>C. kuetzingii</i>	x	
<i>C. parvulum</i>	x	
<i>C. venus</i>	x	
<i>Closterium</i> sp.	x	x
<i>Coelastrum cambricum</i>	x	x
<i>C. microporum</i>	x	
<i>C. proboscideum</i>	x	x
<i>C. reticulatum</i>	x	
<i>Cosmarium angulosum</i>	x	
<i>C. biretum</i> v. <i>trigibberum</i>	x	
<i>C. clepsydra</i>	x	
<i>C. contractum</i>	x	
<i>C. depressum</i>	x	
<i>C. granatum</i>	x	
<i>C. impressulum</i>	x	
<i>C. isthmium</i>	x	
<i>C. protractum</i>	x	
<i>C. pseudibroemei</i>	x	
<i>C. reniforme</i>	x	
<i>C. sexangulare</i>	x	
<i>C. tenue</i>	x	
<i>C. tenue</i> v. <i>minus</i>	x	
<i>Cosmarium</i> sp.	x	xx
<i>Cosmarium</i> spp.	x	
<i>Crucigenia apiculata</i>	x	
<i>C. crucifera</i>	x	
<i>C. irregularis</i>	x	
<i>C. quadrata</i>	x	xx
<i>C. tetrapedia</i>	x	xx
<i>C. truncata</i>	x	
<i>Desmidium aptogonum</i>	x	
<i>D. baileyi</i>	x	
<i>D. grevillii</i>	x	
<i>Dictyosphaeium pulchellum</i>	x	xx
<i>Elakatothrix gelatinosa</i>	x	xx
<i>E. viridis</i>	x	xx
<i>Euastrum ciastonii</i>	x	
<i>Eudorina elegans</i>	x	xx
<i>Francia droescheri</i>		x
<i>F. ovalis</i>	x	x
<i>Gleocystis ampla</i>	x	x
<i>G. gigas</i>	x	x
<i>G. planktonica</i>	x	x
<i>G. vesiculosa</i>		x
<i>Golenkenia gigas</i>	x	
<i>G. paucispina</i>	x	

Table 15-9. (cont)

Taxa	1984–1985 ^a	1978 ^b
<i>G. radiata</i>	x	x
<i>Gonatozygon brebissonii</i>		x
<i>Gonium pectorale</i>	x	x
<i>Kirchneriella contorta</i>	x	
<i>K. lunata</i>	x	
<i>K. lunaris</i>	x	
<i>K. obesa</i>	x	
<i>K. subsolitaria</i>		x
<i>Lagerhemia chodatii</i>	x	
<i>L. quadradiseta</i>		x
<i>Micratinium pusillum</i>	x	x
<i>Micrasterias muricata</i>	x	
<i>M. radiata</i>	x	
<i>Mougeotia</i> sp.	x	x
<i>Nephrocytium acardhianum</i>	x	
<i>Oedogonium</i> sp.	x	
<i>Onychonema laeve</i> v. <i>micracanthum</i>	x	
<i>Oocystis borgei</i>	x	x
<i>O. lacustris</i>	x	x
<i>O. parva</i>	x	
<i>O. pusilla</i>	x	x
<i>Pandorina morum</i>	x	
<i>Pediastrum boryanum</i>		x
<i>P. duplex</i>	x	
<i>P. tetras</i>	x	
<i>Pleurotaenium subcornulatum</i>	x	
<i>P. tridentulum</i>		x
<i>Quadrigula closteriodes</i>	x	
<i>Scenedesmus abundans</i>	x	
<i>S. acuminatus</i>	x	
<i>S. bernardi</i>	x	
<i>S. bijuga</i>	x	
<i>S. brasiliensis</i>	x	
<i>S. brevispina</i>	x	x
<i>S. denticulatus</i>		x
<i>S. dimorphus</i>	x	x
<i>S. intermedium</i>		x
<i>S. longispina</i>	x	
<i>S. opoliensis</i>	x	x
<i>S. quadricauda</i>	x	x
<i>S. spinosus</i>	x	
<i>Scenedesmus</i> sp.	x	
<i>Schroderia judayi</i>	x	
<i>S. scutgera</i>	x	x
<i>Scourfieldii cordiformis</i>	x	
<i>Selenastrum capricornutum</i>	x	x
<i>S. gracile</i>	x	x
<i>S. minutum</i>	x	x
<i>Sorastrum americanum</i>	x	
<i>Sphaerellopsis</i> sp.	x	

Table 15-9. (cont)

Taxa	1984–1985 ^a	1978 ^b
<i>Sphaerocystis planktonica</i>	x	
<i>Spirogyra</i> sp.	x	
<i>Spondylosium leutkemuellerei</i>	x	
<i>S. planum</i>	x	
<i>Stauroastrum anatinum</i>	x	
<i>S. apiculatum</i>	x	
<i>S. chaetoceros</i>	x	x
<i>S. claviferum</i>	x	
<i>S. clevei</i>	x	
<i>S. curvatum</i>	x	
<i>S. gladiusum</i>	x	
<i>S. gracile</i>	x	
<i>S. hexacerum</i>		
<i>S. megacanthum</i>	x	
<i>S. micron</i>	x	
<i>S. paradoxum</i>	x	x
<i>S. pentacerum</i>	x	
<i>S. ravenellii</i>		x
<i>S. rotula</i>	x	
<i>S. small</i>	x	
<i>S. smithii</i>	x	
<i>S. tetracerum</i>	x	
<i>Stauroastrum</i> sp. 1	x	x
<i>Stauroastrum</i> sp. 2		x
<i>Tetraedron caudatum</i>	x	x
<i>T. constrictum</i>	x	
<i>T. gracile</i>	x	x
<i>T. minimum</i>	x	x
<i>T. quadricuspidatum</i>	x	
<i>T. regulare</i>	x	x
<i>T. staurogeniaeforme</i>		x
<i>T. trigonum</i>	x	x
<i>Tetraedron</i> sp.	x	x
<i>Treubaria setigerum</i>	x	
<i>Ulothrix</i> sp.	x	
Undetermined green flagellates		x
<i>Vaucheria</i> sp.	x	
<i>Volvox aures</i>	x	
<i>Westella botryoides</i>	x	x
<i>W. linearis</i>	x	
<i>Xanthidium antilopaeum</i>	x	
<i>X. cristatum</i>	x	x
<i>Xanthidium</i> sp.		x
<i>Zygnema</i> sp.	x	
Unid. coccoid unicells 5-10 µ	x	
Unid. coccoid unicells 11-15 µ	x	
Unid. coccoid colony	x	
Chrysophyta		
<i>Bitrichia</i> sp.	x	
<i>Chromulina mikrop plankton</i>	x	

Table 15-9. (cont)

Taxa	1984-1985 ^a	1978 ^b
<i>C. minima</i>	x	
<i>C. parvula</i>	x	
<i>Chromulina</i> sp. 1	x	
<i>Chrysosphaerella longispina</i>	x	
<i>Dinobryon bavaricum</i>	x	
<i>D. divergens</i>	x	x
<i>D. sertularia</i>	x	
<i>Dinobryon</i> sp.	x	
<i>Kephyrion ovale</i>	x	
<i>Kephyrion</i> sp.	x	
<i>Mallomonas acaroides</i>	x	
<i>M. alpina</i>		x
<i>M. caudata</i>	x	x
<i>M. pseudocoronata</i>	x	x
<i>M. tonsurata</i>	x	x
<i>Mallomonas</i> sp. 1	x	x
<i>Mallomonas</i> sp. 2	x	
<i>Mallomonas</i> spp.	x	
<i>Ochromonas nonnos</i>	x	
<i>Ochromonas</i> sp.	x	
<i>Ophiocytium capitatum</i> v. <i>longispinum</i>		x
<i>Synura caroliniana</i>	x	
<i>S. petersenii</i>		x
<i>S. uvella</i>	x	x
Unid. chrysophyte sp. 1	x	
Unid. chrysophyte sp. 2	x	
Unid. chrysophyte spp.	x	
Cryptophyta		
<i>Cryptomonas caudata</i>	x	
<i>C. curvata</i>	x	
<i>C. erosa</i>	x	x
<i>C. marsonii</i>	x	x
<i>Cryptomonas</i> sp.		x
<i>Rhodomonas minuta</i>	x	x
<i>Rhodomonas</i> sp.		x
Cyanophyta		
<i>Anabaena circinalis</i>	x	
<i>A. planktonica</i>	x	
<i>A. wisconsinense</i>	x	
<i>Anabaena</i> sp.	x	x
<i>Anacystis</i> sp.		x
<i>Aphanizomenon flos-aquae</i>	x	
<i>Aphanocapsa elachista</i>	x	
<i>A. elachista</i> v. <i>conferta</i>	x	
<i>A. elachista</i> v. <i>planktonica</i>	x	
<i>Aphanocapsa pulchra</i>	x	
<i>A. rivularis</i>	x	
<i>Aphanocapsa</i> sp.	x	
<i>A. nidulans</i>	x	
<i>Chroococcus dispersus</i>	x	

Table 15-9. (cont)

Taxa	1984–1985 ^a	1978 ^b
<i>C. lacustris</i>	x	
<i>C. limneticus</i>	x	
<i>Chroococcus</i> sp.		x
<i>Coelosphaerium kuetzingianum</i>	x	
<i>C. naegelianum</i>	x	
<i>Dactylococcopsis fascicularis</i>		x
<i>Gloeotheca linearis</i> v. <i>composita</i>	x	
<i>Lyngbya limnetica</i>	x	x
<i>Lyngbya</i> sp.	x	
<i>Mastigocladus laminosus</i>	x	x
<i>Merismopedia tenuissima</i>	x	x
<i>Microcystis aeruginosa</i>	x	
<i>M. incerta</i>	x	
<i>M. stagnalis</i>	x	
<i>Oscillatoria amphibia</i>	x	
<i>O. formosa</i>	x	
<i>O. geminata</i>	x	x
<i>O. limosa</i>	x	
<i>O. nigra</i>	x	
<i>O. splendida</i>	x	
<i>O. tenuis</i>	x	
<i>Oscillatoria</i> sp.	x	x
<i>Phormidium</i> sp. 1	x	x
<i>Phormidium</i> spp.	x	
<i>Spirulina major</i>	x	x
<i>S. princeps</i>	x	
<i>Spirulina</i> sp.	x	
<i>Schizothrix</i> sp.	x	x
<i>Tolypothrix</i> sp.	x	
Unid. cyanophyte	x	
Euglenophyta		
<i>Euglena acus</i>	x	
<i>E. gracilis</i>	x	
<i>E. minuta</i>	x	x
<i>E. proxima</i>	x	
<i>Euglena</i> sp. 1	x	x
<i>Euglena</i> sp. 2		x
<i>Lepocinclis</i> sp.	x	
<i>Microglena cordiformis</i>	x	
<i>Phacus monilatus</i>	x	
<i>P. obicularis</i>	x	
<i>P. suecicus</i>	x	
<i>P. tortus</i>	x	
<i>Phacus</i> sp.		x
<i>Trachelomonas armata</i>	x	
<i>T. furcata</i>	x	
<i>T. hispida</i>	x	
<i>T. horrida</i>		x
<i>T. oblonga</i>	x	
<i>T. volvocina</i>	x	

Table 15-9. (cont)

Taxa	1984-1985 ^a	1978 ^b
<i>Trachelomonas</i> sp.	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	
Pyrrophyta		
<i>Ceratium carolinianum</i>	x	
<i>C. hirundinella</i>	x	
<i>Glenodinium palustre</i>	x	
<i>G. guadridentis</i>	x	
<i>Glenodinium</i> sp.	x	x
<i>Gymnodinium. aeruginosum</i>	x	
<i>G. excavatum</i>	x	
<i>G. ordinatum</i>	x	
<i>G. palustre</i>	x	
<i>Gymnodinium</i> sp. 1	x	
<i>Gymnodinium</i> sp. 2	x	
<i>Peridinium cinctum</i>	x	
<i>P. cinctum</i> v. <i>tuberosum</i>	x	
<i>P. inconspicuum</i>	x	
<i>P. pusillum</i>	x	
<i>P. umbonatum</i>	x	
<i>P. wisconsinense</i>	x	
<i>Peridinium</i> sp.	x	x

^a Source: Chimney et al. (1985)

^b Source: Wilde (1983)

Table 15-10. Principal Periphyton Species^a Collected from Par Pond^b (Wilde 1985)

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 parvium
Gomphonema subcavatum
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

Cylorophyta

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 comminurale var. *crassum*
Cosmarium dentatum
Cosmarium excavatum f. *duplomajor*
Cosmarium exiguum
Cosmarium goleritum
Cosmarium impressulum
Cosmarium margaritatum
Cosmarium pardalis

Table 15-10. (cont)

Cosmarium phaseolus
Cosmarium psuedoconnatum
Cosmarium schliephakeanum
Cosmarium spp.
Cosmarium subcrenatum
Cosmarium tenue
Cosmocladium saxonicum
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 *reticulata*
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.

Table 15-10. (cont)

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

^a Identifications made by the Academy of Natural Sciences of Philadelphia under subcontract to Du Pont.

^b Collections made from artificial substrates.

Macrophytes

Par Pond

Par Pond aquatic macrophytes are not covered in this section, for details please refer to Chapter 7—Wetlands of Par Pond.

Lower Three Runs

The only data dealing with aquatic macrophytes in Lower Three Runs comes from the Comprehensive Cooling Water Study (CCWS) (Volume IV, Specht 1987) and was collected during the 1984–1985 sampling period. This data may not be representative of the current state of the macrophyte populations in Lower Three Runs since high flows were experienced during the drawdown of Par Pond in 1991.

Summary data from the CCWS appears in Table 15-11 (Specht 1987). Station 42, located just downstream from Par Pond dam, shows some macrophyte development. This is probably attributable to less overstory cover and flow fluctuations from Par Pond. The other two stations show little (Station 43) and no (Station 53) macrophyte development. This is probably because of extensive shading by the riparian tree canopy.

It is possible that the riparian vegetation structure has been altered by the change in flow regimes brought about first by the shutdown of P Reactor and then by Par Pond drawdown. A research program to examine the current status of the riparian and aquatic macrophyte communities in Lower Three Runs might be beneficial in helping to elucidate response of wetland and aquatic plant communities to changes in hydrologic conditions and in-stream flow variation.

Table 15-11. The Annual Mean, Number of Reaches Mapped During Year (M) and Standard Deviation (s), October 1984–September 1985 (Source: Firth et al. 1986)

Species	Area (m ² /m ²)		Volume (m ³ /m ²)		Biomass (g/m ²)		Percent Cover		N
	Mean	s	Mean	s	Mean	s	Mean	s	
Station 42 (LTR-n)									
CAL	0.0002	0.0008	<0.0001	<0.0001	0.0005	0.0021	0.0180	0.0805	20
CER	0.0025	0.0042	0.0003	0.0005	0.3474	0.5316	0.2540	0.4207	20
MISC	0.0022	0.0087	-	-	-	-	0.2226	0.8693	20
MYR	0.0003	0.0011	<0.0001	<0.0001	0.0068	0.0201	0.0343	0.1148	20
POL	0.0004	0.0016	-	-	0.1890	0.7137	0.0420	0.1580	20
POT	0.0270	0.0558	0.0011	0.0028	1.369	3.373	2.696	5.578	20
VAL	0.0008	0.0032	0.0003	0.0011	0.0159	0.0685	0.0818	0.3200	20
Station 53 (LTR-n)									
No vegetation in mapped channel									
Station 43 (LTR-n)									
MISC	0.0049	0.0184	-	-	-	-	0.4851	1.839	20
NU	0.0011	0.0040	<0.0001	<0.0001	0.0284	0.1121	0.0578	0.1996	20

Zooplankton

Par Pond

Introduction

The characterization of zooplankton populations in Par Pond are based on three separate studies performed from January 1984 to June 1985 (Chimney et al. 1986), September 1988 and 1989 (Bowers 1992), and from January 1990 through 1991 (Bowers 1993). The Chimney et al. (1986) and Bowers (1992) monitoring programs were part of larger studies for compliance to the Section 316a 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 lake 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 (see Chapter 17—Regional Lakes Study) (Bowers 1992).

Study Methods

Methods differed in the studies, but sampling locations and laboratory and enumeration techniques were virtually 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, and the Bowers (1992 and 1993) studies employed standard vertical net tows for macrozooplankters (Cladocera and Copepoda), and a plankton pump for microzooplankton pooled over depth (Protozoa and Rotifera). This difference in water column sampling could easily account for the results described in the following sections. Discrete whole-water samples sample only a very small portion of the water column while vertical net tows or pooled pump samples physically integrate the whole water column. The 1984-1985 study sampled at several locations in the basin (Figure 15-8 on page 15-40), while the more recent efforts only sampled at the deep water location near the Par Pond 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 state that population cycles in macrozooplankton can only be truly indicated when sampling frequencies are approximately every 14 days. Without this resolution delineating cohort, cycles are missed. Likewise, protozoans and rotifers, having generation times spanning a few weeks, must be sampled at least every 7 days to observe population cycles during a season.

Group Densities

Introduction

Figure 15-9 on page 15-40 through Figure 15-12 on page 15-42 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

Figure 15-8. Location Map of Par Pond

Figure 15-9. Mean Density of Protozoa in Par Pond

Figure 15-10. Mean Density of Rotifera in Par Pond

Figure 15-11. Mean Density of Cladocera in Par Pond

Figure 15-12. Mean Density of Copepoda in Par Pond

community succession. Numerically, protozoans and rotifers always dominate limnetic communities (Wetzel 1983) as seen in Figure 15-9 on page 15-40 and Figure 15-11 when compared to cladoceran and copepod densities.

Protozoan

Protozoan densities were greatest during cooler months (March 1984, May 1984, December 1985, January 1985, February 1985, September 1988, May 1990, November 1990, and November 1991). Dominant species included *Tintinnopsis cylindrata*, *Vorticella* spp., *Strombidium* spp., *Holophryid* spp. (< 50 µ), *Uronema* spp., and *Diffugia limnetica*.

Rotifera

Rotifera were also cool weather fauna; they were most abundant during September 1984, December 1984, and February 1985. However, there were general increases during 1990–1991. This increase 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 are particularly successful during periods of invertebrate predation because of their hard and spiny lorica and, for some, the ability to rapidly escape and avoid being captured by predatory zooplankters (Stemberger 1985).

Cladoceran

Cladocerans were most abundant during 1984–85 and 1988–89. During 1990 abundance estimates were lower followed by increases during 1991. However, 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 months in 1991 compared with all other sampling dates. Because of the magnitude of this increase, sampling differences might be excluded and the increase considered genuine. Probable causes of this increase can result from increased fecundity and reduced mortality. Most likely, the increase resulted from a lessening of planktivorous fish predation that generally regulates macrozooplankton abundances. Dominant species were continuous during the sampling periods, which included *Tropocyclops prasinus*, *Acanthocyclops vernalis*, *Diaptomus mississippiensis*, and *Epischura nordenskioldi*.

Lower Three Runs

No data are available on the zooplankton of Lower Three Runs.

Macroinvertebrates

Par Pond

Sampling Locations and Methods

From January 1984 through June 1985 benthic macroinvertebrates were sampled quarterly in four areas of Par Pond (Figure 15-13). Quantitative samples were collected using a petite Ponar grab sampler and qualitative samples were collected with a D-frame dip net. In addition, meroplankton samples were collected biweekly during daylight hours and quarterly for 24-hour periods along eight transects in Par Pond by towing paired 0.5 m 505 μ m mesh plankton nets. For details of sampling methods, see Kondratieff et al. (1985).

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 can be found 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 15-13. Macroinvertebrate Sampling Stations for Par Pond

Results

Number of Taxa Collected

For all sampling methods combined, at least 143 macroinvertebrate taxa were collected from Par Pond in 1984-1985 (Table 15-19 on page 15-53). During the sampling events that took place in 1988 and 1989, 82 taxa were collected (Table 15-20 on page 15-58). However, in some instances taxonomic resolution differed between the two studies, so the number of taxa collected may 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 conducted in 1984 and 1985 were probably missed by the sampling conducted in September of 1988 and 1989, due to the relatively smaller total number of samples that were collected in 1988 and 1989.

1984-1985 Meroplankton

Like most lakes, the meroplankton community of Par Pond was generally dominated by dipterans (primarily the phantom midge, *Chaoborus punctipennis*), which composed 28.9 to 90.6% of the organisms collected in the meroplankton samples during the course of the 18-month sampling program (Table 15-12). Chironomid dipterans were also commonly found in the meroplankton. Oligochaetes were the second most abundant group of organisms, accounting for 3.2 to 41.7% of the macroinvertebrates collected during the meroplankton tows. Oligochaetes were almost always collected in the bottom, 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 to 45.5%), pelecypods (clams; 0.0 to 15.8%), and Hydracarina (water mites; 1.2 to 21.7%; Table 15-12). Caddisflies were collected in substantial numbers only at the pump house 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 D2 to 13.6 at the

Table 15-12. Percent Composition (relative abundance) of Major Macroinvertebrate Meroplankton Taxa Collected in Par Pond and Pond B, January 1984–June 1985.

Taxa	Sampling Locations										
	Par Pond									Pond B	
	H1	H2	N1	N2	D1	D2	I1	I2	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

pump house station (Table 15-13). The mean density of organisms ranged from 144.6 organisms/1000 m³ at Station I1 to 711.5 organisms/1000 m³ at the pump house and averaged 374.1 organisms/1000 m³ for all stations and dates combined (Table 15-13). The high density at the pump house relative to other locations was primarily 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. 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 15-14 on page 15-48). Mean species diversity was very similar at all stations, ranging from 1.90 at the Cold Dam to 2.07 in the Intake Arm (Table 15-14). These values were considered moderate, when compared to values from other lentic benthic macroinvertebrate communities (Kondratieff et al. 1985). Diptera dominated the benthic fauna at all stations. Chironomidae were the most abundant Diptera, except at the Cold Dam, where the phantom midge (*Chaoborus punctipennis*) predominated. Typically, *Chaoborus punctipennis* was the most abundant taxon at the deepest sampling locations, while the amphipod, *Hyallela azteca*, and oligochaetes, nematodes, flatworms (Turbellaria), and chironomids of the subfamily Chironominae, were most abundant in shallower waters. The Hot Arm contained much higher relative abundances and densities of turbellarians (*Dugesia tigrina*), nematodes, oligochaetes, leeches (Hirudinea), and clams (mostly *Corbicula fluminea*) than the rest of Par Pond (Table 15-15 on page 15-48 and Table 15-16).

Macroinvertebrate densities ranged from 2416.0 organisms/m² in the Intake Arm to 7224.8 organisms/m² in the Hot Arm (Table 15-14). Mean dry weight biomass ranged from 6.76 to

Table 15-13. Mean Species Richness (no. of taxa) and Mean Density of Organisms in Par Pond and Pond B Macroinvertebrate Meroplankton Samples. January 1984–June 1985.

Sampling Location	Mean	Mean Density
	Species Richness (S.E.)	Organisms/1000 m ³ (S.E.)
<i>Par Pond</i>		
H1	4.7 (0.5)	191.3 (48.7)
H2	6.0 (0.6)	292.1 (69.7)
N1	6.7 (0.5)	368.1 (85.6)
N2	6.9 (0.7)	573.7 (286.9)
D1	5.6 (0.6)	320.9 (86.4)
D2	4.7 (0.4)	425.2 (218.3)
I1	5.4 (0.5)	144.6 (52.3)
I2	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)
<i>Pond B</i>		
B1	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)

41.76 g/m² (Table 15-14). 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 large numbers 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 15-19 on page 15-53). 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).

Table 15-14. 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			Mean Biomass Ash-Free Dry Mass (g/m ²)
	Mean Species Richness (S.E.) ^a	Mean Density as No./m ² (S.E.)	Mean Species Diversity (S.E.)	
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
Intake 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

^aS.E. = standard error

Table 15-15. Percent Composition (relative abundance) of Major Benthic Macroinvertebrate Taxa Collected in Par Pond and Pond B. H = Hot Arm, N = North Arm, D = Cold Dam and I = Intake Arm. February 1984–May 1985.

Taxon	Sampling Area				Pond B
	H	N	D	I	
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

1988–1989 Sampling

A total of 82 macroinvertebrate taxa were collected from dredge samples and dip net samples in Par Pond in September 1988 and 1989 (Table 15-20 on page 15-58). The most abundant groups of organisms in the dredge samples included oligochaetes, snails, clams, chironomids, and the phantom midge (*Chaoborus punctipennis*) (Table 15-17).

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 than in 1984–1985, while the relative abundance of dipterans was somewhat lower (Table 15-15 and Table 15-17). The mean density of organisms in the dredge samples was 5762.2 organisms/m² in 1988 (Hughes and Chimney 1988), while in 1989, the density was almost twice that of 1988, averaging 10,093 organisms/m² (Chimney and Wallis 1989).

Table 15-16. Composition of Benthic Macroinvertebrate Community Presented as Mean Densities (organisms/m²) from Par Pond and Pond B. H = Hot Arm, N = North Arm, D = Cold Dam and I = Intake Arm. February 1984–May 1985.

Taxa	Sampling Area				Pond B
	H	N	D	I	
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
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	3421.5

Table 15-17. Percent Composition (Relative Abundance) 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
Chaoboridac ^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.

Figure 15-14. Macroinvertebrate Sampling Stations for Lower Three Runs

Lower Three Runs

Sampling Locations and Methods

Macroinvertebrates were collected at three stations in Lower Three Runs from November 1983 through September 1985 as Part of the Comprehensive Cooling Water Study (Figure 15-14). Macroinvertebrates were collected from Hester-Dendy multiplate samplers, leaf bags and drift. Macroinvertebrates were also collected in the mouth of Lower Three Runs from October 1982 through September 1983 using Hester-Dendy multiplate samplers and drift nets. For details of sampling methods, see Specht (1987)

Results

Community Composition

The macroinvertebrate community just downstream from the Par Pond dam (Station 42) was greatly influenced by Par Pond. Of the 34 stream sampling stations that were sampled for macroinvertebrates using Hester-Dendy multiplate samplers during the CCWS, this station had by far the highest density of macroinvertebrates (5549.8 organisms/m²; Table 15-18). The high density was due in part to large numbers of Tanytarsini chironomids, which composed 39% of the organisms collected from the multiplate samplers. Other abundant taxa at Station 42 included the chironomid groups Orthocladiinae (15.0%), Chironomini (9.6%), and Tanypodinae (3.3%); hydropsychid caddisflies (3.7%); and Simuliidae (black-flies; 1.7%; Firth et al. 1986). Many of these macroinvertebrates are filter-feeders that fed on the seston inputs from Par Pond.

Downstream at Station 43, densities were comparable to those at many other CCWS stations, averaging 743.5 organisms/m² (Table 15-18). Common taxa at Station 43 included the chironomid groups Chironomini (19.7%), Tanytarsini (17.6%), and Orthocladiinae (17.2%); the stonefly, *Perlesta placida* (5.2%); the mayflies *Ephemerella invaria* (6.5%) and *Stenonema modestum* (2.4%); and the caddisfly *Cheumatopsyche* (2.9%; Firth et al. 1986).

Macroinvertebrate density in the mouth of Lower Three Runs was higher than at Station 43, averaging 1932.3 organisms/m² (Table 15-18). Chironomids comprised 84% of the macro-

Table 15-18. Average Macroinvertebrate Density, Biomass, Taxa Per Sampler and Total Taxa Collected from Hester-Dendy Multiplate Samplers in Lower Three Runs, October 1984–September 1985

Parameter	Station		
	42	43	Creek Mouth
Density (no./m ²)	5549.8	743.5	1932.3
Biomass (g/m ²)	0.549	0.411	0.159
Mean Number of Taxa/Sampler	12.6	17.6	13.8
Total Number of Taxa Collected	56	67	50

invertebrates collected from multiplates in the mouth of the creek. Other common taxa included the mayfly *Stenonema modestum* (5.2%) and the caddisfly *Cheumatopsyche* (3%; Chimney and Cody 1986).

Biomass

Macroinvertebrate biomass declined in a downstream direction, averaging 0.549 g/m² at Station 42, 0.411 g/m² at Station 43, and 0.159 g/m² in the creek mouth (Table 15-18). At Station 42, an average of 12.6 taxa were collected per sampler and a total of 56 taxa were collected during the two-year sampling program, while downstream at Station 43, taxa richness was higher, with a mean of 17.6 taxa per sampler and a total of 67 taxa collected (Table 15-18). In the creek mouth, an average of 13.8 taxa were found on the multiplate samplers, while a total of 50 taxa were collected (Table 15-18).

Table 15-19. Macroinvertebrate Taxa Collected from Par Pond and Pond B, 1984–1985

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

Table 15-19. (cont)

Scientific Name	Common Name		
<i>Koenikea</i> sp.		PP	M
<i>Limnesia</i> sp.		PP, PB	D, M
<i>Neumania</i> sp.		PP, PB	M
<i>Piona</i> sp.		PP, PB	M
<i>Unionicola</i> 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		
<i>Hyalella azteca</i>		PP, PB	D, N, M
Order Isopoda	isopods		
<i>Asellus</i> sp.		PP	D, M
Order Ostracoda	seed shrimp		
unidentified sp. A		PP, PB	M
unidentified sp. B		PP, PB	M
Order Decapoda	crayfish		
<i>Procambarus</i> sp.		PP	N, M
Class Insecta			
Order Collembola	springtails		
<i>Isotomurus palustris</i>		PP	M
Sminthuridae		PB	N
unidentified spp.		PP	D, M
Order Ephemeroptera	mayflies		
<i>Baetis</i> spp.		PP, PB	D, N, M
<i>Caenis diminuta</i>		PP, PB	N
<i>Caenis</i> spp.		PP, PB	D, N, M
<i>Callibaetis floridanus</i>		PP, PB	N
<i>Callibaetis</i> sp.		PP, PB	D, N, M
<i>Paraleptophlebia</i> sp.		PB	N, M
<i>Stenonema</i> sp.		PP	M
Order Odonata	dragonflies and damselflies		
<i>Anax longipes</i>		PP	N
<i>Aphylla williamsoni</i>		PP	D, N, M
<i>Argia fumipennis</i>		PP	M
<i>Argia</i> spp.		PP, PB	N
<i>Basiaeschna janata</i>		PP	N
<i>Brachymesia gravida</i>		PP	N
<i>Celithemis fasciata</i>		PP, PB	D, N
<i>Celithemis ornata</i>		PP, PB	D, N
<i>Celithemis</i> sp.		PP, PB	N, M
<i>Coryphaeschna ingens</i>		PP	N, M
<i>Didymops transversa</i>		PP	N
<i>Dromogomphus spinosus</i>		PP	N
<i>Enallagma divagans</i>		PP, PB	N, M
<i>Enallagma vesperum</i>		PP	N, M
<i>Enallagma hageni</i>		PP, PB	N, M
<i>Enallagma</i> sp.		PP, PB	D, N, M
<i>Epiaeschna heros</i>		PP	N

Table 15-19. (cont)

Scientific Name	Common Name		
<i>Epicordulia princeps</i>		PP	M
<i>Epicordulia regina</i>		PP	N
<i>Erythemis simplicicollis</i>		PP, PB	N
<i>Ischnura</i> spp.		PP	M
Gomphidae			
<i>Gomphus exilis</i>		PP, PB	N
<i>Ladona deplanata</i>		PB	N
<i>Lestes vigilax</i>		PP	D, N
<i>Lestes</i> sp.		PP, PB	N, M
<i>Libellula auripennis</i>		PP, PB	N
<i>Libellula axilena</i>		PP, PB	N
<i>Libellula cyanea</i>		PP, PB	N
<i>Libellula incesta</i>		PP, PB	N
<i>Libellula</i> sp.		PP	N
<i>Nehalennia</i> sp.		PP	N
<i>Pachydiplax longipennis</i>		PP, PB	D, N, M
<i>Perithemis tenera</i>		PP	N, M
<i>Progomphus</i> prob. <i>obscurus</i>		PP	N
<i>Tetragoneuria cynosura</i>		PP, PB	D, N
<i>Tetragoneuria</i> sp.		PP, PB	N, M
<i>Tramea carolina</i>		PB	N
unidentified spp.		PP	N
Order Hemiptera	true bugs		
<i>Belostoma flumineum</i>		PP	N
<i>Belostoma</i> sp.		PP	D, N, M
<i>Merragata brunnea</i>		PP	N
<i>Mesovelia mulsanti</i>		PP, PB	D, N, M
<i>Microvelia</i> sp.		PB	N
<i>Neogerris hesione</i>		PB	N
<i>Neoplea striola</i>		PP, PB	N, M
<i>Pelocoris femoratus</i>		PP	N
<i>Ranatra nigra</i>		PB	N
<i>Ranatra</i> sp.		PP	N
<i>Trichocorixa macrocephala</i>		PP, PB	N
<i>Trichocorixa</i> sp.		PP, PB	N
Order Plecoptera	stone flies		
unidentified sp.		PP	M
Order Coleoptera	beetles		
<i>Agabus</i>		PP, PB	N
<i>Bagous</i> sp.		PP	N, M
<i>Berosus striatus</i>		PB	N
<i>Berosus</i> sp.		PP, PB	N
<i>Bidessus</i> sp.		PB	N
<i>Celina</i> sp.		PP, PB	D, N, M
<i>Coptotomus interrogatus</i>		PB	N
Curculionidae			
<i>Cybister fimbriolatus</i>		PP	N
<i>Derallus altus</i>		PB	N
<i>Disonychia</i> sp.		PP	D, M
Phylum Arthropoda (continued)			

Table 15-19. (cont)

Scientific Name	Common Name		
<i>Donacia</i> sp.		PP, PB	N, M
<i>Dubiraphia bivittata</i>		PP	M
<i>Haliphus</i> prob. <i>americanus</i>		PP	N, M
<i>Haliphus triopsis</i>		PP	N
<i>Haliphus fasciatus</i>		PP, PB	N
<i>Haliphus</i> sp.		PP, PB	N, M
<i>Hydrochus inaequalis</i>		PB	N
<i>Hydroporus</i> prob. <i>hybridus</i>		PP, PB	D, N, M
<i>Hydroporus</i> spp.		PP, PB	D, N, M
<i>Hydrovatus pustulatus</i>		PP	N
<i>Macronychus glabratus</i>		PP	M
<i>Peltodytes dietrichi</i>		PP	N
<i>Peltodytes sexmaculatus</i>		PP	N
<i>Peltodytes</i> sp.		PP	N, M
<i>Pyrrhalta nymphaeae</i>		PP	N
<i>Pyrrhalta</i> sp.		PB	N
<i>Thermonectus basillaris</i>		PP	M
unidentified sp.		PB	N
Noieridae			
<i>Hydrocanthus</i> sp.		PP	N
<i>Susphisellus bicolor punctipennis</i>		PB	N
unidentified sp.		PP	D
Order Trichoptera	caddisflies		
<i>Agrypnia vestita</i>		PB	N
<i>Banksiola</i> sp.		PB	N
<i>Ceraclea maculata</i>		PP	M
<i>Cernotina spicata</i>		PP, PB	D, N, M
<i>Cheumatopsyche</i> sp.		PP	M
<i>Cyrnellus fraternus</i>		PP	M
<i>Hydropsyche</i> sp.		PP	M
<i>Hydroptila</i> sp.		PP	M
<i>Leptocerus americanus</i>		PP, PB	D, M
<i>Oecetis inconspicua</i>		PP, PB	N
<i>Oecetis</i> sp. 1		PB	D, N, M
<i>Oecetis</i> sp. 2		PP	M
<i>Orthotrichia</i> sp.		PP, PB	D, N, M
<i>Oxyethira</i> spp.		PP, PB	D, N, M
<i>Polycentropus</i> sp.		PP, PB	N
<i>Ptilostomis</i> sp.		PP	N
<i>Triaenodes</i> spp.		PP	N, M
Order Lepidoptera	moths		
<i>Eoparargyractis</i> sp.		PP	N, M
<i>Langessa nomophilalis</i>		PP, PB	N, M
<i>Munroessa gyralis</i>		PP	M
<i>Munroessa</i> sp.		PP, PB	N
<i>Neargyractis slossonalis</i>		PB	N
<i>Paraponyx</i> spp.		PP, PB	D, N, M
Pyalidae			
<i>Synclita</i> sp.		PP, PB	N, M
unidentified sp.		PB	N

Table 15-19. (cont)

Scientific Name	Common Name	
Order Diptera	true flies	
Chaoboridae		
<i>Chaoborus punctipennis</i>	PP, PB	D, N, M
Culicidae		
<i>Anopheles</i> sp.	PB	N
<i>Mansonia perturbans</i>	PP	N
Ceratopogonidae		
<i>Bezzia</i> sp.	PP, PB	M
<i>Forcipomyia</i> sp.	PB	M
unidentified spp.	PP, PB	D, M
Tabanidae		
<i>Chrysops</i> sp.	PB	N
Empididae		
unidentified spp.	PP	M
Ephydriidae		
unidentified spp.	PP	M
Tipulidae		
<i>Limonia</i> sp.	PP	N
<i>Pilaria</i> sp.	PB	N
unidentified spp.	PP	N
Psychodidae		
<i>Psychoda alternata</i>	PP	M
<i>Telamatoscopus</i> sp.	PP	M
unidentified spp.	PP, PB	D, M
Simuliidae		
<i>Simulium</i> spp.	PP	M
Order Chironomidae		
Chironominae		
<i>Glyptotendipes</i> sp.	PP, PB	M
<i>Parachironomus</i> sp.	PP, PB	M
unidentified spp.	PP, PB	D, N, M
Orthocladiinae		
unidentified spp.	PP, PB	D, N, M
Tanypodinae		
<i>Ablabesmyia</i> sp.	PP, PB	M
<i>Clinotanytus</i> sp.	PP, PB	M
<i>Labrundinia</i> sp.	PP	M
<i>Procladius</i> sp.	PP, PB	M
<i>Thienemannimyia</i> 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 15-20. 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.

Phylum Nematoda
unknown spp.
Phylum Platyhelminthes
Class Turbellaria
unknown spp
Phylum. Coelenterata
Class Hydrozoa.
Order Hydroida
Family Hydridae
<i>Hydra</i> sp.
Phylum Annelida
Class Oligochaeta
Order Haplotaxina
Family Naididae
<i>Bratislavia unidentata</i>
<i>Dero digitata</i>
<i>Dero flabelliger</i>
<i>Dero nivea</i>
<i>Dero pectinata</i>
<i>Dero</i> sp. A
<i>Dero vaga</i>
<i>Haemonais waldvogeli</i>
<i>Nais communis</i>
<i>Nais pseudobtus</i>
<i>Pristina aequiset</i>
<i>Pristina leidy</i>
<i>Pristinella longisoma</i>
<i>Slavina appendiculata</i>
<i>Specaria josinae</i>
<i>Stylaria lacustris</i>
unknown spp.
Family Tubificidae
<i>Aulodrilus piqueti</i>
<i>Ilyodrilus templetoni</i>
Order Lumbriculida
Family Lumbriculidae
Unknown spp.
Class Hirudinea
unknown spp.
Phylum Mollusca
Class Gastropoda
Order Basommatophora
Family Ancyliidae
unknown spp.
Family Physidae
<i>Physella heterostroph</i>
Family Planorbidae

Table 15-20. (cont)

Helisoma anceps
Helisoma trivolvis
Menetus dilatatus

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.

P. Arthropoda

Class Arachnoidea
Order Hydracarina
unknown spp.

Class Crustacea
Order Amphipoda
Family Talitridae
Hyaella 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.

Table 15-19. (cont)

unknown spp.

Family Noteridae

Hydrocanthus sp.

unknown spp.

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.

Orthoclaadiinae

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.

Table 15-19. (cont)

Family Caenidae

Caenis sp.

Order Hemiptera

Family Belostomatidae

Belostoma sp.

Family Corixidae

unknown spp.

Family Gerridae

unknown spp.

Family Naucoridae

Pelocoris sp.

Family Pleidae

Neoplea sp.

Order Lepidoptera

Family Pyralidae

Paraponyx 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

Oristotrichia sp.

Oxvethira sp.

Fish

Par Pond

Introduction

The fishes of Par Pond have been extensively studied (Table 15-21). Most of these studies have emphasized the effects of elevated temperatures on fish behavior, physiology, and ecology. There have also been a number of 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 study that have been conducted on the fish of Par Pond. This discussion draws heavily on the synopsis of Par Pond data compiled by Wilde and Tilly (1985).

Table 15-21. Principal Reports Describing Fish Studies in the Par Pond System

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

The following discussion does not contain information on the status of the Par Pond fish community since the recent draw-down of Par Pond. The large quantitative and qualitative changes in habitat that resulted from this event undoubtedly caused major changes in the Par Pond fish community. Data collected prior to and following the drawdown have not been analyzed at the time of publication.

Species Composition and Abundance

On the basis of general surveys by Clugston (1973a), Siler (1975), Hogan (1977), Martin (1980), and Bennett and McFarlane (1983), 30 fish species were identified from Par Pond (Table 15-22). Of these species 17 were also reported from Pond C and 14 from Pond B (Figure 15-15). 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 ponds.

Table 15-22. Species of Fish in Par Pond, Pond B, and Pond C^a

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

Cove rotenone studies conducted by Clugston (1973a), 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 mosquito fish (*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/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/acre). Gilbert and Hightower (1981) reported largemouth bass population estimates of Par Pond at 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).

Prey Fish

Prey species (e.g., bluegill) were also significantly more abundant in coves near the Hot Dam than elsewhere in the reservoir (Clugston 1973a, Siler 1975, Hogan 1977). The stand-

Figure 15-15. Fish Sampling Stations for Par Pond

ing crop of prey fish determined from cove rotenone samples in the Hot Arm was almost twice as great as in the North Arm of Par Pond in a study 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

The most extensive and recent fisheries survey of Par pond was conducted during January 1984–June 1985 (Paller and Saul 1985). Sample stations were located in the Hot Arm, which receives heated water; the Intake Arm, where cooling water is withdrawn; the Cold Dam at the lower end of the lake and the North Arm at the upper end of the lake. Fish samples were also 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 15-23). 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 silverside 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 comprised 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 15-23). Dominant species in Pond B were gizzard shad (15.9%), largemouth bass (17.7%) and brook silverside (34.1%). 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 15-24 on page 15-68). Statistical analyses of catch per unit effort for all species combined indicated that angling, gill netting, and electrofishing catches in the Hot Arm were comparable to or higher than in the other Par Pond sample areas. Catch rates for several individual species, including largemouth bass and black crappie, were significantly higher in the Hot Arm than in the other Par Pond sample areas. Catch rates in Pond B were significantly lower than in Par Pond for electrofishing but not angling. Gill-net catch rates were lower in Pond B than in Par Pond during the winter but not the summer. Individual species that exhibited lower

Table 15-23. Species Relative Abundance (percent composition and percent total weight) of Adult Fishes Collected From Par Pond and Pond B.^a January 1984–June 1985.

Fish	Par Pond ^b		Pond B	
	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 silverside	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	2.6	<0.1	1.3	<0.1
(<i>Notropis</i> spp.)				
mosquitofish	. ^d	-	<0.1	<0.1
darters	-	-	<0.1	<0.1
(<i>Etheostoma</i> spp.)				
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	13166		1336	
Total weight		2491.7		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, Intake Arm and North Arm combined.

^c Most were probably juvenile bluegill.

^d Observed by ECS personnel but not collected by any of the four collection techniques.

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. The 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, Intake 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).

Table 15-24. Species Relative Abundance as Percent Composition (and number) of Adult Fishes Collected From Sample Areas in Par Pond. January 1984–June 1985.

Species	Cold Dam	Hot Arm	Intake 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 (<i>Notropis</i> spp.)	8.5 (186)	0.4 (17)	1.3 (38)	2.7 (95)
darter (<i>Etheostoma</i> 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 number	2195	4419	2996	3556

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 m³) than during 1984 (mean of 1254/1000 m³). This decrease affected 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 has been reported in other lakes and reservoirs. In contrast, ichthyoplankton densities in Pond B were similar between 1985 (mean of 1398/1000 m³) and 1984 (mean of 1380/1000 m³). Average total ichthyoplankton density over all sample stations in Par Pond (463/1000 m³) 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 m³ near the Cold Dam, 349.0/1000 m³ in the Hot Arm, 578/1000 m³ in the Intake Arm, and 612/000 m³ 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, it was found that darter density in the Hot Arm (mean of 19/1000 m³) was significantly lower than in the other Par Pond sample areas (means of 55–104/1000 m³).

Analysis of the diel samples (4 samples in a 24-hour period) taken on 6 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 hours, estimated entrainment into the Par Pond pumphouse was 1975.5×10^5 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 fact that night densities were 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, thus 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 (see

“Reproduction” on page 15-74). Other possible thermal effects include reduced condition of largemouth bass (see “Growth and Condition” on page 15-70 and “Diet” on page 15-72) and aggregation of largemouth bass and black crappie in the discharge area.

In spite of 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. The apparent replacement of gizzard shad and carp by lake chubsucker in Par Pond was not considered deleterious by Paller and Saul (1985) since 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 a station near the Hot Dam were generally larger and grew significantly faster than young bass collected at two stations distant from the Hot Arm. The condition factors of all juvenile bass were generally similar, indicating that the growth and body condition of juvenile largemouth bass were not impaired by elevated temperatures in Par Pond.

Martin (1980) compared the relative weights (W_r) of largemouth bass from Par Pond with those of bass from other lakes throughout the U.S. 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 W_r 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. Station and seasonal effects on W_r were also noted by Martin (1980) with the lowest values occurring at the station nearest the thermal effluent in the summer.

Janssen and Giesy (1984) provided a novel explanation for the more frequent occurrences of "thin" bass near the point of thermal discharge into Par Pond. Heated reactor cooling water from Pond C sporadically carried zooplankton and dead and moribund fish into Par Pond. These organisms, produced in Pond C during reactor outages and cool winter periods, were killed when temperatures climbed to lethal levels in Pond C. The presence of the zooplankton attracted blueback herring (*Alosa aestivalis*) to the discharge area in Par Pond; largemouth bass followed to feed on the herring. Dying and dead bluegills (heat killed) from Pond C were also eaten by Par Pond bass which swam into effluent temperatures as high as 46°C 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: 1) significantly lower adult largemouth bass K values in the vicinity of the Hot Dam compared with other areas of Par Pond and 2) significantly lower K values in summer compared to winter in all areas of the pond.

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 calculations (PSD) 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 (K) of bluegill, black crappie and lake chubsucker was not significantly different between the Hot Arm and the other sample areas in Par Pond.

Mosquito Fish

Mosquito fish (*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 between the fat content of *Gambusia* 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 *Gambusia* 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 greater amounts of food than bass taken from an area near the Hot Dam. Unidentifiable fish, 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) 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 diet 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 *Eurycerus lamellatus* were the most abundant cladocerans found in bluegill stomachs at the cooler stations. Ostracods, aquatic insects, and assorted mollusks were present in the diet 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 ponds 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 during the fall. Par Pond

bass depended heavily on fish (primarily brook silversides and small sunfishes) throughout the year. Pond C largemouth bass ate fish (primarily 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 during the remainder of the year. 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 was probably 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 between the Hot Arm and cooler areas in Par Pond and between 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 fish 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 and 40.08°C for fish acclimated to 20°C and 28°C, 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. Fish from Pond C had a higher CTM (Table 15-25 on page 15-74) 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. Largemouth bass were common in 32–35°C water and were found at 36–37°C on one occasion (Clugston 1973a).

Faulke and Smith (1974) reported that mosquito fish on SRS live at higher temperatures (up to 44°C) than the CTM reported for northern populations. Mosquito fish have reportedly been dipnetted from portions of Pond C at temperatures greater than 40°C.

Movements and Body Temperatures

Mark-recapture studies provide evidence for 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 approxi-

mately 6 km distant. Of over 2500 bass tagged and released, 95 were recaptured. Five had moved from the Hot Dam area to the Cold Dam area and five others had moved from the Cold Dam area to the Hot Dam area; each of the other 85 was recaptured within 1500 m of the initial capture location. Du Pont (1976) reported long distance movement (up to 12 km) 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 and usually remained 900 m 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 away from the Hot Dam. The highest body temperatures of specimens from the two areas were 36.2°C and 31.4°C, 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 between body temperatures and water of as much as 3.5°C. 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 (1973a) collected ripe female bluegill from Pond C during every month of the year. Year-round spawning of bluegills in Par Pond is also likely since spawning can occur whenever temperatures exceed 20°C. Bluegill larvae and percidae larvae (probably darters) were col-

Table 15-25. Critical Thermal Maximum Estimates for Bluegill from Two Locations at Different Acclimation Temperatures

Sample Location	Acclimation Temperature, °C ^a		
	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), and Tukey's HSD test (Kirk 1968) demonstrated significant differences among locality means at 24 and 32°C (P < 0.05).

lected 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, Intake 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 over 5000 largemouth bass taken during 1974–1978, Esch and Hazen (1978) proposed that stress, induced by elevated temperatures, played a significant role 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: 1) *Epistylis* spp. is a benign ectocommensal; 2) *A. hydrophila* is the primary etiologic agent of red-sore disease, and 3) the probable route of infection is the surface epithelium of the fish. Esch et al. (1976) found that all centrarchid 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.

Densities of *A. hydrophila* were determined monthly from December 1975 to December 1977 in Par Pond by Hazen (1979). 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. Distribution and survival of *A. hydrophila* has been described by Fliermans et al. (1977), Hazen et al. (1978b), and Hazen and Fliermans (1979). Largest populations occurred from March through June in all areas of Par Pond that were sampled (Table 15-26). Greater population densities occurred below the thermocline when the lake was stratified (Fliermans et al. 1977). Comparison of *A. hydrophila* densities from 147 natural aquatic habitats in 30 states and Puerto Rico (Hazen et al. 1978c) revealed that Par Pond populations are relatively low and are lower than 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) and thermal maxima (45°C). 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

Table 15-26. Seasonal Distribution of *A. Hydrophila*-Like Bacteria at Selected Stations in Par Pond (Source: Fliermans et al. 1977)

Mo and yr	Station 5 (Near Cold Dam)			Station 3 (Middle of Hot Arm)			Station 1 (Near Hot Dam)		
	X ^a	SD ^b	N ^c	X ^a	SD ^b	N ^c	X ^a	SD ^b	N ^c
August 1975 ^d	0.39	0.54	114	0.24	0.38	72	ND ^e		
September 1975 ^f	1.51	1.42	56	3.01	1.06	33	ND ^e		
October 1975	5.22	1.86	57	6.02	1.84	33	ND ^e		
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

^a X, Mean values of *A. hydrophila*-like bacteria per milliliter.

^b SD, Standard deviation.

^c N, Number of determinations.

^d Experiments with reactor not operating.

^e ND, Not determined.

^f Experiments with reactor operating.

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. Sex ratios of *N. cylindratus* were not significantly different in fish taken from areas of Par Pond having different temperature regimes.

Metacercaria of the Trematode *Clinostomum marginatum*

Over a 15-month period beginning in October 1974, approximately 13,500 centrarchids were collected from Par Pond and examined for evidence of infection with metacercaria of the trematode *Clinostomum marginatum* by Hazen and Esch (1978). Species checked included *Lepomis macrochirus*, *L. gulosus*, *L. auritus*, *Pomoxis nigromaculatus* and *Micropterus salmoides*. Except for the largemouth bass, *M. salmoides*, 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 <10% in July and August; there was a jump in September through October to another peak of 30%, and then a steady decline through December when infection percentages were again less than 10%. Neither body condition nor length of the bass were related to infection percentages or metacercaria density. Infection percentages could not be related to the influence of thermal effluent. Infection percentages did vary from location to location within the Par Pond system. A significant rank correlation was established between infection percentage and the amount of littoral zone present 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 amounts of littoral zone present in various locations of the reservoir.

Strigeid Trematodes

Two parasitic worms, both strigeid trematodes (*Ornithodiplostomum pychocheilus* and *Diplostomum scheuringi*), have been collected from mosquitofish in Par Pond, Pond C, and other SRS waters (Aho et al. 1976; Aho 1979; Camp 1980; Aho et al. 1982; Camp et al. 1982). *O. pychocheilus* occurs in the brain and eyes. It is apparently favored by warmer than ambient water temperatures 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. scheuringi*, 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.

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 having unusually high densities of largemouth bass and chubsuckers and unusually low densities of shad. High densities of largemouth bass are undoubtedly due in part to a virtual absence of fishing pressure in Par Pond.

The dense largemouth bass population probably results in considerable competition for food, particularly in the Hot Arm. 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 exhibit some degree of aggregation in the Hot Arm during the winter. This phenomenon is most pronounced among the largemouth bass. Fish may congregate in the Hot Arm during the winter to maintain optimal body temperatures or to forage.

Food is probably the primary limiting factor for largemouth bass in Par Pond and the population appears to be at or near the carrying capacity. Young largemouth bass in Par Pond compare favorably with largemouth bass from other U.S. lakes and reservoirs in terms of condition (K) factor while older largemouth bass in Par Pond are thinner than usual. The condition of largemouth bass in Par Pond is significantly lower in the Hot Arm than elsewhere and significantly lower in summer than 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 have been observed in the pre-cooler to Par Pond (Pond C) but not in Par Pond itself.

Thermal effects resulting from the operation of P Reactor included 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. 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.

In spite of thermal and entrainment effects, Par Pond compared favorably with Pond B on the basis of most of fisheries variables. 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.

Lower Three Runs

Introduction

Fisheries sampling in Lower Three Runs has not been as extensive in most other SRS streams, although two sampling programs have been conducted. The first, conducted during 1984–1985, was part of the Comprehensive Cooling Water Study (CCWS), which was designed to generate information concerning the effects of nuclear-reactor operation on SRS streams. This sampling effort included ichthyoplankton sampling at several sites between the mouth and the Par Pond dam (Paller et al. 1986). The second, conducted during the summer of 1990, was part of an effort to assess fish community structure in SRS streams. This program consisted of electrofishing for adult and juvenile fish at several sample sites between the lower reaches of Lower Three Runs and the Par Pond dam plus two sample stations in tributaries of Lower Three Runs.

Sampling Conducted During the CCWS (1984–1985)

Sampling Methods

Sampling effort during the CCWS emphasized the abundance and distribution of ichthyoplankton (Paller et al. 1986). Samples were collected with 0.5 mm, 0.5 m diameter plankton nets. There were three sampling stations in 1984, one in the Par Pond tailwaters, one near Road A (approximately two-thirds of the distance from Par Pond to the Savannah River), and one in the mouth of Lower Three Runs. There were seven sample stations in 1985, three in the Par Pond tailwaters, one in the creek mouth, and three between the creek mouth and the tailwaters. Samples were collected during the main spawning period for most SRS fishes, February–July 1984 or March–July 1985.

1984 Sampling Program

Most of the 1483 ichthyoplankters collected during 1984 were taken from a tailwater pool just downstream from the Par Pond dam. Densities averaged 625/1000 m³ in the tailwaters compared with 14/1000 m³ at Road A and 24/1000 m³ in the creek mouth (Figure 15-16 on page 15-80). Most of the larvae collected in the Par Pond tailwaters were sunfish/bass, crappie, and yellow perch that were probably spawned in Par Pond and entered Lower Three Runs in Par Pond overflow. Sampling in Par Pond (Paller and Saul 1980) indicated that all three taxa were abundant there (Paller et al. 1986).

1985 Sampling Program

As in 1984, most of the 446 ichthyoplankters collected from Lower Three Runs during 1985 were collected at the sample stations in the Par Pond tailwaters (Figure ***). Minnows and darters numerically dominated the tailwater samples early in the spawning season. However, as the season progressed, crappie, sunfish/bass, and silversides became increasingly prevalent. It is noteworthy that ichthyoplankton densities rapidly declined to comparatively low levels within 400–500 m of the Par Pond dam suggesting that ichthyoplankton conveyed from Par Pond to Lower Three Runs were not transported very far downstream. Ichthyoplankton collected from the four sample stations downstream of the Par Pond tailwaters consisted primarily of darters, sunfish, and suckers—species typical of most streams on SRS. (Paller et al. 1986)

Comparison of 1984 and 1985 Sampling Programs

Comparisons between 1984 and 1985 indicate that Ichthyoplankton densities were fairly similar in the lower half of Lower Three Runs during both years. However, densities in the Par Pond tailwaters were approximately five times higher during 1984 than 1985. The higher densities during 1984 were probably caused by greater discharge from Par Pond into Lower Three Runs during that year, as observed by field personnel (Paller et al. 1986).

Sampling Conducted During the Stream Fisheries Characterization Study

Electrofishing samples were collected from two first-to-second-order tributaries of Lower Three Runs near the crossings of Road B.6 and B.6.4. Both tributaries were small, sand bottom streams. They were heavily shaded and the predominant instream structure consisted of snags and woody debris. The fish assemblages in these streams were numerically dominated by small species including pirate perch, shiners, small sunfishes darters, madtoms, bullheads, and redbfin pickerel. These taxa are typical of unimpacted first and second order streams in and around the vicinity of SRS (Paller 1992).

Electrofishing samples were also collected from three locations on Lower Three Runs—near Donora Station, Patterson Mill, and Stinson Bridge. Creek width ranged from 5–10 m at Donora Station to 10–15 m at Stinson Bridge. Snags and brush provided the dominant instream structure, although aquatic macrophytes were present at some stations. The Stinson Bridge sample yielded few fish since it was collected during a high-water period. The other samples were more representative. The Donora Station fish assemblage was dominated by sunfishes (primarily redbreast and spotted) followed by shiners, pirate perch, and a variety of other taxa. The fish assemblage at the wider, deeper Patterson Mill station was dominated by larger species including spotted sucker, largemouth bass, and creek chubsucker. This transition from a mixed fauna of medium- and small-sized species, most of

Figure 15-16. Fish Sampling Stations for Lower Three Runs

which are generalized insectivores, at stream sites of moderate size (i.e., Donora Station) to a fauna dominated by larger benthic insectivorous and piscivorous species at wider, deeper stream sites (i.e., Patterson Mill) is typical in southeastern coastal plain streams (Paller 1992).

References

- Arnett, N. L. K. Karapatakis, A. R. Mamatey, J. L. Todd. Savannah River Site Environment: Report for 1991. WSRC-TR-92-186, Westinghouse Savannah River Company, Savannah River Site, Siken, SC (1992)
- Beisser, G. S. Feeding Behavior of Subadult Bluegill (*Lepomis macrochirus*) in a Reactor Cooling Reservoir. M. S. Thesis, University of Georgia, GA, 96 pp (1978)
- Bennett, D. H. Preliminary Examination of Body Temperatures of Largemouth Bass (*Micropterus salmoides*) from an Artificially Heated Reservoir. *Arch. Hydrobiol.* 68:376-381 (1971)
- Bennett, D. H., J. W. Gibbons. Reproductive cycles of Largemouth Bass (*micropterus salmoides*) in a Cooling Reservoir. *Trans. Am. Fish. Soc.* 104:77-82 (1975)
- Bennett, D. H. and R. W. McFarlane. The Fishes of the Savannah River Plant. National Environmental Research Park, SRO-NERP-12, Savannah River Ecology Laboratory, Aiken, SC (1983).
- Boschung, H. and P. O'Neil. "The Effects of Forest Clear-Cutting on Fishes and Macroinvertebrates in an Alabama Stream." In: Krumholz, L. A., (ed.). *The Warmwater Stream Symposium - A National Symposium on Fisheries Aspects of Warmwater Streams.* Southern Division, Am. Fish. Soc., Allen Press, Lawrence, KS (1981)
- Bowers, J. A. 1992. Synoptic surveys of regional reservoirs in South Carolina, 1988-1989 (U). WSRC-92-RP-368, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC 29808-0001.
- Bowers, J. A. 1993. The limnology of L Lake: Results of the L-Lake monitoring program 1986-1991 (U). WSRC-92-RP-000, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC 29808-0001. Camp, J. W., Jr., Studies on the Population Biology of *Diplostomulum schewingi* in Mosquito Fish, *Gambusia affinis*. Ph.D. Dissertation, Wake Forest University, Winston-Salem, NC, 111 pp. (1980)
- Camp, J. W., J. M. Aho, G. W. Exch. A Long-Term Study on Various Aspects of the Population Biology of *Ornithodiplostomum ptchocheilus* in a South Carolina Reservoir. *J. Parasitol.* 68:709-718 (1982)
- Chimney M. J. and J. G. Wollis. 1989. Comparison of L-Lake Physical, Chemical and Biological Variables with other Southeastern Reservoirs: September 1989.
- Chimney, J. J. and W. R. Cody. Distribution and Abundance of Zooplankton at Selected Locations on the Savannah River and from Tributaries of the Savannah River Plant: December 1984-August 1985. ECS-SR-41. Report prepared by Environmental & Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1986).
- Chimney, M. J., W. R. Cody, and W. M. Starkel. 1986. Final report on the water quality, phytoplankton and zooplankton of Par Pond and Pond B: January 1984-June 1985. III. Zooplankton. Environmental & Chemical Sciences, Inc. P. O. Box 1393, Aiken, SC 29802 (ECS-SR-20, Subcontract #AX630754). Report to E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC 29801. DPST-85-789-111.
- Chimney, M. J., W. R. Cody, and W. M. Starkel. Final Report on the Water Quality, Phytoplankton, and Zooplankton of Par Pond and Pond B: January 1985-1985, Vols. I, II, III. DPST-85-789. Report prepared by Environmental & Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1985).
- Clugston, J. P. "The Effects of Heated Effluents from a Nuclear Reactor on Species Diversity, Abundance, Reproduction, and Movement of Fish," Ph.D. Dissertation, University of Georgia, Athens, GA (1973).

- DuPont, S. P. The Behavior of Largemouth Bass (*Micropterus salmoides*) in a Reservoir Receiving a Heated Effluent. M. S. Thesis, University of Georgia, Athens, GA, 60 pp. (1976)
- Esch, G. W., T. C. Hazen, R. V. Dimock, J. W. Gibbons. "Thermal Effluent and Epizootiology of the ciliate *Epistylis* and the bacterium *Aeromonas hydrophila* in Association with Centrarchid Fish". Trans. Am. Microsc. Soc. 95:687-693. (1976)
- Esch, G. W. and T. C. Hazen. "Thermal Ecology and Stress - a Case History for Redsores Disease in Largemouth Bass (*Micropterus salmoides*).". In: Thorpe, J. H. and J. W. Gibbons (eds.). Energy and Environmental Stress in Aquatic Systems, U.S. DOE Symp. Ser. CONF-771114 (1978).
- Eure, H. E., G. W. Esch. Effects of Thermal Effluent on the Population Dynamics of Helminth parasites in Largemouth Bass. In: J. W. Gibbons and R. R. Sharitz (eds.), Thermal Ecology, AEC Symp. Ser., CONF-730505 (1974)
- Falke, J. D., M. H. Smith. Effects of Thermal Effluent on Fat Content of the Mosquitofish. In: J. W. Gibbons and R. R. Sharitz (eds.), Thermal Ecology, AEC Symp. Ser. pp. 100-108, CONF-730505 (1974)
- Ferens, M. C., T. M. Murphy. Effects of Thermal Effluents on Populations of Mosquitofish. In: J. W. Gibbons and R. R. Sharitz (eds.), Thermal Ecology, AEC Symp. Ser. pp. 237-245, CONF-730505 (1974)
- Firth, P., J. R. O'Hop, B. Coler, and R. A. Green. Lotic Aquatic Ecosystems of the Savannah River Plant: Impact Evaluation, Habitat Analyses and the Lower Food Chain Communities. ECS-SR-26, Prepared for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1986).
- Gibbons, J. W., D. H. Bennett. Abundance and Local Movement of Largemouth Bass (*Micropterus salmoides*) in a Reservoir Receiving Heated Effluent from a Reactor. In: D. J. Nelson (ed.) Proc. 35th Nat. Symp. Radioecology, U. S. Atomic Energy Commission, Symp. Ser. CONF-710501-P1 (1971).
- Gibbons, J. W., D. H. Bennett, G. W. Esch, and T. C. Hazen. "Effects of Thermal Effluent on Body Condition of Largemouth Bass." Nature 274:470-471 (1978).
- Gibbons, J. W., J. T. Hook, and D. L. Forney. "Winter Responses of Largemouth Bass to Heated Effluent from a Nuclear Reactor." Fish-Cult. 34:88-50 (1972).
- Gilbert, R. J. and J. E. Hightower. Assessment of Tag Losses and Mortality of Largemouth Bass in an Unfished Reservoir. Ga. Coop. Exten. Fish. Research Unit, School Forest Res. Project F-37-2, University of Georgia, Athens, GA (1981).
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report, Vol. III, Water Quality. DP-1697, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Gladden, J. B., W. L. Specht, J. A. Bowers, N. V. Halverson, H. E. Mackey, and E. W. Wilde. Compliance of the Savannah River Plant L-Reactor Cooling System with Environmental Regulations (U). USDOE Report DP-1776 Rev. 1 (UC-702), Savannah River Plant, Aiken SC 29808 (1989).
- Hazen, T. C., G. W. Esch, A. B. Glassman, J. W. Gibbons. Relationship of Season, Thermal Loading, and Red-Sore Disease with Various Hematological Parameters in *Micropterus salmoides*. J. Fish Biol. 12:491-498 (1978b)
- Hazen, T. C., C. B. Fleirmans, R. P. Hirsch, G. W. Esch. Prevalence and Distribution of *Aeromonas hydrophila* in the United States. Appl. Environ. Microbiol. 36:731-738 (1978c)
- Hazen, T. C. and C. B. Fliermans. "Distribution of *Aeromonas hydrophila* in Natural and Manmade Thermal Effluents." Appl. Environ. Microbiol. 38:166-168 (1979).
- Hazen, T. C., G. W. Esch, A. B. Glassman, and J. W. Gibbons. Relationship of Season, Thermal Loading, and Red-Sore Disease with Various Hematological Parameters in *Micropterus salmoides*. J. Fish. Biol. 12:491-498 (1978).
- Hogan, D. C. Distribution and Relative Abundance of Prey Fish in a Reservoir Receiving a Heated Effluent. M. S. Thesis, University of Georgia, Athens, GA (1978)

- Holland, W. E., M. H. Smith, J. W. Gibbons, D. H. Brown. Thermal Tolerances of Fish from a Reservoir Receiving Effluent from a Nuclear Reactor. *Physiol. Zool.* 47:110-118 (1974)
- Hughes, D. W. and M. J. Chimney. 1988. Comparison of L-Lake Physical, Chemical and Biological Variables with other Southeastern Reservoirs. ECS-SR-94. ECS/Normandeau, Aiken, SC.
- Hutchinson, G. E. A Treatise on Limnology. Vol. II.: Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, New York, NY (1967).
- Janssen, J. and J. P. Giesy. "A Thermal Effluent as a Sporadic Cornucopia: Effects on Fish and Zooplankton." *Environ. Biol. Fishes* 11:191-203 (1984).
- Johnson, S. R. The Food Habits of Bluegill, *Lepomis macrochirus*, and Largemouth Bass, *Micropterus salmoides*, in Reservoirs Receiving Heated Effluent from a Nuclear Reactor. M. S. Thesis, University of Georgia, Athens, GA, 91 pp. (1975)
- Kondratieff, B. C., M. J. Chimney, and W. B. Painter. 1985. Final Report on the Macroinvertebrates of Par Pond and Pond B: January 1984–June 1985. DPST-85-790. Environmental and Chemical Sciences, Inc., Aiken, SC.
- Kretchmer, D. W. and M. J. Chimney. L Lake Water Quality: L Lake/Steel Creek Biological Monitoring Program November 1985–December 1991. NAI-SR-138, Normandeau Associates, Inc., New Ellenton, SC (April 1992).
- Langley, T. M., W. L. Marter. The Savannah River Plant Site. DP-1323, E. I. DuPont de Nemours and Company, Savannah River Laboratory, Aiken, SC. 1973
- Lower, M. W. Comprehensive Cooling Water Study Final Report, Volume II, Water Quality. DP-1739-2, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Martin, C. R. "Movements, Growth, and Numbers of Largemouth Bass (*Micropterus salmoides*) in an Unfished Reservoir Receiving a Heated Effluent." M.S. Thesis, University of Georgia, Athens, GA (1980).
- NAI-SR-107. Normandeau Associates, Inc., Aiken, SC.
- Newman, M. C., A. Dancewicz, B. Davis, K. Anderson, R. Bayer, R. Lew, R. Mealy, S. Sandhu, S. Presnell, and J. Knox. Comprehensive Cooling Water Study Water Report, Volume 2, Water Quality, SREL (1986).
- Paller, M. H. and B. M. Saul. 1985. Final report on the adult fish and ichthyoplankton of Par Pond and Pond B: January 1984–June 1985. Prepared by ECS, Inc. for E. I. du Pont de Nemours and Company. ECS-SR-22.
- Prescott, G. W. Algae of the Western Great Lakes Area. W. C. Brown Co., Dubuque, IA (1962).
- Quinn, T., G. W. Esch, T. C. Hazen, J. W. Gibbons. Long Range Movement and Homing by Largemouth Bass (*Micropterus salmoides*) in a Thermally Altered Reservoir. *Copeia* 1978:542-545. (1978).
- Rice, J. A., J. E. Breck, S. M. Bartell, J. F. Kitchell. Evaluating the Constraints of Temperature, Activity, and Consumption on Growth and Largemouth Bass. *Environ. Biol. Fishes* 9:263-275 (1983)
- Siler, J. R. The Distribution of Fishes in Two Cooling Reservoirs With Different Heat Loads. M. S. Thesis, Univ. Georgia, Athens, 94 pp (1975)
- Smith, M. H., S. L. Scott. Thermal Tolerance and Biochemical Polymorphism of Immature Largemouth Bass *Micropterus salmoides* Lacepede. *Bull. Georgia Acad. Sci.* 34:180-184. (1975)
- Smith, G. M. The Freshwater Algae of the United States. 2nd ed., McGraw-Hill, New York, NY (1950).
- Specht, W. L. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. DP-1739-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Stemberger, R. S. 1985. Prey selection by the copepod *Diatomophorus thomasi*. *Oecologia*. 65:492-497.

- Tilly, L. J. "Changes in Water Chemistry and Primary Productivity of a Reactor Cooling Pond (Par Pond)." In: F. G. Howell, J. B. Gentry, and M. H. Smith (eds.). *Mineral Cycling in Southeastern Ecosystems*, U.S. ERDA Symp. Ser. CONF-740513 (1974b).
- Tilly, L. J. "Comparative Productivity on Four Carolina Lakes." *Am. Midl. Nat.* 90:356-365 (1973).
- Tilly, L. J. "Respiration and Net Productivity of the Plankton Community in a Reactor Cooling Reservoir." In: Gibbons, I. W. and R. R. Sharitz (eds.). *Thermal Ecology*, U.S. AEC Symp. Ser. CONF-730505 (1974a).
- Tilly, L. J. *Limnological Database for Par Pond: 1959-1980*. DP-1575, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC, 28 pp. (1981).
- Wetzel, R. G. 1983. *Limnology*. 2nd ed. Saunders College Publ. Philadelphia, PA. Chimney, M. J., W. R. Cody, and W. M. Starkel. Final Report on the Water Quality, Phytoplankton, and Zooplankton of Par Pond and Pond B: January 1985-1985, Vols. I, II, III. DPST-85-789. Report prepared by Environmental & Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1985).
- Wetzel, R. G. *Limnology*. 2nd Ed., Saunders College Publ., Philadelphia, PA (1983).
- Whitford, L. A. and G. L. Schumacher. *A Manual of Freshwater Algae*. Revised ed., Sparks Press, Raleigh, NC (1984).
- Wilde, E. W. "Phytoplankton Distribution in Three Thermally Distinct Reactor Cooling Reservoirs," *Trans. Am. Microsc. Soc.* 102:145-164 (1983).
- Wilde, E. W. and L. J. Tilly. 1985. Influence of P-Reactor Operation on the Aquatic Ecology of Par Pond: A Literature Review. DP-1698. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Wilde, E. W. and L. J. Tilly. Influence of P-Reactor Operation on the Aquatic Ecology of Par Pond: A Literature Review. DP-1698, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Wilde, E. W. Compliance of the Savannah River Plant P-Reactor Cooling System with Environmental Regulations: Demonstrations in Accordance with Sections 316(a) and (b) of the Federal Water Pollution Control Act of 1972. DP-1708. Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1985).

Chapter 16

Savannah River

Chapter Contents

Drainage Description and Surface Hydrology (page 16-3)

Water Chemistry and Quality (page 16-9)

Algae (page 16-19)

Macrophytes (page 16-21)

Zooplankton (page 16-23)

Macroinvertebrates (page 16-25)

Fish (page 16-33)

References (page 16-41)

Drainage Description and Surface Hydrology

General Description

The Savannah River watershed, which drains about 27,388 km², includes western South Carolina, eastern Georgia, and a small portion of southwestern North Carolina (Figure 16-1). The river is formed by the confluence of the Tugaloo and Seneca Rivers in northeast Georgia and flows southeast through the Mountain, Piedmont, and Coastal Plain physiographic regions to the Atlantic Ocean. In its mid and lower reaches (including the SRS region), 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, and includes 5235 km² (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).

Figure 16-1. Map of the Savannah River

Piedmont Region

The Piedmont Region has an intermediate gradient, with elevations ranging from 305 m to 61 m. This region includes 13,548 km² (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, GA, is located near this line. The Savannah River picks up most of its silt load in the Piedmont Region and most of this silt load is deposited in the large reservoirs located in the Piedmont Region (Bauer et al. 1989).

Coastal Plain

The Coastal Plain has a negligible gradient ranging from an elevation of 61 m to sea level. The soils of this region are primarily stratified sand, silts, and clays. The Coastal Plain contains 8631 km² (31%) of the total Savannah River drainage area (27,388 km²), and includes the city of Savannah, GA. In the Coastal Plain, the Savannah River is slow moving. Tidal effects may be observed up to 64 km (40 miles) upriver, and a salt front extends upstream along the bottom of the riverbed for about 32 km (20 miles) (Bauer et al. 1989).

Dredging Operations

The U.S. Army Corps of Engineers regulates flow in the Savannah River by means of three large reservoirs (Thurmond, Hartwell, and Russell) and by locks and dams. Besides being affected by the reservoirs, the river is influenced by dredging, sewage discharge, and industrial activities (Specht 1987). Dredging operations of the Savannah River have been conducted by the U.S. Corps of Engineers between the cities of Savannah and Augusta, GA. This program, initiated in October 1958, was designed to dredge and maintain a 2.7-m navigational channel. The U. S. Corps of Engineers placed 61 sets of pile dikes to constrict the river flow, thereby increasing the flow velocities, and laid a total of 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. 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 in the swampy part of the floodplain along the river boundary of SRS. The breaches are at the mouths of Beaver Dam Creek, Steel Creek, and Fourmile Branch. River water overflows the levee and the creek mouths and fills the swamp at river stages greater than 27 m. During swamp flooding, the water from the creeks flows through the swamp parallel to the main channel flow until it mixes with the main river flow at Little Hell Landing (Bauer et al. 1989).

Effluents Contribution

Historically, the Savannah River has been subjected to various pollution sources that have affected its water quality. Prior to 1975, most domestic and industrial wastes from Augusta, GA, were discharged untreated or poorly treated to the Savannah River. Prior to completion

of a treatment facility in 1979, Aiken County, SC, 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. Under flood conditions, 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 (Shines and Tinney 1983).

Droughts

History

Since the mid-1950s, three severe droughts (1954–1956; 1980–1981; 1985–1989) have occurred 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 of relatively short duration. 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 ($197 \text{ m}^3/\text{sec}$) was, at that time, the lowest since the very dry year of 1955 ($193 \text{ m}^3/\text{sec}$; 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 $152 \text{ m}^3/\text{sec}$ respectively. Since 1963 the U.S. Army Corps of Engineers has attempted to maintain a minimum of $178.4 \text{ m}^3/\text{sec}$ ($630 \text{ ft}^3/\text{sec}$) below the New Savannah River Bluff Lock and Dam at Butler Creek (River Mile 187.4 near Augusta, GA; U.S. Army Corps of Engineers 1988). During the 18-year period 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 $181 \text{ m}^3/\text{sec}$ (Watts 1982), or about $2.3 \text{ m}^3/\text{sec}$ ($86 \text{ ft}^3/\text{sec}$) less than at SRS (Ellenton Landing, River Mile 156.8).

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 the Savannah River Site (SAIC 1989). Low flow tests conducted during 1980 and 1981 established minimum flow requirements of 138 and $117 \text{ m}^3/\text{sec}$ (4873 and $4130 \text{ ft}^3/\text{sec}$) at SRS to ensure three- and two-reactor operation, respectively. Maintaining these flows

required a discharge of 102 m³/sec (13,600 ft³/sec). 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).

Flow Measurements

The U. S. Geologic Survey measures flow at several locations on the Savannah River. Flow statistics for stations at Augusta, near Jackson (SRS Boat Dock), at Burtons Ferry Bridge near Millhaven (U.S. 301), and near Clyo are summarized in Table 16-1. The station near Jackson only measures flow up to 22,000 ft³/sec. The maximum, minimum, and mean daily flows for the periods of record at the four stations are shown in Figure 16-2 through Figure 16-5 on page 16-8.

The water quality of the Savannah River throughout its drainage basin varies considerably, 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 have also affected the water quality of the Savannah River. From 1958 until 1965, downstream reaches of the Savannah River were dredged in order to improve channel alignment and maintain a 2.7-m depth for navigability. This dredging temporarily increased suspended solids, turbidity, and dissolved nutrients. Completion of the 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 has increased the total waste loading (DOE 1982).

Table 16-1. Flow Summary for the Savannah River

Station Name	Station Number	Period of Record	Range									
			Mean		Low		High		7Q10		7-Day Low Flow	
			cms ^a	(cfs) ^b	cms	(cfs)	cms	(cfs)	cms	(cfs)	cms	(cfs)
at Augusta, GA	02197000	1954-1991	265	9374	80	2810	2393	84,500	123	4332	106	3746
near Jackson (SRS Boat Dock) ^c	02197320	1972-1991	-	-	91	3220	-	-	122	4293	107	3773
at Burtons Ferry Bridge near Millhaven (Hwy 301)	02197500	1954-1969, 1983-1991	286	10,095	112	3960	2030	71,700	125	4411	113	3991
near Clyo	02198500	1954-1991	334	11,784	125	4400	2373	83,800	148	5211	128	4513

^a cms = cubic meters per second

^b cfs = cubic feet per second

^c Gauge not rated for flow above 22,000 cfs

Figure 16-2. Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197000

Figure 16-3. Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197320

Figure 16-4. Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197500

Figure 16-5. Maximum, Mean, and Minimum Flow Measurements for the Savannah River at Station 02197500

Water Chemistry and Quality

Studies and Monitoring

Water-Quality Monitoring

The 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 and quarterly for metals. The upstream sampling point (River-2) is located near Jackson, South Carolina, upstream from all SRS stream mouths. The downstream sampling point (River-10) is located at the US 301 crossing of the Savannah River, 16.6 km downstream of the mouth of Lower Three Runs. A third routine river sampling location adjacent to the 681-3G SRS pump house intake canal was maintained from 1973 through 1981 to determine the physiochemical characteristics of the river water adjacent to its second introduction to the SRS cooling canal intakes. The 681-3G pump house river location was moved downstream below the Plant Vogtle effluents to identify any effects these effluents may have on the downriver concentrations (Figure 16-6). The Environmental Monitoring Section collects samples from the Savannah River annually and analyzes them for pesticides and PCBs.

Monitoring Data

Gladden et al. (1985) present water quality data from the three Savannah River monitoring stations from 1973 to 1982. Water quality data from 1983 through 1985 are summarized in Lower (1987). All routine water quality monitoring data can be found in annual SRS envi-

Figure 16-6. Water Quality Sampling Stations for the Savannah River

ronmental reports. Results of water quality monitoring of the Savannah River from 1987 to 1991 are discussed in the following sections.

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 pump house 3G intake canal, and downriver of Steel Creek Landing (Figure 16-6 on page 16-9) and analyzed for standard water quality parameters, nutrients, major ions, and trace elements. Results of this water quality program instituted under the CCWS are discussed in the sections that follow and are documented in SREL (1986) and Lower (1987).

Priority Pollutant Study

In 1984 a special study was conducted to determine the levels of volatile, acid, and base/neutral organic compounds in the Savannah River. Samples were collected from the 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 statistically significant changes were evident for all 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 (Table 16-2). 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 (Jacobsen et al. 1972) and was attributed to the discharge of thermal effluents to Beaver Dam Creek, Fourmile Branch, and Pen Branch/Steel Creek as a consequence of SRS operations and natural warming of colder hypolimnetic release water from Lake Thurmond (Clarks Hill) upstream. Since cessation of reactor operations, there has been no net difference in the mean temperature of Savannah River water.

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 5.5 to 8.2. The mean pH of the Savannah River (for all studies) ranged from 6.88 to 6.98 (Table 16-2).

Physical Characteristics and General Chemistry

Dissolved Oxygen

Mean dissolved oxygen concentrations in the Savannah River (for all studies) ranged from 7.19 to 8.2 mg/l (Table 16-3 on page 16-12). It was noted during the CCWS that percentage of oxygen saturation varied on a seasonal basis and was lowest during the autumn months (SREL 1986).

Conductivity

Mean specific conductance values range from 68.2 to 79.4 $\mu\text{mhos/cm}$ (Table 16-3). The lowest values were generally measured at the 3G intake canal. The slight difference in water

Table 16-2. Savannah River Field Data

	Water Temperature (°C)	pH	Stream Maximum Depth (cm)	Stream Velocity (cm/sec)
<i>Savannah River upriver of SRS near Jackson, SC (CCWS)^a</i>				
Mean	15.9	6.88		86
Range	4.3 - 24.0	5.90 - 7.80	NA	40 - 115
Samples	46	46		39
<i>Savannah River at pumphouse 3G intake canal (CCWS)^a</i>				
Mean	15.8	6.98		67
Range	3.8 - 23.5	5.90 - 8.05	NA	32 - 100
Samples	46	46		38
<i>Savannah River downriver of Steel Creek Landing (CCWS)^a</i>				
Mean	17.1	6.94		84
Range	4.6 - 26.0	6.30 - 7.90	NA	23 - 160
Samples	45	45		39
<i>River-2, upriver of SRS (1987–1991)^b</i>				
Mean	18.2			
Range	9.0 - 28.0	5.8 - 8.0	NA	NA
Samples	60	60		
<i>River-3B, adjacent to SRS (1987–1991)^b</i>				
Mean	17.4			
Range	8.5 - 28	5.5 - 7.8	NA	NA
Samples	60	60		
<i>River-10, downriver of SRS (1987–1991)^b</i>				
Mean	18.2			
Range	8.0 - 27	4.8 - 8.2	NA	NA
Samples	60	60		

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

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 (SREL 1986).

Suspended Solids and Turbidity

Suspended solids concentrations were comparable at all locations sampled for the CCWS and the routine monitoring program. Mean suspended solids concentrations measured during the CCWS ranged from 9.47 to 12.8 mg/l. Mean suspended solids concentrations from 1987 to 1991 ranged from 12.1 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 ranged from 10.1 mg/L to 10.4 mg/L from 1987 to 1991.

Table 16-3. Savannah River Physical Characteristics and General Chemistry

	Dissolved Oxygen (mg/l)	Specific Conductance (mmhos/cm)	Turbidity (NTU)	Total Suspended Solids (mg/l)
<i>Savannah River upriver of SRS near Jackson, SC (CCWS)^a</i>				
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
<i>Savannah River at pumphouse 3G intake canal (CCWS)^a</i>				
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
<i>Savannah River downriver of Steel Creek Landing (CCWS)^a</i>				
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
<i>River-2, upriver of SRS (1987-1991)^b</i>				
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
<i>River-3B, adjacent to SRS (1987-1991)^b</i>				
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
<i>River-10, downriver of SRS (1987-1991)^b</i>				
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

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Major Anions and Cation

Alkalinity, Chloride, and Sulfate

Total alkalinity has varied little since the CCWS. From 1987 to 1991, mean alkalinity was 21 mg CaCO₃/l at all locations (Table 16-4). During the CCWS, means ranged from 16.5 mg CaCO₃/l at the 3G intake canal to 19.6 mg CaCO₃/l upriver of SRS.

Mean concentrations of chlorides and sulfates have been slightly higher during routine monitoring than during the CCWS (Table 16-4). Mean chloride concentrations ranged from 7.8 to 8.2 mg/l for routine monitoring, while the means during the CCWS ranged from 5.53 to 6.29 mg/l. Mean sulfate concentrations ranged from 8.1 to 8.5 mg/l for routine monitoring, and the means during the CCWS ranged from 5.26 to 6.00 mg/l.

Table 16-4. Savannah River Major Anions

	Alkalinity (mg CaCO ₃ /l)	Chloride (mg/l)	Sulfate (mg/l)
<i>Savannah River upriver of SRS near Jackson, SC (CCWS)^a</i>			
Mean	19.6	6.29	6.00
Range	12.3 - 28.5	2.90 - 8.90	2.90 - 9.17
Samples	45	46	28
<i>Savannah River at pumphouse 3G intake canal (CCWS)^a</i>			
Mean	16.5	5.53	5.26
Range	5.63 - 24.0	2.60 - 8.40	2.13 - 8.99
Samples	45	46	28
<i>Savannah River downriver of Steel Creek Landing (CCWS)^a</i>			
Mean	18.7	6.00	5.26
Range	11.6 - 24.5	2.70 - 8.20	1.77 - 8.48
Samples	45	45	28
<i>River-2, upriver of SRS (1987–1991)^b</i>			
Mean	21	7.8	8.1
Range	7.0 - 31	3.2 - 13	4.0 - 22
Samples	60	60	60
<i>River-3B, adjacent to SRS (1987–1991)^b</i>			
Mean	21	8.0	8.5
Range	8.0 - 31	3.9 - 13	5.0 - 22
Samples	60	60	60
<i>River-10, downriver of SRS (1987–1991)^b</i>			
Mean	21	8.2	8.2
Range	10 - 31	2.8 - 12	4.0 - 22
Samples	60	60	60

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Calcium, Magnesium, Sodium, and Potassium

Major cations measured during the CCWS also indicated the presence of Upper Three Runs water at the 3G intake canal site. At all locations during the CCWS, mean calcium, magnesium, sodium, and potassium concentrations were within the following ranges: calcium, 3.07 to 3.42 mg/l; magnesium, 1.21 to 1.34 mg/l; sodium, 6.62 to 7.63 mg/l; potassium, 0.995 to 1.10 mg/l. These ranges are similar to those that have been measured during the routine monitoring program (Table 16-5).

Table 16-5. 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)
<i>Savannah River upriver of SRS near Jackson, SC (CCWS)^a</i>							
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
<i>Savannah River at pump house 3G intake canal (CCWS)^a</i>							
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
<i>Savannah River downriver of Steel Creek Landing (CCWS)^a</i>							
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
<i>River-2, upriver of SRS (1987-1991)^b</i>							
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
<i>River-3B, adjacent to SRS (1987-1991)^b</i>							
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
<i>River-10, downriver of SRS (1987-1991)^b</i>							
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

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987-1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Aluminum, Manganese, and Iron

SREL (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 (Table 16-5).

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 were typically higher than those of any waters of onsite surface streams which do not receive Savannah River source waters for site operations (SREL 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 16-6 on page 16-17). SREL documented that 48 to 56% of this phosphorus was dissolved orthophosphate.

Nitrogen

Concentrations of nitrogen are presented in Table 16-6 on page 16-17. 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 0.312 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 0.095 mg N/l to 0.183 mg N/l. SREL (1986) noted seasonal relationships between ammonia and nitrate, and reflected the influence of temperature on the nitrification processes within the Savannah River waters.

Trace Elements

Low levels of trace elements were measured during the CCWS. The detection limits reported for the routine monitoring program are higher than the concentrations measured during the CCWS; therefore, only CCWS data will be discussed in the section. All trace element monitoring data are presented in Table 16-7 on page 16-18. 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 to 85% of this total organic carbon was present in the dissolved phase. Total organic carbon is not measured as part of the routine monitoring program.

Priority Pollutants

Lower (1987) reported that concentrations of all 88 tested volatile, acid, and base/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) 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.

Table 16-6. Savannah River Nutrients

	Total Phosphorus (mg P/l)	Total Ortho- phosphate (mg PO₄-P/l)	Organic Nitrogen (mg N/l)	Total Kjeldhal Nitrogen (mg N/l)	Ammonia (mg NH₃-N/l)	Nitrite (mg NO₂-N/l)	Nitrate (mg NO₃-N/l)
<i>Savannah River upriver of SRS near Jackson, SC (CCWS)^a</i>							
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
<i>Savannah River at pumphouse 3G intake canal (CCWS)^a</i>							
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
<i>Savannah River downriver of Steel Creek Landing (CCWS)^a</i>							
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
<i>River-2, upriver of SRS (1987–1991)^b</i>							
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
<i>River-3B, adjacent to SRS (1987–1991)^b</i>							
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
<i>River-10, downriver of SRS (1987–1991)^b</i>							
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

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Table 16-7. Savannah River Trace Elements (Total)

	Arsenic (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Lead (mg/l)	Nickel (mg/l)	Zinc (mg/l)
<i>Savannah River upriver of SRS near Jackson, SC (CCWS)^a</i>							
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
<i>Savannah River at pumphouse 3G intake canal (CCWS)^a</i>							
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
<i>Savannah River downriver of Steel Creek Landing (CCWS)^a</i>							
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
<i>River-2, upriver of SRS (1987–1991)^b</i>							
Mean							
Range	NA	<10	<10 - <50	<10 - <50	3 - <100	<10 - <50	<10 - <20
Samples		20	20	20	20	19	20
<i>River-3B, adjacent to SRS (1987–1991)^b</i>							
Mean							
Range	NA	<10 - 10	<10 - <50	<10 - <50	<3 - <100	<10 - 870	<10 - 30
Samples		20	20	20	20	19	20
<i>River-10, downriver of SRS (1987–1991)^b</i>							
Mean							
Range	NA	<10	<10 - <50	<10 - 40	<3 - <100	<10 - <50	<10 - 20
Samples		20	20	20	20	19	20

NA - Not Analyzed.

Blank Spaces - Mean not calculated due to insufficient data in report.

^aCCWS - Comprehensive Cooling Water Study (SREL 1986).

^b1987–1991 - Data taken from SRS Environmental Reports for 1987, 1988, 1989, 1990, and 1991.

Algae

Taxonomic Studies

There have been no known quantitative studies of the Savannah River phytoplankton in the vicinity of SRS. However, attached algae in the river, above, below, and adjacent to the site have been continually monitored since 1951 (Figure 16-7). These ongoing studies, conducted by the Academy of Natural Sciences of Philadelphia (ANSP) include semi-monthly surveys of diatom communities, quarterly cursory studies of both diatom and non-diatom algae, and detailed surveys of attached algae every four years. Results from the studies conducted by the ANSP are summarized in reports published annually by DOE. As stated in the most recent of these reports, these studies are conducted "to determine the effect, if any, of SRS effluent discharges on general river health" (Arnett et al. 1992). The studies have generally concluded that SRS effluents do not have an adverse impact on the health of the Savannah River (Figure 16-8 on page 16-20, Cummins et al. 1991).

Studies Assessing Dry Weight and Chlorophyll *a*

In addition to the studies by the ANSP, which are primarily taxonomic in nature, 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 reports by 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 revealing any evidence of appreciable impacts from SRS operations.

Figure 16-7. Algae Sampling Stations for the Savannah River

Figure 16-8. A Comparison of ANSP Survey Results from 1985 through 1990 Showing No Change in the Overall Water Quality of the Savannah River Over the Period

Macrophytes

There is no information pertaining to aquatic macrophyte development in the stretch of the Savannah River bordering SRS. Since the river is relatively swift and lacking any main-stream backwaters or large structure in this area, one would not expect to find macrophyte beds of any significant area or biomass.

Zooplankton

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

Macroinvertebrates

Sampling Locations and Methods

As part of the comprehensive cooling water study, macroinvertebrates were collected monthly at 9 locations in the Savannah River from October 1983 through September 1985 using Hester-Dendy multiplate samplers. These same locations plus one additional station in 1983–1984 and two additional stations in 1984–1985 were sampled quarterly (November, February, May, and July) for macroinvertebrate drift during daylight hours 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

Number of Taxa Collected

During the two-year study, a total of 146 macroinvertebrate taxa were collected from the Savannah River (Table 16-11 on page 16-29). 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 present 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 to 73.8% of the organisms collected (Table 16-8). The most commonly collected dipterans included chironomids (Chironomini, Orthoclaadiinae, and Tanytarsini) and blackflies (*Simulium*; Chimney and Cody 1986). Other common insect orders included Trichoptera (caddisflies; 18.5 to 30.3%), Ephemeroptera (mayflies; 5.2 to 17.3%), and Plecoptera (stoneflies; 1.2 to 3.1%; Table 16-8). Oligochaetes and amphipods were also locally abundant at one or more stations (Table 16-8). *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 16-9). 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 2751.25 organisms/m² to 7986.0 organisms/m² (Table 16-9). Macroinvertebrate densities tended to be higher at upstream river stations (River Mile 152.2 to 145.7) than at downstream stations (River Mile 141.7 to 128.9; Table 16-9). 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 position above or below the creek.

Macroinvertebrate drift densities ranged from 927.1 to 7298.7 organisms/1000 m³ (Table 4). Drift densities were higher at all stations in 1984–1985 than in 1983–1984 (Table 16-10 on page 16-28). No spatial trends were observed for drift densities, except that densities were usually slightly higher just downstream from both thermal and non-thermal 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/m² (Table 16-9). No distinct spatial or temporal trends were observed for biomass.

Table 16-8. Relative Abundance (Percent) of Major Taxonomic Groups of Macroinvertebrates on Hester-Dendy Multiplate Samplers in the Savannah River, 1984–1985

Taxon	Station								
	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

^aIncludes taxa that each comprised <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 16-9. Mean Number of Taxa Per Sampler, Density and Biomass of Macroinvertebrates Collected on Hester-Dendy Multiplate Samplers in the Savannah River, 1983–1984.

October 1983–September 1984			
Station ^a	Average No. Taxa/Sampler	Average Density	Average Biomass
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

^a River Mile

Source: O'Hop et al. 1985, 1986.

Table 16-10. Macroinvertebrate Drift Density (No/1000 m³) in the Savannah River, October 1983–July 1985

Station	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

Table 16-11. 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		
<i>Ferrissia rivularis</i>	X	X
<i>Laevapex fuscus</i>	X	X
<i>Amnicola</i>	X	X
<i>Pseudosuccinea columnella</i>		X
<i>Physella heterostrophia</i>	X	X
<i>Gyraulus parvus</i>	X	X
<i>Helisoma trivolvis</i>	X	X
<i>Menetus dilatatus</i>	X	X
<i>Campeloma decisum</i>	X	
unidentified gastropods		X
Pelecypoda		
<i>Corbicula fluminea</i>	X	X
unidentified Sphaeriidae	X	X
Isopoda		
<i>Asellus</i>		X
Amphipoda		
<i>Gammarus fasciatus</i>	X	X
<i>Hyalella azteca</i>	X	X
Decapoda		
<i>Palaemonetes paludosus</i>	X	X
<i>Procambarus</i>		X
Hydracarina	X	X
Collembola		X
Isotomidae		X
Ephemeroptera		
<i>Baetis</i>	X	X
<i>Callibaetis</i>		X
<i>Heterocloeon</i>		X
<i>Pseudocloeon parvulum</i>	X	X
<i>Baetisca</i>		X
<i>Caenis</i>	X	X
<i>Danella simplex</i>	X	X
<i>Ephemerella invaria</i>	X	X
<i>Eurylophella temporalis</i>	X	X
<i>Hexagenia</i>		X
<i>Heptagenia</i>	X	X
<i>Pseudiron</i>	X	X
<i>Spinadis</i>		X
<i>Stenacron interpunctatum</i>	X	X
<i>Stenonema modestum</i>	X	X
<i>Paraleptophlebia</i>		X
<i>Neoephemera youngi</i>	X	X
<i>Isonychia</i>	X	X
<i>Tricorythodes</i>	X	X

Table 16-11. (cont)

Taxon	Hester-Dendy	Drift
<i>Leptohyphes</i>	X	
Odonata		
<i>Boyeria vinosa</i>	X	X
<i>Neurocordulia molesta</i>	X	X
<i>Gomphidae</i>	X	X
<i>Macromia</i>	X	X
<i>Libellula</i>		X
<i>Zygoptera</i>		X
<i>Calopteryx</i>		X
<i>Argia</i>	X	X
<i>Enallagma</i>	X	X
<i>Hetaerina</i>	X	X
<i>Lestes</i>		X
Plecoptera		
<i>Nemocapnia carolina</i>	X	X
<i>Alloperla furcula</i>	X	X
<i>Acroneuria abnormis</i>	X	
<i>Agnetina annulipes</i>	X	
<i>Paragnetina fumosa</i>	X	
<i>Perlesta placida</i>	X	X
<i>Perlinella</i>	X	
<i>Clioperla clio</i>	X	
<i>Helopicus bogaloosa</i>	X	
<i>Hydroperla</i>	X	
<i>Isoperla</i>	X	X
<i>Pteronarcys dorsata</i>	X	X
<i>Shipsa</i>		X
<i>Taeniopteryx longicera</i>	X	
<i>Taeniopteryx robiniae</i>	X	X
Hemiptera		
<i>Corixidae</i>	X	
<i>Palmacorixa</i>		X
<i>Sigara</i>		X
<i>Trichocorixa</i>		X
<i>Belostoma</i>		X
<i>Gerridae</i>		X
<i>Hydrometra</i>		X
<i>Mesovelia</i>		X
<i>Nepidae</i>		X
<i>Neoplea</i>		X
Coleoptera		
<i>Curculionidae</i>		X
<i>Elmidae</i>		
<i>Ancyronyx variegatus</i>	X	X
<i>Dubiraphia</i>	X	X
<i>Macronychus glabratus</i>	X	X
<i>Microcylloepus pusillus</i>	X	X
<i>Stenelmis</i>	X	X
<i>Dineutes</i>	X	X
<i>Gyrinus</i>	X	X

Table 16-11. (cont)

Taxon	Hester-Dendy	Drift
<i>Haliphus</i>		X
<i>Peltodytes</i>	X	X
<i>Hydrochus</i>		X
<i>Berosus</i>	X	X
<i>Tropisternus</i>		X
<i>Noteridae</i>	X	X
<i>Dytiscidae</i>		X
<i>Coptotomus</i>		X
<i>Dytiscus</i>		X
<i>Hydroporus</i>		X
<i>Hygrotus</i>		X
<i>Liodes</i>		X
Megaloptera		
<i>Chauliodes</i>	X	X
<i>Corydalus cornutus</i>	X	X
<i>Nigronia</i>	X	
Neuroptera		
<i>Climacia</i>		X
<i>Sisyra</i>		X
Trichoptera		
<i>Brachycentrus</i>	X	X
<i>Micrasema</i>	X	X
<i>Cheumatopsyche</i>	X	X
<i>Hydropsyche</i>	X	X
<i>Macrostemum carolina</i>	X	X
<i>Hydroptila</i>	X	X
<i>Ochrotrichia</i>		X
<i>Orthotrichia</i>	X	
<i>Oxyethira</i>	X	X
<i>Lepidostoma</i>		X
<i>Ceraclea</i>	X	X
<i>Leptocerus americanus</i>		X
<i>Nectopsyche candida</i>	X	X
<i>Oecetis</i>	X	X
<i>Triaenodes</i>		X
<i>Ironoquia</i>		X
<i>Pycnopsyche</i>		X
<i>Chimarra</i>	X	X
<i>Cernotina</i>		X
<i>Cyrnellus</i>	X	X
<i>Neureclipsis</i>	X	X
<i>Nyctiophylax</i>		X
<i>Phylocentropus</i>	X	X
<i>Polycentropus</i>	X	X
<i>Lype diversa</i>	X	X
Lepidoptera		
<i>Munroessa</i>		X
<i>Neargyractis</i>		X
<i>Parapoynx</i>	X	X
<i>Synclita</i>	X	X

Table 16-11. (cont)

Taxon	Hester-Dendy	Drift
<i>Petrophila</i>	X	
Diptera		
Ceratopogonidae		X
Ceratopogoniinae	X	X
Forcipomyiinae	X	X
<i>Chaborus punctipennis</i>	X	X
Chironomidae	X	X
Chironomini	X	X
Orthoclaadiinae	X	X
Tanytarsini	X	X
Tanypodinae	X	X
Culicidae		
<i>Aedes</i>		X
<i>Anopheles</i>		X
<i>Culex</i>		X
<i>Uranotaenia</i>		X
Empididae	X	X
Ephydriidae		X
Psychodidae		X
<i>Bittacomorpha</i>		X
Simuliidae		
<i>Simulium</i>	X	X
Tabanidae		
<i>Chrysops</i>		X
Tipulidae		X
<i>Tipula</i>	X	

Fish

Introduction

Most fisheries studies in the Savannah River can be grouped into two categories: those emphasizing the reproductive requirements and success of striped bass (*Morone saxatilis*) 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. 1985). Interest in this topic has continued, resulting in recent 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 kilometers 29.6 and 187.1. The objectives were 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 regarding the 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 21—Threatened and Endangered Fauna.

Studies Emphasizing Striped Bass Reproductive Success

Early studies concentrated on locating striped bass spawning areas (Smith 1970, McBay 1968, Rees 1973, Rees 1974). These studies suggested that the primary spawning area was in the tidally influenced zone 30–40 km upstream from the Savannah River mouth. Attention subsequently shifted to the effects of the Savannah River tide gates on striped bass eggs and larvae in the tidally influenced lower Savannah River. 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 located 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 these increases 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 researchers (Gilbert, Larson, and Wentworth 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/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 conducted a study on 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 semi-buoyant 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 concerning 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 to evaluate 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 that could result 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 16-12 on page 16-36, Table 16-13 on page 16-37, and Table 16-14 on page 16-38). 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 were usually 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 sampling date, reflecting the influence of seasonal changes in temperature and spawning period on spawning activity. River level also seemed to be an important factor influencing the abundance of species such as blueback herring, minnows, and crappie which often spawn most successfully in flooded areas. However, river level had less influence on the abundance of species such as American shad and striped bass, which spawn directly in the main river channel.

Potential impacts of SRS on the Savannah River ichthyoplankton assemblage were categorized as plume entrainment and intake entrainment. Plume entrainment occurred when larvae drifting down the Savannah River passed through the thermal plumes at the mouths of Beaver Dam Creek and Fourmile Branch (these streams formerly received thermal discharges from the D-Area Power Plant and C Reactor, respectively). Intake entrainment

occurred when fish larvae and eggs were withdrawn from the Savannah River with the water used to cool the SRS reactors.

Investigations of ichthyoplankton distribution and abundance provided no evidence of plume entrainment impacts on the Savannah River ichthyoplankton assemblage during 1982, 1983, or 1984. During 1985 there were indications that spotted sucker larvae may have been reduced in abundance due to passage through the Fourmile Branch plume, although this conclusion was weakened by the small number of larvae that were collected.

Several factors are responsible for the general absence of detectable plume entrainment impacts at SRS. One was flooding of the river. During flood periods, the Savannah River overflowed 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 within 400 m of the creek mouth due to mixing with relatively cool Savannah River water (Bristow and Doak 1983).

The mechanism of intake entrainment at the SRS water intakes differed for fish eggs and fish larvae. Larvae were probably killed by temperature increases and shear forces after being drawn into the reactor cooling system. While some eggs may be destroyed in this fashion, most were lost as they settled to the canal bottom in the relatively quiescent canal waters (McFarlane 1982).

A number of factors influenced intake entrainment at the SRS water intakes including spawning in the intake canals, water withdrawal rate, ichthyoplankton density, and the spatial distribution of ichthyoplankton 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 canal 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 had a particularly important impact. 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.

Impingement/entrainment studies were conducted from 1983–1985 (Paller et al. 1984, 1985, and 1986). During this period an average of 7603 fish were impinged on river water pump intake screens each year. Entrainment losses averaged 10.0×10^6 eggs and 18.8×10^6 larvae annually. Species affected most by impingement were blue-spotted sunfish and threadfin shad. Entrainment losses were primarily American shad and other clupeids.

Additional entrainment-related studies were conducted during 1991 (Dames and Moore 1992). The objectives 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,

Table 16-12. Number and Percent Composition of Fish Larvae and Eggs Collected in the Savannah River and Tributary Creeks, February–July 1983.

Taxa ^a	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 ^b	<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 ^c	1294	20.5	1248	78.3
subtotal	6308	100.0	1424	100.1
total	43,249		7138	
total ichthyoplankton		50,387		

^aNomenclature after Robins et al. 1980.

^bThree additional sturgeon larvae were collected during diurnal samples not included in this report.

^cPrimarily other shad.

Table 16-13. 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 <i>Lepomis</i>)	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

^aStudy area was between RM 29.6 and 187.1 and included two intake canals, the mouths of 28 tributary creeks and 6 oxbows.

Table 16-14. Ichthyoplankton Taxa Collected from the Savannah River, Tributaries, Oxbows, and the Savannah River Intake Canals, February–July 1985. (The study area was between RM 89.3 and 187.1 and included 22 river transects, 2 intake canals, the mouths of 14 tributary creeks, and 5 oxbows.)

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 (<i>Lepomis</i>)	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

RIVIC1 and RIVIC2 were used to compute the data presented in the table.

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, and densities tended 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. It was suggested that these findings be used to generate more accurate estimates of egg entrainment and possibly to design mitigation structures.

Paller (1992) evaluated entrainment losses in light of low Savannah River levels and recent changes in the SRS mission. He noted that entrainment is greatest when periods of high river water usage coincide 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%.

References

- Arnett et al. 1992 - as ref. in Chpt 15
- Bauer, L. R., D. W. Hayes, C. H. Hunter, W. L. Marter, and R. A. Moyer. Reactor Operation Environmental Information Document, Volume 3: Meteorology, Surface Hydrology, Transport and Impacts. WSRC-RP-89-817, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC (1989).
- Bristow and Doak 1983 - Should Be 1982 - Bristow, J. E., E. L. Doak. 1982. A Thermal Infrared Survey of the Savannah River Plant, Aiken, South Carolina. Date of Survey: August 1982. EG&G Energy Measurements, Inc. Las Vegas, NV
- Chimney, J. J. and W. R. Cody. Distribution and Abundance of Zooplankton at Selected Locations on the Savannah River and from Tributaries of the Savannah River Plant: December 1984-August 1985. ECS-SR-41. Report prepared by Environmental & Chemical Sciences, Inc. for Savannah River Laboratory, E. I. du Pont de Nemours and Company, Aiken, SC (1986).
- Dames & Moore. 1992. Ichthyoplankton entrainment study at the SRS Savannah River water intakes. WSRC-TR-92-179. Westinghouse Savannah River Company, Aiken, SC.
- DOE (U.S. Department of Energy). Environmental Assessment, L-Reactor Operation, Savannah River Plant, Aiken, South Carolina. DOE/EA-0195 (1982).
- Dudley, R. G. and K. N. Black. 1978. Effect of the Savannah River tide gate on striped bass eggs and larvae. School of Forest Resources, University of Georgia. Athens, GA.
- Gilbert, R. J., S. Larson, and A. Wentworth. 1986. The relative importance of the lower Savannah River as a striped bass spawning area. School of Forest Resources, University of Georgia, Athens, GA.
- Jacobsen, W. R., R. J. Braun, E. W. Rabon, and L. J. Tilly. Thermal Discharges from the Savannah River Plant. DPST-72-428, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1972).
- Lower, M. W. Comprehensive Cooling Water Study Final Report, Volume II, Water Quality. DP-1739-2, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- McBay 1968 - McBay, L. G. 1968. Location of Sexually Mature Striped Bass. Georgia Game and Fish Commission, Coastal Region Fish Investigation, Report Final Year 1968. Job II - I:27-48.
- McFarlane, R. W. 1982. The occurrence of American shad eggs in the 1G cooling water canal. DPST-82-969. Westinghouse Savannah River Company, Aiken, SC.
- McFarlane, R. W., R. F. Frietsche, and R. D. Miracle. Impingement and Entrainment of Fishes at the Savannah River Plant: An NPDES 316(a) Demonstration. U.S. Department of Energy, Cont. AT(07-2)-1 (1978).
- Newman, M. C., A. Dancewicz, B. Davis, K. Anderson, R. Bayer, R. Lew, R. Mealy, S. Sandhu, S. Presnell, and J. Knox. Comprehensive Cooling Water Study Water Report, Volume 2, Water Quality, SREL (1986).
- Paller, M. H. 1985, J. O'Hara, D. V. Osteen. 1985. Annual report on the Savannah River aquatic ecology program, September 1983 - August 1984, Volume II - Ichthyoplankton. ECS-SR-18. Environmental and Chemical Sciences, Inc. Aiken, SC.
- Paller, M. H. 1992. The influence of Savannah River discharge and changing SRS cooling water requirements on the potential entrainment of ichthyoplankton at the SRS Savannah River intakes. WSRC-RP-92-1001. Westinghouse Savannah River Company, Aiken, SC.
- Paller, M. H., and B. M. Saul. 1986. Effects of thermal discharges on the distribution and abundance of adult fishes in the Savannah River and selected tributaries. November

- 1984 - August 1985. DPST-86-798. Westinghouse Savannah River Company, Aiken, SC.
- Paller, M. H., J. O'Hara, D. V. Osteen, W. Specht, and H. Kania. 1984. Annual report on the Savannah River aquatic ecology program, September 1982 - August 1983, Volume I.
- Rees, R. A. 1973. Statewide Fisheries Investigation, annual progress report federal aid project F-21-4, study 14 job 1. Georgia Department of Natural Resources, Game and Fish Division.
- Rees, R. A. 1974. Statewide Fisheries Investigation, final report federal aid project F-21-5, study 14 job 1. Georgia Department of Natural Resources, Game and Fish Division.
- SAIC (Science Applications International Corporation). Final Report: Analysis of SRP Impacts on the Savannah River During Low Flow Conditions, SAIC, Oak Ridge, TN (1989).
- Shines, J. E. and L. R. Tinney. A Thermal Infrared Survey of the Savannah River Plant, Aiken, South Carolina, Winter Survey, DOE/ONS-8317 (1983).
- Smith 1970 - Smith, L. D. 1979. Life History Studies of Striped Bass. Final Report Anadromous Fish Project: Georgia AFS-2. Georgia Department of Natural Resources, Game and Fish Division.
- Specht, W. L. Comprehensive Cooling Water Study, Final Report, Vol. V: Aquatic Ecology. DP-1739-5, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- U.S. Army Corps of Engineers. Savannah District Long Range Drought Contingency Plan, U.S. Army Corps of Engineers, Savannah District (1988).
- Van DenAvyle et al. 1990 - Van Den Avyle, M. J., M. A. Maynard, R. C. Klinger, V. S. Blaser. 1990. Effects of Savannah Harbor Development on Fishery Resources Associated With The Savannah River National Wildlife Refuge. Georgia Cooperative Fish and Wildlife Research Unit, Athens, GA.
- Wallin, J., R. Klinger, D. Mooneyhan, M. Van Den Avyle. 1991. Reproduction, recruitment, and habitat requirements of striped bass in the Savannah River, annual report 1 July 1990 - 30 June 1991.
- Watts, J. R. Useful Characteristics of the Savannah River, DPST-82-578, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1982).

Chapter 17

Regional Lakes Study

Chapter Contents

Introduction (page 17-3)

Synoptic Sampling Plan (page 17-7)

Longitudinal Transect Sampling Results (page 17-9)

Macronutrients, Phosphorus, and Nitrogen (page 17-13)

Indicators of Eutrophication (page 17-17)

References (page 17-21)

Introduction

Purpose of the Regional Lakes Study

The purpose of this study was to survey 10 South Carolina reservoirs in the Atlantic Coastal Plain and Southern Piedmont area with regard to trophic status, community structure, and biologically balanced community criteria. The study made every possible effort to provide continuity with regard to field and laboratory personnel, sampling protocols, laboratory methods, and processing of biological samples. Bowers (1992) reported the complete results of two 14-day synoptic surveys performed during September 1988 and 1989. The summary given in this chapter focuses on trophic conditions and community structure.

Reservoirs Studied in the Regional Lakes Study

Ten South Carolina reservoirs were sampled: L Lake, SRS; Par Pond, SRS; Pond B, SRS; Lake Moultrie; Lake Marion; Lake Murray; Lake Monticello; Lake Robinson; Lake Richard B. Russell; and Lake Greenwood (Figure 17-1 on page 17-5). Nuclear power or production reactors or fossil-fuel, electric-generating plants are present on all of the lakes. Physical descriptions of the reservoirs and their drainage areas are listed in Table 17-1 and Table 17-2 on page 17-4.

Table 17-1. Physical Characteristics of Regional Reservoirs Used in Comparative Study (Source: Bowers 1992)

Reservoir	Physio-graphic Province	Maximum Depth (m)	Mean Depth (m)	Surface Area (sq km)	Volume (x 10 ⁸ m ³)	Residence Time (days)	Shoreline Length (km)	Drainage Area (x 10 ³ km ²)	Shoreline Development Ratio
Greenwood	Piedmont	21	7	46.1	3.2	82	341	2	--
Marion	Coastal Plain	23.4	3.9	447.6	15.48	31 - 51	529.6	25.43	7.06
Monticello	Piedmont	38.4	17.9	39.6	4.93	--	--	0.044	--
Moultrie	Coastal Plain	23	5.7	263	13.13	34 - 62	160.9	38.21	2.9
Murray	Piedmont	57.8	12.6	205.6	26.08	357	844	5.86	17.7
Robinson	Coastal Plain	9.4	4.2	9.11	0.38	37 - 131	--	0.45	--
Russell	Piedmont	47	12	107.9	12.71	102	885	2.1	24.5
L-Lake	Coastal Plain	19.8	8	4.2	0.31	14 - 33	2.1	--	0.3
Par Pond	Coastal Plain	18	6.2	10.12	0.62	108.8	53	0.093	4.7
Pond B	Coastal Plain	12	4.2	0.81	0.034	--	6.4	--	2

Table 17-2. Land Use in Drainage Areas of Offsite Reservoirs

Reservoir ^a	Area (sq. km)	Agriculture (%)	Forest (%)	Wetlands (%)	Water (%)	Urban (%)	Other ^b (%)
Greenwood	1999.50	32.4	44.1	4.1	2.3	15.2	1.5
Marion	14,540.30	24.7	56	3.8	2.8	11.2	1.5
Monticello	44.00	20	70	0	2	8	0
Moultrie	306.90	4.6	8.9	13.8	70.7	2	0
Murray	3059.60	34.6	44.9	7.4	5.2	7.9	0
Robinson	448.10	42.5	54.1	1.4	1.5	0.5	0
Russell	2100.00	40	60	0	0	0	0

^a Land use data for Greenwood, Marion, Monticello, Moultrie, Murray, and Robinson taken from Kimsey et al. (1982); data for Richard B. Russell taken from James et al. (1985)

^b Other includes mining, federal lands, and non-designated areas.

Figure 17-1. Location of Lakes in the Regional Lakes Study

Sampling Plan

Introduction

When comparing several lakes for water-quality parameters and general biological structure, sampling should be performed to estimate all of the chosen variables within a predetermined timespan (Hutchinson 1957, Mortimer 1974). This strategy minimizes spatial and temporal changes. A time frame of 14 days, during the month of September 1988 and 1989 was chosen for the Regional Lakes Study. Three types of sampling plans were performed at each reservoir to answer specific questions about the 'basins' characteristics, which are described in the following section.

Water Quality Sampling Techniques

Transect sampling at a one-meter depth was performed to detect and quantify longitudinal gradients in each of the ten reservoirs with respect to the readily estimated water-quality parameters, temperature, pH, dissolved oxygen (DO), conductivity, and chlorophyll *a*. Semicontinuous samples were collected at closely spaced intervals along a transect. This transect was divided into approximately 50 equally spaced intervals with the exception of Pond B, which, due to its smaller size, was partitioned into 25 segments.

Offshore sampling was performed at one-meter stations in all lakes consisting of collecting water with a Niskin bottle for total phosphorus, alkalinity, total inorganic nitrogen, turbidity, and dissolved organic carbon (DOC) and estimating Secchi depth. The purpose of this sampling plan was to estimate indicators of water quality and trophic conditions along the longitudinal transect line that cannot be easily detected in an automated fashion.

Sampling was also performed at eight discrete depths at two stations without replication. Sample depths depended on the vertical distribution of temperature in each lake. The chosen depths were

1. just beneath the surface
2. at one meter
3. at the bottom of the mixed layer or epilimnion
4. in the middle of the thermocline or equidistant between the bottom of the epilimnion and the top of the hypolimnion
5. at the bottom of the thermocline or the top of the hypolimnion
6. one meter below the depth of the fifth sample
7. a depth equidistant between samples 6 and 8, one meter above the sediment-water interface

At each depth a Niskin bottle was used to collect water for temperature, pH, DO, total phosphorus, soluble reactive phosphorus, total inorganic nitrogen, nitrate-N, ammonia-N, total inorganic carbon, and total dissolved solids. Photosynthetically active radiation (PAR 400–700 nm) was estimated at every meter from the surface to the 1% level of incident radiation or 10 meters, whichever was detected first.

Phytoplankton, Zooplankton, and Macroinvertebrate Sampling Techniques

Samples were collected to assemble phytoplankton and zooplankton taxa lists and estimates of density (individuals per unit volume/area). Benthic macroinvertebrate samples were gathered to estimate species richness and densities. Sampling was composed of inshore bottom grabs for invertebrates at 2-m and 4-m stations. Triplicate PONAR grabs (petite model 0.023 m², 0.6-mm aperture, US Standard No. 30) were collected at each of the inshore stations. Qualitative dip-net samples were also collected to supplement the PONAR collections using 3 replicate sweeps with the net for 10 man-minutes covering a minimum of 15 m of shoreline.

Longitudinal Transect Sampling Results

Immediately apparent from the estimated means and standard errors (Figure 17-2 on page 17-10 through Figure 17-4 on page 17-11) is the greater between-basin and interannual-basin variation compared to the within-basin variation for all five variables and two sampling years. Temperature ranges of 24° to 32°C at 1 meter reflected summer surface values normally observed in the surface waters of South Carolina (SCWRC 1974). Greater mean temperatures were detected in Pond B and Lakes Marion, Moultrie, Murray, Robinson, and Russell during 1989 than in 1988. These differences reflect ephemeral weather patterns immediately prior to that day's sampling. Values for pH and dissolved oxygen (DO) are very dependent on photosynthetic rates over diel time scales (Wetzel 1983). Early afternoon results exhibit photosynthetic output that elevates both pH and DO and the ambient heterotrophic consumption of oxygen. Station-to-station variation is relatively small. Lake Robinson and Pond B had pH values significantly lower than the other lakes. These "black-water" systems have very low bicarbonate-ion concentrations with little buffering capacity. There were no large differences between the lakes, with values generally indicating a well-aerated epilimnion. However, values less than 6 mg/l, as seen in Pond B in 1988 and Lakes Greenwood and Monticello during 1989, reflect probable low photosynthetic rates and heterotrophic oxygen consumption.

There were no consistent or obvious interannual trends and only some significant correlations between water-quality parameters within any particular lake. The driving forces behind these correlations are photosynthesis that requires a hydrogen donor and nutrients. Significant algal biomass and production, which is often proportional to temperature, removes hydrogen ions from the water column. In poorly buffered waters with a paucity of bicarbonate ion, pH values increase significantly during an afternoon's primary production along with concurrent increases in DO. Therefore, positive correlations between pH and DO are not surprising. The lack of significant correlations between other parameters resulted from the secondary effects of nutrient limitation, heterotrophic oxygen consumption, zooplankton grazing, and sampling variation. These observations have been extensively documented for all types of ponds, natural lakes, impoundments, and open oceanic waters (Steele 1989). Weather conditions profoundly affect the detected gradients. Wind mixing within 24 hours of the sampling period will largely determine the nature of these stochastically determined gradients (Mortimer 1974).

Variation within lakes for any parameter was relatively small compared to between-lake variation. This result implies that there were no significant changes within the water mass for any of the basins during sampling. Furthermore, variations in the biological results were more likely due to biological processes and interactions rather than physical or chemical effects. The transect results also indicate that several sampling stations located along the longitudinal axis of the basin will adequately represent the whole water body.

Figure 17-2. Means and Standard Errors of Temperature in September 1988 and 1989

Figure 17-3. Means and Standard Errors of pH in September 1988 and 1989

Figure 17-4. Means and Standard Errors of Dissolved Oxygen (DO) in September 1988 and 1989

Macronutrients, Phosphorus, and Nitrogen

Alkalinity

Alkalinity (Figure 17-5 on page 17-14) was relatively low in all reservoirs when compared to most lakes in North America (Hutchinson 1967). All of the mean values for both 1988 and 1989 were less than 30 mg/l, which is substantially lower from hardwater lakes having values typically exceeding 100 mg/l. Lake Robinson and Pond B are softwater basins with little buffering capacity.

Phosphorus

Total phosphorus, perhaps the most widely used indicator of trophic status in lakes, is one the best single indicators of potential primary production in community because it is the least abundant algal growth element in freshwater (Rigler 1964, 1966, 1968, 1973a, 1973b). During 1988 L Lake and Lake Marion had the highest concentrations (Figure 17-6 on page 17-14). Pond B, Lake Murray, Lake Robinson, and Lake Russell had the lowest concentrations, which was still approximately 10 mg/l. These magnitudes were significantly greater than oligotrophic systems. Concentrations during 1989 did not alter this general pattern.

Nitrogen

Nitrogen most often limits element of algal growth in freshwater systems when phosphorus concentrations are at saturation for algae in eutrophic basins. Ammonia is the preferred form of nitrogen followed by nitrate and nitrite. During the 1988 and 1989 survey, L Lake, Lake Greenwood, and Lake Monticello had significantly higher concentrations of nitrite/nitrate compared to the other lakes (Figure 17-7 and Figure 17-8 on page 17-15). Ammonia, the preferred pathway of uptake by phytoplankton, was again greatest in L Lake and Lake Monticello.

Conclusions from Water-Quality Variables

Several conclusions are reached from the magnitudes and distributions of the water-quality variables. Alkalinity combined with pH estimates indicate that all of the basins tend to be softwater lakes, particularly Lake Robinson and Pond B. Phosphorus and nitrogen concentrations in L Lake, Lake Marion, Lake Greenwood, and Lake Monticello are indicative of eutrophic systems. Additionally, the vertical water-quality profiles also indicate that South Carolina reservoirs reflect varying degrees of cultural eutrophication.

Figure 17-5. Means and Standard Errors of Alkalinity in September 1988 and 1989

Figure 17-6. Means and Standard Errors of Total Phosphorus in September 1988 and 1989

Figure 17-7. Means and Standard Errors of Nitrate and Nitrite in September 1988 and 1989

Figure 17-8. Means and Standard Errors of Ammonia in September 1988 and 1989

Indicators of Eutrophication

The United States Environmental Protection Agency (USEPA, EPA-NES 1974, *see* EPA 1975) has employed three major indicators of trophic status based on chlorophyll *a*, Secchi disk depth, and total phosphorus. Local, county, state, and federal government agencies have then ranked lacustrine surface waters with these easily used techniques. Figure 17-9 on page 17-18 and Figure 17-10 on page 17-19 illustrate those rankings for the studied basins during the 1988 and 1989 surveys. In 1988 Lake Marion, L Lake, and Lake Greenwood were consistently ranked highest in trophic status at the meso/eutrophic classification. Only Lake Murray was always classified as an oligotrophic reservoir. Pond B shared this distinction in 1989 with Lake Murray immediately following in rank. Successional effects are seen with the L Lake results with regards to water clarity and algal biomass.

Because of the uniqueness of these synoptic surveys, two classic relationships invite assessment. As phytoplankton densities decrease, chlorophyll *a* concentrations will concurrently decline resulting in an increased Secchi depth. Figure 17-11 on page 17-20 illustrates this inverse relationship. The second relationship plots the $\log_{10}$ of chlorophyll *a* versus the $\log_{10}$ of total phosphorus. This linear proportionality (Figure 17-12 on page 17-20), more than any other, provided the founding principles of nutrient limitation (Droop 1973, 1974; Dugdale 1976; Schindler 1977).

The indicators of eutrophication used in this study are widely employed and, historically, have not been completely successful. Only total phosphorus has been a consistent indicator for lakes of all types at all latitudes. In this study total phosphorus was a good indicator of algal biomass. The clustering analyses based on all of the variables further supported the conclusions. These findings suggest three groupings of the ten lakes based on water quality parameters. Pond B and Lake Robinson are clearly very softwater systems well separated from the other eight basins. Par Pond, Lake Moultrie, Lake Murray, and Lake Russell are meso/eutrophic basins with moderate problems of nutrient enrichment. L Lake, Lake Marion, Lake Greenwood, and Lake Monticello have nitrogen and phosphorus concentrations that definitively categorize them as eutrophic systems.

Figure 17-9. Ranking of the Ten Reservoirs According to Three EPA Trophic Indicators During 1988

Figure 17-10. Ranking of the Ten Reservoirs According to Three EPA Trophic Indicators During 1989

Figure 17-11. Relationship Between Secchi Disk Depth and Chlorophyll *a* in the Ten Reservoirs During 1988 and 1989

Figure 17-12. Relationship Between Log 10 of Chlorophyll *a* versus the Log 10 of Total Phosphorus in the Ten Reservoirs During 1988 and 1989

References

- Baxter, R. M. 1977. Environmental effects of dams and impoundments. *Ann. Rev. Ecol. Sys.* 8:255-283.
- Beaver, J. R. and T. L. Crisman. 1990. Seasonality of planktonic ciliated protozoa in 20 sub-tropical Florida lakes of varying trophic state. *Hydrobiologia*. 190:127-135.
- Beaver, J. R. and T. L. Crisman. 1991. Temporal variability in algal biomass and primary productivity in Florida lakes relative to latitudinal gradients, organic color and trophic state. *Hydrobiologia*. 224:89-97.
- Beeton, A. M. 1965. Eutrophication of the St. Lawrence Great Lakes. *Limnol. Oceanogr.* 10:240-254.
- Bowers, J. A. 1992. Synoptic surveys of regional reservoirs in South Carolina, 1988-1989 (U), WSRC-92-RP-368, Westinghouse Savannah River Company, Savannah River Site, Aiken, SC 29808-0001.
- Carpenter, S. R., and J. K. Kitchell. 1984. Plankton community structure and limnetic primary production. *Amer. Naturalist* 124:159-172.
- Carpenter, S. R., J. F. Kitchell, J. R. Hodgson, P. A. Cochran, J. J. Elser, M. M. Elser, D. M. Lodge, D. Kretchmern, and X. He. 1987. Regulation of lake primary productivity by food web structure. *Ecology*, 68:1863-1876.
- Droop, M. R. 1973. Some thoughts on nutrient limitation in algae. *J. Phycol.* 9:264-272.
- Droop, M. R. 1974. The nutrient status of algal cells in continuous culture. *J. Mar. Biol. Assoc. U. K.* 54: 825-855.
- Dugdale, R. C. 1976. Nutrient cycles. In D. H. Cushing and J. J. Walsh, (eds.) *The ecology of the seas*. Saunders and Co. Philadelphia.
- EPA, 1975. Water quality assessment: A screening procedure for toxic and conventional pollutants in surface and ground water-Part 1 (Revised 1985). EPA/600/6-85/002a. ERL/Athens, GA 30613.
- EPA, 1975. Water quality assessment: A screening procedure for toxic and conventional pollutants in surface and ground water-Part 1 (Revised 1985). EPA/600/6-85/002a. ERL/Athens, GA 30613.
- Hutchinson, G. E. 1957. *A treatise on limnology*. Vol. I, Wiley and Sons, London.
- Hutchinson, G. E. 1967. *A treatise on limnology*. Vol. II, Wiley and Sons, London.
- Kennedy, R. H., K. W. Thornton, and D. E. Ford. 1985. Characterization of the reservoir ecosystem. In *Microbial processes in reservoirs*, D. Gunnison. ed. Dr. W. Junk Publ., Dordrecht.
- Kimmel, B. L., and A. W. Groeger. 1986. Limnological and ecological changes associated with reservoir aging. In G. E. Hall and M. J. Van Den Avyle, (eds.), *Reservoir Fisheries management: strategies for the '80's*. Amer. Fish. Soc. pp. 103-109.
- Kimsey, C. D, A. C. Boozer, J. N. Knox, L. E. Turner, K. K. Cain, and G. W. Long. 1982. South Carolina Clean Lakes Classification Survey. Technical Report No. 019-82. South Carolina Department of Health & Environmental Control
- Mortimer, C. H. 1974. Lake hydrodynamics. *Mitt. Int. Ver. Limnol.* 20:124-197.
- Odum, H. T. 1985. Trends expected in stressed ecosystems. *Bioscience* 35:419-422.
- Reckhow, K. H. 1988. Empirical models for trophic state in southeastern U. S. lakes and reservoirs. *Water Res. Bull.* 24:723-734.
- Rigler, F. H. 1964. The phosphorus fractions and turnover time of inorganic phosphorus in different types of lakes. *Limnol. Oceanogr.* 9:511-518.
- Rigler, F. H. 1966. Radiobiological analysis of inorganic phosphorus in lakewater. *Proc. Int. Assoc. Theor. Appl. Limnol.* 16:465-470.
- Rigler, F. H. 1968. Further observations inconsistent with the hypothesis that the molybdenum blue method measures orthophosphate in lakewater. *Limnol. Oceanogr.* 13:7-13.

- Rigler, F. H. 1973a. A dynamic view of the phosphorus cycle in lakes, pp. 539-572. In E. J. Griffith, A. Beeton, J. M. Spencer, and D. T. Mitchell (eds.), *Environmental phosphorus handbook*. Wiley and Sons, Inc., New York.
- Rigler, F. H. 1973b. Feeding rates. pp. 228-254, In W. T. Edmondson and G. G. Vinberg (eds.), *A Manual on methods for the assessment of secondary productivity in fresh waters*. Blackwell Sci. Publ. Oxford.
- Schindler, D. W. 1977. Evolution of phosphorus limitation in lakes. *Science* 195:260-262.
- Schindler, D. W. 1989. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function. *Oikos* 57:25-41.
- Steele, J. H. 1989. The ocean 'landscape'. *Landscape Ecology* 3:185-192
- Thornton K. W., R. H. Kennedy, J. H. Carroll, W. W. Walker, R. C. Gunkey, and S. Ashby. 1981. Reservoir sedimentation and water quality - heuristic model. Proc. of a symposium on surface water impoundments, Am Soc. Civil Eng., Minneapolis, MN.
- Wetzel, R. G. 1983. *Limnology*. 2nd Edition, W. B. Saunders & Co. Philadelphia, PA.

Chapter 18

Commercially and Recreationally Valuable Biota

Chapter Contents

Biota Found on SRS (page 18-3)

Biota Found in the Savannah River (page 18-5)

References (page 18-19)

Biota Found on SRS

Although aquatic and semi-aquatic species of commercial or recreational importance exist in SRS waters, public exploitation is not allowed onsite. In addition to potentially valuable fisheries resources, the SRS environment also supports populations of alligators, bullfrogs, and several species of turtles (softshell, slider, Florida cooter, and snapping turtle) that may have some commercial or recreational value.

Biota Found in the Savannah River

The Savannah River supports both commercial and sports fisheries. Table 18-1 lists the species and catches of fish taken commercially from the river between 1970 and 1979. Many of these fisheries are confined to the marine and brackish waters of the coastal regions of South Carolina and Georgia. Table 18-2 lists the total weight of shellfish caught in the lower Savannah River and adjacent coastal waters between 1972 and 1979.

Table 18-1. Commercial Landing Data for Fish Taken From Savannah River, 1970-1979 (Source: Adapted from Du Pont 1983)

Species	Combined Catches in Georgia and South Carolina									
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
carp	0	250	252	1503	590	998	136	453	136	363
catfish	544	157	222	518	726	181	1043	1043	363	1043
black drum	0	0	0	0	0	227	272	0	0	0
red drum	0	0	0	0	45	0	181	499	136	0
hickory shad	318	384	291	725	91	227	91	136	181	91
Spotted sea trout	0	0	0	324	227	2500	1800	181	181	0
American shad	43,591	25,568	25,439	33,912	26,263	20,412	8618	20,820	54,432	57,607
sturgeon	726	23	1967	551	136	45	363	862	454	227
suckers	0	0	0	0	0	0	91	0	0	0
common eels	0	0	0	0	0	91	0	45	0	45
mullet	0	0	0	0	0	227	0	91	0	0
striped bass	816	735	1013	1071	0	0	0	0	0	0

Table 18-2. Commercial Landing Data for Shellfish Taken from Coastal Regions of Savannah River, 1972-1979 (Source: DOE 1984, Adapted from Du Pont 1982)

Year	Shellfish Catch (kg)			
	Clams	Blue Crabs	Oysters	Shrimp
1972		419,480 ^a	1451 ^b	115,940 ^b
1973	862 ^c	543,957 ^a	2858 ^b	222,128 ^b
1974	-	1,252,072 ^d	6804 ^d	1,141,530 ^d
1975	-	17,237 ^a	3447 ^d	1,264,818 ^d
1976	-	-	-	-
1977	-	63,504 ^a	19,051 ^d	626,286 ^d
1978	1860 ^c	68,040 ^a	-	731,475 ^d
1979	454 ^c	104,781 ^a	9072 ^a	-

^a Wassaw Sound plus Ossabaw Sound

^b DOE (1982)

^c Savannah River landings

^d Northern District, Georgia

Commercial Fishing

Introduction

The commercial fishes of significance near SRS are American shad (*Alosa sapidissima*), channel catfish (*Ictalurus punctatus*), and Atlantic sturgeon (*Acipenser oxyrinchus*). These species, except for sturgeon, are exploited to a limited degree by nonprofessional, local fishermen. Commercial and recreational fisheries for blueback herring (*Alosa aestivalis*) exist in South Carolina (Ulrich et al. 1978), but none are taken commercially in Georgia because of state netting restrictions.

American Shad

American shad stocks appear to be healthy and productive in the Savannah River. Music (1981) reported that commercial catches by Georgia shad fishermen in 1980 in the Savannah River represented 51% of Georgia shad landings in that year, while only 13% of Georgia's commercial shad fishermen operated in the Savannah River. Thus, American shad stocks in the Savannah River may be less heavily exploited and relatively more abundant than stocks in other Georgia rivers. Additionally, Schmitt and Hornsby (1985) reported the development of a previously undocumented sport fishery for American shad in the vicinity of the New Savannah Bluff Lock and Dam; they recommended that the magnitude of this fishery be evaluated.

Striped Bass

Less is known concerning the status of striped bass in the Savannah River. Only recently have researchers documented spawning upstream of tidally influenced regions of the river (ECS 1983; Paller et al. 1984; Paller et al. 1985; Paller et al. 1986). Nevertheless, Gilbert et al. (1986) suggested that striped bass spawning occurs primarily in the tidally influenced portions of the river. It is not clear whether the current spawning of striped bass in upstream regions of the river represents a reestablishment of a spawning stock in this area or is a result of the increased intensity of sampling efforts during 1982–1985 relative to prior sampling programs.

Sport Fishing

Introduction

Sport fishermen are the principal consumers of river fishes, mostly sunfish and crappie. Striped bass, which is classified as game fish in South Carolina and Georgia (Ulrich et al. 1978), is a favorite quarry of fishermen in the Augusta area.

Schmitt and Hornsby (1985) evaluated the sport fishery resources in the Savannah River downstream of the New Savannah Bluff Lock and Dam during 1980–1982. The average annual sport-fishing harvest from the freshwater portions of the river (approximately river mile 21–187) was estimated to range from 171,561 fish/yr in 1982 to 550,282 fish/yr in 1980 (3 yr average = 305,778 fish/yr). The dominant species in the sport harvest were redbreast sunfish (27.2%) and bluegill (24.1%, Table 18-3). The composite category of “bream” accounted for 64% of the total angler catch. The composite category of “catfish” also represented a substantial portion of the sport harvest (14.6%), with bullhead spp. (8.2%) the major reported taxon within this category. Crappie (8%) represented a substantial compo-

Table 18-3. Fish Species Preferred and Caught by Savannah River Sport Fishermen
(Source: DOE 1988, adapted from Schmitt and Hornsby 1985)

Taxon	Percent Angler Effort	Percent Angler Catch
Bream	24.9	64.0 ^a
Redbreast sunfish	8.7	27.2
Bluegill	1.0	24.1
Warmouth	0.1	7.3
Redear sunfish	0.4	4.4
Largemouth bass	25.7	3.2
Crappie	10.7	8.0
Yellow perch	1.3	3.0
Catfish	7.0	14.6 ^a
Bullhead spp.	0.4	8.2
Channel catfish	<0.1	4.2
White catfish	0.5	2.1
Chain pickerel	0.5	0.9
American shad	7.8	1.7
Striped bass	4.7	0.2
Hybrid bass	4.4	0.3
Other	1.9	4.1
Total	100.0	100.0

^a Sum of taxa within category

ment of the sport harvest and was comparable to warmouth (7.3%). No other species (or species group) represented greater than 5% of the sport harvest. Notably, anadromous species (striped bass, 0.2%; American shad, 1.7%) did not contribute substantially to the angler's harvest. However, the authors noted that the American shad harvest may be underestimated because of the development of a fishery for this species near the New Savannah Bluff Lock and Dam, while the assessment for this species emphasized downstream areas of the river.

Angler Preferences

Anglers in the freshwater section of the Savannah River fish predominantly for bream and largemouth bass (Schmitt and Hornsby 1985). Based upon electrofishing studies, the relative abundance of bream in the freshwater section of the river is high, as is the actual angler success rate. The lower abundance of largemouth bass in the freshwater section results in a relatively low angler harvest of this species (Figure 18-1 on page 18-8). Anglers in the estuarine section of the Savannah River fish predominantly for sea trout and striped bass, but success rates for these species are low (Figure 18-2 on page 18-8).

Angler Harvests

Species Preference versus Catch

The proportions of fish species caught by anglers were frequently in sharp contrast to angler preferences. Approximately 35% of angler fishing effort was directed toward bream (composite reporting category plus individual species), while 64% of the harvest was from this category (Table 18-3). The relationship between effort and harvest was even more disparate

Figure 18-1. Comparison of Freshwater Angler Relative Fishing Effort and Fish Harvest by Species (Source: Mackey et al. 1983)

Figure 18-2. Comparison of Estuarine Angler Relative Fishing Effort and Fish Harvest by Species (Source: Mackey et al. 1983)

for largemouth bass; 25.7% of fishing effort was targeted toward this species, while it constituted only 3.2% of the catch. Overall, catfish were not highly desired (approximately 7% of effort), but were caught in slightly greater proportion (14.6%). American shad (7.8% of effort) and striped bass (4.7% of effort) were caught in substantially lower abundances than desired by sport fishermen, the disparity being comparable to that exhibited for largemouth bass.

Catch Versus Availability

Fish species caught by anglers in the Savannah River represent an extremely limited set of those species that are available. Electrofishing collections by Schmitt and Hornsby (1985) throughout the freshwater sections of the lower Savannah River indicated that the taxa caught by anglers represented only 33.1% of the relative abundance (numerical) collected in

Figure 18-3. Relative Abundance of Fish Taxa in Creel, Electrofishing, and Hoop-Net Collections

their electrofishing effort. Similarly, those species that constitute 95.8% of the angler catch constitute only 27.8% of total impingement at the SRS intakes. The species caught by anglers represent 59.8% of the numbers of fish caught by electrofishing and 86.9% of hoop-net sampling from the Savannah River near SRS intakes. However, Paller and Osteen (1985) noted that the electrofishing collections near SRS do not accurately reflect the abundance of minnows and other small species; the same caution applies to hoop-net collections because the hoop nets used for the SRS collections had a maximum mesh size of 37 mm.

Bream

Bream represent the largest component of the anglers' catch in the Savannah River. Although centrarchids were a substantial component of SRS impingement collections, the species impinged were not predominantly those caught by anglers (Figure 18-3). Although redbreast sunfish are abundant in the creel (27.1%) and in the river near the intakes (26.7%), they represented only 5.5% of impingement. Bluegill also show a much higher relative abundance in the anglers' catch than in the river (all methods) and impingement samples. Among the bream caught by anglers, only the spotted sunfish represents a higher relative abundance in impingement (3.5%) than in the creel (1.1%), but the species relative abundance in impingement is less than the relative abundance in electrofishing collections (5.2%).

Crappie, Yellow Perch, and Largemouth Bass

Crappie, yellow perch, and largemouth bass all exhibit higher relative abundances in the creel (8.0%, 3.0%, and 3.2%, respectively) than in impingement (2.9%, 0.8%, and 0.5%, respectively, Figure 18-3 on page 18-9). All three species exhibit higher relative abundance in the river (by at least one collection method) than in impingement, and largemouth bass exhibited higher relative abundance in the river than in the creel. Chain pickerel is a minor component of the creel (0.9%) and has comparable abundance in impingement (0.7%).

Catfish

Impingement relative abundances for all taxa of catfish [bullhead spp. (2.1%), channel catfish (0.8%), and white catfish (1.3%)] were lower than relative abundances for those taxa in the creel (8.2%, 4.2%, and 2.1%, respectively, Figure 18-3 on page 18-9). However, the relative abundances of these taxa in hoop-net collections from the river were substantially higher than for either impingement or angler catches. The disparity between relative abundances of catfish taxa in electrofishing and hoop-net collections suggests that catfish are a substantial component of the Savannah River ichthyofauna, and that electrofishing provides poor estimates of the abundance of these taxa.

American Shad, Striped Bass, and Hybrid Bass

American shad, striped bass, and hybrid bass were minor components in all of the collection methods (angling, electrofishing, hoop-netting, impingement, Figure 18-3 on page 18-9). The abundance of the migratory American shad and striped bass in the Savannah River near the SRS was undoubtedly underestimated during the quarterly sampling program. Nevertheless, the low frequency of these species in impingement collections (approximately 100 collections throughout the year) is highly encouraging because it indicates that adults and juveniles of these species are minimally influenced by impingement mortality associated with SRS operations.

Creel Surveys, 1988 and 1989

During 1988, Schmitt (1989) monitored fishing activity from the New Savannah Bluff Lock and Dam downstream to the ocean using the same design as the previous study (Schmitt and Hornsby 1985). Results of the 1988 survey and comparison with the earlier study are shown in Table 18-4 through Table 18-8 on page 18-15. Overall fishing pressure decreased between the studies, significantly in the estuarine area, but angler preference changed as indicated by fished-for effort increased (Table 18-8). Harvest rates increased and more fish were caught with less effort but most species were of lower average weights (Schmitt 1989). Total numbers for most freshwater species declined between the two studies (Table 18-5 on page 18-12), exceptions were crappie and channel catfish. Significant declines in estuarine harvest of striped bass, flounder, and black drum occurred. Take of silver perch and spotted seatrout increased (Table 18-7 on page 18-14).

Creel surveys were conducted in the estuarine areas of the Savannah and Ogeechee Rivers from October 1989 through March 1990 to provide comparative data and evaluation bases for regulatory changes in the harvest of striped bass (Schmitt 1990). Table 18-9 on page 18-16 through Table 18-8 on page 18-15 summarize the study and show silver perch, spotted seatrout, and channel catfish to be the dominant fish harvested from the Savannah River. Based on the results of the survey, Schmitt (1990) recommends a continued moratorium on the take of striped bass in Georgia waters of the Savannah River.

Table 18-4. Combined annual estimates of angler pressure, harvest, and catch rate for the freshwater and estuarine sections of the Savannah River between December 29, 1979 and December 24, 1982 and January 10, 1988 and December 24, 1988 (Source: Schmitt 1990)

Section of River	Hectares	Fishing Trips	Angler Hours	Fishing Pressure		Fish Harvest		Catch Rate	
				Trips/ha	Hours/ha	Number	Kg	No/h	Kg/h
1979-1982 Survey									
Freshwater									
lower	1476	24,726	117,445	16.8	79.6	102,125	22,737	0.87	0.19
upper	2158	40,156	168,770	18.6	78.2	203,653	45,533	1.21	0.27
both areas	3634	64,882	286,215	17.9	78.8	305,778	68,270	1.07	0.24
estuary	3024	NE	60,964	NE	20.2	38,542	13,737	0.63	0.23
all sections combined	6658	NE	347,179	NE	52.2 ^a	344,320	82,007	0.85 ^a	0.23 ^a
1988 Creel Survey									
Freshwater									
lower	1476	19,012	82,182	12.9	55.7	84,805	14,426	1.03	0.18
upper	2158	35,489	149,844	16.4	69.4	272,194	42,683	1.82	0.28
both areas	3634	54,501	232,026	15.0	63.8	356,999	57,109	1.54	0.25
estuary	3024	NE	40,168	NE	13.3	32,906	11,796	0.81	0.29
all sections combined	6658	NE	272,194	NE	40.9 ^a	389,905	68,905	1.21 ^a	0.27 ^a

^aArea-weighted mean

SRS Impact to Savannah River Fisheries

Historically, SRS impacts to the populations of commercially and recreationally important fish species in the river were primarily from impingement and entrainment during the intake of cooling water. The overall rates of impingement at the SRS intakes were low relative to other cooling water intake facilities in the southeastern region, and impingement losses were concentrated among species of low commercial or recreational value (DOE 1988). Cessation of reactor operation and the concomitant lack of need for large cooling-water withdrawals from the Savannah River should reduce any previous levels of impact substantially.

Table 18-5. Creel Harvest Estimates for the Combined Freshwater Portions of the Savannah River Creel Surveys of 1979–1982 and 1988 (Source: Schmitt 1989)

Species	Number			Weight(kg)				Catch rate ^b		Harvest rate ^c	
	Total	SE ^a	Percent total	Total	SE ^a	Percent total	Average weight (kg)	No./h	kg/h	No./ha	kg/ha
1979–1982 Creel Survey											
striped bass	633	248	0.2	2663	1638	3.9	4.21	.002	.009	0.17	0.73
redbreast sunfish	83,277	12,305	27.2	11,088	1951	16.2	0.13	.291	.039	22.92	3.05
crappie	24,467	3280	8.0	4942	639	7.2	0.20	.085	.017	6.73	1.36
yellow perch	9188	2152	3.0	1309	314	1.9	0.14	.032	.005	2.53	0.36
largemouth bass	9825	1135	3.2	5680	719	8.3	0.58	.034	.020	2.70	1.56
channel catfish	12,804	1680	4.2	4143	1139	6.1	0.32	.045	.014	3.52	1.14
American shad	5253	1690	1.7	7480	2506	11.0	1.42	.018	.026	1.45	2.06
chain pickerel	2880	557	0.9	1239	162	1.8	0.43	.010	.004	0.79	0.34
others ^d	157,451	16,702	51.6	29,726	2670	43.6	0.19	.550	.104	43.33	8.18
total	305,778	21,286	100.0	68,270	4773	100.0	0.22	1.067	.236	84.14	18.77
1988 Creel Survey											
striped bass	198	70	0.1	259	116	0.4	1.31	.001	.001	0.05	0.07
redbreast sunfish	109,440	44,061	30.7	10,604	4168	18.6	0.10	.472	.046	30.12	2.92
crappie	20,952	5899	5.9	3927	1212	6.9	0.19	.090	.017	5.77	1.08
yellow perch	7269	1411	2.0	920	169	1.6	0.13	.031	.004	2.00	0.25
largemouth bass	3409	760	1.0	1979	579	3.5	0.58	.015	.009	0.94	0.54
channel catfish	43,344	20,881	12.1	7800	2927	13.7	0.18	.187	.034	11.93	2.15
American shad	2500	680	0.7	3902	1146	6.8	1.56	.011	.017	0.69	1.07
chain pickerel	1210	327	0.3	732	244	1.3	0.61	.005	.003	0.33	0.20
others ^d	168,678	48,942	47.2	26,986	9920	47.2	0.16	.727	.116	46.42	7.43
total	357,000	69,359	100.0	57,109	11,294	100.0	0.16	1.539	.246	98.24	15.72

^aApproximate standard error

^bRates based on efforts of 286,215 hours (1979-82) and 232,026 hours (1988).

^cRates based on creel area of 3,634 hectares.

^dPrincipal species in the "others" category were bluegill, blue heads, striped mullet, warmouth, and redear sunfish.

Table 18-6. "Other" Species Harvested in the 1979–1982 and 1988 Savannah River Creel Surveys (Source: Schmitt 1989)

Species	Estuary Percentage by number ^a		Species	Freshwater Percentage by number ^a	
	1979–1982	1988		1979–1982	1988
hardhead catfish	30.6	36.4	bluegill	NA ^b	57.4
bluefish	19.7	NA ^b	bullheads	NA ^b	12.2
channel catfish	14.8	27.5	striped mullet	39.2	10.9
crevalle jack	T	6.0	American eel	20.2	NA
striped mullet	9.0	4.2	bowfin	19.0	NA
American eel	9.1	3.5	flier	10.5	0.1
black drum	3.8	NA ^b	redeer sunfish	NA ^b	8.4
pinfish	NA	3.0	warmouth	NA ^b	4.8
sheepshead	2.9	2.1	white catfish	NA ^b	4.7
bullheads	NA	1.8	sucker spp.	3.8	0.5
kingfish	T	1.2	red drum	T	0.4
black crappie	1.2	1.2	bowfin	19.0	0.2
largemouth bass	2.6	0.9	croaker/spot	2.3	0.1
toadfish	0.9	NA	hybrid striped bass	NA ^b	0.1
spotted gar	NA	0.6	golden shiner	0.9	NA
gaftopsail catfish	0.9	0.3	yellowtail	0.8	NA
black sea bass	0.8	NA	spot	0.6	NA
bluegill	0.4	0.3	gar	0.5	NA
redbreast sunfish	0.4	0.3	southern flounder	0.2	0.1
stingray spp.	1.3	0.3	black drum	NA	0.1
			redfin pickerel	0.2	T
			common carp	0.8	T
			spotted sunfish	NA ^b	T

^aPercentages are based on unexpanded creel data.

^bThese species were not included in "others" category for this survey, but were expanded as single species.

Trace (T) = less than 0.05%

NA = Not Any

Table 18-7. Estuarine Harvest Estimates of 1979–1982 and 1988 Savannah River Roving Creel Surveys (Source: Schmitt 1989)

Species	Number			Weight (kg)				Catch rate ^b		Harvest rate ^c	
	Total	SE ^a	Percent total	Total	SE ^a	Percent total	Average weight (kg)	No./h	kg/h	No./ha	kg/ha
1979–1982 Creel Survey											
striped bass	1139	270	2.9	1528	319	9.5	1.34	0.02	0.03	0.38	0.51
striped bass/ white bass hybrid	353	81	0.9	340	86	2.1	0.96	0.01	0.01	0.12	0.11
spotted seatrout	3586	637	9.0	1502	239	9.3	0.42	0.06	0.02	1.19	0.50
red drum	2144	506	5.4	1701	353	10.5	0.79	0.04	0.03	0.71	0.56
croaker/spot	9266	1873	23.3	1336	329	8.3	0.14	0.15	0.02	3.06	0.44
silver perch	3916	1129	9.9	377	98	2.3	0.10	0.06	0.01	1.29	0.12
flounder	886	173	2.2	468	123	2.9	0.53	0.01	0.01	0.29	0.15
white catfish	6967	1304	17.6	2641	549	16.4	0.38	0.11	0.04	2.30	0.87
black drum	1694	424	NA	3598	2807	NA	2.12	0.03	0.06	0.56	1.19
others	9722	2034	28.8	2646	557	38.7	0.27	0.16	0.04	3.21	0.88
total	39,673	3402	100.0	16,137	2986	100.0	0.41	0.65	0.27	13.11	5.33
1988 Creel Survey											
striped bass	6	6	T	3	3	T	0.50	T	T	T	T
spotted seatrout	5843	3167	17.8	2895	1587	24.6	0.50	0.15	0.07	1.93	0.96
flounder	276	89	0.8	93	32	0.8	0.34	0.01	T	0.09	0.03
silver perch	4188	2863	12.7	321	233	2.7	0.08	0.10	0.01	1.39	0.11
red drum	2122	529	6.5	2243	557	19.0	1.06	0.05	0.06	0.70	0.74
croaker/spot	6891	2000	20.9	908	229	7.7	0.13	0.17	0.02	2.28	0.30
white catfish	5443	2542	16.5	2225	921	18.9	0.41	0.14	0.06	1.80	0.74
black drum ^d	521	256	1.6	233	135	2.0	0.45	0.01	0.01	0.17	0.08
bluefish	98	85	0.3	27	26	0.2	0.28	T	T	0.03	0.01
others ^e	7519	2389	22.9	2848	943	24.1	0.38	0.19	0.07	2.49	0.94
total	32,907	6027	100.0	11,796	2042	100.0	0.36	0.82	0.29	10.88	3.90

^aApproximate standard error

^bRates based on estimated efforts of 60,964 hours (1977–1982) and 40,168 hours (1988).

^cRates based on creel area of 3,024 hectares.

^dBlack drum percentages are represented in the “others” category since harvest listed only represents one year of harvest (1982).

^ePrincipal species in the “others” category were hardhead catfish, channel catfish, crevalle jack, and striped mullet.

T (trace) = values less than 05%, .005 No./h, kg/h, No./ha, or kg/ha

NA = Not Any

Table 18-8. Estimated Fished-for Effort (hours) in the Estuarine and Freshwater Sections of the Savannah River Creel in the 1979–1982 and 1988 Surveys (Source: Schmitt 1989)

Species	1979–1982			1988		
	Hours	SE ^a	Percent	Hours	SE ^a	Percent
<i>Estuary</i>						
spotted seatrout	6762	1091	32.5	2805	1027	25.9
striped bass	6640	1175	32.0	81	8	0.8
red drum	1887	559	9.1	5737	1689	53.0
white catfish	1461	464	7.0	1099	692	10.2
croaker/spot	620	264	3.0	152	82	1.4
flounder	590	213	2.8	246	251	2.3
striped hybrid	30	25	0.2	0	0	0
others ^b	2794	1918	13.4	697	383	6.4
total	20,784	2625	100.0	10,817	2131	100.0
<i>Freshwater</i>						
largemouth bass	24,995	4435	25.7	4945	3766	6.5
bream ^c	24,129	3626	24.9	45,893	20,372	59.9
crappie spp.	10,404	1922	10.7	4580	1950	6.0
redbreast sunfish	8407	1599	8.7	3344	1340	4.4
American shad	7604	2551	7.8	7192	2240	9.4
catfish ^c	6772	1023	7.0	6924	3128	9.0
striped bass	4577	1447	4.7	915	484	1.2
striped hybrid	4296	1950	4.4	0	0	0
yellow perch	1241	471	1.3	25	18	T
bluegill	957	380	1.0	NA	NA	NA
white catfish	444	402	0.5	NA	NA	NA
chain pickerel	502	406	0.5	0	0	0
redeer sunfish	428	191	0.4	NA	NA	NA
bullhead spp.	367	158	0.4	NA	NA	NA
warmouth	70	73	0.1	NA	NA	NA
channel catfish	35	22	T	328	225	0.4
others ^d	1864	1004	1.9	2444	1882	3.2
total	97,092	7418	100.0	76,590	21,672	100.0

^aApproximate standard error

^bEstuarine “others” include hardhead catfish, channel catfish, crevalle jack and striped mullet.

^cGeneral category indicated by anglers. “Bream” includes all sunfish, and “catfish” includes all Ictalurids.

^dFreshwater “others” includes bluegill, bullheads, striped mullet, redear sunfish, warmouth, and white catfish in the 1988 survey.

Table 18-9. Savannah River Roving Creel Survey Harvest Estimates for the Period from October 8, 1989 to March 10, 1990 (Source: Schmitt 1989)

Species	Number			Weight (kg)			Harvest rate ^b		
	Total	SE ^a	Percent	Total	SE ^a	Percent	Average Weight (kg)	No/h	kg/h
striped bass	24	25	0.4	5	6	0.2	0.23	T	T
spotted seatrout	1649	1326	25.1	743	597	28.4	0.45	0.16	0.07
flounder	7	6	0.1	1	1	T	0.12	T	T
silver perch	1667	871	25.4	108	55	4.1	0.06	0.16	0.01
red drum	905	554	13.8	670	452	25.6	0.74	0.09	0.06
croaker/spot	27	20	0.4	3	2	0.1	0.12	T	T
white catfish	161	56	2.5	136	46	5.2	0.84	0.02	0.01
channel catfish	1576	562	24.0	770	405	29.5	0.49	0.15	0.07
redbreast sunfish	27	20	0.4	3	2	0.1	0.12	T	T
others	528	219	8.0	176	76	6.7	0.33	0.05	0.02
totals	6571	3161	100.0	2615	1285	100.0	0.40	0.63	0.25

^aApproximate standard errors

^bRates based on estimated total fishing effort of 10,375 hours.

T (trace) = values less than .05 percent, .005 No./h, .005 kg/h, .005 No./ha, or .005 kg/ha

Table 18-10. Savannah River Roving Creel Survey Estimates for the Period from October 8, 1989 to March 10, 1990 (Source: Schmitt 1989)

Species	Fish harvested		Fish released		Total catch		Total catch rates ^b	
	No.	kg	No.	kg ^a	No.	kg	No./h	kg/h
striped bass	24	5.3	355	81.7	379	87.0	0.04	0.01
spotted seatrout	1649	742.6	195	87.6	1844	830.2	0.18	0.08
flounder	7	0.9	0	0	7	0.9	T	T
silver perch	1667	107.8	68	4.1	1735	111.9	0.17	0.01
red drum	905	669.8	41	30.6	946	700.3	0.09	0.07
croaker/spot	27	3.1	32	3.9	59	7.0	0.01	T
white catfish	161	135.7	0	0	161	135.7	0.02	0.01
channel catfish	1576	770.2	45	21.8	1621	792.0	0.16	0.08
redbreast sunfish	27	3.2	0	0	27	3.2	T	T
others	528	176.1	77	25.5	605	201.6	0.06	0.02
totals	6571	2614.7	813	255.2	7384	2869.8	0.71	0.28

^aEstimated weight based on the average weight of harvested fish.

^bCatch rates based on estimated fishing effort of 10,375 hours.

T (trace) = values less than 0.005 No./h and kg/h

Table 18-11. Savannah River Roving Creel Fished-for Estimates for the Period from October 8, 1989 through March 10, 1990 (Source: Schmitt 1990)

Species	Effort		Fished-for Success		Percent of fished-for total harv.	Percent of species' total harv.	Average weight (kg)
	Hours	% Total	No.	kg			
striped bass	316	8.7	0	0.0	0.0	0.0	NA
spotted seatrout	2286	62.8	1178	505.5	98.8	71.4	0.43
red drum	421	11.6	3	12.7	0.3	0.3	4.23
croaker/spot	0	0.0	0	0.0	0.0	0.0	NA
white catfish	0	0.0	0	0.0	0.0	0.0	NA
channel catfish	99	2.7	3	1.0	0.3	0.2	0.33
flounder	0	0.0	0	0.0	0.0	0.0	NA
silver perch	0	0.0	0	0.0	0.0	0.0	NA
redbreast sunfish	0	0.0	0	0.0	0.0	0.0	NA
others	516	14.2	7	7.2	0.6	1.3	1.03
totals	3638	100.0	1191	526.4	100.0	18.1	0.44

NA = Not Any

/

References

- DOE (U.S. Department of Energy). *Impingement and Entrainment at the River Water Intakes of the Savannah River Plant*. CORR-860402, Savannah River Operations Office, Aiken, SC (1988).
- Gilbert, R. J., S. Larson, and A. Wentworth. *The Relative Importance of the Lower Savannah River as Striped Bass Spawning Area*. Final Report on Project F-39, Federal Aid in Fish Restoration Act, School of Forest Resources, University of Georgia, Athens, GA (1986) (draft).
- Music, J. L., Jr. *Assessment of Georgia's 1980 Commercial Shad Season*. Coastal Resources Division, Georgia Department of Natural Resources, Brunswick, GA (1981).
- Paller, M. H., J. O'Hara, D. V. Osteen, W. Specht, and H. Kania. *Annual Report on the Savannah River Aquatic Ecology Program - September 1982 to August 1983, Volume I*. DPST-84-252, Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1984).
- Paller, M. H. and D. V. Osteen. *Annual Report on the Savannah River Aquatic Ecology Program, November 1983 - August 1984, Volume I Adult Fish*. DPST-85-375, Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Paller, M. H., J. O'Hara, and D. V. Osteen. *Annual Report on the Savannah River Aquatic Ecology Program—September 1983 to August 1984, Volume II, Ichthyoplankton*. DPST-85-377, Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1985).
- Paller, M. H., B. M. Saul, and D. V. Osteen. *Distribution and Abundance of Ichthyoplankton in the Mid-Reaches of the Savannah River and Selected Tributaries*. Prepared by Environmental and Chemical Sciences, Inc. for E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1986) (draft).
- Schmitt, D. N. 1989. *Savannah River Creel Survey*. GA Dept. of Nat. Resources, Game and Fish Div., Annual Performance Report, Study IX, Fed. Aid Proj. F-30-16. 27pp.
- Schmitt, D. N. 1990. *Savannah and Ogeechee River Creels*. GA Dept. of Nat. Resources, Game and Fish Div., Annual Performance Report, Study XIII, Fed. Aid Proj. F-30-17. 27 pp.
- Schmitt, D. N. and H. H. Hornsby. *A Fisheries Survey of the Savannah River*. Georgia Department of Natural Resources - Game and Fish Division, Athens, GA (1985).
- Ulrich, G., N. Chipley, J. W. McCord, D. Cupka, J. L. Music, Jr., and R. K. Mahood. *Development of Fishery Management Plans for Selected Anadromous Fishes in South Carolina and Georgia*, Special Publication 14, Marine Resources Center, South Carolina Wildlife and Marine Resources Department (1978).

Part IV

Threatened and Endangered Species

The protection and restoration of biota to a point where their existence is not jeopardized is a principal goal of federal and state environmental programs. Numerous private organizations and other groups have formed at local and national levels to complement governmental protection of those plants and animals collectively referred to as "species of concern". This volume discusses the status of species of concern at SRS, emphasizing the biota that: (1) are listed or proposed as endangered or threatened by the U.S. Department of the Interior, U. S. Department of Commerce, or the State of South Carolina; (2) currently exist onsite either as a permanent or temporary resident; and (3) have habitat preferences or affinities for ecosystems present on SRS. Species that are not currently classified as endangered or threatened by federal or state agencies or whose status is under review are not addressed.

Chapter 19

Laws Protecting Threatened and Endangered Species

Chapter Contents

Federal Endangered Species Act (page 19-3)

State of South Carolina Acts and Programs (page 19-5)

References (page 19-7)

Federal Endangered Species Act

The Endangered Species Act of 1973, as amended (DOI 1973), is intended to prevent the further decline of endangered and threatened species and to bring about the restoration of these species and their habitat. The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) jointly administer this act. As of April 2, 1993, 775 species of native flora and fauna (mammals, birds, reptiles, amphibians, crustaceans, plants, and other life forms) were officially protected by the act (DOI 1993). Of these, 594 species are listed as endangered, and 181 species are listed as threatened. A species can be listed federally under one of two categories—endangered or threatened—depending on its status and the degree of the threat. Endangered refers to a species or subspecies that is in danger of extinction throughout all or a significant portion of its range. Threatened characterizes any species or subspecies that is likely to become endangered in the foreseeable future throughout all or a significant portion of its range. In addition, species may also be classified as “threatened due to similarity of appearance”. This classification is afforded to various species to ensure against excessive taking and to continue necessary protection to similar-appearing species that are still classified as threatened. When a species is proposed for either the endangered or threatened status, areas essential to its survival or conservation may be proposed as “critical habitat”. The process of determining critical habitat is similar to the one for listing a species, and the two procedures often parallel each other. SRS contains no areas that have been designated as critical habitat for any species.

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

State of South Carolina Acts and Programs

The State of South Carolina's program for plants of concern involves the recognition and protection of federally listed species and an unofficial state list (Knox and Sharitz 1990). Rayner et al. (1986) compiled an initial list of endangered and threatened flora for South Carolina. The South Carolina Wildlife and Marine Resources Department's Heritage Trust Program plays a prominent role in collecting data, maintaining occurrence records, and revising the list of rare plants in the state (Knox and Sharitz 1990). The state list has no legislative basis and therefore does not afford legal protection to flora. The Heritage Trust Program and the South Carolina Nature Conservancy use this list to determine habitat protection priorities.

The State of South Carolina does, however, have a Nongame and Endangered Species Conservation Act (Section 50-15, 1976, S. C. Code of Laws). Rules established to implement the act protect federally listed endangered and threatened wildlife that occur in South Carolina (R.123-150), sea turtles (R.123-150.1), and predatory birds of the orders falconiformes (hawks and eagles) and strigiformes (owls) (R.123-160). Additions to the state protection listings can be made by the South Carolina Wildlife and Marine Resources Commission.

References

- Code of Laws of South Carolina. Section 50-15 (1976).
- Department of Interior (DOI). 1993. Box Score Listings and Recovery Plans, Endangered Species Technical Bulletin Vol. XVIII, No. 1, p. 16.
- Department of Interior (DOI), Fish and Wildlife Service. 1973. Endangered Species Act of 1973. P. L. 93-205 (87 Stat. 84)
- Knox, J. N. and R. R. Sharitz. Endangered, Threatened, and Rare Vascular Flora of the Savannah River Plant. Division of Wetlands Ecology, Savannah River Ecology Laboratory, Aiken, SC (1990).
- Rayner, D. A., C. Aulbach-Smith, W. T. Batson, and C. L. Rogers. 1986. Native vascular plants rare, threatened or endangered in South Carolina. Report of South Carolina Advisory Committee on Rare, Threatened, and Endangered Vascular Plants, 24 p.

Chapter 20

Threatened and Endangered Flora

Chapter Contents

Threatened and Endangered Flora Found in South Carolina (page 20-3)

Threatened and Endangered Flora Found on SRS (page 20-5)

References (page 20-9)

Threatened and Endangered Flora Found in South Carolina

Programs for Identifying Species

The State of South Carolina has developed a program for identifying potentially threatened and endangered plant species within the state. An early survey by Jones and Dunn (1983) identified 31 species of plants that they considered endangered or threatened. These species were all found in forested community types, which were the only communities examined. Rayner et al. (1986) compiled the first government sponsored listing of threatened and endangered species in South Carolina. The South Carolina Wildlife and Marine Resources Department's Heritage Trust Program currently lists threatened and endangered species in South Carolina. The South Carolina Nature Conservancy is also very active in the listing of species.

Federally Listed Species Found in South Carolina

Three endangered species, the bunched arrowhead (*Saggitaria fasciculata*), the persistent trillium (*Trillium persistens*), and the small whorled pogonia (*Isotria medeoloides*), are listed for the state of South Carolina by the U.S. Department of the Interior and were mentioned in the L-Reactor Operation Final Environmental Impact Statement (DOE 1984). None of these species have been reported or identified at SRS. Thirteen species listed as federally endangered occur in South Carolina. Only the smooth purple coneflower (*Echinacea laevigata*) is known to occur onsite.

Threatened and Endangered Flora Found on SRS

SRS is populated by a diverse flora with 1322 listed species and varieties of 558 genera (Batson et al. 1985). Within this flora exist several unusual and rare species, eight of which are considered as federally endangered or possibly appropriate for proposed federal listing as threatened or endangered (Table 20-1 on page 20-6). Table 20-2 on page 20-7, compiled from Knox and Sharitz (1990), lists the names and the federal and state status of rare and unusual plants found on SRS. In addition, Table 20-3 on page 20-8, also compiled from Knox and Sharitz (1990), lists plant species of concern that might be found on SRS. Individuals on this list have not been identified onsite, although they are found in communities similar to those that do occur onsite. This listing includes five federally endangered species, one plant proposed for listing, one plant appropriate for proposed listing, and six species possibly appropriate for proposed listing.

A site boundary map (Figure 20-1 on page 20-6) illustrating the locations of rare or threatened plant populations on the SRS was produced from site use permit documents (Knox and Sharitz 1987a, 1987b, 1988a, 1988b).

Table 20-1. Plant Species Listed by the Federal Government, State of South Carolina, or the South Carolina Heritage Trust as Endangered, Threatened, or of Special Concern Known to Currently Occur on the Savannah River Site (Sources: 50 CFR 17.11 and 17.12 (August 1992); Federal Register 54:554-579. South Carolina Code of Laws of 1976, 1988 Cumulative Supplement, R. 123-150. South Carolina Wildlife and Marine Resources Department, Heritage Trust Database 1989)

Species	Status ^a	Observation on or Near SRS
<i>Carex decomposita</i> (cypress knee sedge)	FC2	Steel Creek Delta
<i>Croton elliotii</i> (Elliott's croton)	FC2	karst ponds and bays
<i>Echinacea laevigata</i> (smooth purple coneflower)	E	along Burma Road
<i>Lindera subcoriacea</i> (bog spice bush)	FC2	seepage bogs on SRS
<i>Lobelia boykinii</i> (swamp lobelia)	FC2	Carolina bays on east side of SRS
<i>Myriophyllum laxum</i> (loose water-millfoil)	FC2	freshwater ponds
<i>Nestronia umbellula</i> (North American sandelwood)	FC2	dry wood bluffs along Upper Three Runs
<i>Rhexia aristosa</i> (awned meadow-beauty)	FC2	Craig Pond

^aE = Endangered

FC2 = Currently being reviewed (a candidate species) for listing as a threatened or endangered species by the federal government; not enough information is currently available to warrant listing.

Figure 20-1. Location of Rare and Threatened Plant Species on the Savannah River Site

Table 20-2. Names and Status of Plant Species of Concern Found on SRS

Scientific Name	Common Name	Federal Status ^a	State Status ^a
<i>Astragalus villosus</i>	milk pea	NL	SUR
<i>Baptisia lanceolata</i>	yellow wild indigo	NL	SUR
<i>Bumelia lanuginosa</i>	woolly bumelia	NL	NL
<i>Carex decomposita</i>	cypress knee sedge	C2	SUR
<i>Carex oligocarpa</i>	few-fruited sedge	NL	SUR
<i>Carya myristiciformis</i>	nutmeg hickory	NL	RCT
<i>Coreopsis rosea</i>	pink tickseed	NL	RCT
<i>Croton elliotii</i>	Elliott's croton	C2	SUR
<i>Echinacea laevigata</i>	smooth purple coneflower	E	NCT
<i>Echinodorus tenellus</i>	little burrhead	NL	SCT
<i>Gaura biennis</i>	gaura	NL	SUR
<i>Lindera subcoriacea</i>	bog spice bush	C2	NL
<i>Lobelia boykinii</i>	swamp lobelia	C2	NL
<i>Ludwigia spathulata</i>	Florida false loosestrife or spathulate seedbox	NL	SUR
<i>Myriophyllum laxum</i>	loose water-milfoil	C2	RCT
<i>Nestronia umbellula</i>	nestronia	C2	NL
<i>Nolina georgiana</i>	sandhill lily	NL	SUR
<i>Paronychia americana</i>	nailwort	NL	SUR
<i>Platanthera lacera</i>	green fringed orchid	NL	SCT
<i>Potamogeton foliosus</i>	pondweed	NL	SUR
<i>Quercus durandii</i>	Durand's white oak or bastard white oak	NL	SCT
<i>Rhexia aristosa</i>	awned meadow-beauty	C2	SUR
<i>Rhododendron flammeum</i>	oconee azalea	NL	SCT
<i>Rhynchospora inundata</i>	beak-rush	NL	SUR
<i>Rhynchospora tracyi</i>	beak-rush	NL	SUR
<i>Rorippa sessiliflora</i>	yellow cress	NL	SUR
<i>Sagittaria isoetiformis</i>	quill-leaved swamp potato	NL	SCT
<i>Trepocarpus aethusae</i>	trepocarpus	NL	SUR
<i>Utricularia floridana</i>	Florida bladderwort	NL	SCT
<i>Utricularia olivacea</i>	dwarf bladderwort	NL	SCT
<i>Vallisneria americana</i>	tapegrass	NL	SUR

^aE = endangered

PE = proposed as endangered

C1 = appropriate for proposed listing

C2 = possibly appropriate for proposed listing

C3 = no longer considered for proposed listing

NCE = national concern, endangered

NCT = national concern, threatened

RCE = regional concern, endangered

RCT = regional concern, threatened

SCE = statewide concern, endangered

SCT = statewide concern, threatened

SUR = status unresolved, considered rare

NL = not listed

ESC = extirpated from South Carolina

Source: Knox and Sharitz (1990)

Table 20-3. Names and Status of Plant Species of Concern that May Occur on SRS

Scientific Name	Common Name	Federal Status ^a	State Status ^a
<i>Agalinis aphylla</i>	scale leaf gerardia	NL	SUR
<i>Amphicarpum muhlenbergianum</i>	blue maiden-cane	NL	SUR
<i>Aristolochia tomentosa</i>	wooly Dutchman's pipe	NL	SUR
<i>Bacopa cyclophylla</i>	water-hyssop	NL	SCT
<i>Carex chapmanii</i>	Chapman's sedge	C2	NCT
<i>Delphinium carolinianum</i>	Carolina larkspur	NL	SUR
<i>Elliottia racemosa</i>	Georgia plume	C3	ESC
<i>Halesia parviflora</i>	small-flowered silverbell	NL	SUR
<i>Helenium brevifolium</i>	sneezeweed	NL	RCE
<i>Helenium pinnatifidum</i>	sneezeweed	NL	SUR
<i>Helianthemum georgianum</i>	rockrose	NL	SUR
<i>Helianthus schweinitzii</i>	Schweinitz's sunflower	E	NCT
<i>Hymenocallis coronaria</i>	rocky shoals spider lily	C2	NCT
<i>Ilex amelanchier</i>	sarvis holly	C2	NL
<i>Kalmia cuneata</i>	white wicky	C1	NCE
<i>Lindera melissifolia</i>	pondberry	E	NCE
<i>Litsea aestivalis</i>	pond spice	C3	SUR
<i>Lyonia ferruginea</i>	stagger-bush	NL	SCT
<i>Lysimachia asperulaefolia</i>	rough-leaved loosestrife	E	NCE
<i>Menispermum canadense</i>	moonseed	NL	SUR
<i>Oxypolis canbyi</i>	Canby's cowbane	E	NCE
<i>Ptilimnium nodosum</i>	mock bishop's-weed	PE	NCE
<i>Quercus oglethorpensis</i>	Oglethorpe oak	C2	SUR
<i>Ruellia caroliniensis</i> spp., <i>ciliosa</i>	ruellia	NL	SUR
<i>Scleria baldwinii</i>	Baldwin's nut-rush	NL	SCT
<i>Spiranthes longilabris</i>	giant spiral-orchid	NL	SCT
<i>Stillingia aquatica</i>	Queen's root	NL	SCE
<i>Stylisma pickeringii</i>	Pickering's brewaria	C2	SCT
<i>Trillium pusillum</i> var. <i>pusillum</i>	dwarf or Carolina trillium	C2	NCE
<i>Trillium reliquum</i>	relict trillium	E	NCE

^aE = endangered

PE = proposed as endangered

C1 = appropriate for proposed listing

C2 = possibly appropriate for proposed listing

C3 = no longer considered for proposed listing

NCE = national concern, endangered

NCT = national concern, threatened

RCE = regional concern, endangered

RCT = regional concern, threatened

SCE = statewide concern, endangered

SCT = statewide concern, threatened

SUR = status unresolved, considered rare

NL = not listed

ESC = extirpated from South Carolina

Source: Knox and Sharitz (1990)

References

- Batson, W. T., J. S. Angerman, and J. T. Jones. Flora of the Savannah River Plant, an Inventory of the Vascular Plants on the Savannah River Plant, South Carolina. Savannah River Plant National Environment Research Park Program, SRO-NERP-15 (1985).
- Code of Federal Regulations. Endangered and Threatened Wildlife and Plants: Animal Notice of Review, 50 CFR 17, Federal Register 54 554-579 (1989).
- Code of Federal Regulations. Endangered and Threatened Wildlife and Plants, 50 CFR 17.11 and 17.12, Title 50 (1989).
- Code of Laws of South Carolina, 1976. Code of Laws of South Carolina, 1988 Cumulative Supplement, Chapter 123, Rev 150, The Lawyers Co-operative Publishing Company, Rochester, NY (1988).
- Code of Laws of South Carolina. Chapter 123, Rev 150-160 (1976).
- Code of Laws of South Carolina. Section 50-15 (1976).
- DOE (U.S. Department of Energy). Final Environmental Impact Statement L-Reactor Operation, Savannah River Plant, Aiken, South Carolina. DOE/EIS-0108, U.S. Department of Energy, Savannah River Operations Office, Aiken, South Carolina (1984).
- Jones, S. M. and B. A. Dunn. Endangered and threatened forest plants of South Carolina. Forestry Bulletin No. 37, Department of Forestry, Clemson University, 117 p. 1983.
- Knox, J. N. and R. R. Sharitz. Registration of Locations of Rare or Threatened Plant Populations Based Upon Federal or State of South Carolina Status. Site Use Action Number SU-87-63-R (1987a).
- Knox, J. N. and R. R. Sharitz. Registration of Locations of Rare or Threatened Plant Populations Based Upon Federal or State of South Carolina Status. Site Use Action Number SU-87-64-R (1987b).
- Knox, J. N. and R. R. Sharitz. Registration of Locations of Rare or Threatened Plant Populations Based Upon Federal or State of South Carolina Status. Site Use Action Number SU-87-63-R Amendment (1988a).
- Knox, J. N. and R. R. Sharitz. Registration of Locations of Rare or Threatened Plant Populations Based Upon Federal or State of South Carolina Status. Site Use Action Number SU-87-64-R Amendment (1988b).
- Knox, J. N. and R. R. Sharitz. Endangered, Threatened, and Rare Vascular Flora of the Savannah River Plant. Division of Wetlands Ecology, Savannah River Ecology Laboratory, Aiken, SC (1990).
- Rayner, D. A., C. Aulbach-Smith, W. T. Batson, and C. L. Rogers. Native vascular plants rare, threatened or endangered in South Carolina. Report of South Carolina Advisory Committee on Rare, Threatened, and Endangered Vascular Plants, 24 p. 1986.

Chapter 21

Threatened and Endangered Fauna

Chapter Contents

Invertebrates (page 21-3)

Fishes (page 21-5)

Herpetofauna (page 21-9)

Avifauna (page 21-19)

Mammals (page 21-53)

References (page 21-55)

Invertebrates

Introduction

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

Species Found on SRS

Brother Spike Mussel

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

American Sandburrowing Mayfly

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

Fishes

Introduction

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

Shortnose Sturgeon

Introduction

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

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

Figure 21-1. Shortnose Sturgeon (*Acipenser brevirostrum*)

Habitat

Shortnose sturgeon have been found in rivers, estuaries, and the ocean with their greatest abundance occurring in the estuary of their respective river (Dadswell et al. 1982). The few fish that have been captured at sea were found within a few miles of land near the mouth of an estuarine system. The species is primarily anadromous, but access to the sea is apparently not a requirement for reproductive success. Landlocked populations have been reported in the Holyoke Pool section of the Connecticut River (Taubert 1980a, 1980b) and in the Lake Marion-Moultrie system in South Carolina (Marchette and Smiley 1982).

Spawning

Time of Year

Spawning of shortnose sturgeon occurs between February and May, depending on the latitude. Ripe and spent females have been collected from January to April in the Savannah River (Marchette and Smiley 1982). In South Carolina waters, the spawning season is earlier than in northern rivers; however, the range of spawning temperatures is similar (Marchette and Smiley 1982).

Temperature

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

Spawning Grounds

In northern rivers, the spawning grounds are located in regions of fast flow (40 to 60 cm/s) with gravel or rubble bottoms (Taubert 1980a, 1980b; Buckley 1982; Pekovitch 1979). This has apparently been confirmed for the Savannah River population (Hall et al. 1991). Three areas of potential spawning habitat in the Savannah River have been identified (Collins et al. 1992) at river kilometers 179–190, 220–230, and 275–278. These areas have moderate to strong current (50–100 cm/sec) and a substrate of gravel or submerged logs.

Eggs

Shortnose sturgeon eggs are dark brown to black with a light-gray polar body (Dadswell 1979a, 1979b; Meehan 1910). Eggs are fertilized immediately after extrusion. When released, the eggs sink to the bottom (Pottle and Dadswell 1979). The fertilized eggs are demersal and become adhesive within 20 minutes after fertilization (Meehan 1910). Suitable substrate for egg adhesion is necessary for egg development.

Spawning Frequency

Although shortnose sturgeon populations spawn once a year, spawning apparently is not a yearly event for each individual. Dadswell (1979a, 1979b) reported that females probably spawn a maximum of once every three years and males every other year in the Saint John River. Marchette and Smiley (1982) noted that male shortnose sturgeon in the Pee Dee

River, South Carolina, require two to three years between spawning periods while females require a three- to four-year ripening period.

Stages of Development

Larval Development

Shortnose sturgeon larval development and behavior are not well known. Ichthyoplankton sampling efforts to collect shortnose sturgeon eggs and larvae indicate that the larvae are probably benthic in habit and that they may occupy interstitial spaces in the gravel during early larval stages (Pottle and Dadswell 1979).

Juvenile

Little is known about the life history of juvenile shortnose sturgeon, particularly in southeastern rivers. In northern rivers, juveniles are benthic and feed primarily in deep channels over sandy-mud or gravel-mud bottoms (Dadswell 1979a, 1979b; Taubert 1980a; 1980b). In the Savannah River, juveniles will generally stay within two to five kilometers of the fresh-water/saltwater boundary (Hall et al. 1991).

Growth

Growth data indicate that shortnose sturgeon grow faster in the southern portion of their range (Dadswell 1979a, 1979b), where they may attain a length of approximately 50 cm after only two to four years (Taubert 1980a, 1980b). The maximum size reported for a shortnose sturgeon is 122 cm [fork length (FL)], a 23.6-kg female from the Saint John estuary. The largest male on record is 97 cm (FL), a 9.4-kg individual from the Saint John estuary (Dadswell 1979a, 1979b). Maximum size varies from north to south with the largest maximum sizes reported from northern populations. Of 135 specimens collected by Marchette and Smiley (1982) from South Carolina rivers, the largest was 92.7 cm (FL) and weighed 4.3 kg.

Life Span

The oldest female and male shortnose sturgeon collected to date, both from the Saint John River, were determined to be 67 and 32 years old, respectively (Dadswell 1979a, 1979b). In general, shortnose sturgeon from northern populations have a longer life span than southern populations. Marchette and Smiley (1982) determined a maximum age of 20 years based on 93 shortnose sturgeon collected from South Carolina waters.

Feeding

Feeding by shortnose sturgeon seems to be either benthic or from plant surfaces. Dadswell et al. (1982) found them to be most active during the night or on windy days when water turbidity was high. Fish were more readily captured at night, and stomach analyses showed full gastrointestinal tracts. Marchette and Smiley (1982) observed shortnose sturgeon grazing at night on mollusks attached to the underside of yellow pond lily pads.

Herpetofauna

Introduction

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

Amphibians

The Carolina crawfish frog, also known as the Carolina gopher frog, is a subspecies of *Rana aequalata*. This is the only amphibian species of concern on SRS (out of five species) that is listed as a candidate species for federal protection. The Carolina crawfish frog is a member of the group of stubby-appearing frogs whose habits of nocturnal activity and daytime use of crawfish and gopher tortoise holes or other hiding places conceals them from casual observation. The Carolina subspecies is distinguished by its small, closely packed warts and heavy ventral marking that gives a marbled appearance (Conant 1975). Gibbons and Semlitch (1991) reported hearing the Carolina crawfish frog calling, and the species is infrequently collected on SRS.

Reptiles

Introduction

No reptiles found at SRS are listed as threatened or endangered. The American alligator, however, is listed as "Threatened Due to Similarity of Appearance". This classification means that the species itself is not threatened, but is given special consideration because it closely resembles a listed taxa (in this case, the very rare American crocodile), and its protection and regulation will benefit the endangered species it resembles.

Snakes

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

Alligator

Introduction

The American alligator (*Alligator mississippiensis*) (Figure 21-2 on page 21-10), has been studied extensively at SRS (Murphy 1977, 1981; Smith et al. 1981, 1982a, 1982b; Seigel et

Figure 21-2. American Alligator (*Alligator mississippiensis*)

al. 1986). These earlier studies are summarized in Volume VI of the Comprehensive Cooling Water Study Final Report (CCWS) (Mackey 1987). Seigel (1989) and Brandt (1989) more recently documented work with SRS alligators. The following sections summarize the CCWS (Mackey 1987), Seigel (1989), and Brandt (1989) studies.

Protection History

The American alligator is the largest reptile on SRS, reaching a length in excess of 3.7 m (10 to 12 ft) and a weight of 150 kg (325 lb) (Murphy 1981). Although abundant as late as 1890, populations of alligators in the United States dwindled by the mid-20th century to less than 100,000, primarily as a result of intense hunting and habitat destruction (King 1972). State game laws restricting the harvest of alligators were moderately useful in stabilizing populations, but it was not until federal protection was enacted in the 1960s and 1970s that populations began to recover. Recovery of this species has proceeded to the point where the FWS has reclassified the species from endangered/threatened to threatened due to similarity of appearance (DOI 1992).

General Life History

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

Aquatic Habitats on SRS

Introduction

The two major types of aquatic habitats of importance to alligators on SRS include both riverine (flowing water) and lacustrine (lake) systems (Figure 21-3 and Figure 21-4 on page 21-12). The riverine systems include Upper Three Runs, Lower Three Runs (below Par Pond), Steel Creek, Pen Branch, Fourmile Branch, Beaver Dam Creek, and the SRS section of the Savannah River and its associated swamp. The lacustrine system includes the Par Pond reservoir, Pond B, Pond C, L Lake, numerous Carolina bays, abandoned farm ponds, and beaver ponds.

Alligator Populations in the Par Pond System

Studies on the ecology of alligators on SRS between 1968 and 1981 focused primarily on Par Pond (Figure 21-4 on page 21-12), which harbors the largest population of American alligators onsite. Research on the Par Pond population was initiated by T. Murphy and I. L. Brisbin in 1968, and was summarized by Murphy and Brisbin (1974) and Murphy (1981).

- Mark-recapture data suggested that approximately 66 adults and 40 juvenile alligators were present in Par Pond as of 1976. This is a much lower density of alligators than seen

Figure 21-3. Major Aquatic Habitats at SRS

Figure 21-4. Par Pond System

in other parts of the species' range, especially Louisiana.

- The size structure of the Par Pond population favored large adults (i.e., >2.4 m). The ratio of adults to juveniles in the Par Pond population was 59:41, compared to 31:69 for populations from coastal South Carolina.
- The sex ratio of adult alligators in Par Pond was 79:21 in favor of males, which was significantly different from data reported from Louisiana.
- Murphy found low levels of reproduction at Par Pond, estimating only 2.3 nests/year.
- Growth rates of juvenile alligators from Par Pond were found to be slower than those of juveniles from Louisiana.
- Distributions of alligators in Par Pond changed seasonally, with adult males using thermally affected areas during the winter. The use of these thermally altered sites may have permitted a longer yearly activity period for adult males, with subsequent alteration of the timing of reproduction.

Murphy (1981) suggested that many of the unusual characteristics of the Par Pond population (low reproductive rate, low density, adult-biased population structure) was the result of "reproductive asynchrony", i.e., males coming into breeding condition earlier than females, resulting in a low frequency of mating, and, therefore, fewer nests. However, two alternative explanations might also apply: first, as Murphy (1981) noted, SRS is located near the northwestern edge of the range of the American alligator. Data from other reptiles suggests that northern populations frequently have lower reproductive and growth rates than southern populations (Tinkle 1961, Fitch 1985), probably as a result of shorter growing seasons. Second, most previous studies of alligators have been conducted in marsh habitats, which are better quality habitat for alligators than are the open waters of Par Pond.

The Par Pond system, including Pond B and Pond C (Figure 21-4), harbors the largest and most extensively studied alligator population on SRS. Recent work comparing previous study results with current population estimates has shown an increase and change in distri-

bution by size class. The estimated population size has gone from 110 adults and juveniles in 1974 to 197 total in 1988 (Table 21-1). Although the sex ratio changed from 3.2:1 (male: female) to 2.6:1 between 1977 and 1988 (Table 21-1, Figure 21-5 on page 21-14), this is not considered a statistically significant change. Size distribution changed from a population dominated by large individuals to one of smaller animals (Figure 21-6 on page 21-14). Reproductive success within the Par Pond alligator population has almost doubled the population in the last 14 years. Brandt (1989) calculated an average annual population exponential rate of increase of 0.06 (Figure 21-7 on page 21-15), which projects a population of over 320 individuals by the turn of the century.

Beginning in June 1991, the Par Pond water level was lowered approximately 6 meters resulting in a nearly 50% reduction of the reservoir surface area. Brisbin et al. (1992) estimated the size and response of the alligator population and monitored its behavior from July 1991 through the summer of 1992. Large numbers of alligators were sighted in July after the beginning of the drawdown with approximately a one-third reduction in the population by October of that year (Table 21-2 on page 21-15).

Alligator Populations in Beaver Dam Creek

Beaver Dam Creek has had the highest frequency of alligator sightings in recent studies. This high density of alligators may be the result of the availability of relatively undisturbed, high-quality habitat and the moderate thermal-effluent discharged into the creek. This thermal regime is not extreme enough to exceed the critical thermal maximum of the species and may contribute to alligator success by enhancing growth and survival by allowing year-round foraging and decreased mortality from freezing temperatures. Size distribution of the Beaver Dam Creek population (Figure 21-8 on page 21-16) shows a high representation of juveniles and sub-adults, suggesting successful recruitment into the population (Seigel 1989).

Table 21-1. Estimated Population Size and Sex Ratios for Alligators Inhabiting Par Pond in 1972-1974 and 1986-1988 (Source: Brandt 1989)

Year	Category	Population Estimate and Confidence Interval (method)		Sex Ratio
1974 ^a	Adults	70	29-143 (Lincoln)	3.7:1
	Juveniles	40	19-72 (Lincoln)	1.8:1
	Total	110	48-215 (Lincoln)	3.2:1
1988 ^b	Adults	108	97-120 (Lincoln)	2.5:1
	Juveniles	83	45-121 (Jolly)	3.1:1
	Total	197		2.6:1

^a1974 data from Murphy (1977)

^b1988 total population size includes 6 animals 1.25-1.5 m that were captured but not represented in earlier estimate

Figure 21-5. Size and Sex Structure of Alligators Captured in Par Pond, 1986-1988
(Source: Brandt 1989)

Figure 21-6. Size Distribution of Alligators in Par Pond, 1974-1976 and 1986-1988
(Source: Brandt 1989)

Figure 21-7. Alligator Population Growth in Par Pond 1972-1988 (Source: Brandt 1989)

Table 21-2. Distribution of alligators in the Par Pond reservoir in 1987 and during/after the lowering of the reservoir's water level by 6 m from June to September 1991. (Source: Brisbin et al. 1992)

Region ^a	Surface Area (ha) ^b		Number of Alligators ^c			
	Pre-drawdown	Post-drawdown	July 1987	October 1987	July 1991	October 1991
Main Lake	351.7 (31.4)	245.1 (44.4)	34 (53.1)	18 (52.9)	10 (11.1)	7 (11.7)
North Arm	356.2 (31.8)	145.2 (26.3)	10 (15.6)	4 (11.8)	36 (40.0) ^d	21 (35.0)
Hot Arm	136.6 (12.2)	65.7 (11.9)	5 (7.8)	5 (14.7)	20 (22.2)	12 (20.0)
West Arm	275.5 (24.6)	96.6 (17.5)	15 (23.4)	7 (20.6)	24 (26.7) ^d	20 (33.3)
Total	1120	552.6 (49.3) ^e	64	34	90	60

^aAs shown in Figure 21-4 on page 21-12.

^bNumbers in parentheses represent percentage of the total reservoir surface area, under either pre- or post-drawdown conditions.

^cNumbers in parentheses are percentages of the total number of alligators counted.

^dJuly values for use preference (percentage of alligators observed/percentage of water area available) differ significantly ($P \leq 0.05$) from corresponding values for October of the same year, as determined by X^2 tests.

^ePercentage of the pre-drawdown surface area of the total reservoir.

Figure 21-8. Size Structure of the Beaver Dam Creek Alligator Population as Assessed by Aerial Surveys in 1984 (Source: Seigel 1989)

Alligator Populations in Steel Creek Below L Lake

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

Alligator Populations in Fourmile Branch

During the operation of C Reactor, Fourmile Branch was not a suitable alligator habitat and supported no population. Although Fourmile Branch delta did contain some suitable habitat, no alligators were observed (Murphy 1981). More recent observations showed a relatively high frequency of alligator sightings in Fourmile Branch, and although the population is small, it used the delta and lower stream channel even during reactor operation. The population is probably not self-sustaining and no signs of reproduction have been documented. The source of individuals for the Fourmile Branch population is most likely Beaver Dam Creek due to its close proximity and large alligator population. The continued shutdown of C Reactor since 1984 may lead to sufficient habitat recovery to support an alligator population (Seigel 1989).

Alligator Populations in Pen Branch

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

Alligator Populations in Other SRS Areas

There are other areas on SRS that provide potential alligator habitat, but there is little information on the populations that exist there. Although Lower Three Runs, dammed in 1959 to form Par Pond, supports a self-sustaining population directly below the dam, the remainder of the creek has not been surveyed for alligator use (Murphy 1981). Upper Three Runs provides a minimum of suitable habitat (Murphy 1981) and few alligators have been sighted there (Seigel 1989). Except for Steed's Pond, which supported a moderate population of alligators until it was drained in 1984, there is no evidence that any of the ponds and Carolina bays on SRS support alligator populations (Seigel 1989). The Savannah River swamp system appears to contain suitable habitat for alligators (Murphy 1981), and although alligators are seen there regularly, difficulty in sampling makes it impossible to estimate the size of the population (Seigel 1989).

Avifauna

Introduction

Current and Past Residents

Thirteen species of birds listed as threatened or endangered by the federal or state government are known current or past residents of SRS. This group includes the federally endangered red-cockaded woodpecker (*Picoides borealis*), bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco peregrinus*), Kirtland's warbler (*Dendroica kirtlandii*), and wood stork (*Mycteria americana*); the federal candidate species Benwick's wren (*Thyromanes bewickii*), loggerhead shrike (*Lanius ludovicianus*), and Bachman's sparrow (*Aimophila aestivalis*); and the State of South Carolina listed golden eagle (*Aquila chrysaetos*), American osprey (*Pandion haliaetus*), Cooper's hawk (*Accipiter cooperii*), swallow-tailed kite (*Elanoides forficatus*), and the Savannah sparrow (*Passerculus sandwichensis princeps*).

Visitors

The peregrine falcon has been reported in the past as a rare winter visitor to SRS near Par Pond (Langley and Marter 1973). Kirtland's warbler is also listed as a rare temporary visitor. The golden eagle continues to be a rare transient visitor observed on Par Pond (Mayer et al. 1986). The federal candidate species, Benwick's wren, Bachman's sparrow, and the loggerhead shrike were common in the past (Langley and Marter 1973). The osprey has been observed on SRS but is considered an occasional migrant (Du Pont 1982, DOE 1984). Cooper's hawk has been documented on SRS (DOE 1984), and the swallow-tailed kite was common early in the 1900s in this area, but has not been recorded from SRS (Sprunt and Chamberlain 1970). The Savannah sparrow was reported as an abundant winter resident on SRS in 1973 (Langley and Marter 1973). There is no evidence that any of these birds are residents of, or nest on, SRS (DOE 1984).

Bald Eagle

Introduction

With a wingspan of 1.8 to 2.3 m, the bald eagle (*Haliaeetus leucocephalus*) is the largest raptor commonly observed on SRS. The coloration of an adult bald eagle is unmistakable, being uniformly dark brown with a white head, neck and tail (Figure 21-9 on page 21-20). This species exhibits a variety of plumage coloration patterns associated with the age of the bird. The dark form is characteristic of the first year plumage (Figure 21-10 on page 21-20). Then for the next two years, bald eagles have a mottled plumage. At three years of age, the birds develop into a white-bellied plumage. Bald eagles begin the molt into the characteristic adult plumage during their fourth or early fifth year of age. Adult bald eagles typically weigh between three and five kilograms (Sprunt and Chamberlain 1970).

Figure 21-9. Bald Eagle (*Haliaeetus leucocephalus*)

0-1 Years—Dark Form

1-3 Years—Mottled Plumage

3-4 years—White Bellied Plumage

4-5 Years—Adult Plumage

Figure 21-10. Ventral Appearance of Soaring Bald Eagles

History in South Carolina

The bald eagle is a permanent breeding resident in South Carolina and is most abundant in the coastal region (Sprunt and Chamberlain 1970). It is thought that as many as 200 nesting pairs of bald eagles may have been in the state historically. By the late 1950s, these numbers had dropped to about 100 pairs. This decline in South Carolina and other locations in the eastern United States has been attributed to the negative effect of persistent pesticides and other environmental contaminants on bald eagle reproduction (Murphy and Coker 1978). In 1978, only 15 nesting pairs of eagles could be found in South Carolina (Murphy and Coker 1978). Primarily as a result of restrictions on pesticide use, the numbers of bald eagle nesting pairs in the state have been increasing since 1981 (Mayer et al. 1986). This increase has continued through the present, with 87 nesting pairs being found in South Carolina in 1993.

Inland Colonization

As the numbers of nesting pairs and mating success of bald eagles along the South Carolina coast increased during the early 1980s, greater numbers of fledged young have dispersed into inland areas (Mayer et al. 1986). The successful colonization of more inland portions of the state has largely been the result of the man-made impoundments present on the Santee-Cooper and Savannah River drainages. These impoundments provide both extensive forage habitat and aquatic prey base for bald eagles immigrating inland from coastal territories (Mayer et al. 1986). Apparently because of the lack of comparable impounded habitat (Murphy and Coker 1978), North Carolina and Georgia have not realized similar influxes of nesting birds dispersing inland from coastal areas.

Bald Eagle Use of SRS

Records of bald eagle sightings in the central Savannah River area date back to 1904 (Murphy 1937). The presence of this species on SRS was documented as early as May 1959, when an adult bald eagle was observed on the newly filled Par Pond (Norris 1963). At least two more sightings were recorded for Par Pond during that year. One of these birds, seen in September, was an immature bald eagle (Norris 1963). Par Pond has been and continues to be the location where most of the eagle sightings on SRS have taken place. Jenkins and Provost (1964) reported that two bald eagles had been recorded on SRS, neither being permanent residents, nor breeders. Langley and Marter (1973) also noted that three bald eagles were observed as transient visitants near Par Pond. During a study of American alligators on Par Pond in the early 1970s, T. M. Murphy sighted bald eagles there "once or twice a week" in the winter of 1971-72 (Mayer et al. 1986). Between 1971 and 1975, Murphy noted that bald eagles were regularly seen on Par Pond from late September or early October to mid-March. In the late 1970s and early 1980s, both adult and immature bald eagles were observed on Par Pond during the annual SRS Christmas Bird Count in December (Mayer et al. 1986). Dukes (1984) stated that a few bald eagles had been observed on Par Pond, but that no resident population of this species existed onsite. The use of SRS by this species has apparently increased as a result of the aforementioned inland colonization. Sightings of bald eagles on site have continued to increase (Figure 21-3). Between 1986 and 1992, the estimated numbers of bald eagles wintering on SRS increased from two to six birds (SRFS 1992).

SRS Bald Eagle Study

A one-year study of bald eagle use of SRS was conducted between September 1984 and August 1985 (Mayer et al. 1985). Ground or aerial surveys were conducted on the Par Pond

Figure 21-11. Number of Winter Observations of Bald Eagles During the SRS Christmas Bird Count Surveys on Par Pond and L Lake and the SREL Waterfowl Aerial Surveys

system at least twice per month during this study. The location, date, time of day, number of adult and immature birds, and behavior were recorded. A total of 36 bald eagles were sighted in 31 instances during this 12-month period (Table 21-3 on page 21-23). Most (91.7%) of these sightings were reported in the vicinity of Par Pond (Figure 21-3 on page 21-11). Within that area, the largest number (66.7%) of sightings were specifically on Par Pond (Mayer et al. 1985). Fewer eagles were seen on Pond C (24.2%), Pond B (6.1%), and Pond 2 (3.0%). On Par Pond (Figure 21-3), the Big Lake section adjacent to the Cold Dam had the most use (22.7%), followed by Loyal's Lair (18.2%), and then the Hot Arm, North Arm, and Pump House Cove in the West Arm (each at 13.6%). On Pond C, most of the sightings were between the main lake and Sanctuary Cove. In part, the thermal fish kills on Pond C attract bald eagles to that impoundment (Gladden et al. 1985). A number of sightings on Pond C have been of birds that were feeding on dead fish in the littoral zone (Mayer et al. 1985). Of all the bald eagles sighted during the study, 72% were adults, and 13% (10) were paired birds. Of these five pairs, two were both adults, two were both immatures, and one was an adult/immature pair. Bald eagles were seen during every month of the one-year study period. Most of the birds (63.9%) were seen during the winter and spring months (November through May). This was also the period when most of the immature birds (90.0%) were observed. Only one immature bald eagle was seen in the fall during the study, and none were observed during the summer (Mayer et al. 1985). The conclusion of the study was that bald eagle use of SRS was more common than had been previously known. The apparent increase was postulated to be the result of either poor earlier documentation or a recent increase in the use of the site by this species.

Supplemental SRS Observations

Data collection subsequent to Mayer et al. (1985) continued until January 1986 (Mayer et al. 1986). A total of 22 bald eagles was observed during that additional time period (Table 21-4). Seven of the sighting localities were new records for SRS. Bald eagle use of L Lake was reported within one month of its completion of filling. An immature bird was seen feeding on dead fish in the outflow of L Lake Dam, and three adult bald eagles were observed soaring above the lake (Mayer et al. 1986).

Table 21-3. Bald Eagle Sightings on SRS from September 1984 to August 1985 (Source: Mayer et al. 1985)

Number of Eagles Seen				
Date	Time	Adults	Immatures	Location on SRS
09/10/84	1030	-	1	Pond C, Sanctuary Cove
09/12/84	1415	1 ^a	-	Pond C, Canal Cove
10/17/84	1500	1	-	Par Pond, Loyal's Lair
11/06/84	1130	1	-	Par Pond, Pump House Cove
11/15/84	1425	1	-	Pond B, Pond B Dam
12/03/84	1515	1	-	Par Pond, Cold Dam
12/15/84	0930	1	-	SRS Rd 2, on roadside near New Ellenton barricade
12/15/84 ^b	1030	-	1	Par Pond, Cold Dam
12/19/84	1130	1	-	Pond C, near Boatdock Cove
01/07/85	1100	1	1	Par Pond, North Arm
01/17/85	1630	1 ^c	-	Par Pond, Cold Dam
01/20/85	1030	-	1	Par Pond, Cold Dam
01/22/85	1400	1	-	Par Pond, Loyal's Lair
01/25/85	1300	-	1	Par Pond, Loyal's Lair
02/03/85	1120	1	-	Par Pond, Loyal's Lair
03/20/85	1400	-	2	Par Pond, Hot Arm; flew to pond C
03/25/85	1440	-	2	Par Pond, Pump House Cove
03/30/85	1330	-	1	Par Pond, Cold Dam
04/04/85	1030	1	-	Par Pond, Hot Arm
04/04/85	1600	1	-	Par Pond, North Arm
04/14/85	1230	1	-	Par Pond, Big Lake section; flew to Main Lake
04/19/85	1015	1	-	Upper Three Runs, near mouth
05/02/85	1215	1	-	Savannah River, near Crackerneck GMA
05/13/85	1000	1	-	Pond B
05/25/85	1600	1	-	Pond C, near Sanctuary Cove
06/25/85	1000	1	-	Pond 2
07/03/85	1000	1	-	Pond C, near Sanctuary Cove
07/12/85	0930	2	-	Pond C, near Sanctuary Cove
07/18/85	1030	1	-	Par Pond, South Lake section of West Arm
07/18/85	1400	2	-	Par Pond, West Lake; flew to Hot Arm
08/05/85	0930	1	-	Pond C, near Sanctuary Cove

^aBird had a red band on left wing.

^b1984 annual SRS Christmas Bird Count.

^cBird had a red streamer attached to back.

Figure 21-12. Location of Bald Eagle Sightings on SRS (Source: Mayer et al. 1986)

Table 21-4. Bald Eagle Sightings on SRS from September 1985 to January 1986 (Source: Mayer et al. 1986)

Date	Time	Number of Eagles Seen		Location on SRS
		Adults	Immatures	
09/03/85	1000	1	-	Pond C, near Sanctuary Cove
09/13/85	0945	1	-	Pond C, near Sanctuary Cove
09/14/85	0820	1	-	Par Pond, West Lake
09/14/85	0956	1	-	Par Pond, South Lake
10/05/85	1530	1	-	One mile east of the SRS Rd 8 causeway over the North Arm of Par Pond
10/22/85	1400	1	-	Par Pond, Hot Dam
10/27/85	1145	1	-	Par Pond, Cold Dam; flew down Lower Three Runs
11/13/85	1100	1	-	Par Pond, Cold Dam
11/13/85	1520	1	-	Par Pond, Cold Dam
11/15/85	1020	1	-	H Area, field near junction of SRS Rd E and 4
11/19/85	1430	-	1	L Lake, L-Dam outflow
12/03/85	0915	1	-	Hunt Compartment 44, adjacent to Rd A-13 near 1985 Deer hunt stand and D-19
12/05/85	1030	1	-	Par Pond, West Arm
12/06/85	1500	1	-	L Lake, center of impoundment
12/11/85	1015	1	-	Par Pond, Cold Dam
12/13/85	1445	1	-	L Lake, near Rd B
12/13/85	1530	1	-	L Lake, near L-Reactor effluent canal
12/30/85	1620	1	-	Par Pond, Cold Dam
12/31/85	1045	1	-	Par Pond, West Arm
01/04/86	1045	1	1	Par Pond, Cold Dam
01/04/86	1410	1	-	Par Pond, West Arm, Fran's Inlet

Figure 21-13. Percentage of Adult and Immature Bald Eagles Observed Seasonally on SRS Based on a Total of 197 Birds Observed Between 1959 and 1992

Adult to Immature Ratio

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

Social Organization

Most sightings (95%) of bald eagles on SRS consist of solitary birds; however, social groupings of between two to five bald eagles have been observed. Pairs of birds are the most common social grouping observed. The one social grouping of five bald eagles consisted of all immature birds observed soaring over the Big Lake section of Par Pond in 1992.

Seasonal Use

Banding studies have documented mid-summer migration of bald eagles that have nested in the southeast to the northern states and Canada (Sprunt and Chamberlain 1970). These birds then return south in the fall or early winter to nest and rear their young and remain there until late spring (Sprunt and Chamberlain 1970). Based on the aforementioned 197 sightings, most of the bald eagles were observed on SRS during the fall and winter when this species is nesting and wintering in South Carolina (Figure 21-13). Those birds seen during the summer are most likely transients migrating either north or south.

Diet and Forage Behavior

In South Carolina, the diet of bald eagles consists almost exclusively of fish. However, these raptors are also known to prey on ducks, American coots (*Fulica americana*), herons, and small mammals. Bald eagles will opportunistically feed on carrion, usually in the form of dead fish. This species often reportedly steals food from ospreys rather than foraging for prey themselves (Sprunt and Chamberlain 1970). Observations of foraging activities of bald

eagles on SRS indicate a varied diet composed of fish (largemouth bass, *Micropterus salmoides*), waterfowl (coots and buffleheads, *Bucephala albeola*), small mammals (gray squirrel, *Sciurus carolinensis*), and carrion (thermally killed fish and road-killed small mammals) (Mayer et al. 1986, Mayer et al. 1988).

Records of Marked/Tagged Birds

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

Figure 21-14. Locations of the Two Bald Eagle Nests on SRS

Reproductive Biology

The nesting season for bald eagles in South Carolina is midwinter. The nest, usually built in tall pines, is a huge mass constructed of sticks, bark, grass, moss, and other debris. Bald eagles typically return and add materials to the same nest year after year. After many seasons' use, bald eagle nests can attain very large proportions. The typical clutch consists of two eggs, but can range in size from one to four. The eggs are solid white in color, and average approximately 70 mm in length and 54 mm in diameter. Incubation requires approximately 35 days. Both adults in the nesting pair participate in incubating the eggs and feeding the young (Sprunt and Chamberlain 1970).

Bald Eagle Nesting on SRS

Two bald eagle nesting territories have been documented for SRS (Figure 21-14 on page 21-26). The first nesting location for this species on SRS (the Eagle Bay nesting territory) was discovered on May 21, 1986. By June 6, 1986, the nest and the presence of two juvenile bald eagles was confirmed (Mayer et al. 1988). A total of seven bald eagle chicks were hatched out and fledged from that nest between 1986 and 1988 (Table 21-5 on page 21-27). In 1989, both the nest and the one hatchling produced that season were presumed lost when extreme winds (87 mph) associated with a storm front passed through SRS in April. The South Carolina Wildlife and Marine Resources Department installed a braced wooden and wire platform in the same area of the original nest, and constructed an artificial nest of pine limbs and twigs. The pair initiated a nesting effort in 1990, but had abandoned the nest by February of that year. A pair of great blue herons (*Ardea herodias*) took over and initiated a nesting effort in the eagle nest tree later that same month. In June of 1990, the second bald eagle nesting location (the Pen Branch nesting territory) was discovered. Although initially believed to be the displaced pair from Eagle Bay, neither of the nesting bald eagles at Pen Branch was marked. Two adult birds and two chicks were observed at that nest during the first year. The Eagle Bay nest site was completely inactive in 1991, while the nesting activity at Pen Branch again produced two nestlings (Table 21-5). In 1992, a pair of bald eagles initiated and then abandoned a nesting effort at Eagle Bay. During that same year, the pair at the Pen Branch nest continued to produce two nestlings. In 1993, a pair of eagles initiated a

Table 21-5. Number of Nestlings Produced Annually by the Bald Eagle Nesting Pairs on SRS

Year	Annual Number of Nestlings Produced	
	Eagle Bay Nest Site	Pen Branch Nest Site
1986	2 ^a	-
1987	2	-
1988	3	-
1989	1 ^b	-
1990	-	2 ^a
1991	-	2
1992	-	2
1993	2	2
Total	10	8

^aFirst year for nest

^bSingle nestling present, presumed lost when nest was dislodged during a wind storm

nest at Eagle Bay and two newly hatched bald eagle chicks were observed in the nest in March of that year. Two chicks were again observed at the Pen Branch nest in the 1993 nesting season.

Bald Eagle Management on SRS

The Savannah River Forest Service began an active management program in 1986 for the Eagle Bay nesting territory and in 1990 for the Pen Branch nesting territory. SRS Site Use Permits have been issued for both the Eagle Bay (SU 86-47-F) and Pen Branch (SU 86-47-F-Amendment 1) nesting territories. These management plans encompass primary and secondary management zones for protecting the nesting territories, and key areas along the shores of both Par Pond and L Lake for perching and roosting activity. Through the use of management zones and the distances between the two nests and existing SRS facilities, it is expected that site activities at SRS would have no adverse effect on the bald eagle.

Golden Eagle

History in South Carolina

The golden eagle (*Aquila chrysaetos*) (Figure 21-15) is a rare resident in the mountains of the northwestern section of South Carolina, but is found during the winter in other areas of the state (Sprunt and Chamberlain 1970). Records of this species in the central Savannah River area date back to at least 1933 (Murphy 1937). Even then, the golden eagle was locally considered to be rare (Murphy 1937). There have been no documented nesting records for this species in South Carolina (Mayer et al. 1985, 1986).

Figure 21-15. Golden Eagle (*Aquila chrysaetos*)

Table 21-6. Listing of the Golden Eagle Sightings on SRS

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

^a Based on a number of observations made of what was assumed to be the same individual

Golden Eagle Use of SRS

Sightings of the golden eagle on SRS are very rare (Mayer et al. 1985, 1986). Although SRS is not ideal golden eagle habitat, it does provide potential wintering habitat for this species (Mayer et al. 1985, 1986). Only three golden eagles have been recorded as occurring onsite (Table 21-6). All of the sightings have been on Par Pond. The first was an immature bird that spent several weeks on Par Pond during the December 1972–January 1973 time frame. The second observation was an adult golden eagle sighted during the 1978 SRS Christmas Bird Count survey on Par Pond. The last series of observations made in December 1991 on Par Pond were assumed to have been multiple sightings of the same adult bird. Since recent numbers of this species have not substantially increased in this region of the southeastern United States, the level of use of SRS is also not expected to increase at present.

Red-Cockaded Woodpecker

Introduction

The red-cockaded woodpecker (*Picoides borealis*) (Figure 21-16) was included in the federal list of endangered species in 1970 due to the declines in local populations, its perceived rarity, and the apparent reduction in available nesting habitat (Lennartz and Henry 1984). Although the red-cockaded woodpecker was once common, its current status can be largely attributed to its unique life history requirements and how they are affected by the reduction of mature pine forests. The red-cockaded woodpecker is a native of the southern pine forests of the United States with the largest populations found in the Coastal Plain forests of the Carolinas, Florida, Alabama, Mississippi, Louisiana, and eastern Texas. Populations are also found in the Sandhills forests of the Carolinas. An endangered species recovery plan (Lennartz and Henry 1984) prepared for the U.S. Fish and Wildlife Service describes the life history, ecology, and historic and current status of the species.

Breeding

The red-cockaded woodpecker is a cooperative breeder using auxiliary or helper birds to aid the mated pair with incubation, feeding, and brooding. Clans with helpers generally have higher reproductive success. These clans are nonmigratory and maintain year-round territories around their nesting and roost trees. Clans can range in size from only the mated pair to up to nine birds including helpers and fledglings. The normal clan size is two to four birds prior to nesting and four to six birds after fledging. Nesting season is usually April and May, with clutch initiation in late April or early May. Clutch size is generally between two and five eggs. Incubation takes approximately 10 days, and fledging occurs between 26 to 29

Figure 21-16. Red-Cockaded Woodpecker (*Picoides borealis*)

days after hatching. Juveniles remain in their natal territory through summer into fall. Juvenile females disperse during late fall, winter, and early spring, while some juvenile males may remain with their clan and become helpers (Lennartz and Henry 1984).

Habitat

Cavity Excavation

The red-cockaded woodpecker is the only species to use living pines exclusively for cavity excavation. The birds use many species of pines, preferably over 70 years old, and may actively select for trees suffering from heart rot. The same cavity trees may be used for many years, possibly decades, and the trees used by a clan tend to be clustered in what are referred to as colonies. Trees in most colonies are within a 1500-ft-diameter area in open stands of pine with sparse midstories. Sparse midstory is an important factor because dense hardwood midstories may cause red-cockaded woodpeckers to abandon the area. This may be due to more intense interspecific competition from other woodpecker species inhabiting the wetter habitats that promote thicker midstory stocking (Lennartz and Henry 1984).

Foraging

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

Relationship Between Population Numbers and Suitable Habitat

Since its inclusion as an endangered species, the red-cockaded woodpecker has been the focus of extensive research and population studies. The total number of active colonies on federal lands may exceed 3000. There have been documented losses of active colonies in recent literature. Red-cockaded woodpecker population trends will most likely parallel the trends in availability of suitable habitat. Stands of old-growth pines are a scarce and declining resource throughout the south, with the total acreage of old growth pine having declined by 13% over the last 30 years. There are 130,737 acres of pine on SRS (USFS 1992); of this, less than 1% consists of age classes greater than 80 years. On federal lands there is a significant positive correlation between old-growth longleaf-slash pine and active red-cockaded colonies.

Savannah River Forest Service Wildlife Management Program

Creating Nesting Habitats

Since 1979, the Savannah River Forest Service (SRFS) wildlife management program at SRS has been actively working to improve red-cockaded woodpecker habitat. In 1980, a program was initiated to increase the availability of nesting and foraging habitat. Arboreal midstories were reduced using mechanical (chainsaws, etc.) and chemical (herbicides) applications and prescribed burns. Artificial nesting cavities were also placed in appropriate areas to enhance reproduction. Since 1980, 9344 acres have been altered to enhance populations of the red-cockaded woodpecker (Table 21-7).

Monitored Colonies at SRS

SRFS monitors 35 colony sites of four different categories (Figure 21-17). There are four active colonies that contain productive clans, seven inactive sites that supported active colonies within the last ten years, abandoned sites that supported active colonies more than ten years ago, and recruitment sites containing appropriate habitat (Table 21-8) (Austin 1989a).

Table 21-7. Acres Altered by the Savannah River Forestry Service to Create Nesting Habitats for the Red-Cockaded Woodpecker

Year	Midstory	Prescribed Burns	Artificial Nest Cavities
1980-1989	130	68	2
1990	234	204	28
1991	726	1106	20
1992	634	6232	52
Total	1724	7610	102

Table 21-8. Numbers of Documented Red-Cockaded Woodpeckers on SRS

Year	Individuals	Breeding Pairs
1985	4	1
1990	24	6
1991	30	6
1992	38	8

Figure 21-17. Location of Red-Cockaded Woodpecker Colonies on SRS (As of June 1993)

Table 21-9. Number of Red-Cockaded Woodpeckers on SRS as of June 15, 1993

Group/Cluster	# Adults	# Fledglings
1 ^a	1	
22	3	
3	3	3 nestlings
5	3	1 nestling
15 ^b	1	
16	3 or 4	2
18 ^a	1	2 nestlings
19	5	3
28	2	
39	3	3
40	2	2 nestlings
43	3	3
24-1	2	1 egg
80-5	1	
13	33	14 fledglings, 5 nestlings, and 1 egg

^aGroups 1 and 18 have combined

^bGroup 15 is an intruder

SRS Population Numbers

The 1992 red-cockaded woodpecker population inhabiting SRS consisted of 38 individuals comprising 8 breeding pairs (USFS 1992). The number of fledglings has increased consistently since 1985, indicating positive reproductive success. Since 1988, sex ratios of the total population and fledglings have not changed significantly (Table 21-9).

Ten groups of red-cockaded woodpeckers were active prior to the 1992 breeding season. Eight of these contained at least one male and one female; two groups contained solitary males. In 1992, 5 groups successfully fledged at least 1 young in 1992, producing a total of 13 young (6 males, 7 females); the mean reproductive rate was 1.6 young fledged per breeding pair. Four of the five groups that successfully produced young in 1992 did so on their first attempt. The other group was successful on its second attempt. The remaining three groups were unsuccessful in producing young.

Wood Stork

Introduction

During the last 50 years, the North American breeding population of the wood stork (*Mycteria americana*) (Figure 21-18) has decreased from an estimated 20,000 breeding pairs in the early 1930s to 4800 pairs in 1980 and 3650 pairs in 1983 (Ogden and Nesbitt 1979, Ogden and Patty 1981, DOI 1983). This population decline prompted the United States Fish and Wildlife Service of the Department of Interior (DOI) to list the wood stork as an endangered species (DOI 1984). Since 1980, the number of breeding pairs of wood storks has remained relatively stable at roughly 4500 pairs in 1981, 3700 in 1982, 4000 in 1983, 5100 in 1984, and 5100 in 1985 (Coulter 1986c).

Figure 21-18. Wood Stork (*Mycteria americana*)

Birdsville Colony

The DOI identified 23 colonies of wood storks in Florida and Georgia in the proposed listing (DOI 1983). The Birdsville Colony, the most northern and inland wood stork colony, is located at Big Dukes Pond, a 567 ha cypress swamp, 12.6 km northwest of Millen, Jenkins County, Georgia (32°52'N, 82°03'W). This wood stork colony (Figure 21-19) was believed to be the source of storks observed at the Steel Creek delta in the SRS Savannah River swamp during 1980-1982 (Smith et al. 1982a, 1982b). The SRS Savannah River swamp is 45 km from the Birdsville Colony, a distance within the 60 to 70 km radius that wood storks can travel during daily feeding flights (Bryan and Coulter 1987, Coulter 1993).

Effect of Reactor Operations

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

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

Much of the data and information presented here are summarized from the studies and reports by the Savannah River Ecology Laboratory (SREL) (Meyers 1984; Coulter 1986a, 1986b, 1986c, 1987, 1988, 1989, 1990, 1991, 1993; Bryan 1992a, 1992b).

Savannah River Swamp

The SRS Savannah River swamp comprises about 3800 ha bordering the Savannah River on the southwestern edge of SRS (Jensen et al. 1984). The swamp area, including the deltas

Figure 21-19. Location of Kathwood Lake and the Birdsville Wood Stork Colony

of Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek, contains nonpersistent and persistent emergent wetlands, deciduous forest wetlands (including cypress-tupelo forest), and scrub-shrub wetlands. Earlier studies placed particular emphasis on wood stork use of the Steel Creek delta (Meyers 1984; Coulter 1986a, 1986b) because the forage potential of this area would be reduced due to increased water depths associated with L Reactor restart in October 1985. Although the cooling water used by L Reactor is cooled in L Lake, the waterflow below L Lake increases the depth in areas of the Steel Creek delta where storks have been observed foraging. Because it was anticipated that the Steel Creek delta could be lost as a foraging site for wood storks following L Reactor restart, alternate foraging ponds have been built at the site of Kathwood Lake on the National Audubon Society's Silver Bluff Plantation Sanctuary (Figure 21-19) (Mackey 1985).

Savannah River Ecology Laboratory Studies

The wood stork studies by SREL have changed over the years to reflect an increased understanding of the storks and the habitats in east-central Georgia. In general, the same methods have been maintained throughout the studies so that data collected are comparable between years. However, some differences in the kinds of data collected have been inevitable due to the changing scope of the studies and to different environmental conditions among the years. For example, in 1985 the storks abandoned the colony in Big Dukes Pond and moved to Little Dukes Pond, which is east of Big Dukes Pond. Because of this move, limited information on breeding biology in the early part of 1985 was collected (Coulter 1986b). From 1985 to 1988, drought conditions generally occurred throughout the southeastern United States. Additional data were collected to document the impact of the drought on the storks (Coulter 1986c, 1987, 1988, 1989). Since 1989, the scope of the program has been reduced to monitoring the reproductive success of the storks inhabiting the Birdsville Colony, and stork use of the Savannah River swamp system and Kathwood Lake foraging ponds.

Birdsville Colony Survey

The SREL wood stork surveys began in 1983 (Meyers 1984). During the first year of the study, 1983, there were only a few observations made at the colony. From 1984 through 1989, the study of the breeding biology of the storks was expanded. Since 1980, the maximum number of active nests in the colony has been determined to document colony growth and overall colony reproductive success (Table 21-10). In 1984 and 1985, with more complete data available, unsuccessful nests were also included in measuring breeding success (Coulter 1986c). As shown in Figure 21-20, storks begin to arrive at the Birdsville Colony in early March. Breeding and chick rearing are variable from year to year and usually extend from March through May with fledglings dispersing from the colony from late May through mid-summer. Reproductive success, which is estimated as the number of chicks fledged per nest for 1983 through 1992 in Table 21-11 on page 21-37, has varied from year to year at the Birdsville Colony.

Foraging Surveys 1983-1989

Introduction

Storks have been followed by using a fixed-wing airplane from the colony to foraging sites in all years of the surveys. The majority of foraging sites (75%) were in Jenkins, Burke, and Emanuel counties, Georgia (Hodgson et al. 1987, 1988). The number of storks and other wading birds was counted at each foraging site, and the water depth and the minimum dis-

Table 21-10. Number of Active Nests in the Birdsville Colony

Year	Number of Active Nests	Date Maximum Number of Nests were Counted	Source
1980	About 100 ^a	-	Meyers 1984
1981	Failed	-	Meyers 1984
1982	About 60 ^a	-	Meyers 1984
1983	113 ^b	-	Meyers 1984
1984	About 100	-	Coulter 1986a
1985	About 108	-	Coulter 1986b
1986	160	May 14	Coulter 1987
1987	193	May 26	Coulter 1988
1988	101	May 31	Coulter 1989
1989	126	June 13	Coulter 1990
1990	259	June 1	Coulter 1991
1991	270	May 22	Bryan 1992a
1992	243	May 19	Bryan 1992b

^aEstimated from ground and aerial surveys

^bActual counts from 26 trees

Figure 21-20. Number of Wood Storks in the Birdsville Colony, 1984-1989 (Source: Coulter 1993)

tance to the shore were measured. In 1983, Meyers (1984) recorded five foraging habitat types, including a shrub swamp type that was incorporated into the different swamp types of later surveys. Drainage ditches, hardwood swamps, and natural ponds were added to the types of foraging sites in 1984 (Coulter 1986a). In 1985, a category for Carolina bays was also added (Coulter 1986b). In 1984 and 1985, there were a few sites that did not fit into the general classification, including logging roads and powerline right-of-ways. These were listed as "other" in the survey reports (Coulter 1986a, 1986b). The average straight-line distance for 1983 through 1989 between the colony and the foraging sites is presented in Table 21-12.

Table 21-11. Reproductive Success of Wood Storks at the Birdsville Colony

Year	Mean Number of Young per Nest ^a	Source
1980	About 2 ^b	Meyers 1984
1981	0 ^c	Meyers 1984
1982	No data	Meyers 1984
1983	2.19 ^c	Meyers 1984
1984	2.39 ^d , 2.04 ^e	Coulter 1986a
1985	2.50 ^d , 0.33 ^e	Coulter 1986b
1986	2.86 ^d , 2.68 ^e , 2.16 ^f	Coulter 1987
1987	2.33 ^d , 2.0e, 1.96 ^g	Coulter 1988
1988	1.80 ^d , 0.35 ^e	Coulter 1989
1989	1.88 ^d , 0.63 ^e	Coulter 1990
1990	2.67 ^d , 0.63 ^e	Coulter 1991
1991	1.95 ^e	Bryan 1992a
1992	1.40 ^d , 2.10 ^{e, h}	Bryan 1992b

^aYoung at least five weeks old

^bEstimated from ground or aerial surveys

^cColony failed in 1981

^dChicks at least 50 days old; this does not include whole nests that were lost

^eChicks at least 50 days old; this includes whole nests that were lost

^fIncludes the 25% decline in numbers of nests recorded during the ground censuses

^gIncludes the 20% decline in numbers of nests recorded during the ground censuses

^hPreviously unpublished data

Table 21-12. Mean Distances of Wood Stork Foraging Sites from the Birdsville Colony in 1983 Through 1989

Year	Number of Storks	Mean Distance (km)	Standard Deviation	Source
1983	30	17.39	15.60	Coulter 1986c
1984	55	13.75	13.16	Coulter 1986c
1985	39	11.94	7.87	Coulter 1986c
1986	36	11.85	8.33	Coulter 1987
1987	44	13.2	12.97	Coulter 1988
1988	40	9.1	7.35	Coulter 1989
1989	47	12.1	11.38	Coulter 1990

Foraging Habitats

The foraging habitats described in this section include (in brackets) the comparable category of the U.S. Fish and Wildlife Service system for classifying wetland habitats (Cowardin et al. 1979). Blackgum (*Nyssa sylvatica*) and cypress (*Taxodium distichum*) swamps (palustrine forested) were the predominant species present in the swamp foraging sites. Hardwood swamps (palustrine forested) had a mixture of hardwood tree species including red maple (*Acer rubrum*) and sweetgum (*Liquidambar styraciflua*). Shrub swamps (palustrine scrub-shrub) contained predominantly buttonbush (*Cephalanthus occidentalis*). Natural ponds (palustrine unconsolidated shore/lacustrine littoral unconsolidated shore) contained open water with little or no vegetation. Carolina bays (forested wetland/palustrine scrub-shrub/persistent emergent) are common in east-central Georgia. Man-made ponds (palustrine unconsolidated shore/lacustrine littoral unconsolidated shore) included agricultural and fish ponds. Drainage and agricultural ditches are also common. Open marshes (palustrine emergent) were usually seasonally flooded pastures. Table 21-13 summarizes the types and frequency of foraging habitats commonly used by wood storks from the Birdsville Colony. Water quality parameters (including temperature, pH, dissolved oxygen concentration, turbidity, and conductivity) were measured at each foraging site (Coulter 1986c).

The wood storks foraged in various wetland habitat types (Table 21-13). Storks were followed most frequently to swamps, of which blackgum swamps and cypress swamps were the most commonly used (Hodgson et al. 1988, Coulter 1993). The extent of the canopy cover ranged from completely open (marsh or pond) to completely covered (swamp). Most sites had little understory or woody vegetation. At all sites the water was either still or very slowly moving.

Vegetation Structure

The vegetation structure of a wetland may contribute to its suitability as a foraging site for wood storks, or a dense canopy may obscure a site from a flying stork. The birds may not be able to land if the understory is very thick. Aquatic vegetation may make it difficult for the

Table 21-13. Habitat Types of Wood Stork Foraging Sites in East-Central Georgia in 1983 Through 1989 (Source: Coulter 1986c, 1987, 1988, 1989, 1990)

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

Table 21-14. Water Depth (cm) at Locations Where Wood Storks Landed at Foraging Sites, 1983 Through 1989 (Source: Coulter 1986c, 1987, 1988, 1989, 1990)

Year	Number	Median	50% Range ^a	70% Range ^b	90% Range ^c	Total Range
1983	29	18	13-24	10-31	10-37	0-46
1984	47	21	16-31	12-34	6-44	4-50
1985	20	22	14-25	11-32	11-32	10-39
1986	28	18	12-23.5	7.5-34	6.5-42	6-51
1987	21	22	14-29	12.5-44	11-54	8-63
1988	29	23	18.5-26.5	16.0-34	13.5-40	0-44
1989	43	26	18.5-26.5	16.0-34	13.5-40	7-86

^amedian $\pm$ 25% of sites

^bmedian $\pm$ 35% of sites

^cmedian $\pm$ 45% of sites

birds to wade through the water and grope with their bills. Most sites had little aquatic vegetation, although a few sites had dense submergent or emergent vegetation. Submergent vegetation included such species as *Myriophyllum* spp. and algae; emergents included *Nuphar luteum*, *Nymphaea odorata*, *Utricularia inflata*, *Ludwigia* spp., and various species of duckweeds, sedges, and rushes.

Water Depth

The median water depth at the location where storks landed at the foraging sites was 18-26 cm during the seven years of the survey (Table 21-14). The water depths ranged from 0 to 63 cm. Meyers (1984) suggested that the length of the legs of storks set an upper limit to water depth at about 50 cm. Kahl (1964) stated that wood storks fed in water between 15 and 50 cm deep.

Potential Prey Species

The densities of potential prey species (fish, crustaceans, and amphibians) were determined at sites to which storks were followed. Meyers (1984) reported that storks did not eat fish smaller than 25 mm long. All the fish regurgitated by chicks during the colony surveys were over 25 mm long (Coulter 1986c, 1987, 1988, 1989; Depkin et al. 1992).

Major Diet Components

The regurgitation and stomach samples and recent literature indicate that sunfish comprise the major component of the diet of wood storks. Mosquito fish (*Gambusia*) were common at many sites, but storks do not seem to prefer this species (Ogden et al. 1976, Depkin et al. 1992).

SRS Savannah River Swamp Surveys

Introduction

Wood storks were reported in the vicinity of SRS before the plant was established in 1952 and before the discovery of the Birdsville Colony (Murphy 1937). Murphy, describing the

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

Surveying Techniques

Wood storks foraging on the SRS Savannah River swamp were monitored from an airplane to determine the amount of stork use, the areas used most frequently, and seasonal patterns. Kathwood Lake was included in the SRS survey beginning July 3, 1984, when that area was considered as a possible site for stork foraging ponds. Table 21-15 summarizes the aerial survey periods of the SRS Savannah River swamp from 1983 through 1992. Six areas within the SRS Savannah River swamp were delineated: Beaver Dam Creek delta, Fourmile Branch delta, the swamp between Fourmile Branch and Pen Branch deltas, Pen Branch delta, the swamp between Pen Branch and Steel Creek deltas, and the Steel Creek delta (Figure 21-21 on page 21-41).

Results of the Aerial Surveys

Introduction

Over 800 aerial surveys were conducted to census feeding or roosting storks in the SRS Savannah River swamp from mid-June 1983 through mid-October 1992 (Table 21-15). Wood storks are most commonly observed in the SRS Savannah River swamp during July and August (Table 21-16).

Table 21-15. Number of Aerial Surveys Used to Monitor the Number of Wood Storks on the SRS Savannah River Swamp 1983 Through 1992 (Source: Meyers 1984; Coulter 1986c, 1987, 1988, 1989, 1990, 1993; Bryan 1992a, 1992b)

Year	Month										Total
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1983	0	0	0	4	11	11	9	0	0	0	35
1984	0	0	1	7	15	19	19	20	8	0	89
1985	7	17	19	16	22	19	11	6	4	0	121
1986	10	20	12	11	20	16	10	8	6	1	114
1987	14	19	14	11	16	13	16	9	6	5	123
1988	18	19	21	20	20	16	15	7	3	0	139
1989	11	16	17	11	14	17	6	4	0	0	96
1990	0	0	0	1	3	6	2	0	0	0	12
1991	1	4	4	5	6	5	4	4	0	0	33
1992	4	4	4	6	9	3	6	5	0	0	41

Figure 21-21. The Six Areas of the Savannah River Swamp that were Monitored for Foraging Wood Storks

Results of the 1983 Aerial Surveys

In 1983, storks were observed most frequently in July when they were present during approximately 55% of the surveys, with an average of 30 storks per survey. However, aerial surveys in 1983 did not begin until mid-June. The Steel Creek and Beaver Dam Creek delta areas had the greatest frequency (15%) of stork observations during the surveys and the greatest amount of wood stork use. The Pen Branch and the Fourmile Branch deltas had little stork use during the same period (Coulter 1986c).

Table 21-16. Number of Wood Storks Observed in the SRS Savannah River Swamp During the Summer, 1983 Through 1992

Period	Number of Storks	Percent of Total
Before June	14	0.8
June 1-15	103	5.9
June 16-30	134	7.7
July 1-15	560	32.1
July 16-31	328	18.8
Aug 1-15	141	8.1
Aug 16-31	176	10.1
Sept 1-15	121	6.9
Sept 16-30	143	8.2
After Sept	24	1.4
Total	1744	100.0

Results of the 1984 Aerial Surveys

In 1984, the SRS surveys began in late May. Wood storks were observed most frequently in June and September. Stork use was greatest in June, with an average of 13 storks per survey. Storks were observed most often (21% of the surveys) in the Beaver Dam Creek delta area, but storks were observed during over 10% of the surveys in the Steel Creek and Fourmile Branch deltas and in the swamp between Pen Branch and the Fourmile Branch deltas. Stork use was greatest in the Beaver Dam Creek delta area, followed by the Steel Creek delta, the swamp between Pen Branch and the Fourmile Branch deltas, and the Fourmile Branch delta (Coulter 1986c).

Results of the 1985 Aerial Surveys

In 1985, storks were observed in the swamp during approximately 95% of the July surveys. An average of 21 storks was recorded during the surveys in July, when there was the greatest stork use. Most storks were observed in the Fourmile Branch delta and the swamp between Pen Branch and Fourmile Branch deltas. Storks were observed during 18.5% of the surveys during the entire season. These areas also had the greatest amount of stork use. Storks were observed on the Steel Creek delta during only 3% of the surveys. No storks were observed in the Beaver Dam Creek delta in 1985 (Coulter 1986c).

Results of the 1986 Aerial Surveys

In 1986, 114 aerial surveys were conducted over SRS, and the Kathwood ponds were observed from March 4 through December 3, 1986. Storks in the swamp were seen on July 24 in the Steel Creek delta (25 birds) and in the Fourmile Branch delta (4 birds). Storks were recorded through July and August and on one day in September. Storks were seen during 75% of the surveys in August. Stork use was also greatest in August, with an average of seven storks recorded per survey. Although the numbers of storks were lower in 1986 than in previous years, June, July, and August have been the months when storks have foraged in the SRS swamp most in the past (Coulter 1986c). The Steel Creek and Fourmile Branch deltas received the greatest amount of stork use, and had the greatest frequency of stork observations in 1986. No storks were in the area between the Fourmile Branch and Pen Branch deltas in 1986. In 1985, storks were observed in this area during more surveys than in other areas of the SRS swamp (Coulter 1986b). Fifteen storks were seen in Beaver Dam Creek on July 29. Previously, Beaver Dam Creek was heavily used (Coulter 1987).

Results of the 1987 Aerial Surveys

From March 3 through December 23, 1987, 125 aerial surveys were flown over the SRS swamp. Storks were observed on July 14, when 15 birds were counted in the Steel Creek delta. Birds were recorded for a total of five days in July and on August 21, compared with a total of 17 days in 1986. Storks were seen during 31% of the surveys in July. Stork use was also greatest in July, with an average of nine storks per survey. Although stork numbers were lower in 1987 than in previous years, June, July, and August have been the months when storks have foraged in the SRS swamp most in the past (Coulter 1986c). Steel Creek and Fourmile Branch deltas were the only areas where recorded stork use was observed at SRS in 1987. Steel Creek delta had the greatest frequency of stork observations. No storks were observed in any of the other areas of the SRS swamp in 1987 (Coulter 1988).

Results of the 1988 Aerial Surveys

From March 2 through November 29, 1988, 139 aerial surveys were flown over the SRS swamp. Storks were observed in the SRS swamp during only four surveys. A stork was seen on June 3 in the area between the Steel Creek and Pen Branch deltas. One, two, and three storks were observed in the Steel Creek delta during three of five surveys July 12-20. This level of stork observations was lower than in previous years (Coulter 1989).

Results of the 1989 Aerial Surveys

From March 1 through October 21, 1989, 95 aerial surveys were flown over the SRS swamp. Storks were observed in the swamp on nine occasions between May 12 and September 18. The maximum number of storks seen on a single day was six on August 16 in the Steel Creek delta (Coulter 1990).

Results of the 1990 Aerial Surveys

Only 12 aerial surveys were flown over the SRS swamp in 1990. Twelve storks were observed in the Fourmile Branch delta on June 9, and a single stork was observed in the Steel Creek delta on August 17 (Coulter 1991).

Results of the 1991 Aerial Surveys

From March 27 through October 10, 1991, 33 aerial surveys were flown over the SRS swamp. Storks were observed in the swamp during ten (30.3%) of these surveys with the majority of stork use occurring in June and July (Bryan 1992a). On June 20, 17 storks were observed in the swamp between the Fourmile and Pen Branch deltas, and 22 storks were observed on June 25 in the Fourmile Branch delta.

Results of the 1992 Aerial Surveys

In 1992, 41 aerial surveys were flown over the SRS swamp from March 9 through October 20. Storks were first sighted in the swamp in May, but the majority of sightings occurred in September in the Pen Branch delta and the swamp between it and the Steel Creek delta (Bryan 1992b). The late season use of two areas that have not been used extensively by storks previously coincided with the cessation of the testing of K Reactor, which dumped water into Pen Branch, during that period. Water levels in the Pen Branch delta and the swamp downstream from it presumably fell during this period, making both areas attractive to storks.

Stream Flows and Numbers of Foraging Storks

Sources of Water Flow

The water depth in the Savannah River swamp is dependent on the water flow from two sources. The swamp receives overflow from the Savannah River during flooding. The river flow and the amount of water that reaches the swamp are influenced by the amount of water discharged from the Clarks Hill (Lake Thurmond) Dam, almost 160 km upstream. The water level in the swamp also depends on the water that flows into the swamp from Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek, and other smaller streams on SRS. The waterflow in these streams depends on both rainfall and the outflow of water used

Table 21-17. Number of Observations of Wood Storks in the SRS Savannah River Swamp, June Through September, 1983-1988

Flow Classes in the Creeks (ft ³ /s)	Number of Wood Stork Observations					Total	Percent of Total	Cumulative Percentage
	BDC	FM	FMS	PB	SC			
0 - 50	-	10	2	-	15	27	19.42	19.42
51 - 100	24	19	20	2	18	83	59.71	79.13
101 - 150	1	0	0	0	5	6	4.32	83.45
151 - 200	-	0	1	0	0	1	0.72	84.17
201 - 250	-	0	1	1	0	2	1.44	85.61
251 - 300	-	-	0	1	0	1	0.72	86.33
301 - 350	-	0	0	0	0	0	0.00	86.33
351 - 400	-	0	0	0	-	0	0.00	86.33
401 - 450	-	7	11	0	-	18	12.95	99.28
>450	-	0	0	1	-	1	0.72	100.00
Total	25	36	35	5	38	139	100.00	-

BDC = Beaver Dam Creek delta area

FM = Foulmire Branch delta area

FMS = Foulmire Branch sloughs between Foulmire Branch and Pen Branch deltas

PB = Pen Branch delta area

SC = Steel Creek delta area

Table 21-18. Total Numbers of Wood Storks Observed in the SRS Savannah River Swamp, June Through September, 1983-1988

Flow Classes in the Creeks (ft ³ /s)	Number of Wood Storks					Total	Percent of Total	Cumulative Percentage
	BDC	FM	FMS	PB	SC			
0 - 50	0	97	3	0	92	192	12.43	12.43
51 - 100	291	291	235	27	249	1093	70.74	83.17
101 - 150	1	0	0	0	67	68	4.40	87.57
200	-	0	8	0	0	8	0.52	88.09
201 - 250	-	0	16	1	0	17	1.10	89.19
251 - 300	-	0	0	10	0	10	0.65	89.84
301 - 350	-	0	0	0	0	0	0.00	89.84
351 - 400	-	0	0	6	0	6	0.39	90.23
401 - 450	-	36	101	4	0	141	9.13	99.36
>450	-	0	0	10	-	10	0.65	100.01
Total	292	424	363	58	408	1545	100.01	-

BDC = Beaver Dam Creek delta area

FM = Foulmire Branch delta area

FMS = Foulmire Branch sloughs between Foulmire Branch and Pen Branch deltas

PB = Pen Branch delta area

SC = Steel Creek delta area

Figure 21-22. Percentage of Wood Storks Observed in the SRS Swamps from 1983-1988 Under Different Stream Flow Classes

to cool the reactors and the D-Area power plant on SRS. Meyers (1984) suggested that water depth may affect the suitability of a wetland as a wood stork foraging site on SRS.

Flow Effect on Number of Wood Storks

Table 21-17 and Table 21-18 indicate that both the number of observations of wood storks and the number of wood storks seen during aerial surveys of the SRS Savannah River swamp are greater in the areas of the swamp receiving lower flows, especially in the flow class of 51 to 100 ft³/s (Figure 21-22). The one area that may be different is an area of former river channels or sloughs between the Fourmile Branch and the Pen Branch deltas (Figure 21-21 on page 21-41, Figure 21-22, Table 21-17, and Table 21-18) (Source: *LOCATING SOURCE*).

Fourmile Branch Delta

Fourmile Branch delta has experienced a wide variation in flows since the wood stork surveys of the SRS swamp began. Prior to C-Reactor shutdown in late June 1985, most of the flows to the Fourmile Branch delta were in the 351 to 450 ft³/s range (Table 21-19 on page 21-46). From late June 1985 through the summer of 1986, flows declined to less than 100 ft³/s (Table 21-19), and in the summers of 1987 and 1988, flows were primarily below 50 ft³/s. Stork use prior to late June 1985 was low to moderate, was high to moderate after late June 1985 and in the summer of 1986, but was very low in the summer of 1987 and 1988 (Figure 21-23 on page 21-46) (Source: *LOCATING SOURCE*).

Pen Branch Delta

Wood stork use of the Pen Branch delta area has been the lowest of all the delta areas on SRS (Table 21-18 on page 21-44). This has probably been the result of high flow and ther-

Figure 21-23. Number of Wood Storks Observed in the Fourmile Branch Delta and Sloughs with C Reactor Operating (Prior to June 28, 1985) and after C Reactor Shutdown (After June 28, 1985 through Summer 1986, and During Summer 1987 and 1988).

Table 21-19. Cumulative Percentage of Flow Classes in Fourmile Branch Delta Area for 1983 Through Late June 1985, Late June 1985 Through 1986, and 1987 Through 1988

Flow Class (ft ³ /s)	Pre-Shutdown (1983 through late June 1985)			Post-Shutdown (late June 1985 through 1986)			June 1987 through September 1988		
	Number	Percent of Total	Cumulative Percentage	Number	Percent of Total	Cumulative Percentage	Number	Percent of Total	Cumulative Percentage
0 - 50	0	0.00	0	119	53.36	53.36	239	97.95	97.95
51 - 100	9	3.44	3.44	91	40.81	94.17	5	2.05	100.00
101 - 150	5	1.91	5.35	1	0.45	94.62	0	0.00	100.00
151 - 200	0	0.00	5.35	3	1.35	95.97	0	0.00	100.00
201 - 250	1	0.38	5.73	9	4.04	100.01	0	0.00	100.00
251 - 300	0	0.00	5.73	0	0.00	100.01	0	0.00	100.00
301 - 350	15	5.73	11.46	0	0.00	100.01	0	0.00	100.00
351 - 400	93	35.50	46.96	0	0.00	100.01	0	0.00	100.00
401 - 450	134	51.15	98.11	0	0.00	100.01	0	0.00	100.00
>450	5	1.91	100.02	0	0.00	100.01	0	0.00	100.00
Total	262	100.02	-	223	100.01	-	244	0.00	100.00

Table 21-20. Cumulative Percentage of Flow Classes in Pen Branch Delta Area for 1983 Through 1987 and Following Shutdown in 1988

Flow Class (ft ³ /s)	Pre-Shutdown (1983 through 1987)			Post-Shutdown (June 1988 through September 1988)		
	Number	Percent of Total	Cumulative Percentage	Number	Percent of Total	Cumulative Percentage
0 - 50	0	0.00	0.00	80	65.58	65.58
51 - 100	35	5.72	5.72	42	34.43	100.01
101 - 150	23	3.76	9.48	0	0.00	100.01
151 - 200	65	10.62	20.10	0	0.00	100.01
201 - 250	20	3.27	23.37	0	0.00	100.01
251 - 300	14	2.29	25.66	0	0.00	100.01
301 - 350	29	4.74	30.40	0	0.00	100.01
351 - 400	214	34.97	65.37	0	0.00	100.01
401 - 450	201	32.84	98.21	0	0.00	100.01
>450	11	1.80	100.01	0	0.00	100.01
Total	612	100.01	0.00	122	100.01	-

Table 21-21. Cumulative Percentage of Flow Classes in Steel Creek Delta Area Prior to L-Reactor Restart (1983 Through 1985) and After L-Reactor Restart (1986 through 1988)

Flow Class (ft ³ /s)	Pre-Reactor Restart (1983 through 1985)			Post-Reactor Restart (1986 through 1988)		
	Number	Percent of Total	Cumulative Percentage	Number	Percent of Total	Cumulative Percentage
0 - 50	188	55.46	55.46	1	0.28	0.28
51 - 100	106	31.27	86.73	184	51.40	51.68
101 - 150	33	9.73	96.46	32	8.94	60.62
151 - 200	6	1.77	98.23	42	11.73	72.35
201 - 250	6	1.77	100.00	10	2.79	75.14
251 - 300	0	0.00	100.00	29	8.10	83.24
301 - 350	0	0.00	100.00	5	1.40	84.64
351 - 400	0	0.00	100.00	29	8.10	92.74
401 - 450	0	0.00	100.00	26	7.26	100.00
>450	0	0.00	100.00	0	0.00	100.00
Total	339	100.00	-	358	100.00	-

Table 21-22. Cumulative Percentage of Flow Classes in Beaver Dam Creek Delta Area, June through September, 1983 Through 1988

Flow Classes (ft ³ /s)	Number	Percentage	Cumulative Percentage
0 - 50	34	4.76	4.76
51 - 100	603	84.34	89.10
101 - 150	78	10.91	100.01
Total	715	100.01	-

Figure 21-24. Number of Wood Storks Observed in the Steel Creek Delta Prior to L-Reactor Restart (1983-1985) and After L-Reactor Restart (1986-1988) Versus Flow Classes

mal conditions (Jensen et al. 1988) in this delta with flows in excess of 100 ft³/s most of the time (>90% frequency) during the summer survey months from 1983 through 1987 (Table 21-20 on page 21-47). No storks were observed during the summer months of 1988 under low flow conditions (Table 21-21). Low stork use was observed during the summer of 1988 for the entire SRS Savannah River swamp.

Steel Creek Delta

There was a shift in the summer flows to Steel Creek following L-Reactor restart in the fall of 1985 (Table 21-21 on page 21-47 and Figure 21-24). Flows in excess of 100 ft³/s were common from early June to mid-July in late September in 1986, 1987, and 1988. However, total numbers of storks observed in the three summers (1983, 1984, and 1985) prior to L-Reactor restart and the three summers after restart (1986, 1987, and 1988) were similar in spite of this shift in flow patterns (Table 21-21 on page 21-47). Most of the flow ranges to Steel Creek in the summer months after restart were still in the 51-100 ft³/s flow class during 1986 to 1988 (Table 21-21).

Beaver Dam Creek

Beaver Dam Creek (Table 21-22 on page 21-47) has had low to moderate use over the period of the survey with lower use in the past three summers.

Foraging Use

Data from the aerial wood stork surveys of the SRS Savannah River swamp and the studies at the Birdsville Colony suggest that the SRS Savannah River swamp is probably not used extensively during the breeding or pre-fledging phase of the Birdsville Colony. Most of the observations of storks on SRS occur during the late-nestling or the post-fledging period. High flows (>100 ft³/s) to the SRS Savannah River creeks probably limit the usefulness of the swamp as a foraging site. Low flows (<50 ft³/s) may likewise limit the usefulness of the SRS swamp for stork foraging. During periods of low flow (<50 ft³/s) the streams are more

confined to their channels, and habitats are not suitable for stork foraging. During periods of high flow, water depths may be limiting. Flows and flooding patterns also can influence vegetation patterns, thus influencing available foraging sites. Typical wood stork foraging sites have reduced quantities of both submerged and emergent macrophytes (Coulter 1986c). Moderate flows ($>50 \text{ ft}^3/\text{s}$, but less than $150 \text{ ft}^3/\text{s}$) to the SRS deltas during the summer months would probably benefit and/or assist in maintaining wood stork foraging sites in the SRS Savannah River swamp. Also, larger numbers of wood storks have been observed foraging in the SRS Savannah River swamp during periods following successful breeding and fledging years at Birdsville (1983, 1984, 1986, and 1987) with lower numbers during less successful years (1985 and 1988).

Par Pond

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

In 1992, no storks were observed using the Par Pond reservoir system during 41 aerial surveys (Bryan 1992b).

Wood Stork Use on Kathwood Lake

Introduction

Because preliminary data from the wood stork surveys of the Steel Creek delta indicated that the increased flow following the restart of L Reactor could result in loss of potential

Figure 21-25. Kathwood Lake and Hollow Creek

Figure 21-26. Longitudinal Section Through Kathwood Lake Showing General Features of the Subimpoundments and Water Levels

foraging areas, DOE, the U.S. Fish and Wildlife Service, and the National Audubon Society agreed to construct a series of foraging ponds on the Silver Bluff Plantation Sanctuary (Mackey 1985; Figure 21-19 on page 21-34 and Figure 21-25). The site selected for the foraging ponds is referred to as "Kathwood Lake".

Physical Attributes

The Kathwood Lake site has an area of approximately 15 ha. It is located west of SRS and about 45 km north of the Birdsville Colony. The lake was originally formed for operation of a mill by diking a shallow depression and diverting water via a canal from Hollow Creek (Figure 21-25). Kathwood Lake drained in May 1977, when the wooden water control structure at the lower end of the lake failed. Wood storks (about 24) were observed foraging in pools of water left in the lake bed in September 1977. A few wood storks were observed during aerial surveys at Kathwood Lake in late July and early August 1984 (Mackey 1985, Coulter 1986a).

Water control structures were added to control flow, assist in fish rearing, and to lower the water levels to make subdivisions of the lake available during the wood stork foraging season (Figure 21-26). Construction was completed in the early fall of 1985, and the ponds were stocked beginning in late November 1985.

Wood Stork Use

Wood storks have used the foraging ponds at Kathwood Lake extensively during the summers of 1986 through 1992 (Figures 5-21 through 5-27). Most of these storks have been juveniles, and banded wood storks from the Birdsville Colony have been observed there (Coulter 1987, 1988, 1989, 1990; Bryan 1992a, 1992b). The observed level of use at Kathwood Lake more than compensates for any potential decline in available wood stork foraging sites on the Steel Creek delta.

Figure 21-27. Maximum Number of Wood Storks Observed at Kathwood Lake During Ground Surveys, 1986-1992

Mammals

Introduction

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

Bats

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

Table 21-23. Endangered and Threatened Mammals of South Carolina.

Scientific Name	Common Name	Federal Status ^a	State Status ^b	Critical Habitat ^c	Status on SRS ^d
<i>Myotis grisescens</i>	gray bat	endangered	none	no	unconfirmed
<i>Myotis sodalis</i>	Indiana bat	endangered	endangered	yes	unconfirmed
<i>Myotis leibii</i>	small-footed bat	none	threatened	no	unconfirmed
<i>Plecotus rafinesquii</i>	Rafinesque's big-eared bat	none	endangered	no	rare
<i>Ursus americanus</i>	black bear	none	threatened	no	rare transient
<i>Felis concolor couguar</i>	eastern cougar	endangered	endangered	no	unconfirmed
<i>Felis concolor coryi</i>	Florida opanther	endangered	none	no	unconfirmed
<i>Canis rufus</i>	red wolf	endangered	none	no	unconfirmed

^aFederal Status (USFWS 1992)

^bState Status (SCWMD 1992)

^cCritical Habitat (USFWS 1992)

^dStatus on SRS (Cothran et al. 1991, Golley 1966, USFWS 1992)

Carnivores

The black bear (*Ursus americanus*) is considered a possible rare transient traveling along the Savannah River; no permanent populations of this species are expected to occur on SRS (Cothran et al. 1991). The eastern cougar (*Felis concolor couguar*) and Florida panther (*Felis concolor coryi*) are federally listed as endangered; their home ranges historically included South Carolina (USFWS 1992a). Although there have been reports of cougars in the area, none have been confirmed, and it is unlikely that either of these subspecies is a permanent resident on SRS. The red wolf (*Canis rufus*) once ranged into South Carolina, but the present population of 135 animals exists primarily in captivity (USFWS 1992b).

References

- Brisbin, I. L., Jr., J. M. Benner, L. A. Brandt, R. A. Kennamer, and T. M. Murphy. Long-Term Population Studies of American Alligators Inhabiting A Reservoir: Initial Responses to Water Level Drawdown. Proceeding of the 11th Working Meeting of the IUCN/SSC Crocodile Specialist Group. IUCN. Glan, Switzerland. NO DATE??
- Britton and Fuller - in old EID
- Bryan, A. L. 1992a. The Savannah River Ecology Laboratory Wood Stork Program Annual Report: 1991. Division of Wildlife Ecology and Toxicology, Savannah River Ecology Laboratory, Aiken, South Carolina. 7 pp.
- Bryan, A. L. 1992b. The Savannah River Ecology Laboratory Wood Stork Program Annual Report: 1992. Division of Wildlife Ecology and Toxicology, Savannah River Ecology Laboratory, Aiken, South Carolina. 6 pp.
- Bryan, A. L., Jr. and M. C. Coulter. 1987. Foraging night characteristics of wood storks in East-central Georgia, U.S.A. *Colonial Waterbirds* 10:157-161.
- Collins, M. R., E. T. Kennedy, T. I. J. Smith. Identification of Critical Habitats for Shortnose Sturgeon in the Savannah River. Summary of presentation at the Acipenser/ Polyodon Workshop, 28-30 January 1992, Atlanta Georgia.
- Cothran, E. G., M. H. Smith, J. O. Wolff, and J. B. Gentry. 1991. Mammals of the Savannah River Site, Savannah River Ecology Laboratory, SRO-NERP-21, Aiken, SC.
- Coulter, M. C. 1990. Creation and management of artificial foraging habitats for wood storks. pp. 262-267. In R. S. Mitchell, C. J. Sheviak, and D. J. Leopold (eds.), *Ecosystem*
- Coulter, M.C. 1991. Wood Storks of the Birdsville Colony and Swamps of the Savannah River Site, Savannah River Ecology Laboratory, University of Georgia, Aiken, SC (SREL-42, UC-66e).
- Coulter, M.C. 1993. Wood Storks of the Birdsville Colony and Swamps of the Savannah River Site, Savannah River Ecology Laboratory, University of Georgia, Aiken, SC (SREL-42, UC-66e) 96 pp.
- Depkin, C. D., M. C. Coulter, and A. L. Bryan. 1992. Food of Nestling Wood Storks in East-Central Georgia. *Colonial Waterbirds* 15:219-225.
- Dukes, E. K. The Savannah River Plant Environment. Report DP-1642, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1984).
- Gibbons, J. W. and R. D. Semlitsch. 1991. Guide to the Reptiles and Amphibians of the Savannah River Site, University of Georgia Press, Athens. 131 pp.
- Gladden, J. B., M. W. Lower, H. E. Mackey, W. L. Specht, and E. W. Wilde. Comprehensive Cooling Water Study Annual Report: Vol. XI, Ecology of Par Pond. Report DP-1697-11, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1985).
- Golley, Frank B. 1966. South Carolina Mammals, The Charleston Museum, Charleston, South Carolina.
- Hall, J. W., T. I. J. Smith, S. D. Lamprecht. Movements and Habits of Shortnose Sturgeon, *Acipenser brevirostrum* in the Savannah River. *Copeia*, 1991(3), 695-702.
- Jenkins, J. H. and E. E. Provost. The Population Status of the Larger Vertebrates on the Atomic Energy Commission Savannah River Plant Site. TID-19562, Final Report of AEC, University of Georgia, Athens (1964).
- Langley, T. M. and W. L. Marter. The Savannah River Plant Site. Report DP-1323, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1973).
- Mackey, H. E. Jr. 1985. Agency interaction at the Savannah River Plant under the Endangered Species Act, Proceedings of the Fifth DOE Environmental Protection Information Meeting, Albuquerque, New Mexico, November 6-8, 1985. CONF-841187, Vol. 2:373-745.

- Mackey, H. E., Jr. Comprehensive Cooling Water Study Final Report, Volume VI, Threatened and Endangered Species. DP-1739-6, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC (1987).
- Marchette Mayer, J. J., R. T. Hoppe, and R. A. Kennamer. Bald and Golden Eagles on the Savannah River Plant, South Carolina. *The Oriole*, 50(4):53-57 (1985).
- Mayer, J. J., R. T. Hoppe, and R. A. Kennamer. Bald and Golden Eagles of the SRP. Report SREL-21, UC66e, Savannah River Ecology Laboratory, Aiken, SC (1986).
- Mayer, J. J., R. A. Kennamer, and R. T. Hoppe. Nesting Record for the Bald Eagle on the Savannah River Plant. *The Oriole*, 52(1):53-57 (1988).
- Mayer, J. J., R. T. Hoppe and R. A. Kennamer. Bald and Golden Eagles on the Savannah River Plant, South Carolina. *The Oriole*, 50:53-57.
- Morse, J. C., J. W. Chapin, D. D. Herlong, and R. S. Harvey. Aquatic Insects of Upper Three Runs Creek, Savannah River Plant, South Carolina. Part I: Orders other than Diptera. *Journal Georgia Entomological Society*. 15(1), January 1980, 73-101.
- Morse, J. C., J. W. Chapin, D. D. Herlong, and R. S. Harvey. Aquatic Insects of Upper Three Runs Creek, Savannah River Plant, South Carolina. Part II: Diptera. *Journal Georgia Entomological Society*. 18(3), July 1983, 303-316.
- Murphy, E. E. Observations of the Bird Life of the Middle Savannah Valley. The Charleston Museum, Charleston, SC (1937).
- Murphy, T. M., Jr. and J. W. Coker. The Status of the Bald Eagle in South Carolina, pp. 89-93 in *Proceedings of the Rare and Endangered Wildlife Symposium* (R. R. Odom and L. Landers, eds.). Technical Bulletin WL4, Georgia Department of Natural Resources, Game and Fish Division, Gainesville (1978).
- Muska, C. F., R. A. Matthews. Biological Assessment for the Shortnose Sturgeon, *Acipenser brevirostrum* LeSueur 1818, the Savannah River Plant. DPST-83-754. Savannah River Laboratory, E. I. du Pont de Nemours & Co. 1983.
- Norris, R. A. Birds of the AEC Savannah River Plant Area. *Contributions of the Charleston (SC) Museum Bulletin*, 14:1-78 (1963).
- Waters and Peters - in old EID
- USFS (Savannah River Forest Station). Savannah River Site Wildlife, Fisheries and Botany Status Report - FY 1992. U.S. Department of Agriculture, U.S. Forest Service, Savannah River Forest Station, New Ellenton, SC (1992).
- Sprunt, A. and E. B. Chamberlain. *South Carolina Bird Life*. University of South Carolina Press, Columbia (1970).
- South Carolina Department of Wildlife and Marine Resources. 1992. Threatened and Endangered Animals in South Carolina, Columbia, SC.
- SCWMRD (South Carolina Wildlife and Marine Resources Department). 1992. Threatened and Endangered Animals in South Carolina, Columbia, SC.
- U.S. Fish and Wildlife Service. 1992a. Endangered and Threatened Wildlife and Plants, 50 CFR 17.11 and 17.12, August 29, 1992.
- U.S. Fish and Wildlife Service. 1992b. Endangered and Threatened Species of the Southeastern United States (The Red Book), Southeast Region, January 1992.
- USFS (U.S. Forest Service). 1992. Savannah River Site Wildlife, Fisheries and Botany Status Report - FY 1992, U.S. Forest Service, Savannah River Forest Station, Aiken, SC.
- USFWS (U.S. Fish and Wildlife Service). 1992a. Endangered and Threatened Wildlife and Plants, 50 CFR 17.11 and 17.12, August 29, 1992.
- USFWS (U.S. Fish and Wildlife Service). 1992b. Endangered and Threatened Species of the Southeastern United States (The Red Book), Southeast Region, January 1992.

Index

A

- Acipenser brevirostrum, see Shortnose sturgeon
- Acipenser oxyrinchus, see Atlantic sturgeon
- Adults
 - amphibians 3-14
- Aerial photography
 - Pen Branch delta 6-6
- Aiken Plateau
 - origin 1-5
- Airborne scanner data
 - Pen Branch delta 6-6
- Algae
 - Fourmile Branch 12-17
 - Pen Branch 13-19
 - Upper Three Runs 10-27
- Alkalinity
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-10
 - Pen Branch 13-11
- Alligator
 - see American alligator
- Alligator mississippiensis
 - see American alligator
- Alligators 18-3
- Alosa aestivalis, see Blueback herring
- Alosa sapidissima, see American shad
- Aluminum
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-11
 - Pen Branch 13-13
- Ambystoma talpoideum, see Mole salamander
- American alligator 21-9
 - Beaver Creek Dam
 - size structure graph 21-16
 - Beaver Dam Creek
 - population characteristics 21-13
 - Carolina bays 9-20
 - eggs 21-10
 - foraging 21-10
 - Fourmile Branch 21-16
 - growth 21-10
 - habitats 21-11
 - life history 21-10
 - Par Pond 21-11
 - characteristics 21-12
 - distribution data 21-15
 - distributions 21-12
 - drawdown effects 21-13
 - growth 21-12
 - nests 21-12
 - population graph 21-15
 - population numbers 21-11
 - recent population status 21-12
 - sex ratio 21-12
 - size and sex data 21-13
 - size and sex structure graph 21-14
 - size distribution graph 21-14
 - size structure 21-12
 - Pen Branch 21-16
 - photo 21-10
 - potential habitat 21-17
 - protection history 21-10
 - Steed's Pond 21-17
 - Steel Creek 21-16
- American osprey 21-19
- American sandburrowing mayfly 21-3
- American shad 18-6
 - fishing 18-10
- Ammonia
 - nitrate 10-14
- Amphibian
 - juvenile
 - refuge ponds 3-15
 - movement
 - Rainbow Bay 3-11
 - Sun Bay 3-11
 - occurring
 - 1986-1987
 - Steel Creek 3-18
 - L Lake 3-19
- Amphibians
 - Carolina bays 9-19
 - movement
 - Linda's Pond 3-13
 - Pickerell Pond 3-13
 - occurring
 - Par Pond 3-20
 - SRS 3-6
 - Steel Creek
 - 1981-1982 3-16
 - Sun Bay 3-9
 - refuge ponds 3-14
 - threatened and endangered species 21-9
- Andropogon virginicus, see Broomsedge
- Aquatic insects survey
 - sampling
 - Upper Three Runs 10-33

-
- Upper Three Runs
 - macroinvertebrates
 - results 10-34
 - Aquila chrysaetos*
 - see Golden eagle
 - Aristida affinis*, see Threawn grass
 - Arthropods
 - threatened and endangered species 21-3
 - arthropods 21-3
 - Atlantic sturgeon 18-6
 - Avifauna
 - red-cockaded woodpecker 21-29
 - threatened and endangered species 21-29
 - residents 21-19
 - threatened and endangered species 21-19
 - bald eagle 21-19
 - golden eagle 21-28
 - species on SRS 21-19
 - wood stork 21-33
 - visitor 21-19
 - wood stork 21-33
 - Avifauna, see Birds

B

- Bachman's sparrow 21-19
- bald cypress 2-7
- Bald eagle 21-19, 21-29
 - adult vs. immature
 - number 21-25
 - ratio 21-25
 - chicks 21-27
 - Christmas bird count 21-21, 21-22
 - coloration 21-19
 - diet 21-25
 - eggs 21-27
 - forage behavior 21-25
 - in South Carolina 21-21
 - inland colonization 21-21
 - L Lake 21-23
 - management 21-28
 - Eagle bay 21-28
 - Pen branch 21-28
 - marked/tagged birds 21-26
 - nest 21-27
 - Pen Branch 21-27
 - nesting pairs
 - South Carolina 21-21
 - nestlings produced 21-27
 - nests
 - location 21-26
 - Par Pond
 - sightings 21-22
 - photo 21-20
 - reproduction 21-27
 - Santee-Cooper River 21-21
 - Savannah River 21-21
 - seasonal use of SRS 21-25
 - sightings
 - 1984-1985 21-23
 - 1985-1986 21-24
 - map 21-24
 - social organization 21-25
 - SREL waterfowl aerial surveys 21-22
 - SRS 21-21
 - study 21-21
 - ventral appearance 21-20
 - weight 21-19
 - winter observations 21-22
- Bare soil 6-10
 - Pen branch wetlands 6-10
- Bats
 - Carolina bays 3-44
- Beaver 3-47
 - Carolina bays 9-20
- Beaver Dam Creek
 - alkalinity 11-11
- Beaver Dam Creek 11-1
 - aluminum 11-11
 - American alligator 21-13
 - calcium 11-11
 - chemical assessment studies 11-8
 - chloride 11-11
 - conductivity 11-10
 - description 11-3
 - dissolved oxygen 11-10
 - effluents contribution 11-3
 - flow 11-4
 - sampling stations 11-4
 - iron 11-11
 - magnesium 11-11
 - manganese 11-11
 - map 11-3
 - nitrogen 11-12
 - nutrients 11-12
 - organic carbon 11-13
 - pH measurements 11-8
 - phosphorus 11-12
 - potassium 11-11
 - priority pollutants
 - survey 11-8
 - sodium 11-11
 - sulfate 11-11
 - suspended solids 11-10
 - trace elements 11-13
 - turbidity 11-10
 - water chemistry and quality 11-7
 - comprehensive cooling-water study 11-7
 - sampling stations 11-7
 - water temperature 11-8
 - waterfowl 3-34
- Beavers
 - trapped annually 3-49
 - trapping program 3-48
- Benwick's wren 21-19
- Bewick's wren 21-19
- Birds
 - L Lake 3-35
 - Par Pond 3-34
 - Rainbow Bay 3-23, 3-29
 - see Avifauna

- SRS 3-23
- Steel Creek 3-31
- Sun Bay 3-30
- waterfowl 3-32
- Birdsville Colony 21-34
 - studies 21-34
 - survey 21-35
- Black bear 21-54
- Black cherry 2-6
- Black gum
 - Carolina bays 9-13
- Blackberry 2-6
- Blackgum 2-6
- Blackjack oak
 - Carolina bays 9-13
- Blarina brevicauda, see Shrews
- Blueback herring 18-6
- Bobcat 3-47
- Bobwhite 3-47
- Bottomland hardwood
 - Pen Branch
 - wetlands 6-7
 - Pen branch wetlands
 - 1987 6-10
 - 1990 6-12
 - Pen Branch wetlands
 - 1988 6-11
 - Pen branch wetlands
 - 1989 6-11
 - 1991 6-12
- Bottomland hardwood forest 6-10
 - Pen branch wetlands 6-10
- Bottomland hardwood forests 2-6
- Brandywine Terrace
 - origin 1-5
- Bream
 - fishing 18-10
- Broomsedge 2-6
 - Carolina bays 9-13
- Brother spike mussel 21-3
- Buffleheads
 - waterfowl 3-34
- Bull snake
 - see Pine snake
- Bullfrogs 18-3
- Buttonbush
 - Lost Lake 9-28
 - Pen Branch wetlands 6-7
 - Pen branch wetlands
 - 1991 6-12

C

- Calcium
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-11
 - Pen Branch 13-12
- Canis rufus*
 - see Red wolf 21-54
- Carbon, see also Organic carbon
- Carolina bay 2-7
 - vegetation 2-7
- Carolina Bays 2-8
- Carolina bays 9-1
 - american alligator 9-20
 - amphibians 9-19
 - bats 3-44
 - beaver 9-20
 - black gum 9-13
 - blackjack oak 9-13
 - broomsedge 9-13
 - distribution 9-3
 - egrets 9-20
 - Ellenton Bay 9-5
 - fishes 9-19
 - gallberry 9-13
 - general characteristics 9-3
 - hawks 9-20
 - herpetofauna 3-5
 - hydrology 9-5
 - Invertebrate 9-17
 - lake chubsucker 9-19
 - loblolly 9-13
 - location map 9-4
 - longleaf pines 9-13
 - Lost Lake
 - restoration 9-23
 - macroinvertebrates 9-17
 - maidencane 9-13
 - mammal 3-45
 - drift fences 3-44
 - mammals 3-39
 - habitats 3-45
 - seasonal 3-45
 - mole salamander 9-19
 - mosquitofish 9-19
 - mud sunfish 9-19
 - pitcher plants 9-13
 - Rainbow Bay 9-5
 - red bay 9-13
 - redfin pickerel 9-19
 - reptiles 9-19
 - rice rat 9-20
 - rodents 9-20
 - shrews 9-20
 - size 9-3
 - soils 9-11
 - southern leopard frog 9-19
 - southern toads 9-20
 - spadefoot toads 9-20
 - sumac 9-13
 - sunfish 9-19
 - sweet gum 9-13
 - temperature 9-8
 - Dry Bay 9-8
 - Thunder Bay 9-8
 - threeawn grass 9-13
 - Thunder Bay 9-5
 - turkey oak 9-13
 - vegetation 9-13
 - community types 9-13
 - pattern control 9-13
 - short-term succession 9-15
 - zones 9-13
 - vertebrate 9-19
 - water chemistry 9-7
 - detailed chemical analyses 9-8
 - general chemical characteristics 9-7
 - oxygen 9-8
 - water levels 9-5
 - waterlilies 9-13
 - wood ducks 9-20
 - wood storks 9-20
 - zooplankton 9-18
- Carolina crawfish frog 21-9
- Carolina gopher frog, see Carolina crawfish frog
- Catfish
 - fishing 18-10
- Cattails 6-10
 - Pen branch
 - wetlands
 - 1987 6-10
 - Pen branch wetlands 6-10
 - 1989 6-11
 - 1990 6-12
 - 1991 6-12
- Cephalanthus occidentalis*, see Buttonbush
- Channel catfish 18-6
- Chastain-Tawcaw-Shellbluff Association 1-9

- Chattahoochee River
 - brother spike mussel 21-3
- Chemical assessment studies
 - Beaver Dam Creek 11-8
 - Fourmile Branch 12-15
 - seep line sampling study, 1987 12-15
 - seep line sampling study, 1988 and 1989 12-15
 - seep line sampling study, 1991 and 1992 12-15
 - Fourmile branch 12-8
 - Upper Three Runs 10-8, 10-17
 - changes in M-Area effluent 10-17
 - F/H area Effluent Treatment Facility 10-21
 - M-Area liquid effluent treatment facility 10-17
- Chloride
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-10
 - Pen Branch 13-11
- Christmas bird count
 - bald eagle 21-21
 - bald eagle observations 21-22
- Commercially and recreationally valuable biota
 - feral swine 3-49
- Commercially and recreationally valuable Biota
 - Savannah River
 - Atlantic sturgeon 18-6
- Commercially and recreationally valuable biota
 - aquatic 18-1
 - on SRS 18-3
 - Savannah River 18-5
 - exploitable 3-49
 - mammals 3-48
 - Savannah River
 - American shad 18-6
 - blueback herring 18-6
 - channel catfish 18-6
 - striped bass 18-6
 - terrestrial 3-47
 - unexploitable 3-47
 - vegetation 2-27
 - white-tailed deer 3-49
 - wild turkeys 3-47
- Comprehensive cool water study
 - Pen Branch
 - macroinvertebrates
 - results 13-26
- Comprehensive cooling water studies
 - Fourmile Branch
 - macroinvertebrates
 - results 12-24
- Comprehensive cooling water study
 - Fourmile Branch
 - macroinvertebrates
 - sampling 12-23
 - macrophytes 12-19
 - Fourmile branch
 - water chemistry and quality 12-7
 - Pen Branch
 - macroinvertebrates
 - sampling 13-25
 - macrophytes 13-21
 - water chemistry and quality 13-7
 - Upper Three Runs
 - fish 10-55
 - macroinvertebrates
 - results 10-35
 - sampling 10-33
 - macrophytes 10-29
 - water chemistry and quality 10-7
- Comprehensive cooling-water study
 - Beaver Dam Creek
 - water chemistry and quality 11-7
- Conductivity
 - Beaver Dam Creek 11-10
 - Fourmile Branch 12-9
 - Pen Branch 13-10
- Connecticut River
 - shortnose sturgeon 21-6
- Cooper's hawk 21-19
- Cover type
 - Evergreen forests 2-5
 - forested 2-5
 - grassland 2-5
 - open water 2-5
 - transportation 2-5
- Cover Types 2-5
- Cover types
 - bottomland Hardwood Forests 2-6
 - deciduous forests 2-6
 - forb 2-5
 - industrial 2-5
 - non-forested 2-5
 - Pen Branch
 - wetlands 6-7
 - Pen Branch delta 6-8
 - scrub-shrub 2-5
 - swamp forests 2-7
- Craig's Pond
 - vegetation
 - community types 9-13
 - zones 9-13
- Crappie
 - fishing 18-10
- Creeks, see Streams
- Creel surveys
 - Savannah River 18-11
- Cypress
 - Pen branch wetlands
 - 1988 6-11

Cypress-tupelo

Pen branch

wetlands 6-7

Pen Branch wetlands

1989 6-11

Cypress-Tupelo forest 6-10

Pen branch wetlands 6-10

D

- Deciduous forests 2-6
- Deep water 6-10
 - Pen branch wetlands 6-10
- Deer, see white-tailed deer
- Dissolved oxygen
 - Beaver Dam Creek 11-10
 - Fourmile Branch 12-9
 - Pen Branch 13-8
- Dog fennel
 - Pen branch wetlands
 - 1989 6-11
 - 1990 6-12
- Dog-fennel 2-6
- Dogwood 2-6
- Dolania americana*, see American sandburrowing mayfly
- Dove 3-47
- Dry Bay
 - temperature 9-8
- Duck potato
 - Lost Lake 9-28
- Duckweed 6-10
 - Pen branch wetlands
 - 1987 6-10
 - Pen branch wetlands 6-10

E

- Eagle bay
 - bald eagle
 - management 21-28
- Eastern cougar 21-54
- Echinacena laevigata* 20-3
- Effluent treatment facility monitoring program
 - Upper Three Runs
 - macroinvertebrate
 - results 10-36
- Effluents contribution
 - Beaver Dam Creek 11-3
 - Pen Branch 13-3
- Effluents contributions
 - Fourmile Branch 12-3
- Eggs
 - American alligator 21-10
 - bald eagle 21-27
 - shortnose sturgeon 21-6
- Egrets
 - Carolina bays 9-20
- Ellenton Bay
 - hydrology 9-5
 - vegetation
 - community types 9-15
- Elliptio fraterna*, see Brother spike mussel 21-3
- Elms 2-6
- Evergreen Forests 2-5

F**F/H effluent treatment facility monitoring program****Upper Three Runs****macroinvertebrates****sampling 10-34****Fauna****invertebrate****Carolina bays 9-17****threatened and Endangered 21-1****vertebrate****Carolina Bays 9-19****Federal endangered species act 19-3****Feeding****shortnose sturgeon 21-7****Felis concolor coryi****see Florida panther 21-54****Felis concolor cougar****see Eastern cougar 21-54****Feral swine 3-49****harvest 3-51****hunts 3-49****origination 3-49****trapping program 3-50****Ferns 2-6****Fish****Fourmile Branch 12-37****C reactor****operation 12-38****F- and H-area impacts 12-52****ichthyoplankton 12-45****movements 12-38****sampling stations 12-37****thermal stream sites 12-43****thermal swamp sites 12-40****Pen Branch 13-39****adult 13-39****artificial flow perturbations 13-44****delta/swamp area 13-41****ichthyoplankton 13-42****K reactor****shutdown 13-42****K-Reactor****operation 13-39****larval 13-42****recolonization 13-42****sampling stations 13-41****Upper Three Runs 10-55****comparison to other SRS streams 10-58****differences among different habitats 10-58****ichthyoplankton 10-56****impacts from F- and H-Areas 10-57****sampling stations 10-55****Fishes****Carolina bays 9-19****threatened and endangered species 21-5****Fishing****american shad 18-10****bream 18-10****catfish 18-10****commercial 18-6****crappie 18-10****hybrid bass 18-10****largemouth bass 18-10****sport 18-6****stripped bass 18-10****yellow perch 18-10****Flora****species of concern****SRS 20-7, 20-8****threatened and endangered species 20-1****bunched arrowhead 20-3****federally listed species 20-3****programs for identifying 20-3****small whorled pogonia 20-3****South Carolina 20-3****SRS 20-5****Florida panther 21-54****Flow****Beaver Dam Creek 11-4****Fourmile Branch 12-4****Pen Branch 13-4****Upper Three Runs 10-4****Foraging****American alligator 21-10****red-cockaded woodpecker 21-30****wood stork****Kathwood Lake 21-50****survey 21-35****Forb 2-5****Fourmile Branch 12-1****algae 12-17****alkalinity 12-10****aluminum 12-11****American alligator 21-16****calcium 12-11****chemical assessment studies 12-15****seepage sampling study, 1987 12-15**

- seepage sampling study, 1988 and 1989 12-15
 - seepage sampling study, 1991 and 1992 12-15
 - chloride 12-10
 - conductivity 12-9
 - description 12-3
 - dissolved oxygen 12-9
 - effluents contributions 12-3
 - fish 12-37
 - C reactor
 - operation 12-38
 - F- and H-area impacts 12-52
 - ichthyoplankton 12-45
 - movements 12-38
 - sampling stations 12-37
 - thermal stream sites 12-43
 - thermal swamp sites 12-40
 - flow 12-4
 - sampling stations 12-4
 - herbicides 12-15
 - iron 12-11
 - macroinvertebrates
 - C reactor
 - operation 12-24
 - shutdown 12-27
 - comprehensive cooling water study
 - results 12-24
 - sampling 12-23
 - sampling stations 12-23
 - macrophytes 12-19
 - cessation of C reactor operation 12-19
 - comprehensive cooling water study 12-19
 - magnesium 12-11
 - manganese 12-11
 - nitrogen 12-12
 - nutrients 12-12
 - organic carbon 12-14
 - PCBs 12-15
 - periphyton 12-17
 - pesticides 12-15
 - phosphorus 12-12
 - phytoplankton 12-17
 - potassium 12-11
 - priority pollutants
 - detected 12-14
 - sodium 12-11
 - sulfate 12-10
 - suspended solids 12-10
 - trace elements 12-13
 - turbidity 12-10
 - water chemistry and quality 12-7
 - waterfowl 3-34
 - zooplankton 12-21
- Fourmile branch
- chemical assessment studies 12-8
 - delta 12-3
 - pH measurements 12-8
 - priority pollutant
 - survey 12-8
 - water chemistry and quality
 - comprehensive cooling water study 12-7
 - sampling stations 12-7
 - water temperature 12-8
- Fox 3-47
- fox 3-47
- Fuquay-Blanton-Dothan Association 1-10
- Furbearer
 - census 3-48
- Furbearers 3-48

G**Gallberry**

- Carolina bays 9-13

Girard northeast quadrangle

- land cover maps 2-19

Girard northwest quadrangle

- land cover maps 2-18

Girard quadrangle

- land cover maps 2-21

Golden eagle 21-19, 21-28

- sightings 21-29

- South Carolina 21-28

- use of SRS 21-29

Grapes 2-6**Grassland 2-5****Gray bat 21-53****Greenbriers 2-6****Growth**

- American alligator 21-10

- shortnose sturgeon 21-7

H

Habitat

- deer 3-49
- mammals 3-39
- red-cockaded woodpecker 21-30
- shortnose sturgeon 21-6

Habitat formers

- L Lake 7-5

Habitats

- American alligator 21-11
- mammal 3-42
- wildlife 3-3

Hackberry 2-6

Haliaeetus leucocephalus

- see Bald eagle

Harvest

- feral swine 3-51
- white-tailed deer 3-50

Hawks

- Carolina bays 9-20

Herbicides

- Fourmile Branch 12-15
- Pen Branch 13-17
- Upper Three Runs 10-17

Herpetofauna 3-5

- carolina bays 3-5
- found on SRS 3-5
- L Lake 3-5
- movement
 - Linda's Pond 3-13
 - Pickrel Pond 3-13
 - Rainbow Bay 3-11
 - Sun Bay 3-11

occurring

- 1986-1987
 - Steel Creek 3-18
- L Lake 3-19
- Par Pond 3-20
- Rainbow Bay 3-9
- SRS 3-6
- Steel Creek
 - 1981-1982 3-16

Par Pond 3-5

Pen Branch 3-6

Steel Creek 3-5

threatened and endangered species 21-9

Heterodon simus

- see Hognose snake

Hickories 2-6

Hognose snake 21-9

Hollies 2-6

Holly 2-6

Hunts

- feral swine 3-49
- white-tailed deer 3-49

hunts

- purpose 3-49

Hybrid bass

- fishing 18-10

Hydrology

- Carolina bays 9-5
- Ellenton Bay 9-5
- Rainbow Bay 9-5
- Thunder Bay 9-5

I

I. coriacea, see Gallberry

Ichthyoplankton

 shortnose sturgeon 21-7

 Upper Three Runs

 densities 10-57

 taxa collected 10-56

Ictalurus punctatus, see Channel catfish

Ilex glabra, see Gallberry

Indiana bat 21-53

Introduction 6-9

Invertebrate

 Carolina bays 9-17

Invertebrates

 American sandburrowing mayfly 21-3

 brother spike mussel 21-3

 threatened and endangered species 21-3

Iron

 Beaver Dam Creek 11-11

 Fourmile Branch 12-11

 Pen Branch 13-13

Isotria medeoloides 20-3

J

Jackson quadrangle

land cover maps 2-13

Juvenile

shortnose sturgeon 21-7

K

- K reactor
 - effects
 - Pen Branch wetlands 6-7
 - Pen Branch
 - delta 6-5
- Kathwood Lake
 - physical attributes 21-50
 - wood stork 21-49
- Kirtland's warbler 21-19
- Kjeldahl, see Nitrogen

L

L Lake

- construction
 - vegetation removal 7-5
- habitat formers 7-5
- herpetofauna 3-5
 - occurring 3-19
- littoral-zone change 7-6
- macrophyte planting program 7-7
 - species planted 7-9
- macrophyte plantings 7-3
- map 7-3
- Nelumbo lutea* 7-6
- Potamogeton diversifolius* 7-6
- regional lakes study 17-3
- sampling transects 3-20
- Vallisneria americana* 7-6
- vegetation
 - areal cover and expansion 7-6
 - community composition 7-5
 - coverage 7-6
 - emergent zone 7-7
 - herbaceous 7-5
 - monitoring 7-5
 - submersed and floating-leaved zone 7-7
 - taxa identified 7-5
 - tree 7-6
 - upper emergent/shrub zone 7-8
- waterfowl 3-35
 - observed
 - 1936-1987 3-35
- wetlands 7-1
- Lake chubsucker
 - Carolina bays 9-19
- Lake Greenwood
 - regional lakes study 17-3
- Lake Marion
 - regional lakes study 17-3
- Lake Marion-Moultrie
 - shortnose sturgeon 21-6
- Lake Monticello
 - regional lakes study 17-3
- Lake Moultrie
 - regional lakes study 17-3
- Lake Murray
 - regional lakes study 17-3
- Lake Richard B. Russell
 - regional lakes study 17-3
- Lake Robinson
 - regional lakes study 17-3
- Land cover maps
 - Girard northeast quadrangle 2-19
 - Girard northwest quadrangle 2-18
 - Girard quadrangle 2-21
 - Jackson quadrangle 2-13
 - Long Branch quadrangle 2-16
 - Martin quadrangle 2-23
 - Millet quadrangle 2-22
 - New Ellenton 2-11
 - New Ellenton southwest quadrangle 2-14
 - Shell Bluff quadrangle 2-17
 - Snelling quadrangle 2-20
 - Windsor quadrangle 2-12
- Landcover
 - maps 2-7
- Largemouth bass
 - fishing 18-10
- Larvae
 - shortnose sturgeon 21-7
- Leaf emergence and expansion
 - Pen Branch
 - delta 6-5
- Lesser scaup
 - waterfowl 3-34
- Life history
 - American alligator 21-10
- Life span
 - shortnose sturgeon 21-7
- Linda's Pond
 - herpetofauna 3-13
- Liquidambar styraciflua, see Sweet gum
- Loblolly
 - Carolina bays 9-13
- Loggerhead shrike 21-19
- Long Branch quadrangle
 - land cover maps 2-16
- Longleaf pines
 - Carolina bays 9-13
- Lost Lake
 - buttonbush 9-28
 - duck potato 9-28
 - hydrology 9-26
 - loblolly pine 9-23
 - lotus 9-28
 - monitoring 9-26
 - restoration 9-23
 - 1991 9-28

1992 9-28
objectives 9-24
plan 9-23
plantings 9-28
treatments 9-26
soil 9-26
Lotus
Lost Lake 9-28
Ludwigia 6-10
Pen Branch
wetlands
1987 6-10

Pen branch
wetlands 6-10
Pen Branch wetlands 6-7
1988 6-11
Pen branch wetlands
1989 6-11
1990 6-12
1991 6-12

M

Macroinvertebrate

Upper Three Runs

- aquatic insects survey
- results 10-34

- biomass 10-37

- density 10-40, 10-41

- diversity 10-38

- taxa collected 10-35

- Tims Branch monitoring program

- sampling 10-34

Macroinvertebrates

Carolina bays 9-17

Fourmile Branch

C reactor

- operation 12-24

- shutdown 12-27

- comprehensive cooling water studies

- results 12-24

- comprehensive cooling water study

- sampling 12-23

- sampling stations 12-23

Pen Branch 13-25

- biomass 13-28, 13-31

- comprehensive cool water study

- results 13-26

- comprehensive cooling water study

- sampling 13-25

- densities 13-28, 13-30

- dominant species 13-27, 13-29

- recovery study

- results 13-28

- sampling 13-25

- sampling stations 13-25

- taxa collected 13-28

- taxa richness 13-29

Upper Three Runs 10-33

- aquatic insects survey

- sampling 10-33

- biomass 10-35, 10-40, 10-41

- comprehensive cooling water study

- results 10-35

- comprehensive cooling water study

- sampling 10-33

- densities 10-37

- density 10-35

- drift densities 10-35

- effluent treatment facility monitoring program

- results 10-36

- F/H effluent treatment facility monitoring program

- sampling 10-34

- sampling stations 10-33

- taxa collected 10-39, 10-40

- taxa collected at all stations 10-36

- Tims Branch monitoring program

- results 10-39

Macrophytes

Fourmile Branch 12-19

- cessation of C reactor operation 12-19

- comprehensive cooling water study 12-19

Pen Branch 13-21

- cessation of K-reactor operations 13-21

- comprehensive cooling water study 13-21

- taxa collected 13-21

Upper Three Runs 10-29

- comprehensive cooling water study 10-29

Magnesium

Beaver Dam Creek 11-11

Fourmile Branch 12-11

Pen Branch 13-12

Maidencane

Carolina bays 9-13

Mallards

- waterfowl 3-33

Mammal

- habitats 3-42

- population studies 3-39

Mammals 3-39

- Carolina bays 3-39, 3-45

- drift fences 3-44

- habitats 3-45

- seasonal 3-45

- commercially and recreationally valuable biota 3-48

- edible 3-48

- furbearers 3-48

- game 3-48

- game, edible, and fur-bearing 3-43

- habitat 3-39

- occurring on SRS 3-40

- Rainbow Bay 3-39

- Steel Creek 3-39, 3-43

- Sun Bay 3-39

- threatened and endangered species

- bats 21-53

- carnivores 21-54

- list 21-53

Manganese

Beaver Dam Creek 11-11

Fourmile Branch 12-11

Pen Branch 13-13

Map

flora

threatened and endangered species 20-6

Maps

bald eagle

 nests 21-26

 sightings 21-24

Beaver Dam Creek 11-3

Fourmile Branch

 map 12-3

L Lake 7-3

location of Carolina bays 9-4

Pen Branch 13-3

soils 1-7

Martin quadrangle

land cover maps 2-23

Migratory waterfowl 3-47

Millet quadrangle

land cover maps 2-22

Mink 3-47

Mole salamander

Carolina bays 9-19

Mollusks

aquatic 21-3

threatened and endangered species 21-3

Mosquitofish

Carolina bays 9-19

MSS

factors affecting 6-9

wetlands classification 6-9

Mud flat 6-10

Pen branch

wetlands 6-10

Mud sunfish

Carolina bays 9-19

Muskrat 3-47

Myotis grisescens

see Gray bat

Myotis leibii

see Small-footed bat 21-53

Myotis sodalis

see Indiana bat

N

Nelumbo lutea, see Lotus

Nest

 bald eagle 21-27

Nest Box Surveys 3-37

Nests

 red-cockaded woodpecker 21-31

New Ellenton quadrangle

 land cover maps 2-11

New Ellenton southwest quadrangle

 land cover maps 2-14

Nitrate, see Nitrogen 10-14

Nitrogen

 Beaver Dam Creek 11-12

 Fourmile Branch 12-12

 Pen Branch 13-13

 Upper Three Runs 10-14

Nutrients

 Beaver Dam Creek 11-12

 Fourmile Branch 12-12

 Pen Branch 13-13

 Upper Three Runs 10-14

Nymphaea odorata, see Waterlilies

Nymphoides aquaticum, see Waterlilies

Nyssa sylvatica, see Black gum

O

Oaks 2-6

black-jack 2-6

bluejack 2-6

laurel 2-6

turkey 2-6

Opossum 3-47**Orangeburg Association 1-11****Organic carbon****Beaver Dam Creek 11-13****Fourmile Branch 12-14****Pen Branch 13-15****Upper Three Runs 10-14****Oryzomys palustris, see Rice rat****Osprey 21-19****Otter 3-47**

P

P. palustris, see Longleaf pines

Panicum spp., see Maidencane

Par Pond

American alligator 21-11

drawdown

American alligator 21-13

herpetofauna 3-5

regional lakes study 17-3

waterfowl 3-34

PCBs

Fourmile Branch 12-15

Pen Branch 13-17

Upper Three Runs 10-17

Pee Dee River

shortnose sturgeon 21-6

Pen Branch 13-1

algae 13-19

alkalinity 13-11

aluminum 13-13

American alligator 21-16

bald eagle

nest 21-27

calcium 13-12

chloride 13-11

conductivity 13-10

corridor

acreages 6-18

Delta

Expansion 6-3

delta 13-4

acreages 6-18

aerial photography 6-6

1987 6-17

1988 6-17

1990 6-17

airborne scanner data 6-6

boardwalk 6-5

boardwalk location 6-5

K reactor shutdown 6-7

leaf emergence and expansion 6-5

phenological observations 6-5

phenology pattern

1989-1990 6-15

1991-1992 6-16

phenology station locations 6-5

SPOT HRV data 6-6

tail 6-5

tail location 6-5

description 13-3

dissolved oxygen 13-8

effluents contribution 13-3

fish 13-39

adult 13-39

artificial flow perturbations 13-44

delta/swamp area 13-41

ichthyoplankton 13-42

K reactor

shutdown 13-42

K-Reactor

operation 13-39

larval 13-42

recolonization 13-42

sampling stations 13-41

flow 13-4

1987-1988 6-14

1989-1990 6-15

1991-1992 6-16

sampling stations 13-4

herbicides 13-17

herpetofauna ?-6

iron 13-13

macroinvertebrates 13-25

biomass 13-28, 13-31

comprehensive cool water study

results 13-26

comprehensive cooling water study

sampling 13-25

densities 13-28, 13-30

dominant species 13-29

recovery study

results 13-28

sampling 13-25

sampling stations 13-25

taxa collected 13-27, 13-28

taxa richness 13-29

macrophytes 13-21

cessation of K-reactor operations 13-21

comprehensive cooling water study 13-21

taxa collected 13-21

magnesium 13-12

manganese 13-13

map 13-3

nitrogen 13-13

nutrients 13-13

organic carbon 13-15

PCBs 13-17

- periphyton 13-19
- pesticides 13-17
- pH measurements 13-8
- phytoplankton 13-19
- potassium 13-12
- priority pollutants
 - detected 13-15
 - survey 13-8
- sodium 13-12
- sulfate 13-11
- suspended solids 13-9
- trace elements 13-13
- turbidity 13-9
- water chemistry and quality 13-7
 - comprehensive cooling water study 13-7
- water temperature 13-8
- waterfowl 3-34
- wetland
 - change summary 6-12
- Wetlands
 - revegetation 6-3
- wetlands
 - 1987 6-10
 - bottomland hardwood 6-10
 - cattails 6-10
 - duckweed 6-10
 - Ludwigia 6-10
 - scrub-shrub 6-10
 - 1988
 - bottomland hardwood 6-11
 - cypress 6-11
 - Ludwigia 6-11
 - scrub-shrub 6-11
 - willow 6-11
 - 1989
 - bottomland hardwood 6-11
 - cattails 6-11
 - dog fennel 6-11
 - Ludwigia 6-11
 - scrub-shrub 6-11
 - willow 6-11
 - 1990 6-11
 - bottomland hardwood 6-12
 - cattails 6-12
 - dog fennel 6-12
 - Ludwigia 6-12
 - scrub-shrub 6-12
 - willow 6-12
 - 1991 6-12
 - bottomland hardwood 6-12
 - buttonbush 6-12
 - cattails 6-12
 - Ludwigia 6-12
 - scrub-shrub 6-12
 - willow 6-12
 - changes 6-7
 - cover types 6-7
 - K reactor operation 6-7
 - K reactor shutdown
 - buttonbush 6-7
 - cattail 6-7
 - Ludwigia 6-7
 - scrub-shrub 6-7
 - willow 6-7
 - multispectral scanner
 - data clusters 6-9
 - MSS
 - methodology 6-9
 - of willow 6-7
 - old-field 6-7
 - willow 6-10
 - zooplankton 13-23
- Pen branch
 - bald eagle
 - management 21-28
- delta
 - phenology pattern
 - 1987-1988 6-14
 - SPOT HRV data 6-8
- delta K reactor operation
 - Ludwigia 6-7
- wetlands 6-1
 - 1988 6-11
 - 1989 6-11
 - bare soil 6-10
 - bottomland hardwood forest 6-10
 - cattails 6-10
 - Cypress-Tupelo forest 6-10
 - deep water 6-10
 - duckweed 6-10
 - Ludwigia 6-10
 - mud flat 6-10
 - multispectral scanner
 - introduction 6-9
 - wetlands classification 6-9
 - non-persistent emergent marsh 6-7
 - persistent marsh 6-7
 - scrub-shrub 6-7, 6-10
 - shallow water 6-10
 - willow 6-10
- Peregrine falcon 21-19
- Periphyton
 - Fourmile Branch 12-17
 - Pen Branch 13-19
 - Upper Three Runs 10-27
- Persea borbonia, see Red bay
- Persimmon 2-6
- Persistent trillium 20-3

- Pesticides
 - Fourmile Branch 12-15
 - Pen Branch 13-17
 - Upper Three Runs 10-17
- pH measurements
 - Beaver Dam Creek 11-8
 - Fourmile branch 12-8
 - Pen Branch 13-8
 - Upper Three Runs 10-9
- Phenology pattern
 - Pen Branch
 - 1987-1988 6-14, 6-16
 - 1989-1990 6-15
- Phenology stations
 - Pen Branch delta 6-5
- Phosphorus
 - Beaver Dam Creek 11-12
 - Fourmile Branch 12-12
 - Pen Branch 13-13
 - Upper Three Runs 10-14
- Phytoplankton
 - Fourmile Branch 12-17
 - Pen Branch 13-19
- Pickerel Pond
 - herpetofauna 3-13
- Picoides borealis
 - see Red-cockaded woodpecker 21-29
- Pigs, see Feral swine
- Pine snake 21-9
 - threatened and endangered species candidate 21-9
- Pines
 - loblolly 2-5
 - longleaf 2-5, 2-6
 - slash 2-5
- Pinus taeda, see Loblolly
- Pitcher plants
 - Carolina bays 9-13
- Pituophis melanoleucus
 - see Pine snake
- Plants see Vegetation 7-5
- Plecotus rafinesquii
 - see Rafinesque's big-eared bat 21-53
- Pleistocene marine terraces
 - map 1-5
 - origin 1-5
- Pond B
 - regional lakes study 17-3
- Population
 - white-tailed deer 3-50
- Potassium
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-11
 - Pen Branch 13-12
- Priority pollutant
 - Fourmile branch survey 12-8
- Priority pollutants
 - Beaver Dam Creek survey 11-8
 - Fourmile Branch detected 12-14
 - Pen Branch detected 13-15 survey 13-8
 - Upper Three Runs detected 10-14 survey 10-8
- Protection history
 - American alligator 21-10
- Public hunts, see Hunts

Q

Q. laevis, see Turkey oak

Quercus marilandica, see Blackjack oak

R

- Rabbit 3-47
- Raccoon 3-47
- Rafinesque's big-eared bat 21-53
- Rainbow Bay
 - birds 3-23, 3-29
 - herpetofauna
 - occurring 3-9
 - herpetofauna
 - movement 3-11
 - hydrology 9-5
 - mammals 3-39
- Rana aerolata, see Carolina crawfish frog
- Reactor operation
 - wood stork 21-34
- Red ash 2-7
- Red bay
 - Carolina bays 9-13
- Red maple 2-6
- Red wolf 21-54
- Redbay 2-6
- Red-cockaded woodpecker 21-29
 - breeding 21-29
 - cavity excavation 21-30
 - foraging 21-30
 - habitat 21-30
 - management program 21-31
 - nests 21-31
 - photo 21-30
 - population 21-33
 - population/habitat relationship 21-31
- Red-cockaded woodpeckers
 - monitored colonies 21-31
- Redfin pickerel
 - Carolina bays 9-19
- Refuge pond
 - amphibian
 - juvenile 3-15
- Refuge ponds
 - amphibians
 - adults 3-14
- Regional lakes study 17-1
 - algae 17-9
 - alkalinity 17-13
 - chlorophyll a 17-17
 - dissolved oxygen 17-9
 - eutrophication 17-17
 - macronutrients 17-13
 - nitrogen 17-13
 - pH measurements 17-9
 - phosphorus 17-13
 - phytoplankton 17-17
 - purpose 17-3
 - reservoirs studied 17-3
 - sampling plan 17-7
 - temperature 17-9
 - zooplankton 17-9
- Rembert-Hornsville Association 1-10
- Reptile
 - movement
 - Rainbow Bay 3-11
 - Sun Bay 3-11
 - occurring
 - L Lake 3-19
- Reptiles
 - Carolina bays 9-19
 - movement
 - Linda's Pond 3-13
 - Pickerel Pond 3-13
 - occurring
 - 1986-1987
 - Steel Creek 3-18
 - Par Pond 3-20
 - SRS 3-6
 - Steel Creek
 - 1981-1982 3-16
 - Sun Bay 3-9
 - threatened and endangered species 21-9
- Reservoirs
 - regional lakes study 17-1
- Residents
 - avifauna 21-19
- Rhus copallina, see Sumac
- Rice rat
 - Carolina bays 9-20
- Ring-necked ducks
 - waterfowl 3-34
- Rodents
 - Carolina bays 9-20
- Ruddy ducks
 - waterfowl 3-34

S

- Sagittaria fasciculata 20-3
- Sagittaria latifolia, see Duck potato
- Saint John River
 - shortnose sturgeon 21-6
- Sampling stations
 - Beaver Dam Creek
 - flow 11-4
 - water chemistry and quality 11-7
 - Fourmile Branch
 - fish 12-37
 - macroinvertebrates 12-23
 - Fourmile branch
 - flow 12-4
 - water chemistry and quality 12-7
 - Pen Branch
 - fish 13-41
 - flow 13-4
 - macroinvertebrates 13-25
 - Upper Three Runs
 - fish 10-55
 - flow 10-4
 - macroinvertebrate 10-33
 - water chemistry and quality 10-7
- Sampling transects
 - herpetofauna
 - L Lake 3-20
 - Steel Creek 3-17
- Santee-Cooper River
 - bald eagle 21-21
- Sarracenia spp., see Pitcher plants
- Sassafras 2-6
- Savannah River
 - bald eagle 21-21
 - brother spike mussel 21-3
 - creel surveys 18-11
 - feral swine 3-49
 - fishing
 - SRS impacts 18-12
 - flow
 - 1989-1990 6-15
 - 1991-1992 6-16
 - shortnose sturgeon 21-5
- Savannah river
 - flow
 - 1987-1988 6-14
- Savannah River swamp
 - Pen Branch delta 6-5
 - water flow 21-43
 - wood stork 21-34
- Savannah sparrow 21-19
- Scrub-Shrub 2-5
- Scrub-shrub 6-10
 - Pen branch
 - wetlands
 - 1987 6-10
 - Pen Branch wetlands
 - 1988 6-11
 - Pen branch wetlands 6-10
 - 1989 6-11
 - 1990 6-12
 - 1991 6-12
- scrub-shrub
 - Pen Branch wetlands 6-7
- see Bunched arrowhead 20-3
- see Persistent trillium 20-3
- see Small whorled pogonia 20-3
- see small whorled pogonia 20-3
- see Smooth purple coneflower 20-3
- Set-aside areas 2-31
- Shallow water 6-10
 - Pen branch wetlands 6-10
- Shell Bluff quadrangle
 - land cover maps 2-17
- Shortnose sturgeon 21-5
 - eggs 21-6
 - feeding 21-7
 - growth 21-7
 - habitat 21-6
 - ichthyoplankton 21-7
 - juvenile 21-7
 - larvae 21-7
 - life span 21-7
 - spawning 21-6
 - frequency 21-6
 - temperature 21-6
 - time of year 21-6
 - spawning grounds 21-6
- Shrews
 - Carolina bays 9-20
- Skunk 3-47
- Slider turtle
 - population size structure 3-22
- Slider turtles
 - growth rates 3-21
 - size structure 3-21
- Small-footed bat 21-53

- Smooth purple coneflower 20-3
- Snelling quadrangle
 - land cover maps 2-20
- Snipe 3-47
- Sodium
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-11
 - Pen Branch 13-12
- Soil groups
 - Chastain-Tawcaw-Shellbluff Association 1-9
 - description 1-9
- Soil maps
 - Pleistocene marine terraces 1-5
- Soil survey 1-7
 - map description 1-7
 - tabular data 1-7
- Soils 1-1
 - Carolina bays 9-11
 - map of SRS 1-9
 - mapping units 1-8
 - maps 1-7
 - orders on SRS 1-7
 - origin 1-5
 - Pleistocene marine terraces 1-5
 - series on SRS 1-7
 - SRS characteristics 1-7
 - survey 1-7
 - textural classification 1-6
 - texture 1-6
 - use 1-3
- Soils group
 - Blanton-Lakeland association 1-10
 - Orangeburg association 1-11
 - Rember-Hornsville association 1-10
 - Troup-Pickney-Lucy association 1-11
 - Vaocluse-Ailey association 1-11
- Sorex longirostris, see Shrews
- South Carolina Nature Conservancy 20-3
- South Carolina Wildlife and Marine Resources Department
 - 20-3
 - wild turkeys 3-47
- Southern leopard frog
 - Carolina bays 9-19
- Southern toads
 - Carolina bays 9-20
- Spadefoot toads
 - Carolina bays 9-20
- Spawning
 - frequency
 - shortnose sturgeon 21-6
 - shortnose sturgeon 21-6
 - temperature 21-6
 - time of year 21-6
- SPOT HRV Data
 - Pen Branch delta
 - cover types 6-8
- SPOT HRV data
 - Pen Branch delta 6-6
- Squirrel 3-47
- SREL waterfowl aerial surveys
 - bald eagle observations 21-22
- State of South Carolina
 - threatened and endangered species laws 19-5
- Steed's Pond
 - American alligator 21-17
- Steel Creek
 - American alligator 21-16
 - birds 3-23, 3-31
 - herpetofauna 3-5
 - occurring
 - 1981-1982 3-16
 - 1986-1987 3-18
 - sampling transects 3-17
 - mammals 3-39, 3-43
 - turtle traps 3-17
 - waterfowl 3-33
- Streams
 - Beaver Dam Creek 11-1
 - Fourmile Branch 12-1
 - Pen Branch 13-1
 - Upper Three Runs 10-1
- Striped bass 18-6
- Stripped bass
 - fishing 18-10
- Sulfate
 - Beaver Dam Creek 11-11
 - Fourmile Branch 12-10
 - Pen Branch 13-11
- Sumac
 - Carolina bays 9-13
- Sun Bay
 - birds 3-23, 3-30
 - herpetofauna
 - movement 3-11
 - occurring 3-9
 - mammals 3-39
- Sunderland Terrace
 - origin 1-5
- Sunfish
 - Carolina bays 9-19
- Suspended solids
 - Beaver Dam Creek 11-10
 - Fourmile Branch 12-10
 - Pen Branch 13-9
- Swallow-tailed kite 21-19
- swallow-tailed kite 21-19
- Swamp
 - forests 2-7

survey
 wood stork 21-39
 waterfowl 3-34
Sweet bay 2-6
Sweet gum
 Carolina bays 9-13

T

Terrestrial resources

commercially and recreationally valuable biota 3-47

Threatened and endangered species

American alligator 21-9

American osprey 21-19

American sandburrowing mayfly 21-3

amphibians 21-9

arthropods 21-3

avifauna 21-19

species on SRS 21-19

Bachman's sparrow 21-19

bald eagle 21-19

bats 21-53

Benwick's wren 21-19

black bear 21-54

brother spike mussel 21-3

candidate

hognose snake 21-9

loggerhead shrike 21-19

carnivores 21-54

Carolina crawfish frog 21-9

Cooper's hawk 21-19

eastern cougar 21-54

fauna 21-1

fishes 21-5

Flora

SRS

list 20-6

flora

bunched arrowhead 20-3

federally listed species 20-3

location map 20-6

programs for identifying 20-3

small whorled pogonia 20-3

South Carolina 20-3

SRS 20-5

Florida panther 21-54

golden eagle 21-19, 21-28

gray bat 21-53

herpetofauna 21-9

Indiana bat 21-53

invertebrates 21-3

Kirtland's warbler 21-19

laws 19-1

federal endangered species act 19-3

state of South Carolina 19-5

loggerhead shrike 21-19

mammals 21-53

mollusks 21-3

osprey 21-19

peregrine falcon 21-19

Rafinesque's big-eared bat 21-53

red wolf 21-54

red-cockaded woodpecker 21-29

reptiles 21-9

Savannah sparrow 21-19

shortnose sturgeon 21-5

small-footed bat 21-53

swallow-tailed kite 21-19

wood stork 21-33

Threawn grass

Carolina bays 9-13

Thunder Bay

hydrology 9-5

temperature 9-8

Timber

acreage 2-27

management plan 2-27

planted acres 2-28

seeded acres 2-28

seedlings planted 2-28

type cut 2-30

type sold 2-29

value 2-27, 2-29

value cut 2-30

value sold 2-29

Tims Branch monitoring program

Upper Three Runs

macroinvertebrate

results 10-39

macroinvertebrates

sampling 10-34

total phosphorus, see Phosphorus

Trace elements

Beaver Dam Creek 11-13

Fourmile Branch 12-13

Pen Branch 13-13

Upper Three Runs 10-14

Trapping program

beavers 3-48

feral swine 3-50

wild turkey 3-47

Trillium persistens 20-3

tupelo 2-7

Turbidity

Beaver Dam Creek 11-10

-
Fourmile Branch 12-10	Turtles
Pen Branch 13-9	Florida cooter 18-3
Turkey oak	L Lake 3-5
Carolina bays 9-13	slider 18-3
Turkey, see Wild Turkeys 3-47	snapping 18-3
Turtle	softshell 18-3
Par Pond 3-5	Typha spp.
Turtle traps	see cattail 6-7
Steel Creek 3-17	

U

Upper Three Runs 10-1

- algae 10-27

- American sandburrowing mayfly 21-3

- chemical assessment studies 10-8, 10-17

 - changes in M-Area effluent 10-17

 - F/H area effluent treatment facility 10-21

 - M-Area liquid effluent treatment facility 10-17

- feral swine 3-49

- fish 10-55

 - comparison to other SRS streams 10-58

 - comprehensive cooling water study 10-55

 - differences among different habitats 10-58

 - ichthyoplankton 10-56

 - impacts from F- and H-Areas 10-57

 - sampling stations 10-55

- flow 10-4

 - sampling stations 10-4

- herbicides 10-17

- invertebrates 21-3

- macroinvertebrate

 - biomass 10-37, 10-41

 - diversity 10-38

 - taxa collected at all stations 10-36

 - Tims Branch monitoring program

 - results 10-39

- macroinvertebrates 10-33

 - aquatic insects survey

 - results 10-34

 - sampling 10-33

 - biomass 10-35, 10-40

 - comprehensive cooling water study

 - results 10-35

 - sampling 10-33

 - densities 10-37

 - density 10-35, 10-40, 10-41

 - drift densities 10-35

 - effluent treatment facility monitoring program

 - results 10-36

 - F/H effluent treatment facility monitoring program

 - sampling 10-34

 - sampling stations 10-33

 - taxa collected 10-35, 10-39, 10-40

 - Tims Branch monitoring program

 - sampling 10-34

 - macrophytes 10-29

 - comprehensive cooling water study 10-29

 - nitrogen 10-14

 - nutrients 10-14

 - organic carbon 10-14

 - PCBs 10-17

 - periphyton 10-27

 - pesticides 10-17

 - pH measurements 10-9

 - phosphorus 10-14

 - priority pollutants

 - detected 10-14

 - survey 10-8

 - trace elements 10-14

 - water chemistry and quality 10-7

 - comprehensive cooling water study 10-7

 - sampling stations 10-7

 - water temperature 10-8

 - zooplankton 10-31

 - Ursus americanus

 - see Black bear 21-54

V

Vacciniums 2-6
Vaucluse-Ailey Association 1-11

Vegetation
 history 2-3

Vegetation 2-1

 Carolina bays 9-13

 community types 9-13

 pattern control 9-13

 short-term succession 9-15

 zones 9-13

commercially and recreationally valuable biota 2-27

Cover type

 non-forested 2-5

Cover types

 forested 2-5

cover types 2-5

Craig's Pond

 community types 9-13

 zones 9-13

Ellenton Bay

 community types 9-15

L Lake

 areal cover and expansion 7-6

 community composition 7-5

 coverage 7-6

 emergent zone 7-7

 herbaceous 7-5

 monitoring 7-5

 submersed and floating-leaved zone 7-7

 taxa identified 7-5

 tree 7-6

 upper emergent/shrub zone 7-8

maps 2-7

of species 2-5

set-aside areas 2-31

successional patterns 2-25

swamp 2-7

Vegetation, see Macrophytes

Vertebrate

 Carolina bays 9-19

Visitor

 avifauna 21-19

W

- Water ash 2-7
- Water chemistry
 - Carolina bays 9-7
 - detailed chemical analyses 9-8
 - general chemical characteristics 9-7
 - oxygen 9-8
- Water chemistry and quality
 - Beaver Dam Creek 11-7
 - comprehensive cooling-water study 11-7
 - Fourmile branch 12-7
 - comprehensive cooling water study 12-7
 - Pen Branch 13-7
 - comprehensive cooling water study 13-7
 - Upper Three Runs 10-7
 - comprehensive cooling water study 10-7
- Water levels
 - Carolina bays 9-5
- Water temperature
 - Beaver Dam Creek 11-8
 - Fourmile branch 12-8
 - Pen Branch 13-8
 - Upper Three Runs 10-8
- Waterfowl 3-32
 - Beaver Dam Creek 3-34
 - buffleheads 3-34
 - effects of wetlands drainage 3-33
 - Fourmile Branch 3-34
 - L Lake 3-35
 - lesser scaup 3-34
 - mallards 3-33
 - observations on SRS 3-32
 - Par Pond 3-34
 - Pen Branch 3-34
 - population
 - studies 3-33
 - ring-necked ducks 3-34
 - ruddy ducks 3-34
 - Steel Creek 3-33
 - swamp 3-34
 - wood ducks 3-33
- Waterlilies
 - Carolina bays 9-13
- Wetlands
 - L Lake 7-1
 - Pen Branch 6-1
- Wetlands classification
 - Pen branch
 - wetlands 6-9
- White-Tailed Deer 3-49
- White-tailed deer
 - harvest 3-50
 - hunts 3-49
 - population 3-50
- Wicomico Terrace
 - origin 1-6
- Wild turkey 3-47
 - trapped and removed 3-47
 - trapping program 3-47
- Wild turkeys 3-47
 - South Carolina Wildlife and Marine Resources Department 3-47
- Wildlife 3-1
 - habitats 3-3
 - herpetofauna 3-5
 - mammals 3-39
- Willow 6-10
 - Pen branch
 - wetlands
 - 1987 6-10
 - Pen branch wetlands 6-10
 - 1988 6-11
 - 1989 6-11
 - 1990 6-12
 - 1991 6-12
- Windsor quadrangle
 - land cover maps 2-12
- Wood ducks
 - Carolina bays 9-20
 - waterfowl 3-33
- Wood stork 21-33
 - Birdsville Colony 21-34
 - studies 21-34
 - breeding 21-35
 - flow effect 21-45
 - forage survey
 - methods 21-35
 - foraging
 - diet 21-39
 - habitat 21-38
 - prey 21-39
 - vegetation 21-38
 - water depth 21-39
 - Kathwood Lake 21-49
 - foraging 21-50
 - numbers 21-43
 - Beaver Dam Creek 21-48

-
- Four Mile Creek 21-45
 - Pen Branch 21-45
 - Steel Creek 21-48
 - population 21-33
 - pre-SRS 21-39
 - Savannah River Ecology Laboratory studies 21-35
 - Savannah River swamp 21-34
 - stream flows 21-43
 - survey
 - swamp 21-39
 - swamp
 - foraging 21-48
 - survey 21-39
 - swamp survey
 - 1984 21-42
 - 1985 21-42
 - 1987 21-42
 - methods 21-40
 - results 21-40
 - Wood storks
 - Carolina bays 9-20
 - Woodcock 3-47
 - Woodducks
 - nest box surveys 3-37

Y

Yellow perch
fishing 18-10
Yellow poplar 2-6

Z

Zooplankton

Carolina bays 9-18

Fourmile Branch 12-21

Pen Branch 13-23

Upper Three Runs 10-31

END

DATE

FILMED

3/18/94