GLOSSARY

absorbed dose
Energy transferred to matter when ionizing radiation passes through it. Absorbed dose is measured in rads.

absorption
The process by which the number and energy of particles or photons entering a body of matter are reduced by interaction with the matter.

acclimation
The acclimation or adaptation of a particular species over several generations to a marked change in the environment.

activity
A measure of the rate at which a material is emitting nuclear radiation, usually given as the number of nuclear disintegrations per unit of time. A unit of radioactivity is the curie (Ci), which equals 3.7×10^{10} disintegrations per second.

adsorption
The adhesion of a substance to the surface of a solid or solid particles.

AEC
Atomic Energy Commission. A five-member commission established by the Atomic Energy Act of 1954 to supervise the use of nuclear energy. The AEC was dissolved in 1975 and its functions transferred to the Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA); ERDA became the U.S. Department of Energy (DOE) in 1977.

aerobic
Processes that can occur only in the presence of oxygen.

air quality
A measure of the levels of pollutants in the air.

air quality standards
The prescribed level of pollutants in the outside air that cannot be exceeded legally during a specified time in specified areas.

air sampling
The collection and analysis of air samples for detection or measurement of radioactive substances.

alluvial
Deposited by a stream or running water.

ambient air
The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. (It is not the air in immediate proximity to emission sources.)

anaerobic
Processes that occur in the absence of oxygen.

anion
A negatively charged ion.

AC-1 aquaculture
Culture of aquatic organisms

aquatic biota
The sum total of living organisms of any designated aquatic area.

aquifer
An underground bed or stratum of earth, gravel, or porous stone that contains water. The water can be pumped to the surface through a well or it might emerge naturally as a spring.

archaeological sites (resources)
Areas or objects modified or made by man and the data associated with these features and artifacts.

arenaceous limestone
Limestone with a texture or appearance of sand.

artifact
An object produced or shaped by human workmanship of archaeological or historic interest.

ash
Inorganic residue remaining after ignition of combustible substances.

atmosphere
The layer of air surrounding the earth.

backfill
Material used to refill an excavation.

background exposure
See exposure to radiation.

background radiation
Normal radiation present in the lower atmosphere from cosmic rays and earth sources. Background radiation varies considerably with location.

bedrock
Any solid rock exposed at the earth's surface or overlain by unconsolidated surface material such as soil, gravel, or sand.

benthos

The plant and animal life whose habitat is the bottom of a sea, lake, or river.

beta particle

An elementary particle emitted from a nucleus during radioactive decay. It is negatively charged, is identical to an electron, and is easily stopped by, for example, a thin sheet of metal.

bioaccumulation factor

Concentration of a substance (e.g., chemical or radionuclide) in fish flesh or other body parts divided by the concentration of that substance in the water in which the fish is living.

biocide

Chemical agent used to prevent or remove fouling organisms such as bacteria, fungi, algae, clams, etc., from entering or fouling intake and heat exchangers of powerplant/reactor cooling water systems.

biofouling

Aquatic organisms such as bacteria, fungi, algae, clams, etc., that colonize water-flow structures, often causing restricted water flow (i.e., cooling water systems of powerplants/reactors).

biological dose

The radiation dose, measured in rems, absorbed in biological material.

biosphere

The portion of the earth and its atmosphere capable of supporting life.

biostratigraphy

The study of stratigraphy via fossilized remains.

biota

The plant and animal life of a region.

blowdown

Water discharged from a recirculating cooling system to control concentration of salts or other impurities.

BOD

Biological oxygen demand, the oxygen required for oxidation of soluble organic matter by bacterial action in the presence of oxygen.

Btu

British Thermal Unit, a unit of heat; the quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit. One Btu equals 1055 joules (or 252 calories).

°C

Degree Celsius. The Celsius temperature scale is related to the Fahrenheit scale as follows:

$$°F = °C \frac{9}{5} + 32$$

cancer

The name given to a group of diseases that are characterized by uncontrolled cellular growth.

carbon monoxide

A colorless, odorless gas that is toxic if breathed in high concentration over a certain period of time. It is a normal component of most automotive exhaust systems.

carcinogen

An agent capable of producing or inducing cancer.

carcinogenic

Capable of producing or inducing cancer.

Carolina bay

Wetland area found on the Southeastern Atlantic coastal plain; a shallow depression.

cc

Cubic centimeters, cm^3 or cc (1 cc = 1 milliliter).

CCDF

Complementary cumulative distribution function.

Ci

See curie.

clastic dike

A sedimentary dike formed by broken rocks from overlying or underlying material.

cold shock

A rapid decrease in water temperature that may result in fish mortality.

concentration

The amount of a substance contained in a unit quantity of a sample.

condensate

Water obtained by cooling the steam (overheads) produced in an evaporator system. Also, any liquid obtained by cooling saturated vapor.

CO_2

Carbon dioxide, a colorless, odorless, nonpoisonous gas that is a normal component of the ambient air.

coolant

A substance, usually water, circulated through a processing plant to remove heat.

cooling tower

A structure designed to cool water by evaporation. In this EIS, the water being cooled absorbs heat to condense the steam in the evaporator system.

correlatable

Able to establish a connection between geological formations or events.

Cretaceous

End of Mesozoic era, between 136 and 65 million years ago.

crystalline metamorphic rock

Rock consisting wholly of crystals.

cumulative effects

Additive environmental, health, and socioeconomic effects that result from a number of similar activities in an area.

curie (Ci)

A unit of radioactivity equal to 3.7×10^{10} (37 billion) disintegrations per second. A curie is also a quantity of any nuclide or mixture of nuclides having one curie of radioactivity.

daughter

A nuclide formed by the radioactive decay of another nuclide, which is called the parent.

decay heat

The heat produced by the decay of radioactive nuclides.

decay, radioactive

The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in the emission of nuclear radiation (alpha, beta, or gamma).

decomposition

The breakdown of a substance into its constituent parts.

delta T (ΔT) TC

Change in temperature.

demography

The statistical study of human populations including size, density, distribution, and vital statistics such as age, sex, and ethnicity.

depauperate

Poor or impoverished, falling short of what occurs naturally; i.e., reduced numbers and species of biological organisms.

depositional regimes

A systematic laying or throwing down of material over a substantial area.

detector

Material or device (i.e., instrument) that is sensitive to radiation and can produce a response signal suitable for measurement or analysis.

detritus

Dead organic tissues and organisms in an ecosystem.

distillation

Separation process achieved by creating two or more coexisting zones that differ in temperature, pressure, or composition.

DOE

United States Department of Energy.

dose

The energy imparted to matter by ionizing radiation. The unit of absorbed dose is the rad, equal to 0.01 joules per kilogram of irradiated material in any medium.

dose commitment

The dose that an organ or tissue receives during a specified period of time (e.g., 50 or 100 years) as a result of intake (by ingestion or inhalation) of one or more radionuclides from 1 year's release.

dose equivalent

A term used to express the amount of effective radiation when modifying factors have been considered. It is the product of absorbed dose (rads) multiplied by a quality factor and any other modifying factors. It is measured in rems (Roentgen equivalent man).

dose rate

The radiation dose delivered per unit time (e.g., rems per year).

dosimeter

A small device (instrument) that measures radiation dose (e.g., film badge or ionization chamber) and is carried by a radiation worker.

drift

Mist or spray carried out into the atmosphere with the effluent air from cooling towers.

DWPF

Defense Waste Processing Facility, under construction at the Savannah River Plant. It is designed to process defense waste into a suitable form for terminal storage or disposal.

D_2O

Deuterium oxide or heavy water.

ecology

The science dealing with the relationship of all living things to each other and to the environment.

ecosystem

A complex of the community of living things and the environment forming a functioning whole in nature.

EDC

See environmental dose commitment.

effluent

Liquid waste discharged into the environment, usually into surface streams. In this EIS, effluent refers to discharged wastes that are nonpolluting in their natural state or as a result of treatment.

effluent standards

Defined limits of waste discharge in terms of volume, content of contaminants, temperature, etc.

EIS

Environmental impact statement, a document prepared pursuant to Section 102(2)(c) of the National Environmental Policy Act (NEPA) of 1969 for a major Federal action significantly affecting the quality of the human environment.

electron

An elementary particle with a unit negative charge and a mass 1/1837 of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.

element

One of the 105 known chemical substances that cannot be divided into simpler substances by chemical means. All nuclides of an element have the same atomic number.

emission standards

Legally enforceable limits on the quantities and kinds of air contaminants that may be emitted into the atmosphere.

endangered species

Plants and animals in an area that are threatened with either extinction or serious depletion.

energy

The capacity to produce heat or do work. Electrical energy is measured in units of kilowatt-hours.

entrainment

The capture and inclusion of organisms in the cooling water systems of powerplants/reactors. The organisms involved are generally 9 to 13 millimeters long, depending on the intake screen mesh size, and include phyto- and zooplankton, fish eggs and larvae (ichthyoplankton), shellfish larvae, and other forms of aquatic life.

environment
The sum of all external conditions and influences affecting the life, development, and ultimately, survival of an organism.

environmental dose commitment (EDC)
A dose representing exposure to, and ingestion of, environmentally available radionuclides for 100 years following 1 year's release of radioactivity.

environmental fate
The result of the physical, biological, and chemical interactions of a substance released to the environment.

environmental transport
The movement through the environment of a substance; it includes the physical, chemical, and biological interactions undergone by the substance.

Eocene
Lower Tertiary Period, after Paleocene but before Oligocene.

epoch
Length of time (geology).

erosion
The process in which uncovered soil and clay are carried away by the action of wind or water.

estuarine
Pertaining to an area where salt and fresh water come together and are affected by tides.

exposure to radiation
The incidence of radiation on living or inanimate material by accident or intent. Background exposure is the exposure to natural background ionizing radiation. Occupational exposure is the exposure to ionizing radiation that takes place during a person's working hours. Population exposure is the exposure to a number of persons who inhabit an area.

°F
degree Fahrenheit. The Fahrenheit temperature scale is related to the Celsius scale as follows:

$$°C = \frac{(°F - 32)}{1.8}$$

fall line
Imaginary line marking the point that most rivers drop steeply from the uplands to the lowlands.

fallout
The descent to earth and deposition on the ground of particulate matter (which might be radioactive) from the atmosphere.

fault
A fracture or a zone of fractures within a rock formation along which vertical, horizontal, or transverse slippage has occurred.

faunal
Animal and plant fossils of a certain rock unit.

feldspar
Most common group of aluminum silicate minerals (containing other metals, such as potassium, sodium, and iron) that form rock.

ferruginous
Containing iron oxide.

fission
The splitting of a heavy atomic nucleus into two approximately equal parts, which are nuclei of lighter elements, accompanied by the release of energy and generally one or more neutrons. Fission can occur spontaneously or can be induced by neutron bombardment.

fission products
Nuclei formed by the fission of heavy elements (primary fission products). Also, the nuclei formed by the decay of the primary fission products, many of which are radioactive.

fluvial
Relating to, or living in or near, a river.

flux
Rate of flow through a unit area.

food chain
The pathways by which any material entering the environment passes from the first absorbing organism through plants and animals to humans.

fuel
A substance used to produce heat (e.g., from chemical energy by combustion, or from nuclear energy by nuclear fission).

gal
Gallon.

gamma rays
High-energy, short-wave length electromagnetic radiation accompanying fission and emitted from the nucleus of an atom. Gamma rays are very penetrating and require dense (e.g., lead) or a thick layer of materials for shielding.

gamma spectrometry

Identification and quantification of radioisotopes by measurement of the characteristic gamma rays emitted by elements undergoing radioactive decay.

g/cm^2

Grams per square centimeter, a measure of pressure. Atmospheric pressure is about 1055 g/cm^2.

genetic effects

Radiation effects that can be transferred from parent to offspring; radiation-induced changes in the genetic material of sex cells.

geology

The science that deals with the earth: the materials, processes, environments, and history of the planet, especially the lithosphere, including the rocks and their formation and structure.

g/L

Grams per liter.

glauconitic

Mineral aggregate containing glauconite, giving it a green color.

gneiss

Rock formed from bands of granular minerals alternating with bands of minerals that are flaky, or have elongate prismatic habits.

gradient

Slope, particularly of a stream or land surface.

groundwater

The supply of water under the earth's surface in an aquifer.

gypsum

Mineral containing hydrous calcium sulfate.

half-life (effective)

The time required for a radionuclide contained in an organism to reduce its activity by one half as a combined result of radioactive decay and biological elimination.

halogens

The group of five chemically related nonmetallic elements that include fluorine, chlorine, bromine, iodine, and astatine.

hardwoods

Trees that are angiosperms and yield wood that has a hard consistency.

health physics

The science concerned with recognition, evaluation, and control of health hazards from ionizing radiation.

heat exchanger
A device that transfers heat from one fluid (liquid or gas) to another or to the environment.

heavy metals
Metallic elements of high molecular weight, such as mercury, chromium, cadmium, lead, and arsenic, that are toxic to plants and animals at known concentrations.

heavy water
Water in which the molecules contain oxygen and deuterium, an isotopic form of hydrogen that is heavier than ordinary hydrogen.

high-level waste
High-level liquid waste or the products from the solidification of high-level liquid waste or irradiated fuel elements if discarded without reprocessing.

historic resources
The sites, districts, structures, and objects considered limited and nonrenewable because of their association with historic events or persons, or social or historic movements.

holding pond
A pond constructed to retain water from a cooling water system before release to a water body.

Holocene
Epoch of Quaternary Period from end of Pleistocene to present time.

hydraulic conductivity
Water flow rate in liters per day through a 1-square-foot cross-section under a unit hydraulic gradient.

hydraulic (water) head
Height of water with a free surface above a subsurface point.

hydrocarbons (HC)
Organic compounds consisting primarily of hydrogen and carbon. Hydrocarbons are emitted in automotive exhaust and from the incomplete combustion of fossil fuels such as coal.

hydrograph
Graph showing water characteristics such as velocity, or flow, in relation to time.

hydrology
The science dealing with the properties, distribution, and circulation of natural water systems.

hydrosphere
The water portion of the surface of the earth as distinguished from the solid portion, the lithosphere.

hydrostratigraphic unit
Rock or soil body extending laterally for a considerable distance; sometimes abbreviated HSU.

ichthyoplankton
The early life stages of fish (eggs and larvae) that spend part of their life cycle as free-floating plankton.

impingement
The process by which aquatic organisms too large to pass through the intake screens of a powerplant/reactor become caught on the screens and unable to escape.

incorporated places
Political units incorporated or combined as cities, boroughs, towns, and villages.

indigenous labor pool
An area's native labor pool composed of workers normally residing in the area who do not leave the area after termination of a construction project.

induced radioactivity
Radioactivity that is created when substances are bombarded with neutrons, as in a reactor.

inert gas
A gas that is totally unreactive.

in-movers
Workers who move into an area during construction and leave when the project is finished. As referred to in this document, in-movers also include some weekly travelers.

insolation
Solar radiation incident on the water surface.

intensity
The energy or the number of photons or particles of radiation incident on a unit of time. Intensity of radioactivity is the number of atoms disintegrating per unit of time.

interfluvial
Falling in the area between two streams.

ion
An atom or molecule that has gained or lost one or more electrons and thus has become electrically charged.

ion exchange

Process in which a solution containing soluble ions to be removed is passed over a solid ion exchange column, which removes the soluble ions by exchanging them with labile ions from the surface of the column. This process is reversible; the trapped ions can be eluted from the column and the column regenerated.

ionization

The process whereby ions are created. Nuclear radiation can cause ionization, as can high temperatures and electric discharges.

ionizing radiation

Radiation capable of displacing electrons from atoms or molecules, thereby producing ions.

irradiation

Exposure to radiation.

isotope

An atom of a chemical element with a specific atomic number and atomic weight. Isotopes of the same element have the same number of protons but different numbers of neutrons.

kaolin

Clay mineral group characterized by a silicon oxygen sheet and an aluminum-hydroxyl sheet alternately linked to form a two-layer crystal lattice.

kilometer

A metric unit of length equal to 0.62137 mile.

leachate

Liquid that has percolated through solid waste or other media and has extracted from the solids dissolved or suspended materials into the liquids.

leaching

The process whereby a soluble component of a solid or mixture of solids is extracted as a result of percolation of water around and through the solid.

leukemia

A form of cancer characterized by extensive proliferation of nonfunctional, immature white blood cells (leukocytes).

lignite

A brownish-black coal between stages of peat and sub-bituminous coal.

limonite

Hydrous ferric oxides occurring naturally but having unknown origins.

liters per second
A metric unit of flow rate equal to 15.85 gallons per minute.

lithology
Rock descriptions by color, structure, grain size, etc.

lithosphere
The solid part of the earth composed predominantly of rock.

long-lived nuclides
Radioactive isotopes with half-lives greater than 30 years.

lps
Liters per second.

m^3/m
Cubic meters per minute.

m^3/s
Cubic meters per second.

macroinvertebrates
Those invertebrates that can be seen by the unaided eye that are retained in a U.S. Standard sieve (0.595 millimeters).

BB-4 macrophytes
Aquatic plants that can be either submerged or emergent.

marine terrace
Narrow coastal strip altered by marine deposit and erosion.

maximum permissible dose
That dose of ionizing radiation established by competent authorities as an amount below which there is no appreciable risk to human health; at the same time, it is below the lowest level at which a definite hazard exists.

mechanical draft (cooling tower)
A type of cooling tower that uses fans to provide air flow for promoting evaporative cooling (see natural draft).

megawatt (MW)
A unit of power equal to 1000 kilowatts (kW) or 1 million (10^6) watts.

mg
Milligram (one-thousandth of a gram).

mica
Variously colored, or colorless mineral silicates, crystallizing in monoclinic forms that separate into thin leaves.

micro (μ)
Prefix indicating one millionth. One microgram equals one-millionth of a gram or 10^{-6} gram.

micrometer (μm)
A unit of length equal to one one-millionth (10^{-6}) of a meter.

micron
A micrometer (10^{-6} meter).

migration
The natural travel of a material through the air, soil, or groundwater.

ml
Milliliter (one-thousandth of a liter).

mm
Millimeter (one-thousandth of a meter).

mobility
The ability of a chemical element or a pollutant to move into and through the environment.

moderator
A material used to slow neutrons from fission to thermal energies.

molecule
A group of atoms held together by chemical forces. A molecule is the smallest unit of a compound that can exist by itself and retain all its chemical properties.

monitoring
Process whereby the level and quality of factors that can affect the environment and human health are measured periodically to regulate and control potential impacts.

mrem
Millirem (one-thousandth of a rem).

mutagen
Physical, chemical, or radiative agent capable of inducing mutation (above the spontaneous background level).

mutagenesis
The occurrence or induction of mutation, a genetic change that is passed on from parent to offspring.

mutation
An inheritable change in the genetic material (in a chromosome).

nano
Prefix indicating one thousandth of a micro unit; one trillionth; 1 nanocurie = 10^{-9} curie.

National Register of Historic Places
A list maintained by the National Park Service of architectural, historic, archaeological, and cultural sites of local, state, or national significance.

natural draft (cooling tower)
A type of cooling tower that relies on the difference in density between the entering air and internal heated air to provide air flow for promoting evaporative cooling (see mechanical draft).

natural radiation or natural radioactivity
Background radiation.

nCi
Nanocuries, 10^{-9} curies.

NEPA
National Environmental Policy Act of 1969.

neutron
An uncharged elementary particle with a mass slightly greater than that of the proton and found in the nucleus of every atom heavier than hydrogen. A free neutron is unstable and decays with a half-life of about 13 minutes into an electron and a proton.

neutron flux
Number of neutrons flowing through a specified area per unit of time.

NH_3
Ammonia, a pungent, reactive colorless gas, which is irritating to the eyes and moist skin in high concentrations.

NO_x
The oxides of nitrogen, primarily NO and NO_2. These are often produced in the combustion of fossil fuels. In high concentration they constitute an air pollution problem.

nodes
The intersection of horizontal and vertical grids.

NRC
U.S. Nuclear Regulatory Commission.

nuclear energy
The energy liberated by a nuclear reactor (through fission or fusion) or by radioactive decay.

nuclear powerplant
A facility that converts nuclear energy into electrical power. Heat produced by a reactor is used to make steam to drive a turbine that drives an electric generator.

nuclear reaction
A reaction in which an atomic nucleus is transformed into another element, usually with the liberation of energy as radiation.

nuclear reactor
A device in which a fission chain reaction is maintained and which is used for irradiation of materials or the generation of electricity.

nucleus
The small, positively charged core of an atom that contains nearly all of the atom's mass.

nuclide
An atomic nucleus specified by its atomic weight, atomic number, and energy state. A radionuclide is a radioactive nuclide.

once-through (cooling system)
A cooling system that utilizes water from a river one time for cooling and then returns it to the river.

organic degreasers
Cleaning agents having organic chemical structures.

outcrop
Part of a geologic formation above the surface of the earth.

Paleocene
Epoch of Tertiary Period between the Gulfian of the Cretaceous Period and before the Eocene.

particulates
Solid particles small enough to become airborne.

pD
The negative log of the deuterium (heavy hydrogen) ion concentration in solution; analogous to the term pH, which refers to the normal hydrogen ion concentration.

peneplain
Almost featureless, plain land surface.

perched
A water-bearing area of small lateral dimensions lying above a more extensive aquifer.

periphyton
Plankton (attached) plants that occur in water. BB-4

permeability

Ability of water to flow through porous rock or soil.

person-rem

The radiation dose commitment to a given population; the sum of the individual doses received by a population segment.

pH

A measure of the hydrogen ion concentration in aqueous solution; specifically, the negative logarithm of the hydrogen ion concentration. Acidic solutions have a pH from 0 to 7; basic solutions have a pH greater than 7.

photon

Electromagnetic radiation; a quantum of electromagnetic energy having properties of both a wave and a particle but without mass or electric charge.

physiography

Description of earth surface features, including air and water as well as land.

BB-4 phytoplankton

Planktonic (floating) plants that occur in water.

Piedmont province

Large area forming a plateau at the base of the Appalachian mountains, extending from New Jersey to Alabama.

piezometric maps

Lines of equal groundwater pressure drawn on a map.

piezometric surface

The surface to which water in an aquifer would rise by hydrostatic head.

Plant stream

Any natural stream on the Savannah River Plant. Surface drainage of the Plant is via these streams to the Savannah River.

Pleistocene

An epoch of the Quaternary Period between Pliocene and Holocene.

Pliocene

An epoch of the Tertiary Period between Miocene and Pleistocene.

plume

The visible emission into the air from a flue, chimney, or cooling tower. Also, a segment or area within a body of water that has measurably distinct characteristics (e.g., higher temperatures as from heated effluent).

pollution

The addition of any undesirable agent to an ecosystem in excess of the rate at which they can be degraded, assimilated, or dispersed by natural processes.

ppb

Parts per billion (10^{-9}); one thousandth of a part per million.

ppm

Parts per million. This unit is commonly used to represent the degree of pollutant concentration when the concentration is small. In air, ppm is usually volume pollutant per one million volumes of air; in water, a weight per one million weight units.

primary road

Interstate, state, and regional routes including rural arterial routes and their extensions into or through urban areas.

pyrite

Isometric mineral: FeS_2 (iron sulfide).

quality factor

The factor by which absorbed dose, in rads, is multiplied to obtain a quantity expressing the irradiation incurred by various biological tissues taking into account the biological effectiveness of the various types of radiation.

quartz

Crystalline silica: SiO_2.

quartzite

Very hard, metamorphosed sandstone.

Quaternary age

The period from the end of the Tertiary age to the present.

rad

Acronym for radiation absorbed dose, the basic unit of absorbed dose equal to the absorption of 0.01 joule per kilogram of absorbing material.

radiation

The emitted particles and photons from the nuclei of radioactive atoms. Some elements are naturally radioactive whereas others are induced to become radioactive by bombardment in a reactor. Naturally occurring radiation is indistinguishable from induced radiation.

radiation detection instrument

Devices that detect and record the characteristics of ionizing radiation.

radiation monitoring

Continuous or periodic determination of the amount of radiation present in a given area.

radiation protection

Legislation, regulations, and measures to protect the public and industrial laboratory workers from harmful exposure to radiation.

radiation shielding

Reduction of radiation by interposing a shield of absorbing material between a radioactive source and a person, laboratory area, or radiation-sensitive device.

radiation standards

Permissible exposure levels of radiation and regulations governing same.

radioactivity

The spontaneous decay or disintegration of unstable atomic nuclei, accompanied by the emission of radiation.

radioisotopes

Nuclides of the same element (same number of protons in their nuclei) that differ in the number of neutrons and that spontaneously emit particles or electromagnetic radiation.

receiving waters

Rivers, lakes, oceans, or other bodies of water into which treated or untreated wastewaters are discharged.

recirculating (cooling system)

A cooling system that uses the same water cyclically to absorb heat and be cooled again. A percentage of new water must be added continuously to make up for evaporative and blowdown losses.

rem

Acronym for roentgen equivalent man, the unit of dose for biological absorption. It is equal to the product of the absorbed dose in rads, a quality factor, and a distribution factor.

residence time

The period of time during which a substance resides in a designated area.

roentgen (R)

A unit of exposure to ionizing radiation equal to or producing one coulomb of charge per cubic meter of air.

runoff

The portion of rainfall, melted snow, or irrigation water that flows across ground surface and eventually is returned to streams. Runoff can carry pollutants into receiving waters.

sandstone

Clastic rock containing large, individual particles visible to the unaided eye.

sanitary landfilling
An engineered method of solid waste disposal on land in a manner that protects the environment. Waste is spread in thin layers, compacted to the smallest practical volume, and covered with soil at the end of each working day.

SCDHEC
South Carolina Department of Health and Environmental Control

screen
Tool used to allow particles of a certain size through while retaining larger particles.

secondary road
A rural, major collector route.

sedimentation
The settling of excess soil and mineral solids of small particle size contained in water.

seep lines
Small zone where water leachate percolates slowly to the surface; a series of groundwater or leachate springs.

seismic
Pertaining to any earth vibration, especially an earthquake.

seismicity
The tendency toward the occurrence of earthquakes.

settling tank
A tank in which settlable solids are removed by gravity.

sewage
The total of organic waste and wastewater generated by an industrial establishment or a community.

sewer
Any pipe or conduit used to collect and carry away sewage or stormwater runoff.

sewerage
The entire system of sewage collection, treatment, and disposal.

shield
An engineered body of absorbing material used to protect personnel from radiation.

short-lived nuclides
Radioactive isotopes with half-lives no greater than about 30 years (e.g., cesium-137 and strontium-90).

siliceous cement
Cement with an abundance of silica.

siltstone
Silt having the texture and composition of shale, but lacking its fine lamination.

sink
An area from which water drains or is removed.

sludge
The precipitated solids (primarily oxides and hydroxides) that settle to the bottom of the storage tanks containing liquid high-level waste.

slug
Small, isolated body of water.

slurry
A suspension of solid particles (sludge) in water.

softwoods
Trees, particularly evergreens and shrubs, that produce seeds in a cone.

SO_2
Sulfur dioxide, a heavy pungent colorless gas (formed in the combustion of coal). SO_2 in high concentration is considered a major air pollutant.

SO_x
The oxides of sulfur, primarily SO_2 and SO_3. SO_x is a common air pollutant.

sparger
A discharge nozzle that provides quick dispersion of one fluid (liquid or gas) into another.

spill
The accidental release of radioactive material.

spray irrigation
The practice of dispersing treated aqueous effluents by spraying land in controlled amounts. Treated effluent is rich in nutrients that can be utilized by plants.

SREL
Savannah River Ecological Laboratory, an ecology research institution operated by the University of Georgia under contract from DOE.

SRL
Savannah River Laboratory.

SRP
Savannah River Plant.

stable
Not radioactive.

stack
A vertical pipe or flue designed to exhaust gases and suspended particulates.

stack gases
Gases emitted from a stack.

stationary source
A source of emissions into the environment that is fixed rather than moving, as an automobile.

storage
Retention of radioactive waste in manmade containment, such as a tank or vault, in a manner permitting retrieval; distinguished from disposal, which implies no retrieval.

storage coefficient
Volume of water released from storage in a vertical column of 0.93 square meter when the water table declines 0.93 meter.

stratified
Formed or arranged in layers.

stratigraphy
Division of geology dealing with the definition and description of rocks and soil of both major and minor natural divisions.

study area
A specific geographic area isolated from surrounding areas for the purpose of examining and analyzing specific phenomena and activities.

surface water
All water on the surface, as distinguished from groundwater.

surficial deposit
Most recent geological deposit lying on bedrock or on or near the earth's surface.

Tertiary age
First period of Cenozoic era, thought to be between 65 and 2 million years ago.

thermal pollution
Degradation of water quality by introduction of a heated effluent.

threshold dose
The minimum dose of a given substance that produces a measurable environmental factor.

tolerance
The relative capability of an organism to endure an unfavorable environmental factor.

topography
The configuration of a surface area, including its relief or relative elevations and the position of its natural and manmade features.

toxicity
The quality or degree of being poisonous or harmful to plant or animal life.

transmissivity
The rate at which water of prevailing kinematic viscosity is transmitted through a unit width under a unit hydraulic gradient.

Triassic Period
First period of the Mesozoic era, thought to be between 225 and 190 million years ago.

tritium (H-3)
A radioactive isotope of hydrogen, a weak beta emitter with a half-life of 12.5 years.

TSP
Total suspended particulates, the concentration of particulates in suspension in the air irrespective of the nature, source, or size of the particulates.

turbidity
Measure of sediment or suspended foreign particle concentration in solution.

unconsolidated
Loosely arranged or unstratified sediment.

USGS
United States Geological Survey.

venting
Release of gases or vapors under pressure to the atmosphere.

waste heat
Heat in materials at temperatures that are close to ambient and hence not valuable for production of power. Waste heat must be discharged to the environment.

water pollution
Presence of one or more contaminants in such degree as to be detrimental to the intended use of the water.

watershed
The area drained by a stream.

water table
The upper surface of groundwater.

wetland
Land or areas containing much soil moisture. BP-4 BC-19

zooplankton
Planktonic (floating) animals that supply food for fish.

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APPENDIX A

IDENTIFICATION OF COOLING WATER ALTERNATIVES FOR EVALUATION IN THE EIS

A.1 INTRODUCTION

This appendix describes the cooling water alternatives considered for K- and C-Reactors and the D-Area coal-fired powerhouse. It also discusses the process used to identify the cooling water alternatives that are evaluated in this environmental impact statement (EIS).

A.2 INITIAL ALTERNATIVES

As documented in the Thermal Mitigation Study (DOE, 1984), DOE initially considered two categories of cooling water alternatives: (1) those that would provide some reduction in the temperature of thermal discharges but that would not meet the 32.2°C Class B water classification standard of the State of South Carolina; and (2) those that could meet the 32.2°C water classification standard.

A.2.1 ALTERNATIVES NOT MEETING THE 32.2°C STANDARD

For alternatives that would not meet Class B water classification standards (such as rubble dams, small cooling lakes, and the current once-through cooling water systems), the South Carolina legislature and the U.S. Environmental Protection Agency (EPA) would have to approve a new stream classification (i.e., a change in the designation of several onsite streams from Class B to some other classification) after DOE had submitted a use attainability analysis in accordance with EPA regulations (40 CFR 131).

Because of the concern over both the applicability of EPA and State regulations that prohibit designating the use of a stream for waste transport or waste assimilation and the inapplicability of criteria contained in EPA's regulations [40 CFR 131.10(g)] by which a change in designated uses could be justified, DOE eliminated from further consideration those alternatives that would not meet Class B water classification standards.

The following items describe the initial cooling water alternatives for K- and C-Reactors that were eliminated:

- Spray canals. This alternative would add a gravity-powered spray cooling system to the cooling water outlets of K- and C-Reactors to cool the discharged water by spraying it into the air before it enters the receiving water body. Both the 68°C maximum discharge temperature and the 66°C average summer temperature would be only slightly below the water temperatures that result from direct discharge (i.e., 73°C and 71°C, respectively).

- Small lakes. This system would use five to ten small rubble dams each on Four Mile Creek and Pen Branch to create small lakes; it would provide some thermal mitigation, compared to direct discharge, to the lower portions of these waterways and to the Savannah River swamp. Under extreme summer conditions, the 45°C discharge temperatures would represent a 28°C reduction below direct discharge (73°C), but they would not meet the 32.2°C temperature standard at any time during the year.

- Small lakes with upstream spray cooling (one set). This alternative is very similar to the small lakes alternative (above), but would include a gravity spray module in the outfall canal. It would result in some limited thermal mitigation in comparison to direct discharge, but would not provide much more cooling than the small lakes alternative alone. The 32.2°C water classification standard would not be met at any time during the year.

- Small lakes with upstream and downstream spray cooling (two sets). This alternative would add two gravity spray cooling modules to the basic small lakes alternative described above. The first spray system would obtain some cooling before the discharge water enters the receiving water body. The second spray module would be in the last shallow lake formed in either stream. The cooling from this system would be about 5°C greater than that resulting from the small lakes with upstream spray cooling (one set) described above. In comparison to direct discharge, this alternative would reduce water temperatures from 73°C to 39°C under extreme summer conditions and from 69°C to 34°C during the spring. It would be in compliance with the 32.2°C temperature limit only during the winter (29°C).

- Energy recovery systems. The systems that were considered included both onsite steam generation and the use of a Rankine cycle to generate electricity. The option of onsite steam generation would remove only 0.3 percent of the heat from the effluent stream, or a 0.3°C drop in effluent temperature at the outfall. The Rankine cycle would lower the effluent temperature from 71°C to 49°C. (See Appendix I for details.)

A.2.2 ALTERNATIVES MEETING THE 32.2°C STANDARD

For those alternatives that could meet the Class B water classification standards, DOE identified subcategories of potential generic cooling water systems for K- and C-Reactors and for the D-Area coal-fired powerhouse. The subcategories identified for K- and C-Reactors consisted of cooling towers, cooling lakes and ponds, and cooling lake/pond and cooling tower combinations. For the D-Area powerhouse, the subcategories included cooling towers, direct discharge to the Savannah River, and increased flow with mixing. DOE then developed minimum requirements for the identification in more detail of the specific alternatives in each subcategory. These requirements included sufficient surface area in cooling lakes or ponds for heat dissipation, and sufficient cooling capacity in once-through and recirculating cooling towers to attain a 32.2°C discharge temperature during extreme meteorological conditions.

Using these minimum requirements, DOE initially identified 22 potential cooling water alternatives for K- and C-Reactors and four alternatives for D-Area. The following list describes these alternatives:

K-Reactor Alternatives

K-1 1400-acre once-through cooling lake between Pen Branch and Four Mile Creek above the railroad track

K-2 1400-acre recirculating cooling lake between Pen Branch and Four Mile Creek above the railroad track

K-3 1300-acre once-through cooling lake on Pen Branch with an embankment 1219 meters below Road C

K-4 1300-acre recirculating cooling lake on Pen Branch with an embankment 914 meters below Road C

K-5 Recirculating cooling tower TC

K-6 Once-through cooling tower

K-7 Once-through cooling tower to a 600-acre once-through cooling lake on Indian Grave Branch with an embankment about 305 meters above the confluence with Pen Branch

K-8 800-acre cooling lake with a 400-acre hot arm to a once-through cooling tower with an embankment located about 610 meters above Road A on Pen Branch

K-9 1600-acre once-through cooling lake with an embankment in the same location as the 800-acre lake with 400-acre hot arm (above)

K-10 1700-acre once-through cooling lake on Pen Branch with an embankment about 2134 meters below Road C, and the reactor discharge pumped to the cooling lake

C-Reactor Alternatives

C-1 1200-acre once-through cooling lake on Four Mile Creek with an embankment about 1.6 kilometer above Road A

C-2 1200-acre recirculating cooling lake on Four Mile Creek with an embankment about 1.6 kilometer above Road A

C-3 1400-acre once-through cooling lake between Pen Branch and Four Mile Creek below the railroad track

C-4 Recirculating cooling tower TC

C-5 Once-through cooling tower

C-6 Once-through cooling tower to a 500-acre once-through cooling lake on a tributary of Four Mile Creek with an embankment about 305 meters above the confluence with Four Mile Creek

C-7 800-acre cooling lake with a 400-acre hot arm to a once-through cooling tower with an embankment on Four Mile Creek about 1280 meters above Road A

C-8 1700-acre once-through cooling lake on Four Mile Creek with an embankment about 1280 meters above Road A

C-9 1700-acre once-through cooling lake on Four Mile Creek with an embankment about 152 meters above Road 4, and the reactor discharge pumped to the cooling lake

K- and C-Reactors Alternatives

K/C-1 3000-acre recirculating cooling lake on Mill Creek with an embankment about 610 meters above the confluence with Tinker Creek

K/C-2 3000-acre once-through cooling lake on Mill Creek with an embankment about 610 meters above the confluence with Tinker Creek

K-, C-, and L-Reactors Alternatives

K/C/L-1 3000-acre once-through and recirculating cooling lake on Mill Creek with an embankment about 610 meters above the confluence with Tinker Creek

D-Area Powerhouse Alternatives

D-1 Direct discharge to the Savannah River
D-2 Once-through cooling tower
D-3 Increased flow with mixing
D-4 Recirculating cooling tower

A.3 SCREENING OF ALTERNATIVES

After the identification of the 26 cooling water alternatives that could meet Class B water classification standards, DOE used a screening process to determine which of these systems would be the most reasonable for implementation.

As documented in the Thermal Mitigation Study, the screening process consisted of the successive application of exclusionary criteria and discriminatory criteria. The application of "exclusionary" criteria led to the elimination of five cooling-lake alternatives for K- and C-Reactors. The "exclusionary" criteria are listed below:

1. The temperature of the receiving stream shall not exceed 32.2°C after mixing unless a Section 316(a) demonstration can be successfully performed.

2. The temperature of a receiving stream shall not be raised more than 2.8°C above ambient after mixing unless a Section 316(a) demonstration can be successfully performed.

3. Cooling lakes shall have a minimum surface area of 400 acres at a temperature of 32.2°C or less to support a successful Section 316(a) demonstration.

4. The average annual production loss shall be equal to or less than 10 percent for the purpose of screening.

This screening step eliminated the following alternatives:

No.	Alternative	Reasons for elimination
		K-Reactor
K-2	1400-acre recirculating cooling lake	Too small to provide needed cooling capacity
K-4	1300-acre recirculating cooling lake	Too small to provide needed cooling capacity
K-9	1600-acre once-through cooling lake	Hot arm of about 500 acres would not provide required cooling capacity
		C-Reactor
C-2	1200-acre recirculating cooling lake	Too small to provide needed cooling capacity
C-8	1700-acre once-through cooling lake	Hot arm of about 500 acres would not provide required cooling capacity

DOE screened the possible alternatives for the D-Area coal-fired powerhouse in the same manner as that used for the two reactors. However, it did not apply the criteria for maintaining a surface area of 400 acres at 32.2°C or less. The process found all four of the possible alternatives for the powerhouse to be feasible and eliminated none at this point.

The final step in the screening process was the application of the five "discriminatory" criteria listed below to identify "reasonable compliance alternatives":

1. Environmental impacts (i.e., thermal and flow effects resulting from the effluent discharge; habitat modifications such as impacts to wetlands and uplands; water quality; intake/discharge rates; impingement and entrainment; impacts to endangered and threatened species; and transport of radionuclides)

2. Implementation schedule (i.e., the estimated time to construct the alternative)

3. Costs (capital and operating)

4. Engineering and construction (i.e., the technical feasibility of engineering and constructing the alternative, such as pumping hot water over long distances, close approaches to wet bulb temperatures, nonstandard engineering and construction techniques)

5. Relative operating complexity (i.e., multiple reactor cooling systems versus recirculation systems versus once-through systems)

After the application of the discriminatory criteria, DOE eliminated the following nine alternatives:

No.	Alternative	Reasons for elimination
		K-Reactor
K-3	1300-acre once-through cooling lake	Environmental impacts, production loss, relative costs
K-10	1700-acre once-through cooling lake	Environmental impacts, relative costs, scheduling
		C-Reactor
C-1	1200-acre once-through cooling lake	Environmental impacts, production loss, relative costs
C-9	1700-acre once-through cooling lake	Environmental impacts, relative costs, scheduling
		K- and C-Reactors Combined
K/C-1	3000-acre recirculating cooling lake	Relative costs, production loss, operating complexity, engineering considerations
K/C-2	3000-acre once-through cooling lake	Environmental impacts, operating complexity, relative costs
		K-, C-, and L-Reactors Combined
K/C/L-1	3000-acre once-through and recirculating cooling lake	Operating complexity, scheduling

No.	Alternative	Reasons for elimination
	D-Area Powerhouse	
D-2	Once-through cooling tower	Relative costs, operating complexity compared to direct discharge
D-4	Recirculating cooling tower	Relative costs, operating complexity compared to direct discharge

As a result of the successive application of the exclusionary and discriminatory criteria, DOE identified the following alternatives as reasonable for implementation for K- and C-Reactors and the D-Area coal-fired powerhouse:

K-Reactor Alternatives

K-1 1400-acre once-through cooling lake between Pen Branch and Four Mile Creek above the railroad track

K-5 Recirculating cooling tower

K-6 Once-through cooling tower TC

K-7 Once-through cooling tower to a 600-acre once-through cooling lake on Indian Grave Branch with an embankment about 305 meters above the confluence with Pen Branch

K-8 800-acre cooling lake with a 400-acre hot arm to a once-through cooling tower with an embankment located about 610 meters above Road A on Pen Branch

C-Reactor Alternatives

C-3 1400-acre once-through cooling lake between Pen Branch and Four Mile Creek below the railroad track

C-4 Recirculating cooling tower TC

C-5 Once-through cooling tower

C-6 Once-through cooling tower to a 500-acre once-through cooling lake on a tributary of Four Mile Creek with an embankment about 305 meters above the confluence with Four Mile Creek

C-7 800-acre cooling lake with a 400-acre hot arm to a once-through cooling tower with an embankment on Four Mile Creek about 1280 meters above Road A

D-Area Powerhouse Alternatives

D-1 Direct discharge to the Savannah River

D-2 Increased flow with mixing

A.4 ALTERNATIVES CONSIDERED IN THIS EIS

As part of the scoping process, DOE invited interested parties to comment on the alternatives it would consider in this environmental impact statement (Federal Register, 50 FR 30728). Because of unfavorable topographic features in the areas around K- and C-Reactors and the resulting high capital costs for constructing large cooling lakes, DOE proposed that this statement consider only the once-through and recirculating cooling towers. In addition, DOE proposed that it not perform a detailed evaluation of the alternative calling for direct discharge of D-Area effluents to the Savannah River because of its higher capital costs, the longer schedule for implementation, and the potential reduction in habitat for endangered species that would be caused by the reduction in flow in Beaver Dam Creek. During the scoping period, DOE received no comments related to its preliminary determination of reasonable alternatives to be considered in the environmental impact statement.

Based on the screening process as documented in the Thermal Mitigation Study (DOE, 1984) and DOE's preliminary determination (50 FR 30728), DOE has decided to consider in detail in this environmental impact statement the alternatives of once-through and recirculating cooling towers for the K- and C-Reactors in addition to the "no-action" alternative (required by the Council on Environmental Quality for implementing the procedural provisions of the National Environmental Policy Act). For the D-Area coal-fired powerhouse, the Department has decided to consider in detail the alternatives of increased pumping to the raw water basin, direct discharge to the Savannah River, and "no action."

AD-1 Since the completion of the Thermal Mitigation Study and the Draft EIS (DOE,
1986), further design evaluations and studies have been initiated to determine
AD-2 optimal performance parameters and to achieve lower costs. These evaluations
and studies have indicated that, in several areas, optimization of performance
BB-1 and cost savings can be realized in the construction and operation of once-
BB-2 through towers without introducing major changes in the nature or magnitude of
the environmental impacts. These areas include the consideration of gravity-
BB-3 feed versus pumped-feed towers, natural-draft versus mechanical-draft towers,
BC-4 and a chemical injection system for either dissipation or neutralization of
chlorine biocide versus holding ponds (and their sizing). Similarly, these
BC-5 evaluations and studies have also led to the development of thermal perform-
BC-6 ance criteria that, when incorporated in the final design of a once-through
cooling-tower system, would reduce the potential for cold shock (i.e., reduce
BC-14 the difference between ambient stream temperatures and stream temperatures
BD-1 when the cooling water is being discharged) to fish.

REFERENCES

DOE (U.S. Department of Energy), 1984. Thermal Mitigation Study, Compliance with Federal and South Carolina Water Quality Standards, Savannah River Plant, Aiken, South Carolina, DOE/SR-5003, Savannah River Operations Office, Aiken, South Carolina.

DOE (U.S. Department of Energy), 1986. Draft Environmental Impact Statement, Alternative Cooling Water Systems, Savannah River Plant, Aiken, South Carolina, DOE/EIS-0121D, Savannah River Operations Office, Aiken, South Carolina. TC

APPENDIX B

THERMAL MODELING

B.1 INTRODUCTION

The thermal performance information presented in Sections 2.2, 2.3, and 2.4 of this environmental impact statement (EIS) was calculated with the aid of three models. The Cooling-Tower Performance (CTPERF) model computes effluent stream (water and air) temperatures as a function of influent stream properties and tower design. The Surface-water Heat, Savannah River Plant (SHSRP) model computes downstream temperatures along the SRP streams (Four Mile Creek, Pen Branch, Steel Creek, and Beaver Dam Creek) that receive cooling water effluent. The latter computation is performed as a function of effluent stream and extant meteorological properties. The Savannah River Dilution - D-Area (SRDD) model computes the temperature or dilution distribution in the Savannah River from D-Area based on discharge design and river flow.

In addition to a discussion of these three thermal performance models, this appendix also provides a brief description of the model (FOG) that has been used to calculate cooling system fogging, icing, visible plumes, and drift deposition.

B.2 COOLING-TOWER PERFORMANCE MODEL (CTPERF)

B.2.1 MODEL DESCRIPTION

The cooling of artificially heated water, such as the heated secondary cooling water at C- and K-Reactors, is a surface transport phenomenon between the water and the heat receptor (in this case the atmosphere). The cooling towers described in Chapter 2 of this EIS are efficient in this heat transfer because they maximize the exposed surface area of the water (via droplet formation) and introduce a heat sink (air) that does not contain residual heat from tower operation (due to the buoyancy of the heated air stream).

The heat-transfer process involves, chiefly, the transfer of latent heat due to the evaporation of a small portion of the water; a secondary cooling process is the transfer of heat due to the temperature difference between air and water. The theoretical limit to which the influent water temperature can be cooled is determined by the temperature and moisture content of the influent air stream. The wet-bulb temperature (t_{wb}), which is the temperature of saturated air at the same enthalpy (heat content) as the influent air, is an indication of the temperature and moisture content of the influent air and, as such, represents the theoretical limit to which the influent water temperature can be cooled. Practically, the cold-water temperature approaches, but does not equal, the wet-bulb temperature. The closeness of the approach depends on tower design parameters such as air-water contact time and droplet size (Perry, 1963).

The present analysis is based on the generally accepted Merkel equation (Perry, 1963).

$$\frac{KaV}{L} = \int_{t_2}^{t_1} \frac{dt}{h' - h} \tag{1}$$

where K = mass transfer coefficient, $gm/hr/m^2$
a = contact area, m^2/m^3 of tower volume
V = active cooling volume, m^3
L = water flow rate, gm/hr
h' = enthalpy of saturated air at the water temperature, cal/gm
h = enthalpy of influent air stream, cal/gm
t_1 = temperature of influent water stream, °C
t_2 = temperature of effluent water stream, °C

Equation 1 expresses the mechanism of each droplet of water being surrounded by a film of air and the enthalpy difference between the film and surrounding air providing the driving force for the heat transfer. The left-hand side of Equation 1 is entirely in terms of tower-operating parameters, while the right-hand side is entirely in terms of air and water properties.

The latter characteristic of Equation 1 facilitates its use to compute tower performance. Tower design conditions (t_1, t_2, and t_{wb}) completely specify the value of the integral on the right-hand side of Equation 1. This value, called the tower characteristic, is dependent only on tower design parameters. Accordingly, t_2 can be obtained by implicitly solving Equation 1 for any given air wet-bulb temperature (t_{wb}), which defines h, hot-water temperature (t_1), and tower characteristic (determined, as described above, from design conditions). In addition, effluent air temperature is calculated by a heat balance approach; that is, the heat lost by the water in the tower is equated to the heat gained by the air.

As discussed above, the enthalpy difference h'-h is the driving force for cooling. The larger this difference, the more rapid the cooling of the water. Mathematically, the right-hand side of Equation 1 is the area under the $\frac{1}{h' - h}$ vs. t curve from t_2 to t_1.

At large values of t (i.e., close to t_1), the fraction $\frac{1}{h'-h}$ is very small.

As t decreases, the fraction correspondingly increases until, at $t = t_{wb}$, the fraction becomes infinite (the theoretical limit of cooling). This behavior of the integral can be related to the left-hand side of Equation 1, which indicates (for given flow rates) the tower characteristics. The cooling of the water from its initially high temperatures is very rapid and uses a small fraction of the tower. The cooling of the water at low temperatures is very slow and uses the major part of the tower. In terms of tower design, the size of the tower increases (approximately) exponentially for each increment of cooling desired.

The air flow rate is specified (constant) for the fan-driven mechanical draft tower. For the natural draft tower, the air flow rate is a function of the density difference between the incoming and outgoing air. The dry air flow rate can be derived by applying the Bernoulli equation and continuity to the tower inlet and outlet cross-sections. The result is:

$$G = A_2 U_2 \left(\frac{\rho_1}{1 + H_1} \right)$$

where: $$U_2^2 = \frac{2 g_c y \left(\frac{\rho_1 - \rho_2}{\rho_2} \right)}{1 + k \frac{\rho_2}{\rho_1} \left(\frac{A_2}{A_1} \right)^2}$$ BB-3 BC-4 BC-14 BC-15

g_c = 980 dynes/gm
y = tower height, m
ρ = density of air, gm/m^3
k = loss coefficient
A = cross-section area, m^2
U = air velocity, m/sec
H = absolute humidity, gm-water/gm-dry air
G = dry air flow rate, gm/sec
subscript 1 = tower inlet
subscript 2 = tower outlet

CTPERF model results have shown excellent comparison with published tower design curves (Hickey and Cates, 1973).

B.2.2 MODEL USE

Table B-1 contains mean and maximum monthly wet bulb temperatures for the period 1952-1982 (Morris, 1987a). Tower effluent water temperatures, also given in Table B-1, are based on vendor supplied information. CTPERF was used to calculate performance equations relating effluent air temperatures and flow rates as a function of influent air wet bulb temperature and relative humidity. BB-3 BC-4

Once-through tower influent water temperatures, T_1, were based on monthly average reactor intake (Savannah River) temperatures (DOE, 1984a). These reactor intake temperatures were elevated by the temperature rise through the reactor heat exchangers, which can be described (Neill and Babcock, 1971; NUS Corporation, 1984) as

$$\Delta T = 65.79 - .6568\, T_{in} \qquad (2)$$

where ΔT = maximum reactor power secondary cooling water temperature rise across reactor heat exchangers, °C
T_{in} = reactor intake temperature, °C

Adding T_{in} to Equation 2 yields

$$T_1 = 65.79 + .3433\, T_{in} \qquad (3)$$

Table B-1. Monthly Average and Maximum Cooling-Tower Temperatures (°C)

Temperature	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wet-bulb temperature												
Monthly average[a]	4	6	11	14	18	22	23	23	21	14	10	6
Monthly maximum[b]	20	20	21	24	25	26	27	27	26	25	23	21
Savannah River temperature												
Monthly average	8	8	11	15	18	21	23	23	22	19	15	11
Once-through tower effluent temperature												
Monthly average	19	20	23	24	26	28	29	29	28	24	23	21
Monthly maximum	28	28	28	30	30	31	32	32	31	31	29	28
Recirculating tower effluent temperature												
Monthly average	14	15	18	20	23	26	27	26	25	20	18	15
Monthly maximum	25	25	26	28	28	29	30	30	29	28	27	26

[a]Based on average dry bulb temperature and relative humidity.
[b]Based on maximum monthly dry bulb and coincident relative humidity.

BB-3
BC-14
BC-15

Recirculating influent water temperatures are determined by imposing Equation 3 on the tower performance calculations. That is, rather than specifying the influent tower water temperature, T_1, and calculating the effluent water temperature, T_2, the calculation imposes the functional relationship

$$T_1 = 65.79 + .3433T_2 \quad (4)$$

onto the implicit cooling-tower calculations. Effluent natural draft water temperatures were used as influent water temperatures for the mechanical draft tower in the recirculating system. BB-3 BC-4

B.2.3 MODEL RESULTS

The above information was used to calculate the effluent air performance equations for once-through (design conditions: T_2 = 32.2°C, T_{wb} = 27.8°C) and recirculating (natural draft design conditions: T_2 = 38.1°C, T_{wb} = 26.7°C; mechanical draft design conditions: T_1 = 38.1°C, T_2 = 29.4°C, T_{wb} = 26.7°C) towers (Morris, 1987a). These results were used in simulating environmental effects (fogging, icing, aesthetics, deposition) from the effluent air stream (see Section B.5). Table B-1 includes the mean and maximum monthly effluent water temperature for each system type. The effluent water temperatures listed in Table B-1 are those included in the Chapter 2 thermal performance analyses. BB-3 BC-4 BC-14 BC-15

The once-through towers are designed to meet State Class B water classification standards of a maximum instream temperature of 32.2°C at the point of discharge to the creeks. Table B-1 shows that the tower discharge will meet this requirement for all monthly maximum conditions.

The recirculating towers are also designed to meet State Class B water classification standards. However, because the effluent water also serves as influent water, this system has been designed to further lower the water temperature. A comparison of once-through and recirculating tower effluent temperatures in Table B-1 illustrates this difference.

B.3 SURFACE-WATER HEAT, SAVANNAH RIVER PLANT MODEL (SHSRP)

B.3.1 MODEL DESCRIPTION

As in the case of CTPERF, the cooling of artificially heated surface waters is a transport phenomenon between the water and the heat receptor (the atmosphere). Unlike the cooling towers, however, other processes contribute to this heat transfer.

The flux of heat across the water surface has various components that can be either positive (heat entering the water) or negative (heat exiting the water). The major processes are solar radiation, atmospheric radiation, back radiation from the water body, evaporation, and conduction.

The net solar heat flux, ϕ_{sn}, consists of incident solar radiation minus reflected solar radiation. The incident, clear-sky, solar radiation is a function of latitude, time of day, and time of year. In addition, reflection, scattering, and absorption by gases, water vapor, and particulates in the atmosphere will affect this term. Accordingly, empirical representations are usually used to calculate the temporal distribution of incident solar radiation at a particular site. Reflected solar radiation from the water surface ranges from 5 to 10 percent of incident radiation (Thackston and Parker, 1971). A value of 6 percent was used in producing the baseline data for this study. The reduction of incident solar radiation by cloud cover is described by the factor $(1 - .65c^2)$ where c is the cloud cover (range of 0 to 1). The net temporal distribution of solar radiation used as the baseline for this study was produced by the UHSPOND code (Codell and Nuttle, 1980). The back radiation from the water surface is essentially "black body" radiation. The latter is described by the Stephan-Boltzmann law (Bird, Stewart, and Lightfoot, 1966):

$$\phi_b = \varepsilon\sigma(T_s + 273)^4 \qquad (5)$$

TE

where ε = atmospheric emissivity (1 for a theoretical black body)
σ = Stephan-Boltzmann constant (1.17×10^{-6} Cal/m^2 - day - $^\circ$K)
$T_s + 273$ = absolute temperature of the water surface in $^\circ$K

The emissivity of the water is well-known as 0.97 (Ryan and Stolzenbach, 1972). The long-wave atmospheric radiation, ϕ_a, is also described by Equation 5, except that the temperature used is that of the atmosphere, T_a. The emissivity of the atmosphere can be empirically described as

$$\varepsilon = 9.4 \times 10^{-6} (T_a + 273)^2 (1 + .17c^2) \qquad (6)$$

where the cloud-cover term describes the darkening of the sky and the attendant increase in emissivity. The net atmospheric radiation, ϕ_{an}, is taken as 97 percent (the water surface reflecting 3 percent) of the incident radiation (Ryan and Stolzenbach, 1972).

The evaporative heat flux, ϕ_e, from the water surface is mechanically equivalent to the latent heat of vaporization of the water being evaporated into an atmospheric boundary layer (which is in equilibrium with the water surface) and subsequently transported to the atmosphere. This transport (convection) of heat has two components: forced convection (due to the wind) and free convection (due to buoyancy effects).

The forced convection term, ϕ_{e1}, is empirically described as

$$\phi_{e1} = kW_2 (e_s - e_a) \qquad (7)$$

TE

where k = a constant
W_2 = the wind speed 2 meters above the water surface in meters per second
e_s = the saturated vapor pressure at the temperature of the water surface in mm Hg
e_a = the vapor pressure of the air (mm Hg)

The form of the free convection term, ϕ_{e2}, is taken from experimental work of free convection over a flat plate modified by the fact that water vapor is lighter than air (and, therefore, evaporation increases the buoyancy forces) (Ryan and Stolzenbach, 1972). The result is

$$\phi_{e2} = 18.4\ (T_{sv} - T_{av})^{1/3}\ (e_s - e_a) \tag{8}$$

TE

where $T_v = (T + 273)/(1 - .378e/p)$
$e = e_a$ and $T = T_a$ for $T_v = T_{av}$
$e = e_s$ and $T = T_s$ for $T_v = T_{sv}$
p = atmospheric pressure in mm Hg

The total evaporative heat flux, ϕ_e, is then the sum of $\phi_{e1} + \phi_{e2}$. A value of $k = 31.3$ (for the units given above) has been found to be appropriate (Ryan and Stolzenbach, 1972).

Previous studies have shown that the evaporative heat flux as calculated by Equations 7 and 8 is too large. A multiplicative constant, C, can be defined that results in a better approximation to the actual flux. A value of 0.78 has been found elsewhere (Firstenberg and Fisher, 1976) and is used here.

Heat conducted from the water to the atmosphere via the atmospheric boundary layer must be transported analogously to the convection of evaporative heat flux. The heat conduction flux, ϕ_c, is related to ϕ_e through the Bowen Ratio; that is

$$\phi_c/\phi_e = R(T_s - T_a)/(e_s - e_a) \tag{9}$$

where R = .46 mm Hg/°C (Ryan and Stolzenbach, 1972).

The total heat flux, ϕ, into the water surface is then:

$$\phi = \phi_{sn} + \phi_{an} - \phi_b - \phi_e - \phi_c \tag{10}$$

Equation 10 allows the total heat flux to be calculated, given the solar radiation, air temperature, cloud cover, water temperature, wind speed, and relative humidity. For a given set of meteorological conditions, the only variable in this list is the water temperature, T_s. For the site streams, where the flow will be vertically well mixed (due to turbulent and shallow flow) and plug flow in character (due to the long, narrow nature of the streams and the assumed steady flow and meteorology), the equation describing the conservation of heat can be written as (Harleman, 1972)

$$\frac{UdT}{dx} = \frac{\phi}{\rho c d} \tag{11}$$

where U = average cross-section velocity, m/sec
T = water temperature, °C
x = downstream distance, m
ρ = density of water, gm/m^3
c = specific heat of water, cal/gm-°C

d = depth, m
ϕ = total heat flux into the water surface, cal/m^2-sec

Equation 11 quantitatively expresses that the change in heat content of the creek over a given distance (left-hand side of equation) is equal to the heat passing through the water surface over this distance (right-hand side of equation). For a given discharge and a given distance, all parameters in Equation 11 are known except for T and ϕ. Equation 11 together with Equation 10 allows the computation of T vs. x.

To facilitate the computation and illustrate the behavior of the solution, the concepts of surface-heat-exchange coefficient and equilibrium temperature are introduced. The surface-heat-exchange coefficient, K, relates the change in heat transfer rate to the change in water surface temperature (Edinger and Geyer, 1965):

TC

$$K = \frac{-\partial\phi}{\partial T} \qquad (12)$$

The equilibrium temperature, T_e, is the temperature that the water approaches for a given set of meteorological conditions (analogous to the wet-bulb temperature for cooling towers) and is that temperature at which $\phi = 0$ (calculated from Equation 10). Integrating Equation 12 and noting the definition of T_e yields:

$$\phi = -K\,(T - T_e) \qquad (13)$$

which, when substituted in Equation 11, results in:

$$\frac{dT}{T-T_e} = \frac{-KW}{cQ}\,dx \qquad (14)$$

where Q = flow rate, m^3/sec
W = surface width, m
$Q/W = Ud$

Equation 14 can be integrated (for constants K, Q, W, and T_e) to give:

$$\frac{T_1 - T_e}{T_2 - T_e} = \exp \frac{KW}{\rho cQ}\,(x_2 - x_1) \qquad (15)$$

where the subscript 1 indicates the inflow location and subscript 2 indicates the outflow location.

In typical applications (e.g., steam power plants) where the heat-exchange temperature rise is relatively small (e.g., 10°C), Equation 15 can be directly applied. However, for such applications as the highly elevated discharge temperatures from the existing C- and K-Reactor systems, the value of K cannot be considered constant over the large ranges of temperature, $T_1 - T_2$. This is illustrated in Figure B-1, which shows K vs. T for typical site summer meteorological conditions. [Analogous to the cooling-tower analysis, the rate of cooling at high temperatures (high K) is much more rapid than that at low temperatures (low K) due to the exponential relationship between K and

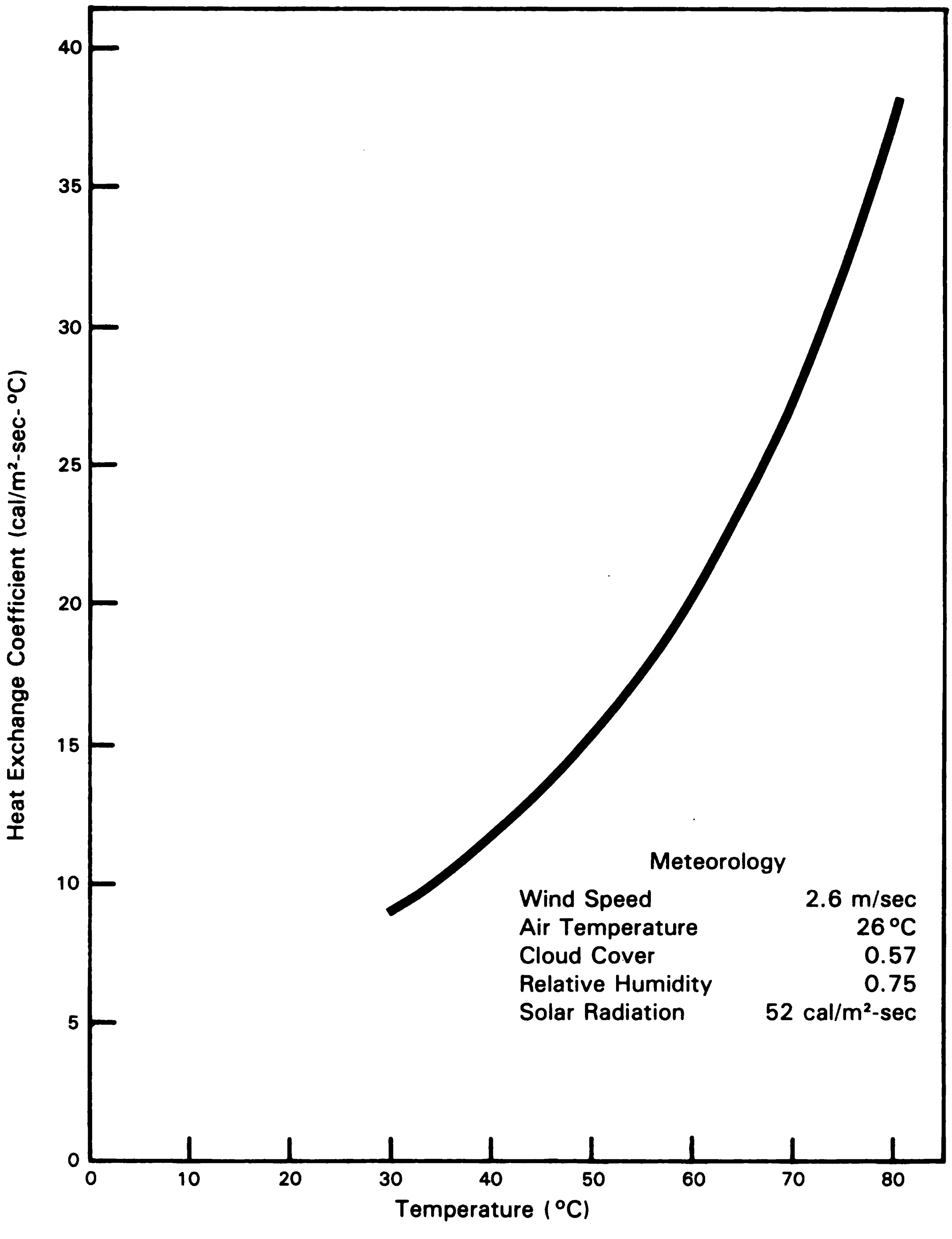


Figure B-1. Heat Exchange Coefficient vs Temperature (Typical Summer Conditions)

the water temperature]. Accordingly, SHSRP computes Equation 15 iteratively; that is, a series of small temperature steps, $T_1 - T_2$, are taken and the summation of the corresponding values of $x_2 - x_1$ is calculated. The process is repeated until the summation matches the required value.

SHSRP results have been compared with analytic solutions to the heat balance problem (Ryan, 1972). With the conditions for which analytic solutions are feasible (i.e., constant stream width), the two methodologies were in exact agreement. The results of SHSRP, with variable stream width, were also compared with temperatures measured in the thermally loaded SRP streams, Pen Branch and Four Mile Creek. Ground truth and remote sensing data for eight dates, which covered all seasons and a variety of operating modes, were used for the comparison. The Pearson product-moment correlation coefficients, which measure the linear relationship (or trend) between the measured and predicted temepratures, were found to be 0.93 and 0.86 for Pen Branch and Four Mile Creek, respectively. These coefficients indicate that SHSRP is a valuable tool in predicting SRP stream temperatures. The difference from a perfect correlation (coefficient = 1) could be explained by the error inherent in the measured temperatures, the uncertainty of the extant ambient flows, and the fact that the measurements are instantaneous, whereas the model uses daily average information.

B.3.2 MODEL USE

BC-4
BC-14
BC-15
SHSRP was used to calculate downstream temperature distributions during monthly average and extreme meteorological conditions for the various cooling-system alternatives for C- and K-Reactors and the D-Area powerhouse. Meteorological conditions (wind speed, air temperature, cloud cover, solar radiation, and relative humidity) were taken as those measured at Bush Field for the 30-year period 1953 to 1982 (NCDC, 1983). Table B-2 contains the minimum, mean, and maximum monthly average meteorological parameter values for the period of record.

BC-4
BC-14
BC-15
Equilibrium temperatures for daily average meteorological conditions were calculated for the 30-year period, and monthly averages of these values are given in Table B-2. Extreme monthly meteorological conditions were chosen as those extant during the months corresponding to the maximums in Table B-2. Average monthly meteorological conditions are the mean monthly averages given in the same table.

B.3.3 MODEL RESULTS

The above information was used to calculate the downstream temperatures in Four Mile Creek, Pen Branch, and Beaver Dam Creek during monthly average and extreme meteorological conditions. Downstream temperatures for the various alternatives and creeks, as illustrated in Figure B-2, are compiled in Tables B-3 through B-5.

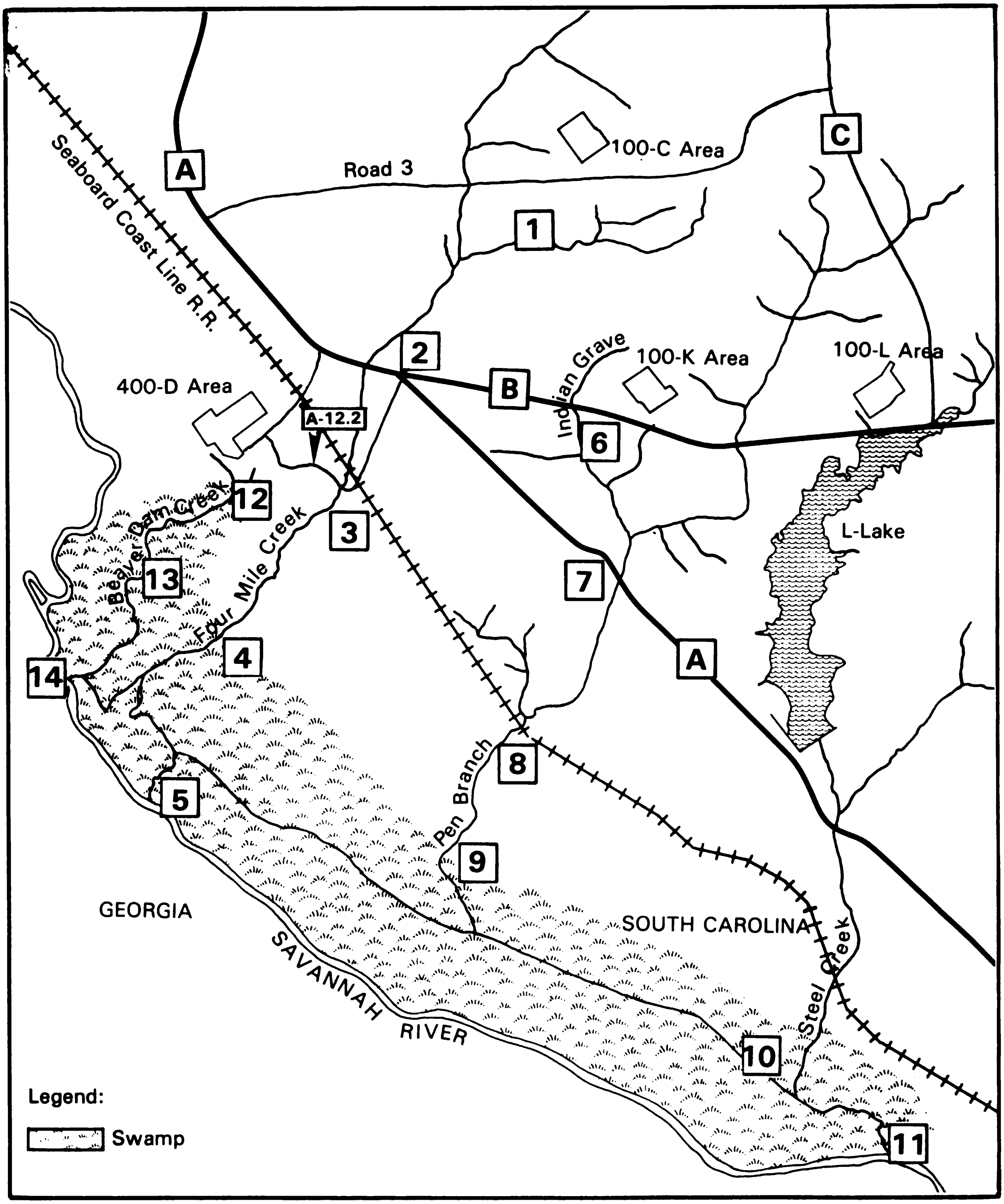
BC-4
BC-14
BC-15
The tower discharge temperatures are based on the appropriate values from Table B-1. The once-through tower discharge flow rate is 11 cubic meters per second and the recirculating tower discharge (blowdown) flow rate is 0.7 cubic meter per second (Morris, 1987a). The annual average Four Mile Creek (at Road A-7) and Pen Branch (at Road B) flows, other than reactor effluent, are approximately 0.5 and 0.3 cubic meter per second, respectively, and are assumed to be at equilibrium temperature (Morris, 1987b).

BC-4
BC-14
BC-15

Table B-2. Monthly Minimum, Mean, and Maximum Meteorological Parameters Used in the Analysis of Downstream Temperatures

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wind speed, m/sec												
Minimum monthly average	2.3	2.9	3.2	2.6	2.3	2.1	2.1	2.1	1.9	1.9	2.0	2.3
Mean monthly average	3.2	3.5	3.6	3.4	2.9	2.8	2.6	2.5	2.5	2.6	2.8	3.0
Maximum monthly average	3.8	4.3	4.3	4.5	3.6	3.7	3.1	2.9	3.2	3.3	3.4	3.8
Air temperature, °C												
Minimum monthly average	2	4	7	14	19	23	24	24	20	15	9	4
Mean monthly average	7	8	12	17	21	25	26	26	23	17	12	8
Maximum monthly average	13	13	16	19	24	27	28	28	25	20	14	13
Cloud cover, fraction												
Minimum monthly average	.35	.27	.40	.36	.42	.37	.40	.32	.31	.16	.33	.46
Mean monthly average	.58	.54	.56	.50	.55	.56	.61	.54	.53	.42	.47	.54
Maximum monthly average	.73	.78	.73	.65	.77	.67	.80	.72	.71	.67	.61	.70
Solar radiation, cal/m^2-sec												
Minimum monthly average	21	27	34	43	43	48	40	41	36	30	27	20
Mean monthly average	26	34	41	51	53	56	53	52	44	40	31	25
Maximum monthly average	33	44	48	57	61	65	64	63	54	49	36	28
Relative humidity, fraction												
Minimum monthly average	.59	.53	.56	.60	.63	.61	.66	.68	.71	.64	.63	.62
Mean monthly average	.71	.67	.66	.66	.71	.72	.75	.76	.77	.74	.72	.72
Maximum monthly average	.82	.76	.73	.79	.79	.80	.82	.84	.83	.83	.77	.80
Equilibrium temperature, °C												
Minimum monthly average	3	7	10	18	23	27	28	27	23	17	11	5
Mean monthly average	8	10	15	21	25	28	30	29	26	20	13	9
Maximum monthly average	14	15	18	23	28	30	31	31	28	22	16	13

BC-4
BC-14
BC-15



Note: The path of Four Mile Creek shown above is for once-through systems only. For natural flow or recirculating system the entire creek flow enters the Savannah River at point 5.

Scale (kilometers) 0 1 2 3 4 5

Figure B-2. Locations Corresponding to Downstream Temperatures in Tables B-3 through B-5

Table B-3. Downstream Temperature Distributions (°C) for Four Mile, Pen Branch, and Beaver Dam Creeks with Existing System[a]

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C-Reactor												
(Four Mile Creek)												
Discharge (1)[b]	69(70)	69(71)	70(72)	71(73)	72(73)	73(74)	74(75)	74(75)	73(75)	72(74)	71(73)	70(72)
Road A (2)	49(51)	49(51)	50(52)	53(55)	55(57)	57(58)	57(58)	58(58)	57(58)	55(57)	52(53)	50(52)
Road A-13 (3)	42(45)	42(44)	44(45)	46(48)	49(51)	50(51)	51(52)	51(52)	50(51)	49(50)	45(47)	43(45)
Swamp Delta (4)	32(35)	33(35)	34(36)	38(39)	40(42)	42(43)	43(43)	43(44)	42(42)	39(40)	35(37)	33(35)
Mouth (5)	24(27)	24(27)	27(29)	30(32)	33(35)	35(36)	36(37)	36(37)	34(35)	31(33)	27(29)	25(27)
Ambient Creek[c]	9(19)	11(19)	15(24)	19(25)	22(27)	25(31)	25(29)	25(29)	23(28)	21(25)	13(23)	13(18)
K-Reactor												
(Pen Branch)												
Discharge (6)	69(70)	69(71)	70(72)	71(73)	72(73)	73(74)	74(75)	74(75)	73(75)	72(74)	71(73)	70(72)
Road A (7)	61(63)	60(62)	61(63)	63(65)	66(67)	67(68)	68(69)	68(69)	68(69)	67(68)	64(66)	62(64)
RR Bridge (8)	52(54)	51(53)	52(54)	55(56)	57(59)	59(60)	59(60)	60(60)	59(60)	58(59)	54(56)	53(55)
Swamp Delta (9)	42(44)	42(44)	43(44)	46(48)	48(50)	50(51)	51(51)	51(51)	50(51)	48(49)	45(46)	43(45)
Above Steel												
Creek (10)	16(21)	17(21)	20(22)	24(26)	27(29)	29(30)	30(31)	30(31)	28(29)	24(26)	20(22)	17(20)
Mouth (11)	13(17)	15(18)	18(21)	21(23)	24(27)	27(28)	28(29)	28(29)	26(27)	22(24)	17(19)	14(17)
Ambient Creek[d]	8(18)	10(18)	15(22)	18(23)	21(24)	23(27)	23(27)	23(26)	21(26)	19(23)	13(21)	12(17)
D-Area												
(Beaver Dam Creek)												
Discharge (12)	18(27)	16(22)	21(27)	24(29)	28(32)	29(34)	28(33)	28(33)	27(33)	27(34)	26(33)	19(31)
Swamp Delta (13)	17(25)	16(21)	20(26)	24(28)	27(31)	28(33)	28(33)	28(32)	27(32)	26(32)	24(30)	18(28)
Mouth (14)	17(22)	17(21)	20(24)	24(27)	27(29)	29(31)	30(31)	29(31)	28(30)	25(29)	22(27)	18(23)
Ambient creek[e]	8(15)	9(14)	12(17)	15(20)	19(22)	21(25)	23(27)	23(26)	23(26)	20(23)	17(22)	12(18)

a. Temperatures are monthly average - monthly extremes are in parentheses.
b. Corresponds to stream locations shown as squares on Figure B-2.
c. U.S. Geological Survey data for water year 1985 for station 02197342; Four Mile Creek at Road A-7 (USGS, 1986).
d. U.S. Geological Survey data for water year 1985 for station 02197341; Pen Branch at Road B (USGS, 1986).
e. Average U.S. Geological Survey data for water years 1976-1985 for station 01297320; Savannah River near Jackson, S.C. (USGS; 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986).

BC-4
BC-14
BC-15

Table B-4. Downstream Temperature Distributions (°C) for Four Mile, Pen Branch, and Beaver Dam Creeks with Once-Through Towers for Each Reactor and for the Increased Pumping Alternative for D-Area[a]

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C-Reactor (Four Mile Creek)												
Discharge (1)[b]	19(28)	20(28)	23(28)	24(30)	26(30)	28(31)	29(32)	29(32)	28(31)	24(31)	23(29)	21(28)
Road A (2)	18(26)	18(26)	21(26)	23(28)	25(29)	28(30)	29(31)	29(31)	27(30)	23(29)	21(27)	19(26)
Road A-13 (3)	17(24)	17(24)	21(25)	23(28)	25(29)	28(30)	29(31)	28(31)	27(30)	23(28)	20(26)	18(25)
Swamp Delta (4)	15(22)	16(22)	19(23)	22(26)	25(28)	27(30)	28(30)	28(30)	26(29)	22(26)	19(24)	16(22)
Mouth (5)	13(20)	14(20)	18(21)	20(24)	23(27)	26(28)	27(29)	27(29)	25(27)	20(24)	17(21)	14(19)
Ambient Creek[c]	9(19)	11(19)	15(24)	19(25)	22(27)	25(31)	25(29)	25(29)	23(28)	21(25)	13(23)	13(18)
K-Reactor (Pen Branch)												
Discharge (6)	19(28)	20(28)	23(28)	24(30)	26(30)	28(31)	29(32)	29(32)	28(31)	24(31)	23(29)	21(28)
Road A (7)	18(27)	19(27)	22(27)	24(29)	26(30)	28(31)	29(32)	29(32)	28(31)	24(30)	22(28)	20(27)
RR Bridge (8)	18(26)	18(26)	21(26)	23(29)	26(30)	28(31)	29(31)	29(31)	28(30)	24(29)	21(27)	19(26)
Swamp Delta (9)	16(24)	17(24)	20(25)	23(27)	25(29)	28(30)	29(31)	28(31)	27(30)	23(28)	20(26)	18(24)
Above Steel Creek (10)	10(17)	12(17)	16(19)	18(21)	21(24)	24(26)	26(27)	25(27)	23(24)	18(21)	15(18)	11(16)
Mouth (11)	10(15)	12(16)	16(19)	18(20)	21(24)	24(26)	25(27)	25(26)	22(24)	17(21)	15(17)	11(15)
Ambient Creek[d]	8(18)	10(18)	15(22)	18(23)	21(24)	23(27)	23(27)	23(26)	21(26)	19(23)	13(21)	12(17)
D-Area[e] (Beaver Dam Creek)												
Discharge (12)	18(27)	16(22)	21(27)	24(29)	28(30)	29(32)	28(30)	28(31)	27(31)	27(32)	26(31)	19(31)
Swamp Delta (13)	17(25)	16(21)	20(26)	24(28)	27(30)	28(31)	28(30)	28(31)	27(30)	26(31)	24(29)	18(28)
Mouth (14)	13(20)	14(19)	17(21)	20(24)	24(27)	26(29)	27(29)	27(29)	25(27)	21(26)	19(23)	14(21)
Ambient creek[f]	8(15)	9(14)	12(17)	15(20)	19(22)	21(25)	23(27)	23(26)	23(26)	20(23)	17(22)	12(18)

a. Temperatures are monthly average - monthly extremes are in parentheses.
b. Corresponds to stream locations shown as squares on Figure B-2.
c. U.S. Geological Survey data for water year 1985 for station 02197342; Four Mile Creek at Road A-7 (USGS, 1986).
d. U.S. Geological Survey data for water year 1985 for station 02197341; Pen Branch at Road B (USGS, 1986).
e. Increased pumping alternative for D-Area. This alternative is equivalent to existing system for average conditions.
f. Average U.S. Geological Survey data for water years 1976-1985 for station 01297320; Savannah River near Jackson, S.C. (USGS; 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986).

BC-4
BC-14
BC-15

Table B-5. Downstream Temperature Distributions (°C) for Four Mile, Pen Branch, and Beaver Dam Creeks with Recirculating Towers for Each Reactor and for the Increased Pumping Alternative for D-Area[a]

Location	Month											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
C-Reactor (Four Mile Creek)												
Discharge (1)[b]	14(25)	15(25)	18(26)	20(28)	23(28)	26(29)	27(30)	26(30)	25(29)	20(28)	18(27)	15(26)
Road A (2)	9(16)	11(16)	15(18)	18(21)	22(25)	25(27)	27(28)	26(28)	23(25)	17(21)	14(18)	10(15)
Road A-13 (3)	8(15)	11(16)	15(18)	18(21)	22(25)	25(28)	27(29)	26(28)	23(25)	17(21)	14(17)	9(15)
Swamp Delta (4)	8(15)	10(15)	14(17)	19(21)	22(26)	26(28)	27(29)	27(29)	24(26)	17(20)	13(16)	9(14)
Mouth (5)	7(14)	10(14)	14(17)	17(19)	20(23)	24(25)	25(26)	25(25)	21(23)	15(19)	13(15)	8(13)
Ambient Creek[c]	9(19)	11(19)	15(24)	19(25)	22(27)	25(31)	25(29)	25(29)	23(28)	21(25)	13(23)	13(18)
K-Reactor (Pen Branch)												
Discharge (6)	14(25)	15(25)	18(26)	20(28)	23(28)	26(29)	27(30)	26(30)	25(29)	20(28)	18(27)	15(26)
Road A (7)	11(19)	12(18)	16(20)	19(24)	23(27)	26(28)	27(29)	27(29)	24(27)	19(25)	15(21)	12(19)
RR Bridge (8)	9(17)	11(17)	15(19)	19(23)	23(26)	26(28)	27(29)	27(29)	24(27)	18(23)	15(19)	11(17)
Swamp Delta (9)	8(15)	11(16)	15(18)	19(22)	23(26)	26(28)	28(29)	27(29)	24(26)	17(21)	14(17)	9(15)
Above Steel Creek (10)	7(14)	10(14)	14(16)	15(17)	17(20)	21(23)	23(24)	22(23)	18(19)	13(17)	12(15)	8(12)
Mouth (11)	10(14)	11(15)	15(19)	18(20)	21(24)	25(26)	25(27)	23(24)	20(23)	13(19)	15(17)	11(14)
Ambient Creek[d]	8(18)	10(18)	15(22)	18(23)	21(24)	23(27)	23(27)	23(26)	21(26)	19(23)	13(21)	12(17)
D-Area[e] (Beaver Dam Creek)												
Discharge (12)	18(27)	16(22)	21(27)	24(29)	28(30)	29(32)	28(30)	28(31)	27(31)	27(32)	26(31)	19(31)
Swamp Delta (13)	17(25)	16(21)	20(26)	24(28)	27(30)	28(31)	28(30)	28(31)	27(30)	26(31)	24(29)	18(28)
Mouth (14)	15(22)	15(19)	18(23)	22(26)	26(28)	27(30)	27(29)	27(30)	26(29)	24(28)	22(26)	16(24)
Ambient creek[f]	8(15)	9(14)	12(17)	15(20)	19(22)	21(25)	23(27)	23(26)	23(26)	20(23)	17(22)	12(18)

a. Temperatures are monthly average - monthly extremes are in parentheses.
b. Corresponds to stream locations shown as squares on Figure B-2.
c. U.S. Geological Survey data for water year 1985 for station 02197342; Four Mile Creek at Road A-7 (USGS, 1986).
d. U.S. Geological Survey data for water year 1985 for station 02197341; Pen Branch at Road B (USGS, 1986).
e. Increased pumping alternative for D-Area. This alternative is equivalent to existing system for average conditions.
f. Average U.S. Geological Survey data for water years 1976-1985 for station 01297320; Savannah River near Jackson, S.C. (USGS; 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986).

BC-4
BC-14
BC-15

The existing system discharge flow is approximately 11 cubic meters per second and consists of heat exchanger effluent (at Savannah River temperature raised according to equation 2 of Section B.2.2) plus auxiliary flow (assumed to be at Savannah River temperature). The D-Area discharge flow is about 2.6 cubic meters per second (up to 4.0 cubic meters per second during extreme conditions for the increased pumping alternative); its temperature is equal to the Savannah River temperature plus 8°C (plus 5°C during maximum flow conditions for the increased pumping alternative).

BC-4
BC-14
BC-15

Tables B-3 and B-4 indicate the large, incremental change in stream temperatures from the existing system to the once-through towers. A further decrease in stream temperatures (as well as a large decrease in stream flow) occurs when recirculating towers are used (Table B-5). Downstream temperatures can increase when recirculating systems are used because the equilibrium temperatures (which the stream temperatures approach) are higher than those of the discharge while the flow is small. Downstream temperatures can increase because of both positive heat flux (into the water surface) and mixing with creek flow (other than reactor effluent).

The heat balance, and therefore the equilibrium temperature, takes into account spatial and temporal variations in vegetative cover of the streams. Four Mile Creek and Pen Branch were broken down into three spatial regimes [upper reach, middle reach, and lower (swamp) reach]; Beaver Dam Creek was considered to consist of an upper and lower reach. The percent of vegetative shading was defined for each month of the year for each reach (Morris, 1987b). Values ranged from less than 10 percent in the winter (all reaches) to 90 percent in the swamp during the summer.

BC-4
BC-14
BC-15

B.4 SAVANNAH RIVER DILUTION - D-AREA MODEL (SRDD)

B.4.1 MODEL DESCRIPTION

The dispersion of a source of water with a temperature (or concentration) elevated above that of the receiving water can be thought of as occurring in two steps. The "near field" is the area in the immediate vicinity of the discharge in which the mechanical mixing engendered by the difference in discharge and receiving water momentum dominates the dispersion process. After the discharge momentum has dissipated, the "far field" mechanism of receiving water turbulence causing mixing of the discharge and receiving waters is dominant. If the discharge momentum is relatively small (i.e., discharge velocity approximately equal to receiving water velocity), the near field can be (conservatively) neglected.

The far field dispersion of a steady nondecaying point source discharge into a current of velocity, u, can be described by (NRC, 1977):

TC

$$\frac{\partial uC}{\partial x} = \frac{\partial}{\partial y} K_y \frac{\partial C}{\partial y} + \frac{K_z}{\partial_z} \frac{\partial C}{\partial z} \quad (16)$$

where C = temperature or concentration excess above ambient
u = ambient velocity, m/sec
x = downstream distance, m
y = lateral distance (i.e., perpendicular to current), m
z = depth, m
K_y, K_z = lateral and vertical diffusion coefficient, m^2/sec

Longitudinal diffusion is assumed to be negligible when compared with advection in the same direction. Also, temperature can be considered to be a non-decaying (i.e., no heat transfer to the atmosphere) source within the region of interest because the affected areas are small. In any case, omission of surface heat transfer is a conservative assumption.

Equation 16 states that the excess concentration is moved downstream by advection (movement by the current, left side of Equation 16) and laterally and vertically in the direction of decreasing concentration by turbulence (first and second term on right side of Equation 16, respectively). If u, K_y, and K_z are taken to be constants, then Equation 16 becomes:

$$u \frac{\partial C}{\partial x} = K_y \frac{\partial^2 C}{\partial y^2} + K_z \frac{\partial^2 C}{\partial z^2} \qquad (17)$$

For an infinite receiving water, laterally and vertically surrounding the discharge point, the analytical solution to Equation 17 is:

$$\frac{C}{C_0} = \frac{Q}{4\pi \times \sqrt{K_y K_z}} \exp\left[\frac{-u(y_s - y)^2}{4K_y x}\right] \exp\left[\frac{-u(z_s - z)^2}{4K_z x}\right] \qquad (18)$$

where C_o = excess temperature (or concentration) of the discharge
Q = discharge flow, m^3/sec
y_s = lateral distance of source from coordinate origin
z_s = vertical distance of source from coordinate origin

and the discharge is assumed at $x = 0$.

The Gaussian distribution of Equation 18 can be generalized for a receiving water of finite dimensions by adding images of the concentration distribution, Equation 18, from the bounding surfaces; that is, the infinite distribution of Equation 18 can be "folded" back into the water body at the boundaries, with the folded excess concentrations each being a component of the total excess concentrations. One can picture an infinite number of folds (e.g., the left-hand side of the lateral distribution would be folded at the left boundary; the resulting distribution would then laterally exceed the right boundary and would have to be folded there, etc.) for each side (of the source) for both the lateral (shorelines) and vertical (surface and bottom) directions (i.e., four infinite series). The mathematical description of these images or folds is (NRC, 1977):

$$\frac{C}{C_0} = \frac{Q}{4\pi \times \sqrt{K_y K_z}} f(y)\, f(z) \qquad (19)$$

TC

where:

$$f(w) = \sum_{m=-\infty}^{\infty} \exp\left[\frac{-u(2mW + w_s - w)^2}{4 K_w x}\right] + \sum_{m=-\infty}^{\infty} \exp\left[\frac{-u(2mW - w_s - w)^2}{4 K_w x}\right]$$

and w = y or z
W = B (receiving water width) if w = y or D (receiving water depth) if w = z

Note that f(y) and f(z) describe the infinite folds of the first and second exponential terms, respectively, of Equation 18.

A further refinement of the analysis stems from the assumption of a point source discharge. Equation 19 can be generalized to account for an arbitrary discharge geometry by integrating over the discharge dimensions (i.e., consider the discharge an infinite number of point sources), where Q would then be the discharge flow per unit discharge size (i.e., length for a line source or area for a plane source). Such an integration of Equation 19 would have to be performed numerically and would be very time-consuming, computationally. Accordingly, an analytical approximation to this integration has been used.

The areal nature of the discharge source is accounted for by taking a virtual source distance x_v; x_v corresponds to the distance, x, at which (for $y = y_s$ and $z = z_s$) C/C_o equals 1 in Equation 19. Accordingly, Equation 19 is modified by replacing x with $x + x_v$. The use of a virtual source distance assures conservation of mass, avoids the mathematical singularity at x = 0, and ensures that the calculated concentration (or temperature) at the source is equal to that being discharged.

B.4.2 MODEL USE

The model described in Section B.4.1 was generalized for use in calculating the temperature distribution in the Savannah River from the multiple-source D-Area sparge discharge system. Based on preliminary design assumptions, the system would consist of approximately 65 discharge pipes, 20 centimeters in diameter and 9 meters long, spaced at 3-meter intervals and aligned along the river bank. SRDD models such a system by considering each of the discharge pipes as a component to the overall temperature (or concentration) distribution. Distances x are measured, for each pipe, from that pipe (x = 0 is taken at the upstream pipe). Virtual source distances, x_v, are calculated individually for each pipe (i.e., C/C_o equals 1 at each pipe, accounting for the contributions of all upstream sources).

The total discharge flow is 2.6 cubic meters per second, 0.04 cubic meter per second per discharge pipe; the discharge water velocity is 1.2 meters per second, and its excess temperature is 8°C (above the temperature of the river). Table B-6 lists the Savannah River parameters used in the analysis. The approximate river cross-section at the discharge (average width = 61 meters, average depth = 3.2 meters) was known for a base river flow of 188 cubic meters per second. Log-log interpolations of river gage heights at Jackson for this flow (gage height = 2.28) and for 490 cubic meters per second [gage height = 4.62 meters (USGS, 1981)] were performed for the seasonal

Table B-6. Savannah River Parameters Used in Analysis

Parameter	Winter average	Spring average	Summer average	Summer extreme
Flow (m^3/sec)	345.0	371.0	212.0	159.0
Width (m)	70.0	71.0	65.0	59.0
Depth (m)	4.6	4.8	3.5	2.9
Temperature (°C)	8.0	17.0	23.0	28.0
Horizontal diffusion coefficient (m^2/sec)	.26	.26	.26	.26
Vertical diffusion coefficient (m^2/sec)	.0026	.0026	.0026	.0026

flows. The change in gage height between the interpolated value and that at the base flow was assumed to be the change in average depth at the discharge. Typically, as the flow increases, the width, depth, and velocity of the river increases. Average widths were assumed to be the mean of 61 meters (known width at the base flow) and that width that would result in the same average river velocity as that at the base flow. These assumptions will result in river dimensions that accede to the typical river dimension-flow characteristics described above.

For the region near the discharge (about 100 meters from the discharge), the temperature distribution will be (for a given velocity) insensitive to the river dimensions. This occurs because the plume has not had time to grow sufficiently such that the images from the far boundaries (Georgia shoreline and river bottom) are important. In addition, the temperature at any given coordinate decreases with increasing river velocity. This is apparent from Equation 19, which shows that the river velocity, u, enters the temperature function as exp(-u).

The chosen horizontal diffusion coefficient is based on studies of the Savannah River approximately 20 kilometers downstream (Steel Creek) from the discharge (Du Pont, 1981, Appendix A). The vertical diffusion coefficient is typically one to two orders of magnitude smaller than the horizontal diffusion coefficient (NRC, 1977; Yotsukura and Sayre, 1976; Fischer, 1969). Calculations with K_z = 0.0026 and 0.026 square meter per second indicate that the former yields larger values of maximum isotherm width and cross-sectional area. However, at distances farther downstream than considered here, the discharge will be fully mixed vertically and the distribution will be independent of K_z. K_z = 0.0026 square meter per second was used in the analysis.

B.4.3 MODEL RESULTS

Table B-7 lists the river withdrawal and discharge temperatures along with the
zones of passage for each seasonal case. The discharge temperatures for this BC-4
alternative, unlike the others, are based on elevating measured Savannah River BC-14
temperatures (rather than being measured discharge temperatures). This is BC-15

Table B-7. Temperatures and Zone of Passage Sizes for D-Area Coal-fired Powerhouse Direct Discharge into Savannah River

Parameter	Winter average	Spring average	Summer average	Summer extreme
Temperature (°C)				
Withdrawal from river	8.0	17.0	23.0	28.0
Discharge	16.0	25.0	31.0	36.0
Maximum river cross-sectional area (percent of total) having temperature (°C) less than				
2.8 (excess)	99.7	99.7	99.5	99.3
32.2 (absolute)	100	100	100	99.7
Maximum river width (percent of total) having temperature excess (°C) less than				
2.8 (excess)	95	95	94	93
32.2 (absolute)	100	100	100	96

BC-4 because comparison between river and discharge are relevant and need to be on
BC-14 the same basis. The extreme summer conditions result in the smallest zones of
BC-15 passage. Figure B-3 shows the maximum cross-sectional area (as a fraction of the total), and downstream extent (meters from the discharge pipe farthest upstream) as a function of excess temperature for extreme summer conditions. Excess temperatures corresponding to those extents less than 3 meters downstream from the discharge pipe located farthest downstream will actually exist intermittently in the river; that is, such isopleths (greater than 2.8°C) exist near each discharge pipe but will dissipate between pipes.

Figure B-3 also shows the suggested width and cross-sectional area of the zone of passage. This figure shows that the direct discharge will be well within the suggested zone-of-passage criteria.

B.5 FOG MODEL

The occurrences of ground-level fogging, icing, elevated visible plumes, and ground deposition rates of dissolved solids in drift in the environmental impact statement were calculated by the NUS computer code FOG (Fisher, 1974). The FOG model provides predictions of these environmental impacts over a geographical area surrounding the site. For these analyses, sequential hourly meteorological data representative of the geographical areas surrounding C-Area and K-Area at the Savannah River Plant were used for the 5-year period from January 1975 to October 1979.

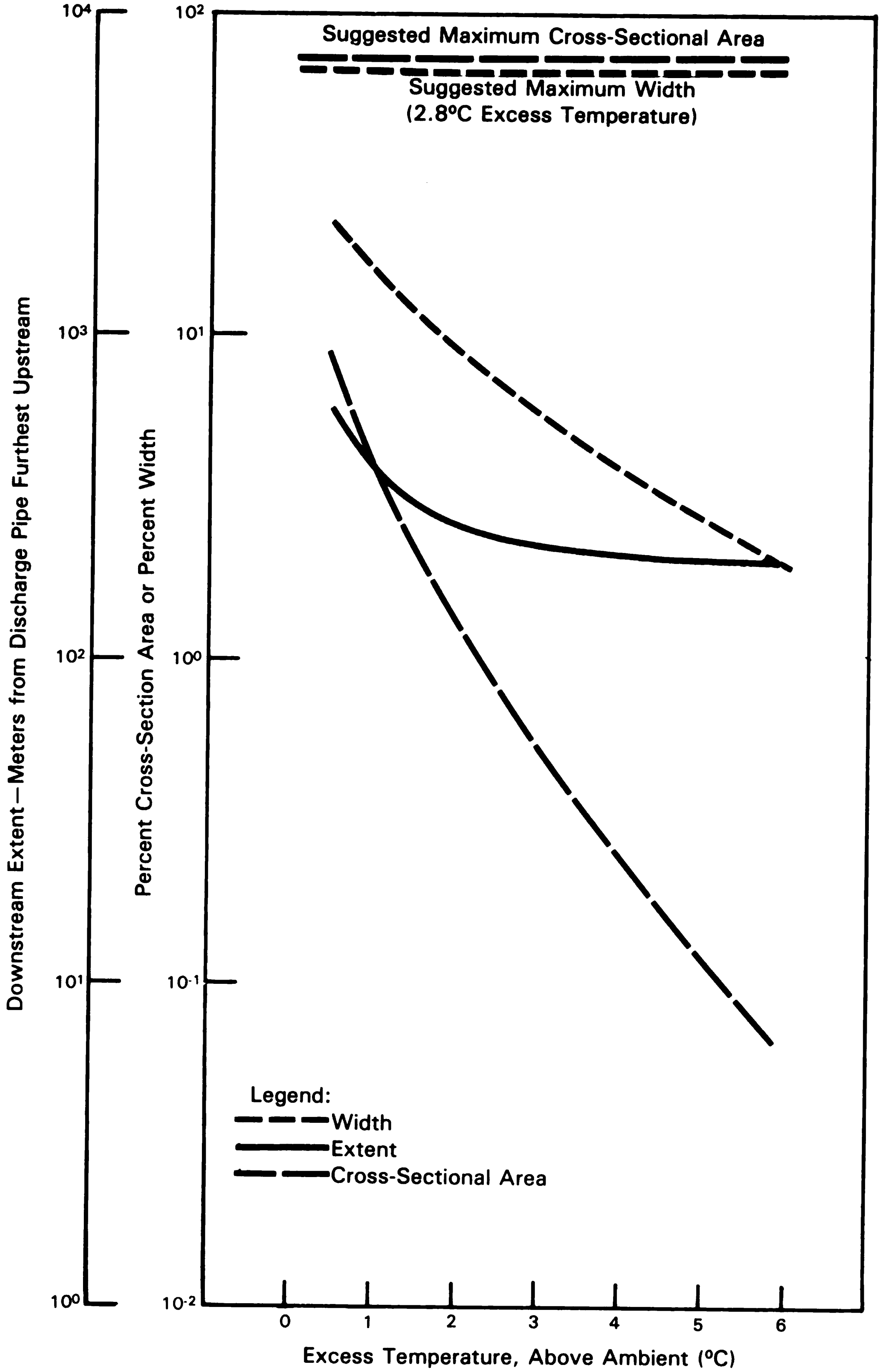


Figure B-3. Extreme Summer Plume Characteristics

The FOG model simulates the dispersion of a plume from evaporative cooling systems using sequential meteorological data. It defines a bent-over plume using the Briggs plume rise equations (Briggs, 1969) out to the distance at which the plume levels off, and Gaussian dispersion equations at greater distances. The plume buoyancy employed in the calculations is computed from the effluent temperature and airflow rate at the exit of the cooling tower and from the ambient dry-bulb temperature and relative humidity. The merging of plumes from the round, mechanical-draft, multifan cooling towers is considered using equations developed by Briggs (1974) for a cluster of cells.

The plume is assumed to propagate rectilinearly, and any meandering effects due to wind shifts are neglected. Atmospheric stability classes are those calculated from the standard deviation of wind direction fluctuations or, if these data are unavailable, from those reported by the National Weather Service for every hour for the period under consideration. The dispersion parameters used were those of Pasquill-Gifford (DOE, 1984c). Formulations for critical wind speed relative to the aerodynamic downwash of the exhaust plumes, in the wake of the tower under high wind conditions, are also included in the FOG model.

In addition to the preliminary design information contained in Chapter 2, the following assumptions were made in the analysis of fogging, icing, visible plumes, and ground deposition rates of dissolved solids:

- Circulating water flow = 11.3 cubic meters per second
- Drift rate (percent of circulating water flow) = 0.006 percent
- Total dissolved solids concentrations (TDS) in influent water = 53 parts per million
- Cycles of concentration for recirculating towers = 3
- Drift droplet size (mass median diameter) = 376 microns
- Air flow rate for mechanical draft recirculating tower = 13,848 cubic meters per second

B.5.1 INDUCED GROUND-LEVEL FOGGING

For the purposes of these analyses, induced ground-level fog is defined as a reduction in ground-level visibility to 1000 meters or less as a result of the operation of the cooling system. Huschke (1959) defines the 1000-meter distance as the limit on visibility above which fog is not considered to occur. The water content of the plume at ground level is calculated by means of the Gaussian dispersion analysis discussed above; all moisture in excess of that required to saturate the ambient air is assumed to form condensed water droplets. An empirical equation (Pettersen, 1956) is then used to relate the atmospheric water content to the horizontal visibility.

B.5.2 INDUCED GROUND-LEVEL ICING

The frequencies of occurrence of various ice thicknesses resulting from the operation of the cooling towers were also calculated by FOG code subroutines that simulate the formation and accumulation of ice and calculate the frequencies of ice occurrences.

The ice-formation routines predict accumulations of ice around a cooling system from the impingement of condensed water and drift droplets. Calculations of ice buildup are made for horizontal flat surfaces (e.g., roads). The rate of ice buildup can be limited either by the liquid water delivery rate to the collecting surface or by the heat balance necessary to sustain freezing conditions.

The dispersion of the relatively small condensed water droplets is treated the same as that of the vapor plume (i.e., by diffusion), while the transport of the drift droplets follows the ballistic trajectory method employed for the salt deposition calculations. The FOG model performs an energy balance on the surface or volume of interest. Ice formation is assumed to occur only when the ambient temperature is less than 0°C. Ice buildup on horizontal ground-level surfaces is assumed to result only from fallout of the drift droplets. Because the much smaller condensed water droplets have negligibly small settling velocities, the condensed water droplets are assumed not to impinge on flat horizontal surfaces. Melting due to solar radiation is included in the simulation for flat surfaces.

B.5.3 ELEVATED VISIBLE PLUMES

The FOG code was also used to calculate the frequencies of occurrence of elevated visible plumes over each grid point under consideration. The total flux of air through a cross-section of the plume normal to the plume axis is calculated at successive downwind distances. The amount of entrained air is computed as the difference between the total air flow and the air flow leaving the cooling system. The entrained air and effluent air from the cooling system are assumed to be thoroughly mixed isobarically and thermodynamic properties of the resulting mixture are calculated. A visible plume is predicted to occur at a particular point if calculations show that the mixed plume is supersaturated.

B.5.4 DRIFT DEPOSITION

Drift deposition analysis by the FOG code involves the following three calculations: (1) the sequential release of the entrained drift droplets from the effluent plume; (2) the subsequent horizontal transport of the drift droplets; and (3) the deposition rates at prespecified downwind distances for each wind direction.

It is assumed in the FOG model that the initial concentration of drift droplets follows a Gaussian distribution normal to the plume axis. The release of the entrained droplets at any point within the plume depends on the relative magnitudes of the terminal fall velocity of the droplets and the vertical velocity of the air in the plume. At each downwind distance under consideration, these two velocities are compared for each of the various size categories of drift droplets, and a fraction of the droplets released. This process is repeated until all drift droplets are released from the plume. This drift is carried by the ambient wind until it is deposited on the ground. The rate of fall of the drift droplets depends on the droplet size, which is changed by evaporation processes. These, in turn, depend on the physical and transport properties of both the liquid droplets and the surrounding air. A stepwise procedure is employed in the FOG code to compute the trajectory of the droplets by considering these transport, evaporation, and settling rate effects.

Drift deposition rates are calculated for each sequential meteorological record and these are then summarized to obtain the deposition (mass per unit area-year) over the entire grid.

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BC-4 Carolina.
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APPENDIX C

ECOLOGY

C.1 INTRODUCTION

This appendix is based primarily on information from three documents: the Comprehensive Cooling Water Study (Du Pont, 1985, 1987), which presents data collected in 1982 and additional data collected through August 1985; a report that summarizes impingement and entrainment impacts at the SRP from 1983-1985 (DOE, 1987); and a report on studies conducted at the site to evaluate the potential effects of chlorination and dechlorination activities related to proposed cooling towers for K- and C-Reactors (Wilde, 1987).

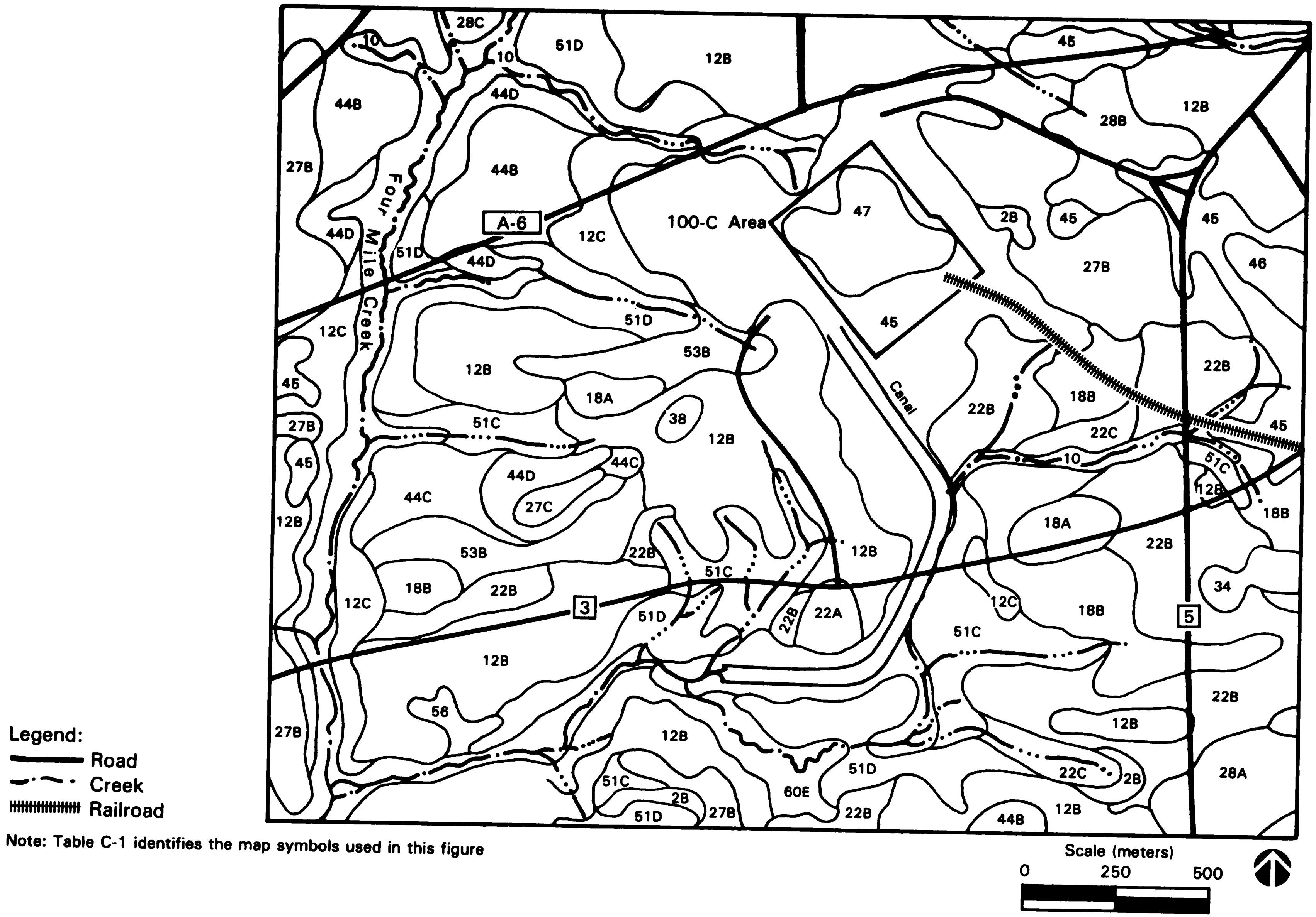
BB-1
BB-16
BD-5

In 1972, the Savannah River Plant became a National Environmental Research Park. The Plant has one of the most intensively studied environments in the country. More than 700 scientific publications have resulted principally from research efforts by three organizations at the Plant: the Savannah River Laboratory, the Savannah River Ecology Laboratory, and the U.S. Forest Service (Wiener and Smith, 1981). Other research efforts include (1) surveys of the aquatic ecology of the Savannah River since 1951 by the Academy of Natural Sciences of Philadelphia, (2) temperature and flow monitoring of the river since 1959 by the United States Geological Survey (USGS), (3) remote sensing of the Plant using aerial imagery, and (4) various ecological studies by the State of South Carolina and by industry. In addition, visiting scientists from other universities and laboratories in the United States have performed research. This appendix includes these studies as appropriate.

This appendix emphasizes Beaver Dam Creek, Four Mile Creek, Pen Branch, the Savannah River swamp, the Savannah River, and their important biota. These areas could be affected by the cooling water alternatives considered in this environmental impact statement. Important biota are those species that are (1) commercially or recreationally valuable, (2) endangered or threatened, (3) important to the well-being of the species included in categories 1 and 2, or (4) critical to the structure and function of the ecosystem.

C.2 SOILS

Soils are an important component of the environment because they influence the occurrence and distribution of the vegetation, wildlife, and potential land use. Figures C-1, C-2, and C-3 show the distribution of soils in the vicinity of C-Reactor, K-Reactor, and the D-Area coal-fired powerhouse, respectively; Table C-1 lists the characteristics of the soils shown in these figures. The C-Reactor soil map covers an area of approximately 1670 acres, while the K-Reactor map covers approximately 1770 acres. C- and K-Areas contain 19 soil types, of which udorthents and arents and urban are the most prevalent. These soils consist of material that has been previously deposited or material that remains after some of the soil has been removed; the material contains fragments or discontinuous layers of diagnostic horizons or layers. Streambed soils of Four Mile Creek and Indian Grave Branch consist primarily of Osier loamy sand; reactor operations have scoured and eroded these soils. The



Note: Table C-1 identifies the map symbols used in this figure

Figure C-1. Distribution of Soil Types in the C-Reactor Area

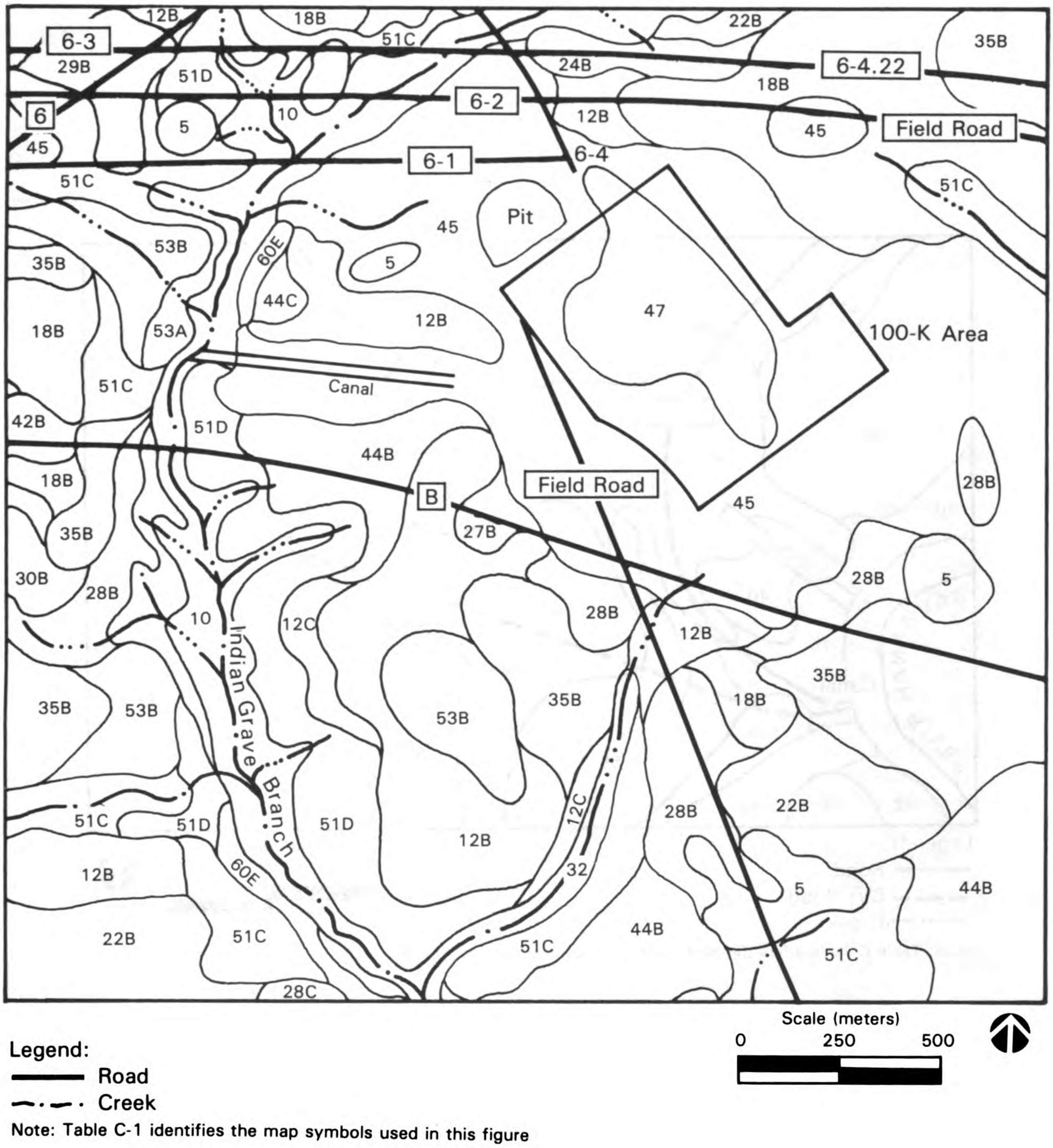
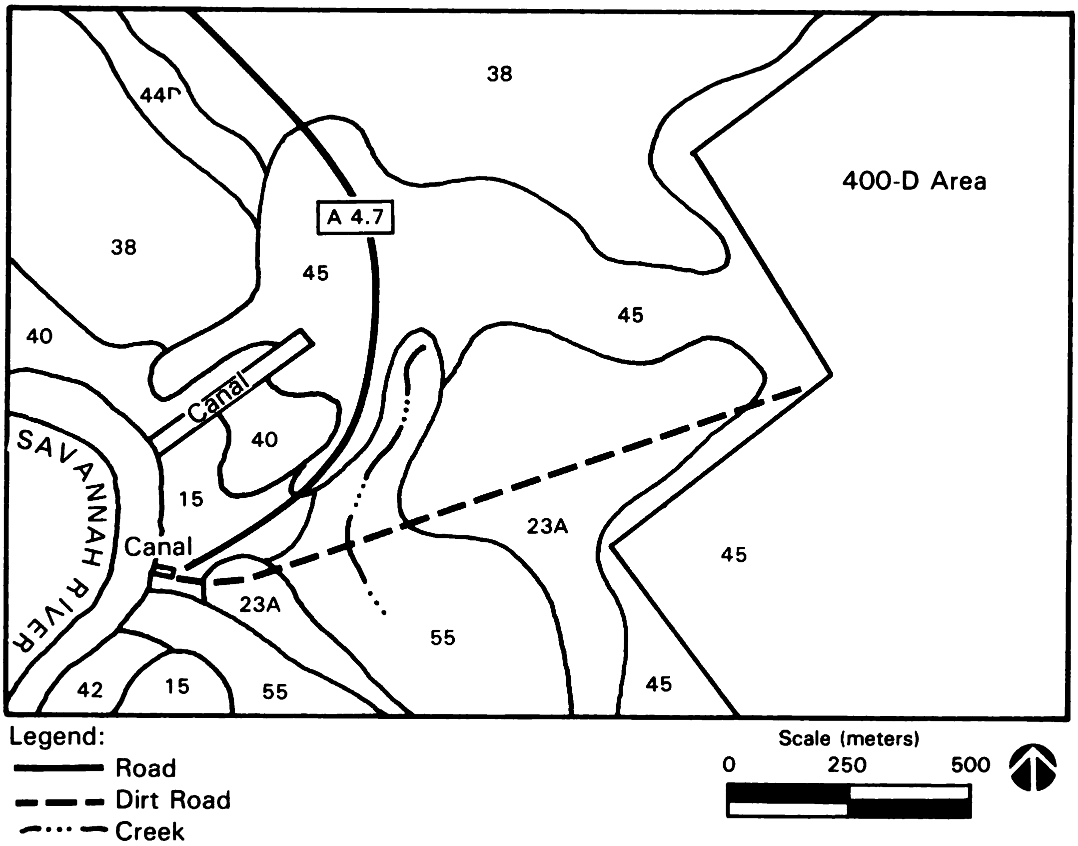


Figure C-2. Distribution of Soil Types in the K-Reactor Area



Note: Table C-1 identifies the map symbols used in this figure

Figure C-3. Distribution of Soil Types in the D-Area

Table C-1. Occurrence, Distribution, and Selected Characteristics of Soils Surrounding C-Reactor, K-Reactor, and D-Area[a]

Map symbol	Soil name	Texture (A horizon)	Drainage class
2	Ailey	Loamy sand	Well drained
5	Arents and udorthents	Sand or loam or sandy clay loam	Poorly drained
10	Osier	Loamy sand	Poorly drained
12	Blanton	Sand	Well drained
15	Tawcaw	Silty clay	Poorly drained
18	Dothan	Loamy sand	Well drained
22	Fuquay	Loamy sand	Well drained
23	Smithboro	Silt loam	Poorly drained
27	Lakeland	Sand	Well drained
29	Neeses	Loamy sand	Well drained
30	Norfolk	Loamy sand	Well drained
34	Ogeechee	Loamy fine sand	Poorly drained
35	Orangeburg	Loamy sand	Well drained
38	Rembert	Sandy loam	Poorly drained
40	Shellbluff	Loam	Poorly drained
42	Toccoa	Clay loam	Well drained
44	Troup	Sand	Well drained
45	Udorthents and arents	Loam	Poorly drained
46	Udorthents-Urban	Sandy clay loam	Well drained
47	Urban	Variable	Variable
50	Vaucluse	Loamy sand	Well drained
51	Vaucluse-Ailey complex	Loamy sand	Well drained
53	Wagram	Loamy sand	Well drained
55	Chastain	Loam	Poorly drained
56	Williman	Loamy fine sand	Poorly drained

a. Additional information for Figures C-1, C-2, and C-3: Capital letters that follow numerical map symbols designate slope classes: A = 0-2 percent, B = 2-6 percent, C = 6-12 percent, D = 12-18 percent, E = 18-25 percent.

dominant texture of the surficial horizons is loamy sand and sand; slopes typically range less than 12 percent, and most soils are well drained.

Figure C-3 shows the distribution of soils between the D-Area powerhouse and the Savannah River. The D-Area soil map covers an area of approximately 880 acres and consists of five major soil types. The udorthents-arents soil complex comprises more than 50 percent of the area. These soils consist of deposited material or material that remains after the surface layers have been removed or disturbed. The remaining soil types consist of Chastain clay loam, Smithboro loam, Tawcaw silty clay, Shellbluff loam, and Toccoa clay loam, all of which are frequently flooded and, except for the Toccoa series, are poorly drained. The Toccoa series is moderately well drained with good permeability.

C.3 VEGETATION - GENERAL SITEWIDE

The Savannah River Plant is located in an area where the oak-hickory-pine forest and the southern mixed forest intermingle (Kuchler, 1964). The southern floodplain forest (Kuchler, 1964), which adjoins major rivers such as the Savannah, is present. Dominant canopy species of the oak-hickory-pine forest include hickory, shortleaf and loblolly pine, white oak, and post oak. Beech, sweetgum, magnolia, slash and loblolly pine, white oak, and laurel oak characterize the canopy of the southern mixed forest. Typically, the southern floodplain forest consists of tupelo, many species of oak, and bald cypress. Species representative of each forest type exist on the Savannah River Plant. In addition, farming, fire, adaptive features, and topography have strongly influenced SRP vegetation. No virgin forest is in the region (Braun, 1950).

Since 1952, the U.S. Forest Service has managed the land surface at the Savannah River Plant for the Department of Energy and its predecessors. The Forest Service manages the land for multiple-use purposes, including environmental and ecological research areas, wildlife management areas for threatened or endangered species, and timber management areas (USDA, 1983).

Table C-2 summarizes the nine major land cover classes for SRP. The dominant land-use type is upland pine/hardwood (70.1 percent) followed by wetland (20.4 percent). The SRP wetlands are about 66 percent bottomland hardwood forests, primarily along streams and in the river swamp. A relatively small percentage (14 percent) of SRP wetlands are cypress and tupelo swamp forest, found predominantly in the Savannah River swamp. Normally, scrub-shrub and emergent marsh areas occur in thermal and post-thermal areas (Du Pont, 1985).

Table C-3 summarizes the wetland land-use types for the major SRP stream wetland communities.

C.3.1 FOUR MILE CREEK

Four Mile Creek, with Beaver Dam Creek, drains more than 22,480 acres. The Four Mile Creek floodplain has approximately 1900 acres of wetlands, primarily bottomland hardwood (72 percent) (Table C-3). Downstream from C-Reactor, open water and emergent marsh near the stream have replaced the original hardwood community. Away from the thermally affected areas in the floodplain, there is a hardwood canopy occupying 445 acres. Overall, C-Reactor discharges have affected about 1147 acres of Four Mile Creek wetlands. Discharges from F- and H-Areas and beaver activity have flooded original bottomland hardwood areas above the K-Reactor outfall, allowing scrub-shrub (260 acres) and emergent marsh (50 acres) wetlands to become established (Du Pont, 1985).

C.3.2 PEN BRANCH

Pen Branch and Indian Grave Branch drain about 13,590 acres above the swamp. Indian Grave Branch receives the effluent cooling water from K-Reactor. Pen Branch has about the same amount of wetlands (1725 acres) as Four Mile Creek (Table C-3). Similar to Four Mile Creek, emergent marsh (115 acres) and water (145 acres) are common below the K-Reactor discharge. Some hardwoods exist on the outer perimeter of the thermally affected areas (325 acres), but most

Table C-2. Land Use Types[a]

Land cover class	Area (acres)	Percentage
Upland pine/hardwood	135,100	70.1
Clear areas/power lines	11,200	5.8
Roads	4,100	2.1
Production areas	3,100	1.6
Subtotal	153,500	79.6
Wetland		
Bottomland hardwoods	25,900	13.4
Cypress-tupelo	5,500	2.9
Water[b]	4,400	2.3
Scrub-shrub	1,900	1.0
Emergent marsh	1,500	0.8
Subtotal	39,200	20.4
Total	192,700	100.0

a. Adapted from Du Pont, 1985.
b. Includes Savannah River.

occur in nonthermal tributaries (340 acres) or upstream of the K-Area cooling water releases (Du Pont, 1985).

C.3.3 BEAVER DAM CREEK

Beaver Dam Creek is a small stream that conveys thermal effluents from the D-Area coal-fired powerhouse. The creek is located 1 to 3 kilometers west of Four Mile Creek. A narrow band of bottomland hardwoods and scrub-shrub forest borders the stream from the D-Area process-water outfall to the Savannah River swamp (Du Pont, 1985).

C.3.4 SAVANNAH RIVER SWAMP

About 9400 acres (8 percent) of the Savannah River swamp forest lies on the Savannah River Plant from Upper Three Runs Creek to Steel Creek. The swamp is primarily cypress-tupelo forest (47 percent) and drier bottomland-hardwood islands (40 percent; Table C-4). On the islands, a few pine trees are able to survive (2.2 percent). The remainder of the swamp consists of scrub-shrub vegetation communities near the entry points of the thermal and post-thermal streams. Dense cypress-tupelo forest has been replaced by the mixture of scrub-shrub, and persistent and nonpersistent marsh vegetation in these delta areas. Delta areas comprise about 15 percent of the swamp, have more plant heterogeneity, and are changing (Du Pont, 1985).

Table C-3. Areas of Major SRP Stream Corridor Wetlands Communities (acres)[a]

Stream system	BH	SS	EM	CT	W	Total	Percent of total
Four Mile Creek							
Above C-Reactor (nonthermal)	925	255	50	0	0	1230	
Below C-Reactor (thermal)	445	0	65	0	150	660	
Total	1,370	255	115	0	150	1,890	8.3
Pen Branch							
Above K-Reactor (nonthermal)	725	60	0	0	0	785	
Below K-Reactor (thermal,	325	0	115	0	145	585	
nonthermal tributaries)	340	5	10	0	0	355	
Total	1,390	65	125	0	145	1,725	7.6
Other (Upper Three Runs, Lower Three Runs, Steel Creeks)	18,170	645	260	15	35	19,125	84.1
Total SRP	20,930	965	500	15	330	22,740	

a. Adapted from Du Pont, 1985.

Abbreviations:

BH - Bottomland hardwoods
SS - Scrub-shrub
EM - Emergent marsh
CT - Cypress-tupelo swamp forest
W - Open water

C.4 WILDLIFE

The Savannah River Plant was approximately two-thirds forested and one-third cropland and pasture when the U.S. government acquired it 35 years ago (Dukes, 1984). The abandoned fields were allowed to pass through vegetational succession or were planted in pine. The Plant is now 90 percent forested. The Plant is large, topographically variable, and diverse in vegetational history. It is in an area where major habitat types come together and intersperse. Human access is limited; therefore, faunal and floral diversity and abundance are high (DOE, 1984).

Because the proposed alternatives will primarily affect the fauna in the floodplains/wetlands, this section emphasizes species that depend on floodplain/wetland habitats for some part of their life cycle.

Table C-4. Area of Land Cover Classes Found in SRP Swamp (March 31, 1981)[a,b]

Class	Area (acres)	Percent of swamp
Persistent emergent marsh (PE)	135	1.4
Nonpersistent emergent marsh (NPE)	375	4.0
Scrub-shrub (SS)	385	4.1
Mixed deciduous swamp forest (MDSF)	4430	47.2
Mixed deciduous bottomland forest (MDBF)	3775	40.2
Needle-leaved evergreen forest (NEF)	205	2.2
Open water in swamp (W)[c]	65	0.7
Unclassified (U)	20	0.2
Total	9390	100.0

a. Obtained by analyzing multispectral scanner data (2440 meters AGL) provided by the Energy Measurements Group of EG&G, Las Vegas, Nevada.
b. Adapted from Du Pont, 1985.
c. Does not include 545 acres of Savannah River water adjacent to the swamp; probably includes some algal beds.

C.4.1 AMPHIBIANS AND REPTILES

Of the more than 90 species of reptiles and amphibians known to occur at the Plant, 61 use the SRP streams and wetlands. Most of these species inhabit post-thermal stream and swamp habitats in the vicinity of Steel Creek (Du Pont, 1985). The following list (adapted from Du Pont, 1985) contains the semiaquatic species of reptiles and amphibians characteristic of SRP streams and swamps:

Amphibians

Salamanders - greater siren
two-toed amphiuma

Frogs - green treefrog
bird-voiced treefrog
bullfrog
bronze frog
pickerel frog
pig frog

Reptiles

Snakes - brown water snake
banded water snake
red-belly water snake
mud snake
rat snake
rainbow snake
cottonmouth

Turtles - snapping turtle
stinkpot
striped mud turtle
slider turtle
river cooter
Florida cooter

Alligators - American alligator

Other species might occasionally occupy these habitats. A complete listing of species is in Du Pont, 1985.

No amphibians or reptiles persist on a routine basis in areas of severe thermal alteration. However, some species of frogs live in aquatic habitats that experience elevated temperatures and have deposited eggs in aquatic sites where lethal temperatures occurred (Du Pont, 1985).

Frogs and toads exhibit life history changes under elevated thermal conditions, particularly as tadpoles, by developing and metamorphosing more rapidly and at a smaller size than larvae living under normal temperature conditions (Du Pont, 1985).

The slider is the most prevalent species of turtle. This species apparently thrives in areas of moderately elevated water temperatures where it experiences faster growth rates and attains larger body sizes than turtles from local natural habitats. This can be attributed to improved diet quality, a longer growing season, and more rapid ingestion rates (Du Pont, 1985).

The striped mud turtle has been collected near the thermally elevated delta of Pen Branch. Original captures of this species were near Steel Creek before L-Reactor shutdown in 1968. No biological responses of this species to thermal conditions have been identified (Du Pont, 1985).

American alligators inhabit thermally affected streams such as Beaver Dam Creek and refuge areas along Four Mile Creek and Pen Branch (see Section C.6 details). A few other reptile species, primarily water snakes and turtles, might also occur in these areas, but not in numbers characteristic of ambient-temperature streams in the region (Du Pont, 1985).

C.4.2 AVIFAUNA

Several researchers have studied SRP avifauna. Norris (1963) surveyed the Plant in 1963. Fendley (1978) began a study in 1973 of the wood duck in the Steel Creek drainage system that has continued to the present. Angerman has conducted winter bird counts for several years (DOE, 1984). Dukes (1984) has summarized the avifauna studies.

Biologists have identified 213 species of birds at SRP. Angerman (1979; 1980) listed 59 species during recent Christmas bird counts. Game birds, particularly quail and dove, were abundant before the U.S. Government acquired the land. For a few years, the removal of land from agriculture did not decrease the quail population. In the early 1960s, this population reached a record high but began to decline because the conversion of agricultural fields to forests reduced the carrying capacity of the land.

Wild turkey, although present at Plant acquisition, were not very numerous. In 1972, the South Carolina Wildlife and Marine Resources Department started a program at the Plant for breeding wild turkey to stock other parts of the State. Thirty-six birds were released on the Plant between 1972 and 1974. Population growth was slow at first, but the turkey population has increased greatly in the last few years. To date, about 135 turkeys have been captured to restock other areas of the State.

Waterfowl are present primarily during winter migrations. After the construction of Par Pond, winter waterfowl species increased in number and diversity. An estimated 10,000 to 15,000 ducks and coots spend the winter at the Plant. Most of these birds are on Par Pond, other large ponds, and Carolina bays. Another 1000 to 2000 ducks spend the winter in the lower swamps and on the Savannah River. Wood ducks and hooded mergansers are the only waterfowl that commonly nest at the Plant.

In general, when clearing or cutting operations open wetland areas of the swamp or streams, a suitable habitat develops for ducks, wood storks, and other birds not normally found in mature cypress and tupelo stands. The increased flows and temperatures from reactor effluents to Four Mile Creek, Steel Creek, and Pen Branch have resulted in the development of such openings in the swamp. During the summer of 1972, bird surveys conducted on the deltas of Upper Three Runs Creek, Pen Branch, and Steel Creek in areas with similar densities of dead or living trees found no significant differences in non-aquatic bird communities in species diversity or richness in the natural (Upper Three Runs Creek), thermal (Pen Branch), and post-thermal (Steel Creek) swamps. However, more woodpeckers, crows, and herons occurred at Pen Branch than at Upper Three Runs Creek. The introduction of thermal effluents has produced a large stand of dead trees that serve as nesting and feeding sites for the large woodpecker and crow populations. Crows and herons represented more than 50 percent of the birds at Pen Branch Delta. Low numbers of these same species were seen near the open channel of Upper Three Runs Creek. When the canopy at Pen Branch was opened, suitable habitats became available to these larger species. The nonaquatic bird populations of the Four Mile Creek delta would be similar to those at Pen Branch.

A comparison of the number of mallards observed during 1982 aerial surveys in the Steel Creek delta area, Pen Branch delta, Four Mile Creek delta area, and Beaver Dam Creek revealed that this species used the delta areas of Four Mile, Steel, and Beaver Dam Creeks extensively. However, waterfowl were not observed in Pen Branch Delta. Mallard use of the Four Mile Creek delta area was generally higher than use of Steel Creek. Mallard use of the Four Mile Creek delta area was associated with open channels that branch off the main delta at a 90-degree angle. These channels are used heavily by waterfowl except when the water level is higher (flooding) or when the water is hotter.

The wood stork, an endangered species, forages on the site and is discussed in Section C.6.

C.4.3 MAMMALS

The Savannah River Plant has more than 40 species of mammals. The population of a few species increased rapidly and some species decreased after the Government closed the Plant to the public in 1952. The most notable expansion was in the deer herd; the present population is estimated at about 3500. The population grew so rapidly that by the mid-1960s deer-vehicle collisions were common and range deterioration was apparent. Controlled public hunts were started in 1965 to reduce the deer population. From 1965 to 1983, hunters harvested an average of 1126 deer annually.

When the occupants relocated in 1952 for SRP, they abandoned some domestic hogs that multiplied and became detrimental to young forest plantations. Initially, a controlled program of shooting and trapping was used to reduce the hog population. Currently, deer hunters can shoot these feral hogs, and through 1983 had eliminated about 700. The present estimated population of feral hogs is between 500 and 1000. Except for deer, beaver, and feral hogs there is no authorized predation at SRP.

The following eight species of mammals are considered semiaquatic and are generally associated with the wetland/floodplain habitats:

Order Insectivora - Shrews and Moles

Family Talpidae
Condylura cristata - Star-nosed mole

Order Lagomorpha - Rabbits and Hares

Family Leporidae
Sylvilagus palustris - Marsh rabbit

Order Rodentia - Rodents

Family Castoridae
Castor canadensis - Beaver

Order Rodentia - Rodents (continued)

Family Cricetidae
Ondatra zibethicus - Muskrat
Oryzomys palustris - Rice rat

Order Carnivora - Carnivores

Family Procyonidae
Procyon lotor - Raccoon

Family Mustelidae
Lutra canadensis - River otter
Mustela vision - Mink

Order Marsupialis - Marsupials

Family Didelphiidae
Didelphis marsupialis - Opossum

None of these semiaquatic mammals inhabit reactor effluent streams during periods of elevated water temperatures. Beaver and otter, however, reoccupy these streams within 24 hours of reactor shutdown (Du Pont, 1985).

C.5 AQUATIC BIOTA

Six major aquatic habitat types occur at SRP: small ponds, Carolina bays, reservoirs, streams, and the Savannah River and its associated floodplain swamp. The surface areas of these waters vary in size, from less than 1 acre to about 2700 acres. Flows in the various streams range from intermittent to more than 11 cubic meters per second.

Water flow patterns through the swamp system bordering the Savannah River are complex; these patterns change depending on water levels in the Savannah River. Patterns are quite diverse; distinct water courses alternate with braided channels and broad flats of barely perceptible water movement. Many fish species use the swamp system as a spawning and rearing ground. Its use depends on high water levels, which increases spawning habitat. The swamp is one of the most variable habitats, exhibiting depth fluctuations of 4 meters or more along with the input of thermal effluents.

C.5.1 AQUATIC FLORA

Attached algae (periphyton) are the predominant primary producers in running-water environments like the Savannah River. Much of the phytoplankton (floating algae) community consists of true planktonic forms, as well as detached periphytic forms, that are discharged from upstream reservoirs and from backwaters and tributary streams.

Diatoms dominate the algal flora of the Savannah River. Although blue-green algae are at times an important component, particularly at upstream locations that are subject to organic enrichment from municipal effluents, industrial effluents, and agricultural runoff. The greatest algal diversity consistently occurs during the summer, coincident with low river flow and decreased turbidity, which allows greater light penetration.

Approximately 400 species of algae have been identified from the Savannah River near SRP (Patrick, Cairns, and Roback, 1967). Since 1951, when algal studies began, the diversity has decreased. Patrick, Cairns, and Roback (1967) suggested that this reflects an increase of organic loading to the river from the area above the Plant (ANSP, 1961, 1974).

Aquatic macrophytes in the river, most of which are rooted, are limited to shallow areas of reduced current in oxbows and along the shallow margins of tributaries. Eight species of vascular plants have been identified from the river adjacent to SRP; the most abundant are water milfoil, hornwort, alligator weed, waterweed, and duck potato.

Flora are greatly reduced in the SRP streams that receive thermal effluents, reflecting the influence of high flows and elevated water temperatures. The thermal gradient ranges from temperatures too high for most living organisms (70°C), through a thermophilic bacteria and algal zone, to near-ambient temperatures where the water enters the Savannah River. In addition, the streams are sufficiently narrow to produce nearly horizontal and vertical thermal constancy; thus, the only refuges from the hot water are in tributaries or adjacent sloughs. Reactor effluent has increased the total flow to 10-20 times the normal stream flow. This flow has broadened and eroded the streambeds; eliminated rooted, aquatic vascular plants (macrophytes); reduced the overhead canopy, exposing the stream to sunlight; and accumulated silt deposits in some peripheral zones along the banks.

C.5.1.1 Beaver Dam Creek

Beaver Dam Creek immediately below the D-Area discharge structure is characterized by a deep (1 to 2.5 meters) channel and a substrate of shifting sand, fly ash, organic deposits, and occasional clay outcrops (Du Pont, 1985). Riparian vegetation is dominated by a narrow band of bottomland hardwoods and scrub-shrub forest, where wax myrtle, tag alder, willow, and buttonbush are dominant. Emergent macrophytes are present in off-channel areas, such as in oxbows, behind sand bars, and in swamp areas along the margins of the stream near the delta. These areas are dominated by cattail, cutgrass, and water primrose. Aquatic flora is dominated by thermophilic bacteria and blue-green algae (Du Pont, 1985).

C.5.1.2 Four Mile Creek

A relatively deep (0.3 to 1.5 meter), fast-flowing (about 140 centimeters per second) zone occurs where the main flow of Four Mile Creek courses toward the Savannah River (Du Pont, 1985). The flora is sparse, reflecting the influence of high flow and elevated (greater than 40°C) water temperatures. The substrate is primarily sand, organic matter, silt, and clay. In backwaters and shallow areas, particularly on clay outcrops, thick mats of blue-green algae cover the bottom. Riparian vegetation is dominated by tag alder and wax myrtle. Farther downstream toward the swamp, the stream is braided over a marsh-like area where a few standing dead bald cypress remain. In this area, defined and deeper channels are relatively free of vegetation. There are, however, thick growths of emergent macrophytes dominated by sedges, cutgrass, false nettle, and water purslane. In the shallower areas, thick mats of bluegreen algae cover the bottom.

C.5.1.3 Pen Branch

The upper reaches of Pen Branch are characterized by a substrate of sand and silt clay, while deep organic deposits occur in the many side channels (Du Pont, 1985). Blue-green algal mats similar to those in Four Mile Creek cover the substrate. Riparian vegetation includes sedges, grasses, wax myrtle, and buttonbush. Duckweed is abundant in the many side pools and channels.

The delta region of Pen Branch is characterized by an open and closed canopy of living and dead bald cypress and tupelo. Many channels braid through the area and the flow is generally in a shallow sheet. The dominant vegetation consists of smartweed, arrowhead, creeping burhead, water primrose, sedges, and duckweed. Fewer emergent plants are located at the closed canopy areas of the delta.

C.5.2 AQUATIC FAUNA

C.5.2.1 Macroinvertebrates

The structure and function of macroinvertebrate assemblages can indicate longterm conditions in a stream, due to their sensitivity to stress from pollution, and can be used in water quality evaluation (Weber, 1973). Thermal discharges have complex effects on macroinvertebrate communities (Hutchinson, 1976; Ward and Stanford, 1982). Increased water temperatures can accelerate or delay the emergence patterns of aquatic insects (Wise, 1980) and increase or decrease the number of generations (Parkin and Stahl, 1981; Rodgers, 1980). In some cases, elevated thermal regimes can significantly reduce species richness (Ferguson and Fox, 1978; Howell and Gentry, 1974). Other macroinvertebrate taxa can respond positively to increased water temperatures. For example, relative abundances of oligochaetes, nematodes, gastropods, and chironomid midges increase with thermal enrichment (Nichols, 1981; Rasmussen, 1982; Laybourn, 1979; Wood, 1982; Vincent, 1967; Ferguson and Fox, 1978).

To evaluate the response of macroinvertebrates to thermal stress and the longterm recovery of the macroinvertebrate community, samples were collected from nonthermal (Meyers Branch), thermal (Beaver Dam Creek, Four Mile Creek, and Pen Branch), and post-thermal (Steel Creek) streams, and from swamp locations on SRP between November 1983 and May 1984 (Du Pont, 1985). In addition, samples were collected at the mouths of Upper Three Runs Creek, Steel Creek, and Lower Three Runs Creek from September 1982 through August 1983 (Specht et al., 1984).

The number of macroinvertebrate taxa collected from each stream station varied considerably between thermal and nonthermal stations (Table C-5). The thermally perturbed sites had the fewest taxa. Many of the taxa recorded at these sites were not resident species, but were species that had invaded and colonized during reactor shutdown periods; most were eliminated when the reactor restarted.

In general, fewer macroinvertebrate taxa and lower densities of organisms were collected from thermal sites than from post-thermal or nonthermal sites (Table C-5). The macroinvertebrate communities of the thermal sites were dominated by oligochaetes (segmented worms), nematodes (round worms) and Diptera (primarily midges), while thermally sensitive taxa, such as mayflies, stoneflies, and caddisflies were absent or occurred in very low densities. Nonthermal and post-thermal sites exhibited more diverse assemblage of macroinvertebrate taxa. At thermal sites, collector-gatherers clearly dominated the macroinvertebrate functional groups, while at nonthermal sites there was a more even distribution of functional groups, indicative of a more balanced biological community.

C.5.2.2 Fish

The Savannah River and its associated swamp and tributaries exhibit a diverse fish fauna typical of other southeastern coastal plain rivers and streams. Many ecological studies during the past 30 years have included the adult fish of the Savannah River. Matthews (1982) reviewed those studies published by the Academy of Natural Sciences of Philadelphia between 1951 and 1976.

Table C-5. Composition of Stream Macroinvertebrate Community, Presented as Sum of Densities (no./m^2), December 1983 - May 1984[a]

	Stations[b]							
	Mildly thermal	Severely thermal			Nonthermal			
Taxa	1	2	3	4	7	8	11	12
Coelenterata	75	0	0	0	0	0	84	0
Turbellaria	0	0	0	0	10	17	117	8
Nematoda	12,747	4,965	6,707	2,763	3,750	1,205	10,284	5,221
Annelida								
Oligochaeta	19,718	412	6,178	45,612	15,185	18,001	8,812	7,923
Hirudinea	0	0	0	0	0	0	75	0
Crustacea								
Isopoda	0	0	0	0	8	0	83	0
Amphipoda	302	2	8	84	385	27	302	1,001
Decapoda	0	0	0	0	0	0	0	0
Hydracarina	557	8	6	75	640	210	2,354	590
Insecta								
Collembola	0	8	0	0	8	8	8	8
Odonata	153	0	0	0	0	302	0	75
Ephemeroptera	17	86	87	161	3,727	4,511	4,987	1,871
Plecoptera	0	0	0	0	385	2,172	2,455	2,955
Hemiptera	0	0	0	0	0	0	0	0
Megaloptera	0	0	0	0	49	6	2	17
Neuroptera	0	0	0	0	0	0	0	0
Trichoptera	127	151	11	120	5,347	2,489	2,981	4,368
Lepidoptera	0	0	0	0	0	0	8	0
Coleoptera	17	0	42	97	2,022	1,415	1,786	1,058
Diptera	5,860	3,023	19,575	13,287	100,199	66,233	76,290	84,085
Gastropoda	1,971	17	358	1,512	75	379	22	316
Pelecypoda	4,828	0	2	0	302	3,779	75	12,828

a. Source: Du Pont, 1985.
b. Stations 1 (Beaver Dam Creek), 2 and 3 (Four Mile Creek), 4 (Pen Branch), 7 and 8 (Steel Creek), 11 and 12 (Meyers Branch).

Bennett and McFarlane (1983) summarized the general distribution of fish within the major drainage systems of the Savannah River Plant. McFarlane, Frietsche, and Miracle (1978) and Dudley, Mullis, and Terrell (1977) reported the results of fisheries studies in the portion of the river near the Plant. In addition, the Georgia Game and Fish Division (1982) reported on an electrofishing survey conducted at 24 locations between the New Savannah River Bluff Lock and Dam and Port Wentworth. Rulifson, Huish, and Thoesen (1982) compiled data on anadromous species, many of which are important in the Savannah River. The most intensive study to date of the fish community of the SRP streams and the Savannah River (Du Pont, 1985) began in 1983.

This section summarizes the influence of thermal effluents on the fish community, specifically the distribution and abundance of adult and larval fish communities in nonthermal, post-thermal, and thermal streams; the effects of entrainment and impingement of adults and ichthyoplankton; the movement of fish into thermal streams; and the thermal tolerance of larval fish (Du Pont, 1985).

Fishes of Savannah River Plant Streams

Adult Fish of SRP Streams

Adult fish sampling began in September 1983 in nonthermal (Meyers Branch), thermal (Pen Branch and Four Mile Creek), and post-thermal (Steel Creek) streams (Figure C-4).

Nonthermal Streams - Relative abundance was greatest at the Meyers Branch station near Road 9 during the March 17 collection (Table C-6). The collection (401 fish) was dominated numerically by the yellowfin shiner (63 percent), bluehead chub (7 percent), pirate perch (5 percent), tessellated darter (5 percent), redbreast sunfish (4 percent), and spotted sunfish (3 percent). Steel Creek near Road B exhibited similar species composition and abundance during the March 10 collection; this collection (270 fish) was composed of 14 species and was dominated by yellowfin shiner (52 percent), bluehead chub (10 percent), northern hogsucker (9 percent), redbreast sunfish (9 percent), and flat bullhead (5 percent).

Post-Thermal Streams - The March 14, 1983, collection (Table C-6) from Steel Creek represented 23 species and 292 individuals. This sample exhibited the greatest species diversity, possibly due to its proximity to the Savannah River swamp. The collection was dominated by shiners (75 percent), darters (6 percent), and bullheads and madtoms (12 percent). This assemblage is a mixture of species usually associated with both stream channels and pools, backwaters, and vegetated areas along the channel.

Thermal Streams - Three locations were sampled on Pen Branch upstream of the K-Reactor outfall. A sample of site PB1, collected on April 2, 1984, was dominated by species associated with benthic-detritus microhabitats; it consisted of 76 individuals and 10 species (Table C-6). This sample was dominated by the mud sunfish (30 percent), brown bullhead (17 percent), dollar sunfish (16 percent), lake chubsucker (14 percent), and pirate perch (10 percent). Noticeably absent were species generally associated with fast-flowing water (i.e., darters).

Seventeen species of fish totaling 99 individuals were collected on March 29, 1984. Species composition was dominated by yellowfin shiner (42 percent) and sunfish (15 percent). Although there was a reduction in the total number of fish collected between September and March, the species composition remained nearly the same, indicating some degree of stability for the fauna.

One other location on Pen Branch exhibited relative abundance and species composition similar to those of the other streams surveyed. On March 26, 1984, 145 individuals representing 16 species were collected (Table C-6). The most abundant species were the yellowfin shiner (40 percent), sunfish (16.5 percent), and madtom (13.8 percent). TC

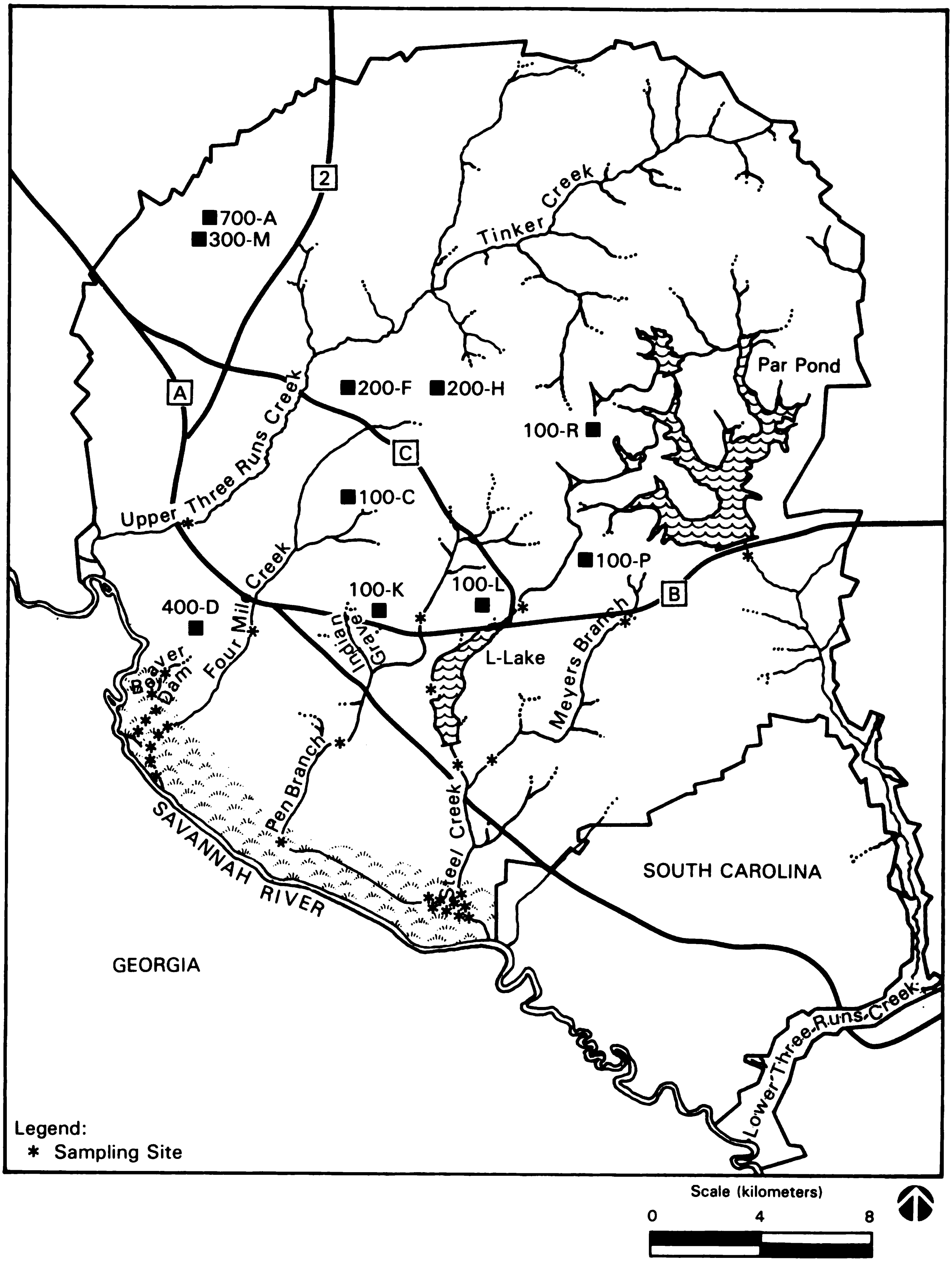


Figure C-4. Fisheries Sampling Sites in SRP Creeks

Table C-6. Number of Fish Collected in SRP Streams, September 1983 - April 1984[a]

	Location[b]									
	Nonthermal				Post-thermal	Thermal				
Species	MB Sept.	MB Mar. 17	SC 1 Sept.	SC 1 Mar. 10	SC 2 Mar. 14	PB 1 Apr. 2	PB 2 Sept.	PB 2 Mar. 29	PB 3 Sept.	PB 3 Mar. 26
American eel	3 (1.0)[c]	6 (1.5)		7 (2.6)	9 (3.1)	1 (13.1)	2 (1.0)	2 (2.0)	2 (0.8)	
Pirate perch	15 (5.2)	20 (4.9)				8 (10.5)	23 (11.9)	8 (8.1)	9 (3.7)	11 (7.6)
Creek chubsucker						1 (1.3)	3 (1.6)	2 (2.0)	6 (2.5)	2 (1.4)
Lake chubsucker	3 (1.0)	2 (0.5)	1 (0.7)	2 (0.7)	2 (0.7)	11 (14.5)	1 (0.5)	1 (1.0)		
Northern hogsucker	3 (1.0)	5 (1.2)	9 (6.1)	25 (9.3)						
Banded pygmy sunfish					1 (0.3)					
Bluespotted sunfish		1 (0.2)								
Warmouth					1 (0.3)					
Dollar sunfish					2 (0.7)	12 (15.8)	1 (0.5)			
Mud sunfish	2 (0.7)					23 (30.3)	2 (1.0)	2 (2.0)		
Redbreast sunfish	19 (6.5)	15 (3.7)	19 (12.8)	25 (9.3)	6 (2.1)	1 (1.3)	9 (4.7)	5 (5.1)	16 (6.6)	17 (11.7)
Spotted sunfish	16 (5.5)	13 (3.3)	1 (0.7)	1 (0.4)	11 (3.8)		14 (7.3)	8 (8.1)	14 (5.8)	7 (4.8)
Flier					1 (0.3)					
Largemouth bass	2 (0.7)				1 (0.3)				1 (0.4)	
Unknown shiner	1 (0.3)						16 (8.3)		11 (4.6)	
Creek chub				1 (0.4)						
Bluehead chub	24 (8.2)	29 (7.2)	24 (16.2)	27 (10.0)	1 (0.3)		11 (5.7)	7 (7.1)	18 (7.5)	3 (2.1)
Pugnose shiner					1 (0.3)					
Coastal shiner					36 (12.3)					
Dusky shiner					154 (52.7)			3 (3.0)		
Yellowfin shiner	167 (57.4)	251 (62.6)	79 (53.4)	141 (52.2)	27 (9.2)		84 (43.5)	42 (42.4)	138 (57.3)	58 (40.0)
Lined topminnow					1 (0.3)					1 (0.7)
Mosquitofish				2 (0.7)	1 (0.3)					

Table C-6. Number of Fish Collected in SRP Streams, September 1983 - April 1984[a] (continued)

Species	Location[b]									
	Nonthermal				Post-thermal	Thermal				
	MB Sept.	MB Mar. 17	SC 1 Sept.	SC 1 Mar. 10	SC 2 Mar. 14	PB 1 Apr. 2	PB 2 Sept.	PB 2 Mar. 29	PB 3 Sept.	PB 3 Mar. 26
Redfin pickerel	6 (2.1)	3 (0.7)				2 (2.6)	15 (7.8)	3 (3.0)		1 (0.7)
Chain pickerel					3 (1.0)			2 (2.0)	1 (0.4)	4 (2.8)
Yellow bullhead	1 (0.3)		2 (1.4)		1 (0.3)	4 (5.3)	6 (3.1)	3 (3.0)		
Brown bullhead					2 (0.7)	13 (17.1)		1 (1.0)		
Flat bullhead	2 (0.7)	6 (1.5)	8 (5.4)	15 (5.6)			4 (2.1)	1 (1.0)	4 (1.7)	6 (4.1)
Speckled madtom	6 (2.1)	9 (2.2)	2 (1.4)	17 (6.3)	15 (5.1)				9 (3.7)	7 (4.8)
Margined madtom	5 (1.7)	12 (2.9)		2 (0.1)			2 (1.0)	5 (5.1)	9 (3.7)	11 (7.6)
Tadpole madtom								1 (1.0)		2 (1.4)
Tessellated darter	12 (4.1)	19 (4.7)		1 (0.4)	12 (4.1)			4 (4.0)		1 (0.7)
Savannah darter		6 (1.5)							1 (0.4)	7 (4.8)
Sawcheek darter					1 (0.3)					
Blackbanded darter	4 (1.4)	4 (0.9)	3 (2.0)	4 (1.5)	3 (1.0)				2 (0.8)	7 (4.8)
Number of fish	291	401	148	270	292	76	193	99	241	145
Number of species	18	16	10	14	23	10	.15	17	15	16

a. Source: Du Pont, 1985.
b. Location Codes: MB = Meyers Branch
SC 1 = Steel Creek at Road B
SC 2 = Steel Creek at Cypress Bridge
PB 1 = Pen Branch above Road C
PB 2 = Pen Branch at Road C
PB 3 = Pen Branch at Road B
c. Percent composition in parentheses.

Movement of fish into the channels of thermal creeks (Pen Branch and Four Mile Creek) during reactor outages is directly related to the duration of a reactor outage. Thirty species of fish were collected in thermal creeks; 24 species were common to both Pen Branch and Four Mile Creek. Centrarchids were the fish collected most commonly, accounting for 47 percent and 45 percent of the fish collected from Pen Branch and Four Mile Creek, respectively. Other dominant taxa included the lake chubsucker (16-26 percent), the golden shiner (11-12 percent), and the longnose gar (1-14 percent).

However, samples collected from Four Mile Creek above the delta during a 50-day reactor shutdown in February 1984 were dominated exclusively by mosquitofish (Du Pont, 1985).

In general, fewer adult fish and a reduced species composition were noted from thermal streams than from post-thermal or nonthermal streams (Table C-6). The adult fish communities of the thermal streams above the outfalls were dominated by small fish (i.e., shiners and sunfish). However, during reactor shutdowns, the thermal streams below the outfall were dominated by mosquitofish. Post-thermal areas exhibited the greatest species diversity and reflected species composition typical of small headwater streams.

Ichthyoplankton of SRP Streams

Ichthyoplankton were sampled at 5 nonthermal, 16 post-thermal, and 14 thermal sites in SRP streams from mid-March through July 1984 (Paller et al., 1984). Nonthermal sites included three locations on Upper Three Runs Creek and two locations on Meyers Branch. Post-thermal sampling sites included three locations in Lower Three Runs Creek and 13 stations in Steel Creek. Three thermal streams, Beaver Dam Creek, Four Mile Creek, and Pen Branch, were sampled.

Nonthermal Streams - Ichthyoplankton abundance in the nonthermal stream-swamp area during 1984 was dominated by centrarchids (sunfish), catostomids (suckers), and percids (darters) (Table C-7). The spotted sucker was the most abundant species (55 percent) in the upper reaches of Upper Three Runs Creek, while crappie (21 percent) were the most prevalent species at the creek mouth. Ichthyoplankton densities were moderate to low (mean = 42 per 1000 cubic meters) at all stations. Meyers Branch was dominated by sunfish or bass (45 percent) and darters (30 percent). Densities were relatively low at the station near the mouth (18-67 per 1000 cubic meters), suggesting very little ichthyoplankton transport into Steel Creek from the upper reaches of Meyers Branch, which exhibited densities of 23 to 183 per 1000 cubic meters. The greater densities in the upper part of Meyers Branch might be related to more suitable spawning habitat. Several beaver dams in this area might provide good habitat for centrarchid spawning.

Post-Thermal Streams - During 1984, a total of 2785 ichthyoplankters were collected from Steel Creek and Lower Three Runs Creek (Table C-7). Relative abundance was much higher than that found in the nonthermal or thermal streams and was primarily the result of the locations of the sample collections. Generally, densities at swamp and creek mouth stations were substantially higher than at creek stations upstream from the swamp. The most dominant taxa during all collections were centrarchids (sunfish and bass, 28 percent),

Table C-7. Number and Relative Abundance of Ichthyoplankton Collected from Nonthermal, Post-Thermal and Thermal Creeks of the Savannah River Plant March 14 - June 3, 1984

	Onsite creeks[b]							
	Nonthermal		Post-thermal			Thermal		
Taxa	UTR	MB	SC	SCMB	LTR	BDC	FMC	PB
American shad			13(0.9)			1(0.5)		
Gizzard or threadfin shad	12(5.6)[c]	3(2.0)	12(0.9)		23(1.7)	19(8.6)	16(7.9)	
Blueback herring	4(1.9)		65(4.7)		20(1.5)	9(4.1)	21(10.3)	
Unidentified shad or herring	3(1.4)		14(1.0)		16(1.2)	3(1.4)	4(2.0)	
Spotted sucker	118(55.1)		14(1.0)		3(0.2)	4(1.8)		
Unidentified suckers	3(1.4)	4(2.7)	57(4.1)		15(1.1)			4(10.5)
Pirate perch			41(3.0)			3(1.4)		
Sunfish and/or bass	3(1.4)	66(44.9)	387(28.1)		626(46.1)	84(37.9)	65(32.0)	1(2.6)
Crappie	44(20.6)		34(2.5)		266(19.6)	25(11.3)	5(2.5)	
Yellow perch	2(0.9)		12(0.9)	2(4.1)	29(2.1)	1(0.5)	1(0.5)	5(13.2)
Darters	9(4.2)	44(29.9)	167(12.1)	13(26.5)	158(11.6)	20(9.0)	1(0.5)	10(26.3)
Mudminnows			5(0.4)					
Swampfish			10(0.7)					1(2.6)
Minnows	9(4.2)	14(9.5)	356(25.8)	33(67.3)	16(1.2)	15(6.8)	14(6.9)	10(26.3)
Carp	2(0.9)					1(0.5)	3(1.5)	
Pickerel			1(0.1)					
Topminnow								1(2.6)
Mosquitofish					1(0.1)			3(7.9)
Silverside		1(0.7)	29(2.1)		23(1.7)	8(3.6)	28(13.8)	
Unidentifiable ichthyoplankton	5(2.3)	15(10.2)	162(11.7)	1(2.0)	161(11.9)	29(12.6)	45(22.2)	3(7.9)
Total	214	147	1379	49	1357	222	203	38
Grand total	361			2785			463	
Number of locations sampled	3	2	13	3	3	5	6	3

a. Adapted from Du Pont, 1985.
b. Key: UTR=Upper Three Runs Creek; MB=Meyers Branch; SC=Steel Creek; SCMB=Steel Creek above Meyers Branch; LTR=Lower Three Runs Creek; BDC=Beaver Dam Creek; FMC=Four Mile Creek; PB=Pen Branch.
c. Percent composition in parenthesis.

minnows (25 percent), and darters (12 percent). Blueback herring (4 percent) were abundant in the creek mouths during April. The mean ichthyoplankton density was 175 per 1000 cubic meters during the March-to-June sampling period.

The predominant taxa collected from Lower Three Runs Creek were sunfish or bass (46 percent), crappie (20 percent), and darters (12 percent). The high densities collected in Lower Three Runs Creek were a result of samples collected immediately downstream of the Par Pond Dam (mean density = 1062 per 1000 cubic meters); they represent intense spawning activity in this tailwater area in combination with larval production in Par Pond that might have overflowed into the tailwater.

Thermal Streams - The D-Area effluent entering Beaver Dam Creek is considerably cooler than the reactor effluent (70°C) entering the other thermal creeks. Temperature data collected as part of the ichthyoplankton sampling program during 1984 indicated that the upper reaches of Beaver Dam Creek (Road A-12) averaged 20° to 25°C, while Four Mile Creek near Road A-13 averaged 30° to 45°C during the April-through-May sampling period. Temperatures decreased in Beaver Dam Creek from Road A-12 to the lowermost swamp station due to the gradual cooling of the water as it progressed downstream. However, temperatures increased at the mouth, probably due to an influx of heated water from Four Mile Creek through a channel connecting the lower reaches of Four Mile and Beaver Dam Creeks.

Ichthyoplankton densities in thermal streams ranged from total absence to very low abundance. Ichthyoplankton collected in the reactor streams between the outfalls and the swamp are believed to represent individuals that were transported into the streams from adjacent refugia, including nonthermal tributary streams, during periods of high river flow. These refugia appear to support self-sustaining (i.e., reproducing) populations of fish. In addition, ichthyoplankton abundance in thermal portions of the Savannah River swamp appears to be quite variable and strongly influenced by water levels in the Savannah River. It is also possible that the thermally impacted areas are utilized for spawning during high river flows, when flow patterns for the heated water are altered drastically.

A total of 463 ichthyoplankters was collected from the three thermal streams [Beaver Dam Creek (222), Four Mile Creek (203), and Pen Branch (38)] during the March-to-June 1984 sampling period (Table C-7). Sunfish or bass dominated the catch at both Beaver Dam Creek (38 percent) and Four Mile Creek (32 percent) while minnows (10 percent) and darters (10 percent) were dominant at Pen Branch. Beaver Dam Creek exhibited greater ichthyoplankton density and species diversity than the other thermal streams, but it did not produce the density of ichthyoplankton expected (considering the level of thermal loading observed was not much greater than in the more productive areas of the post-thermal Steel Creek delta).

C-Reactor did not operate during most of March 1984; therefore, mean temperatures in Four Mile Creek were only 5° to 10°C above Savannah River temperatures. Ichthyoplankton were not collected from the Road A station or the thermal delta during March, but were found in low densities in the swamp and creek mouth. Blueback herring were the most dominant in the delta while brook silversides were most dominant in the creek mouth.

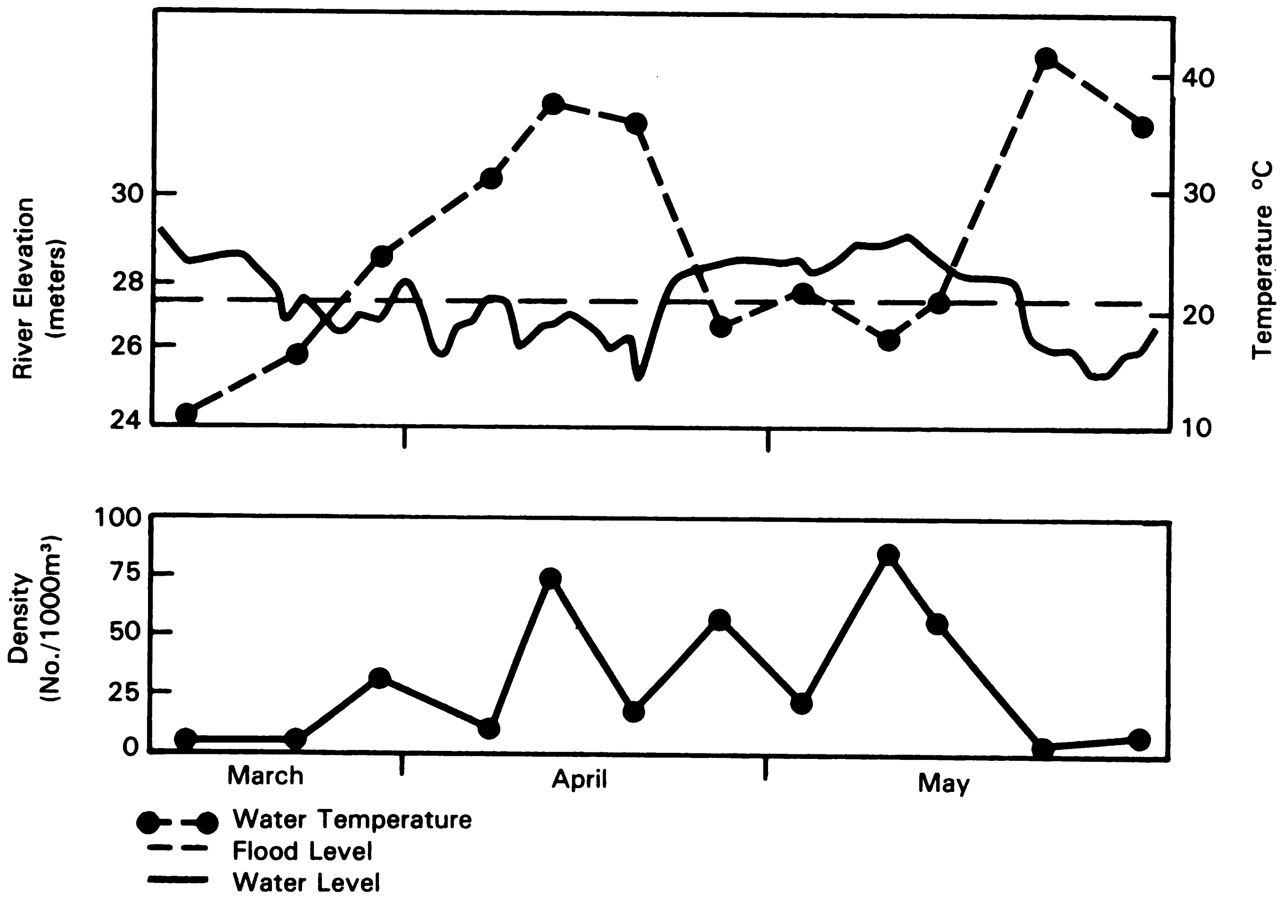
C-Reactor was operating during April and May 1984; it produced temperatures in Four Mile Creek ranging from 33.9° to 50.1°C at Road A, and from 30.1° to 44.8°C at Road A-13. As expected, Four Mile Creek produced very little ichthyoplankton in its upper reaches (the area above Road A) with the exception of brook silverside and unidentifiable eggs; these eggs probably drifted into the channel of the creek from adjacent refuge areas. Temperatures in the heated swamp were lower and much more variable (18° to 42°C) due to the alteration of water flow patterns during river flooding. The extreme temperature variability in the heated swamp was due to the intermittent intrusion of relatively cool river water into the swamp during periods of high river level (Figure C-5). The river water displaced the thermal plume and created suitable habitat for fish in areas that had been thermally unsuitable. Most of the larvae collected from the swamp during April and May apparently were spawned during periods of high river level when the swamp was inundated with river water. Some larvae were collected when the temperatures were high during April; however, these might have drifted into the thermal swamp from adjacent cool-water refuge areas.

Few ichthyoplankton (38) were collected from Pen Branch during the March-to-June 1984 sampling period. Ichthyoplankton were either absent from the samples or present in low densities. The dominant species in the delta was the mosquitofish. This species is more tolerant of high temperatures than most, with an ultimate maximum temperature of 37.3°C (Hart, 1952). Most individuals were found in somewhat cooler refuge areas along the shoreline of the main thermal channel. Darters and minnows dominated the catch from above the reactor discharge area.

Researchers observed that, generally, ichthyoplankton densities at swamp and creek mouth stations were substantially higher than at creek stations upstream from the swamp. Sampling in the vicinity of the post-thermal Steel Creek delta revealed that spawning activity differs substantially in the different microhabitats available in that area. The deep-water, open-canopy areas were clearly the most productive for ichthyoplankton, with centrarchids (sunfish and bass), cyprinids (minnows), and percids (darters) dominating the collections. Although clupeids (herring and shad) were collected in the delta/swamp areas, the numbers were much lower than the numbers observed at creek mouth stations. Generally, it appears that anadromous species make minimal use of swamp areas for spawning and restrict spawning activities to creek mouth areas.

Ichthyoplankton densities in thermal streams were low. Ichthyoplankton collected in the reactor streams between the outfalls and the swamp are believed to represent individuals that were transported into the streams from adjacent refugia, including nonthermal tributary streams. These refugia appear to support self-sustaining (i.e., reproducing) populations of fish. Ichthyoplankton that are transported into the reactor effluent streams when reactors are operating are undoubtedly killed.

Ichthyoplankton abundances in thermal portions of the Savannah River swamp are quite variable and appear to be strongly influenced by water levels in the Savannah River. During periods of high river flow, ichthyoplankton appear to be transported into the thermally impacted portions of the swamp from adjacent unimpacted areas. It is also possible that the thermally impacted areas are



Source: Adapted from Du Pont (1985)

Figure C-5. A Comparison of the Ichthyoplankton Density in the Four Mile Creek Delta with Water Temperature and Savannah River Level

utilized for spawning during high river flows, because flow patterns for the heated water are drastically altered during such periods.

Ichthyoplankton densities in Beaver Dam Creek are lower than expected considering the low degree of thermal enrichment. Factors other than temperature probably are influencing fish spawning activities in this area of the swamp.

Adult Fish of the Savannah River Swamp System

The Savannah River Swamp System (SRSS) represents a very heterogeneous system of habitats supporting a diverse fish community of 60 to 65 species. Most species are resident; however, seven are either anadromous or catadromous. Anadromous (migrating from saltwater to freshwater to spawn) species include blueback herring, American shad, hickory shad, striped mullet, mountain mullet, and Atlantic needlefish. The only catadromous (migrating from freshwater to saltwater to spawn) species is the American eel. Several recreationally and commercially important species have been collected in the swamp; thus, the SRSS could be an important spawning habitat and nursery grounds for these species. This section summarizes the data collected on the adult fish community in the swamp system from October 1983 to April 1984 (Du Pont, 1985).

Adult fish were collected at three areas in the swamp: the Steel Creek delta; the Four Mile Creek delta, and a channel near Pen Branch (near Stave Island).

More than 1500 fish representing 40 species were collected from the swamp. The high species diversity was due to the wide array of habitat types available. The Steel Creek delta sample consisted of 32 species, of which brook silversides, various shiners, and largemouth bass dominated all catches.

Species diversity at stations in the delta-swamp area of Pen Branch were similar - 21 species dominated by brook silversides and various shiners.

Four Mile Creek stations differed among themselves and also from the other three delta-swamp stations. Fifteen species of fish were collected; gizzard shad and largemouth bass were the dominant species. Compared to the other stations, minnows were poorly represented at this station.

Researchers captured 149 migratory fish. The dominant species were longnose gar (48 percent), blueback herring (23 percent), channel catfish (10 percent), and various shad (12 percent). Researchers first observed blueback herring during the first week of March, while American shad did not appear until the last week of March. Conversations with local fishermen suggest that American shad were more numerous than blueback herring or hickory shad during 1984, and that a major run of blueback herring did not occur in Steel Creek.

Several trends are evident concerning the structure of fish communities within the SRSS. It appears that the increased species composition and the dominance by centrarchids and cyprinids are attributed to the diversity of microhabitats in the area. The swamp system is composed of extensive open water channels and macrophyte beds of various size. Centrarchids (bass and sunfish) and various suckers dominated the areas with extensive cover while minnows and brook silverside were most prevalent in the shallow open-water areas beneath the closed canopy. The swamp areas below the thermal streams were lower in habitat diversity and species composition.

Fishes of the Savannah River

The following introductory information was obtained from DOE (1987) which cites the primary source documents containing the data. TC

Streams of the southeastern Atlantic Coastal Plain generally contain a diverse fish fauna. One hundred six fish species have been reported from the Savannah River drainage basin; seventy-one species of anadromous and fresh water fish are known to occur in the river in the SRP vicinity. TC

The Savannah River supports both recreational and commercial fisheries. Bream and largemouth bass are the species most sought after by sport fishermen in freshwater sections of the river downstream of the New Savannah Bluff Lock and Dam. Channel catfish are taken by both sport and commercial fishermen. Anadromous species of importance in the Savannah River include American shad (Alosa sapidissima), hickory shad (Alosa mediocris), Atlantic sturgeon (Acipenser oxyrhynchus), shortnose sturgeon (Acipenser brevirostrum), and striped bass (Morone saxatilis). Both shortnose sturgeon and striped bass are protected from commercial harvest, and the shortnose sturgeon is listed as an endangered species. The catadromous American eel (Anguilla rostrata) is harvested commercially in some sections of the river.

Several identifiable factors potentially affect the productivity of Savannah River fish populations. Two areas of the lower Savannah River have been identified where water quality is substantially degraded because of wastewater input: below the New Savannah Bluff Lock and Dam from Butler Creek to downstream of Spirit Creek and in the Savannah Harbor area. Potential contributors to declining anadromous fish stocks include dams and impoundments, inadequate fishway facilities, reduction in spawning habitat, reduction in nursery areas, dredge and fill projects, poor food availability, and the location, type and magnitude of effluents into the Savannah River. BB-3

The species composition and relative abundance of Savannah River fish in the vicinity of the SRP were examined during 1982-1985 (ECS, 1983; Paller et al., 1984; Paller and Osteen, 1985; Paller and Saul, 1986). Collections were made along transects in the Savannah River and in the 1G and 3G intake canals using both electrofishing and hoop-netting techniques. Savannah River collections from four transects near the SRP intakes between RM 152.2 and 157.3 were analyzed for this evaluation. Collections were made quarterly from March 1982 to September 1985.

Scientific and common names of fish collected or known to occur in the Savannah River near SRP are presented in Table C-8. The dominant species collected in the Savannah River and the SRP intake canals during 1982-85 are presented in Table C-9. Other species comprising less than one percent of reported catches for either location or sampling gear are presented in Table C-10.

Adult Fishes of the Savannah River and Creek Mouths

This section summarizes the results of adult fish collections at 12 locations in the Savannah River, the intake canals, and the lower mouths of the five major SRP creeks. The data cover the sampling period from October 1982 to

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Table C-8. Scientific and Common Names of Fish Collected or Known To Occur in the Savannah River Near the SRP

Order	Family	Species	Common Name
Acipenseriformes	Acipenseridae	Acipenser oxyrhynchus	Atlantic sturgeon
		Acipenser brevirostrum	Shortnose sturgeon
Semionotiformes	Lepisosteidae	Lepisosteus osseus	Longnose gar
		Lepisosteus platyrhincus	Florida gar
		Lepisosteus oculatus	Spotted gar
Amiiforms	Amiidae	Amia calva	Bowfin
Anguilliformes	Anguillidae	Anguilla rostrata	American eel
Clupeiformes	Clupeidae	Alosa aestivalis	Blueback herring
		Alosa sapidissima	American shad
		Dorosoma cepedianum	Gizzard shad
		Alosa mediocris	Hickory shad
		Dorosoma petenense	Threadfin shad
Salmoniformes	Umbridae	Umbra pygmaea	Eastern mudminnow
	Esocidae	Esox niger	Chain pickerel
		Esox americanus	Redfin pickerel Grass pickerel
Cypriniformes	Cyprinidae	Cyprinus carpio	Carp
		Hybognathus nuchalis	Silvery minnow
		Hybopsis rubrifrons	Rosyface chub
		Nocomis leptocephalus	Bluehead chub
		Notemigonus crysoleucas	Golden shiner
		Notropis chalybaeus	Ironcolor shiner
		Notropis cummingsae	Dusky shiner

Table C-8. Scientific and Common Names of Fish Collected or Known To Occur in the Savannah River Near the SRP (continued)

Order	Family	Species	Common Name
Cypriniformes	Cyprinidae (cont.)	Notropis emiliae	Pugnose minnow
		Notropis hudsonius	Spottail shiner
		Notropis hypselopterus	Sailfin shiner
		Notropis leedsi	Bannerfin shiner Ohoopee shiner
		Notropis lutipinnis	Yellowfin shiner
		Notropis maculatus	Taillight shiner
		Notropis petersoni	Coastal shiner
		Notropis niveus	Whitefin shiner
	Catostomidae	Carpiodes cyprinus	Quillback carpsucker
		Erimyzon oblongus	Creek chubsucker
		Erimyzon sucetta	Lake chubsucker
		Minytrema melanops	Spotted sucker
		Moxostoma anisurum	Silver redhorse
Cyprinidontiformes	Cyprinodontidae		Unid. killifish
Siluriformes	Ictaluridae	Ictalurus brunneus	Snail bullhead
		Ictalurus catus	White catfish
		Ictalurus natalis	Yellow bullhead
		Ictalurus nebulosus	Brown bullhead
		Ictalurus platycephalus	Flat bullhead
		Ictalurus punctatus	Channel catfish
		Noturus gyrinus	Tadpole madtom
		Noturus insignis	Margined madtom

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Table C-8. Scientific and Common Names of Fish Collected or Known To Occur in the Savannah River Near the SRP (continued)

Order	Family	Species	Common Name
Siluriformes	Ictaluridae (cont.)	Noturus leptacanthus	Speckled madtom
		Pylodicitis olivaris	Flathead catfish
Percopsiformes	Amblyopsidae	Chologaster cornuta	Swampfish
	Aphredoderidae	Aphredoderus sayanus	Pirate perch
Atheriniformes	Belonidae	Strongylura marina	Atlantic needlefish
	Cyprinodontidae	Fundulus lineolatus	Lined topminnow
		Fundulus chrysotus	Golden topminnow
		Fundulus notti	Starhead topminnow
	Poeciliidae	Gambusia affinis	Mosquitofish
	Atherinidae	Ladidesthes sicculus	Brook silverside
Perciformes	Percichthyidae	Morone chrysops	White bass
		Morone saxatilis	Striped bass
	Centrarchidae	Acantharchus pomotis	Mud sunfish
		Centrarchus macropterus	Flier
		Elassoma zonatum	Banded pygmy sunfish
		Enneacanthus chaetodon	Blackbanded sunfish
		Enneacanthus gloriosus	Bluespotted sunfish
		Lepomis auritus	Redbreast sunfish
		Lepomis cyanellus	Green sunfish
		Lepomis gibbosus	Pumpkinseed
		Lepomis gulosus	Warmouth

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Table C-8. Scientific and Common Names of Fish Collected or Known To Occur in the Savannah River Near the SRP (continued)

Order	Family	Species	Common Name
Perciformes	Centrarchidae (cont.)	Lepomis macrochirus	Bluegill
		Lepomis marginatus	Dollar sunfish
		Lepomis microlophus	Redear sunfish
		Lepomis punctatus	Spotted sunfish
		Micropterus salmoides	Largemouth bass
		Micropterus coosae	Redeye bass
		Pomoxis annularis	White crappie
		Pomoxis nigromaculatus	Black crappie
	Percidae	Etheostoma fricksium	Savannah darter
		Etheostoma fusiforme	Swamp darter
		Etheostoma hopkinsi	Christmas darter
		Etheostoma inscriptum	Turquoise darter
		Etheostoma olmstedi	Tessellated darter
		Etheostoma serriferum	Sawcheeker darter
		Perca flavescens	Yellow perch
		Percina nigrofasciata	Blackbanded darter
		Percina caprodes	Logperch
	Mugilidae	Mugil cephalus	Striped mullet
	Agonidae	Agonostomos monticola	Mountain mullet
	Gobiidae	Awaous tajasica	River goby
Pleuronectiformes	Soleidae	Trinectes maculatus	Hogchoker

a. Source: DOE, 1987.

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Table C-9. Percent Composition of Abundant[a] Fish Species[b] Collected in the Savannah River and SRP Intake Canals, 1982-85[c]

	Savannah River		Intake Canals	
Taxa	Electro-Fishing Percent	Hoop Netting Percent	Electro-Fishing Percent	Hoop Netting Percent
Flier	0.30	1.21	0.09	1.55
Redbreast sunfish	26.73	7.09	10.04	12.69
Bluegill	8.44	4.32	24.07	19.95
Spotted sunfish	5.22	0.86	1.83	1.55
Warmouth	1.25	1.04	0.85	0.26
Pumpkinseed	0.17	0.35	2.30	1.04
Redear sunfish	1.63	0.95	4.13	1.81
Dollar sunfish	2.74	0.00	8.38	0.26
Bluespotted sunfish	0.98	0.00	2.34	0.00
Largemouth bass	7.69	0.00	6.04	0.00
Black crappie	2.07	4.75	0.89	27.20
Yellow perch	1.08	0.00	6.47	0.78
BB-3 Bowfin	3.83	1.04	1.91	1.04
Blueback herring	1.73	0.17	0.51	0.00
American shad	1.25	0.26	0.00	0.00
Gizzard shad	2.44	0.86	2.76	2.59
Threadfin shad	1.96	0.00	0.94	0.00
Spotted sucker	11.21	0.78	5.23	3.37
Lined topminnow	0.00	0.00	1.20	0.00
Pirate perch	1.49	0.00	0.47	0.00
Chain pickerel	3.29	0.00	10.97	0.26
Grass pickerel	1.08	0.00	1.70	0.00
Longnose gar	0.81	2.51	0.26	0.52
White catfish	0.07	8.47	0.00	0.26
Flat bullhead	0.24	31.98	0.04	11.92
Brown bullhead	0.00	1.47	0.00	0.00
Channel catfish	0.41	24.29	0.09	8.55
Brook silverside	1.29	0.00	0.94	0.00
Striped mullet	1.42	0.00	2.00	0.00
American eel	3.32	3.11	0.13	2.33
Other species	5.86	4.49	3.42	2.07

a. Species comprising greater than one percent of collections for either sampling method or location.
b. Scientific and common names of Savannah River fish species are presented in Table C-8.
c. Source: DOE, 1987.

Table C-10. Fish Species[a] Collected in Low Abundance[b] in the Savannah River or SRP Intake Canals, 1982-85[c]

Mud sunfish	Eastern silvery minnow
Redeye bass	Ohoopee shiner
White crappie	Notropis spp.
Striped bass	Unidentified minnow
White bass	Golden shiner
Hybrid bass	Hogchoker
Tesselated darter	Redfin pickerel
Logperch	Esox spp.
Blackbanded darter	Spotted gar
Lake chubsucker	Florida gar
Chubsucker	Snail bullhead
Highfin carpsucker	Speckled madtom
Silver redhorse	Eastern mudminnow
Quillback carpsucker	Mosquitofish

a. Scientific and common names of Savannah River fish species are presented in Table C-8.
b. Less than one percent of collections for any sampling method or location identified in Table C-9.
c. Source: DOE, 1987.

BB-3

August 1983, and are based on studies conducted by Environmental and Chemical Sciences, Inc., under contract to E. I. du Pont de Nemours and Company (Paller et al., 1984).

Researchers collected nearly 10,000 adult fish representing 66 species in the river, the intake canals, and the lower reaches of the major SRP creeks during the sampling period.

The electrofishing collections (Table C-11) indicated that sunfishes, especially redbreast, were the most abundant small species (except minnows), while bowfin and spotted sucker were among the most abundant large species during most or all of the year. Flat bullhead and channel catfish were important species, as indicated by hoop net collections, comprising 32 to 63 percent of the catch. Largemouth bass never comprised less than 7.9 percent of the electrofishing samples during any collection period. Other important species were American eel, white catfish, longnose gar, striped mullet, silver redhorse, chain pickerel, and quillback carpsucker.

Species composition varied due to seasonal changes in fish movement and activity (e.g., spawning). The most conspicuous change was a decrease in the relative abundance of sunfish during January (Table C-11). Bowfin, spotted sucker, flat bullhead, and channel catfish were more abundant during January. The greatest number of species was captured during May (37), possibly because of migratory movements or seasonal changes in activity related to spawning. Recruitment of young of the year might have increased the relative abundance of some species during August.

Table C-11. Percent Composition by Number and Weight of Fishes Collected Quantitatively by Electrofishing in the Savannah River and Creek Mouths, October 1982 - August 1983[a]

	1982		1983					
	October		January		May		August	
Taxa	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Bowfin	13.6	53.3	15.1	37.9	2.4	20.6	4.8	36.4
American eel	3.6	1.3	0.3	0.3	1.2	1.4	2.4	1.7
Blueback herring	2.4	0.1	0.0	0.0	0.3	0.2	0.0	0.0
American shad	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.1
Gizzard shad	1.9	1.6	4.5	1.6	2.1	1.7	1.5	1.7
Threadfin shad	0.0	0.0	2.3	0.1	3.3	0.5	0.8	0.0
Quillback carpsucker	0.0	0.0	0.0	0.0	0.3	9.2	0.3	7.0
Spotted sucker	13.5	26.5	22.7	32.0	6.9	26.0	5.3	18.7
Silver redhorse	0.9	2.2	1.4	2.3	2.1	9.6	1.0	4.2
Unidentified redhorse	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Golden shiner	0.0	0.0	0.3	0.1	0.5	0.1	0.4	0.0
Flier	0.0	0.0	0.9	0.1	0.3	0.1	0.0	0.0
Bluespotted sunfish	0.0	0.0	0.0	0.0	5.7	0.1	0.7	0.0
Redbreast sunfish	22.4	1.9	7.1	0.5	13.9	4.0	22.7	4.1
Pumpkinseed	0.0	0.0	0.3	0.1	0.6	0.1	1.8	0.2
Warmouth	1.2	0.1	0.0	0.0	1.8	0.4	1.2	0.2
Bluegill	11.2	0.5	2.6	0.2	5.5	1.0	9.0	1.2
Dollar sunfish	1.4	0.0	0.0	0.0	4.8	0.2	7.3	0.3
Redear sunfish	3.3	0.8	7.7	2.4	3.6	1.9	2.7	1.9
Spotted sunfish	7.1	0.9	4.8	0.2	9.3	1.3	9.3	1.2
Largemouth bass	7.9	4.0	8.5	3.9	9.8	7.8	9.0	4.9
White crappie	0.7	0.1	0.3	0.1	0.1	0.1	0.0	0.0
Black crappie	0.7	0.1	3.7	0.7	2.0	0.6	1.1	0.5
Striped mullet	1.5	1.5	1.1	0.4	2.4	4.3	6.7	9.3
White bass	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Striped bass	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Yellow perch	2.0	0.4	2.0	0.2	2.7	0.9	2.1	0.6
Pirate perch	0.9	0.1	0.0	0.0	0.9	0.1	2.1	0.0
Redfin pickerel	0.7	0.1	5.4	0.1	3.4	0.2	1.6	0.1
Chain pickerel	1.3	0.2	3.4	1.2	11.2	2.1	3.7	1.7
Mudminnow	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Longnose gar	0.5	0.4	4.0	2.8	1.7	3.8	0.9	1.1
Florida gar	0.0	0.0	0.0	0.0	0.4	0.5	0.0	0.0
White catfish	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Brown bullhead	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Flat bullhead	0.0	0.0	0.3	0.1	0.2	0.1	0.1	0.2
Channel catfish	0.2	0.8	0.0	0.0	0.3	0.6	1.1	2.4
Carp	0.3	3.2	1.4	13.1	0.0	0.0	0.0	0.0
Hogchoker	0.8	0.1	0.0	0.0	0.1	0.1	0.2	0.1
Total percent	100.0	99.9	100.1	99.9	99.9	100.0	99.8	99.7
Total number	1628		352		2365		2175	
Total wt. (kg)		670.1		248.1		468.2		505.8

a. Source: Du Pont, 1985.

The sampling stations were located in four basic habitat types: the river proper, intake canals, the mouths of thermal creeks (Four Mile and Beaver Dam Creeks), and ambient creeks (Upper Three Runs, Lower Three Runs, and Steel Creeks).

In general, bluegill, black crappie, and chain pickerel were more abundant in the intake canals than in the other habitats, probably due to their preference for slow-moving water and weed beds. Redbreast sunfish were generally most abundant in the river and bowfin in the ambient creeks, especially Steel Creek. Four Mile Creek attracted numerous gar, bowfin, and gizzard shad during January, but was largely devoid of fishes during the other months. Channel catfish and various bullheads clearly dominated the hoopnet collections at all stations and seasons, probably due to gear selectivity. During the study period, the mean weekly water temperature of the thermal creeks was 14°C; it was 7°C in ambient creeks during the January sampling period. Largemouth bass and sunfishes dominated May catches at both thermal and ambient creek stations, although only 46 fish were collected in thermal creeks compared to 244 in ambient creeks. During May, the mean temperature was 31°C in the thermal creeks and 19.2°C in ambient creeks. Very few fish were collected from the thermal creeks during October or August (4 and 24, respectively). The mean temperature of the thermal creeks during the sampling periods was 27.7°C in October and 32°C in August; it was 15.0°C and 23°C, respectively, during the same months in ambient creeks.

Although the researchers did not sample small fishes and minnows quantitatively, they documented species occurrence and distribution. Species abundance was consistently less in the intake canals than in the river; mosquitofish, brook silversides, and lined topminnows were the most abundant in the canals. Small fish were absent from the mouths of Four Mile Creek and very scarce in Beaver Dam Creek during May and August. The low number of minnow species and small fish collected in these creeks paralleled the large fish collections and are probably the result of high temperatures during May and August (24.5°C to 41.2°C).

Researchers used the number of fish collected quantitatively with electrofishing to estimate the relative density (number of fish per 100 meters of shoreline) (Du Pont, 1985). The relative densities of fishes in the 1G and 3G intake canals (0.5 to 8.4 per 100 meters) were equivalent to the relative density in the river; however, the average weight of fish in the intake canals was approximately 40 percent lower than that in the river because of the predominance of bluegill and other small sunfishes. The seasonal relative abundances in the intake canals were comparable to those in the river.

Relative densities and seasonal trends in the mouths of the ambient temperature creeks were similar to those in the river, with low densities in January (0.3 to 0.5 per 100 meters) and higher densities in the other months (Table C-12). In contrast, the relative density in thermally influenced Four Mile Creek peaked during January (5.9 per 100 meters) at levels greater than those at the other transects (0.2 to 2.9 per 100 meters); this indicates a wintertime aggregation of fishes in the heated waters, which were as much as 7°C warmer than ambient river temperatures. Fish avoided Four Mile Creek during May, August, and October because of the excessively high water temperatures (29° - 41°C compared to 16° - 25°C in ambient creeks). Densities in Beaver Dam Creek during May and August (2.8 and 1.3 per 100

Table C-12. Mean Relative Density of Fishes (No./100 m of Shoreline) at Electrofishing Sample Sites in the Savannah River, Intake Canals, and Tributary Creeks, October 1982 - August 1983[a]

	1982		1983					
	October		January		May		August	
Location	Total fish	Mean no./ 100 m	Total fish	Mean no./ 100 m	Total fish	Mean no./ 100 m	Total fish	Mean no./ 100 m
				RIVER TRANSECTS				
RM 128.9	-[b]	-	-	-	168	7.0	83	3.5
RM 129.1	-	-	-	-	252	10.5	120	5.0
RM 137.1	123	5.1	22	0.9	70	2.9	128	5.3
RM 141.5	189	7.9	36	1.5	133	5.5	137	5.7
RM 141.7	189	7.9	70	2.9	131	5.5	145	6.0
RM 150.4	167	7.0	52	2.2	189	7.9	146	6.1
RM 150.8	133	5.5	15	0.6	155	6.5	133	5.5
RM 152.0	-	-	-	-	191	8.0	81	3.4
RM 152.2	-	-	-	-	114	4.8	87	3.6
RM 155.2	143	6.0	13	0.5	122	5.1	115	4.8
RM 157.0	123	5.1	4	0.2	70	2.9	87	3.6
RM 157.3	161	6.8	42	1.8	118	4.9	155	6.5
				INTAKE CANALS				
1G RM 157.1	144	6.0	35	1.5	161	6.7	148	6.2
3G RM 155.3	121	5.0	11	0.5	201	8.4	199	8.3
				CREEKS				
Lower Three Runs	-	-	-	-	73	6.1	51	5.4
Steel	69	8.6	3	0.5	97	8.1	101	8.4
Four Mile	4	0.7	47	5.9	12	1.0	8	0.7
Beaver Dam	-	-	-	-	34	2.8	16	1.2
Upper Three Runs	60	5.0	2	0.3	74	6.3	235	19.6

a. Source: Du Pont, 1985.
b. (-) locations not sampled.

meters, respectively) were higher than in Four Mile Creek, but considerably lower than those in ambient creeks or river stations. Temperatures in Beaver Dam Creek were 5° to 7°C above ambient river temperatures, but were not as high as those in Four Mile Creek.

Researchers determined the approximate distances between the capture and recapture sites for 68 fish that were tagged in the river, canals, and creeks during the sampling program (Du Pont, 1985). Ninety-one percent were recaptured within 15 days at or near the point of tagging, indicating limited short-term movements. However, tag returns by fishermen indicated that some fish undertook extensive migrations (as far as 55 miles) upstream or downstream from the tagging location over a period of weeks or months.

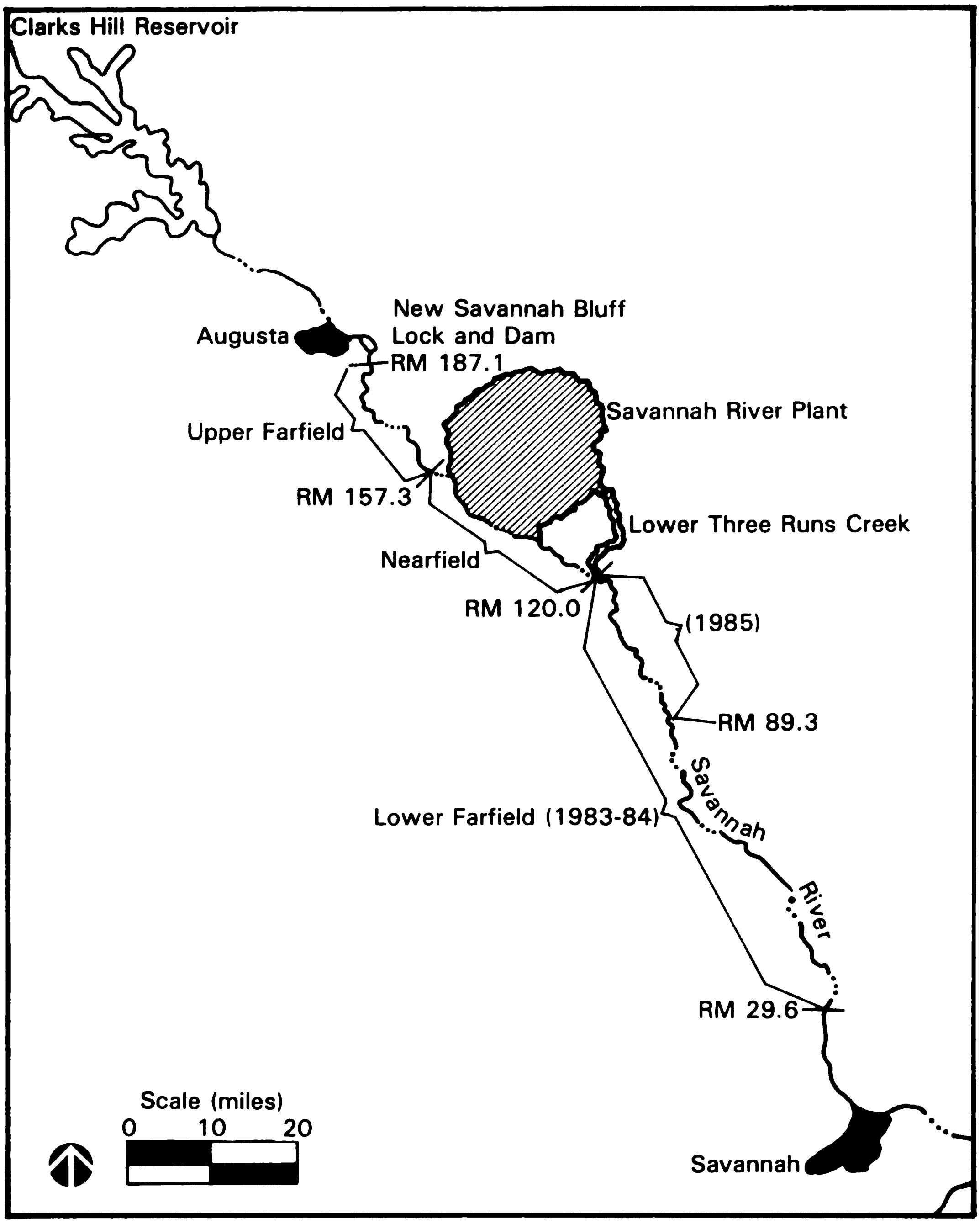
Ichthyoplankton Abundance in the Savannah River

The abundance of ichthyoplankton is one measure of the reproductive success of fishes; concentrations of ichthyoplankton can indicate important spawning sites, identify impacted and control areas, and provide information for entrainment and impingement losses.

Recent studies on ichthyoplankton of the mid- and lower reaches of the Savannah River began in 1982 and ended in 1985 (ECS, 1983; Paller et al., 1984; Paller, O'Hara, and Osteen, 1985; Paller, Saul, and Osteen, 1986). The 1982 studies were restricted in scope, and included seven river transects between RM 141.5 and RM 157.3 and SRP intake canals 1G and 3G (Figure C-6, Table C-13). The 1983 and 1984 studies included 26 river transects between RM 29.3 and RM 187.1, and the two intake canals. The 1985 study was slightly truncated, and included 21 river transects between RM 89.3 and RM 187.1 and the two intake canals. Sampling in 1982 was conducted on alternate weeks from March through August, while in subsequent years, sampling was conducted weekly from February through July. This consideration of entrainment at the SRP will emphasize ichthyoplankton collections in the vicinity of the SRP intake canals during 1983-1985.

The ichthyoplankton assemblage in the Savannah River consists of a variety of species which differ in recreational, economic and ecological importance. BB-3
Among the most abundant ichthyoplankton taxa in the Savannah River are gizzard and/or threadfin shad, American shad, blueback herring, sunfishes, crappie, minnows and suckers (Table C-14). Generally, the clupeids (including anadromous American shad and blueback herring, and resident gizzard and threadfin shad) dominated collections in the Savannah River during 1983-1985. The blueback herring, while somewhat less abundant, is another anadromous species used for commercial purposes in some coastal areas. Some species, such as the largemouth bass and other centrarchids, were comparatively abundant as adults in the Savannah River, but scarce in the ichthyoplankton collections because their eggs and larvae reside in sheltered areas where they are unlikely to become entrained in currents and carried into open water. Such species are less susceptible to SRP entrainment impacts than those that produce drifting eggs and larvae.

All clupeid taxa exhibited considerable variation in abundance among years. American shad eggs and larvae increased in relative abundance from 1.4 percent to 50.7 percent of collections between 1983 and 1985. Concurrently, blueback



Source: DOE, 1987

Figure C-6. Map of the Savannah River Showing the Location of the Savannah River Plant, Lower Farfield, Nearfield, and Upper Farfield Sections of the River

Table C-13. Summary of Sampling Locations and Sampling Times for the Savannah River Ichthyoplankton Program[a]

	Year				
River Mile	1982	1983	1984	1985	
Upper Farfield					
187.1		X	X	X	
176.0		X	X	X	BB-3
166.6		X	X	X	
Nearfield					
157.3	X	X	X	X	
157.1[b]	X	X	X	X	
157.0	X	X	X	X	
155.4	X	X	X	X	
155.3[b]	X	X	X	X	
155.2	X	X	X	X	
152.2		X	X	X	
152.0		X	X	X	
150.8	X	X	X	X	
150.4	X	X	X	X	
145.7				X	
141.7		X	X	X	
141.5	X	X	X	X	
137.7		X	X	X	
129.1		X	X	X	
128.9		X	X	X	
Lower Farfield					
120.0		X	X	X	
110.0		X	X	X	
97.5		X	X	X	
89.3		X	X	X	
79.9		X	X		
69.9		X	X		
60.0		X	X		
50.2		X	X		
40.2		X	X		
29.6		X	X		
Duration	March -August	February -July	February -July	February -July	
Frequency	Biweekly	Weekly	Weekly	Weekly	

a. Source: DOE, 1987.
b. SRP Intake Canals

Table C-14. Percent Composition of Fish Eggs and Larvae Collected in the Savannah River, 1983-85[a]

Taxa	1983[b]	1984[b,c]	1985[c,d]
American shad	1.4	14.0	50.7
Blueback herring	12.1	4.5	2.2
Gizzard and/or threadfin shad	19.9	10.8	9.9
Unid. clupeid	6.7	7.6	3.3
Striped bass	0.2	3.0	5.4
Spotted sucker	5.0	4.3	8.1
Unid. sucker	0.8	0.7	0.4
Pirate perch	8.0	0.3	0.1
Yellow perch	3.5	1.1	0.2
Darter	2.6	2.7	0.7
Sunfish (Lepomis)	2.1	6.9	0.7
Unid. sunfish	1.1	4.0	0.3
Crappie	16.6	13.5	0.3
Mudminnow	<0.1	<0.1	0.0
Swampfish	<0.1	<0.1	<0.1
Minnow (Cyprinid)	14.0	13.5	3.7
Carp	3.6	3.2	4.6
Mosquitofish	<0.1	<0.1	<0.1
Topminnow		<0.1	<0.1
Needlefish	<0.1	0.1	<0.1
Silverside	0.2	0.2	0.1
Catfish and/or bullhead	0.1	<0.1	0.1
Pickerel	0.3	0.1	<0.1
Sturgeon	<0.1	<0.1	0.1
Gar	<0.1	<0.1	0.0
Unidentified	1.7	9.8	9.2
Total numbers	36,941	18,267	22,698

a. Source: DOE, 1987.
b. Based on 26 transects between RM 29.6 and 187.1.
c. Does not include intake canals.
d. Based on 21 transects between RM 89.3 and 187.1.

herring decreased from 12.1 percent (1983) to 2.2 percent (1985) of collections. Gizzard and/or threadfin shad relative abundance paralleled the decline in blueback herring.

Some of the decline in the relative abundance of blueback herring from 1984 to 1985 could be attributable to the reduction of sampling effort in the lower reaches of the Savannah River, because this section of the river appears to be a major spawning area for the species (Table C-15a). However, the decrease in density from 1983 through 1985 was also observed in the mid-reaches of the

Table C-15a. Mean Ichthyoplankton Densities (No./1000 m^3) at Savannah River Transects During February-July 1983.[a]

River mile	American shad	Blueback herring	Striped bass	Other shad[b]	Minnows	Sunfish	Crappie	Total Ichthyo-plankton[c]
				LOWER FARFIELD				
29.6	5.3	11.7	2.7	8.3	4.8	1.5	13.6	67.8
40.0	4.5	16.1	1.4	17.2	6.1	1.1	15.6	89.2
50.2	6.4	20.8	0.5	21.3	12.1	1.9	21.0	118.1
60.0	7.1	32.4	5.1	18.7	11.8	3.4	26.8	144.0
69.9	4.7	19.7	0.5	20.1	6.1	2.0	12.1	87.2
79.9	4.5	26.9	0.8	40.7	6.3	2.0	16.9	124.9
89.3	7.6	32.7	2.3	59.2	9.0	2.4	25.4	171.5
97.5	12.3	39.2	1.1	54.1	10.9	2.6	29.8	191.1
110.0	18.3	13.4	1.3	15.7	17.7	2.5	21.7	136.6
120.0	8.2	8.6	11.3	7.7	12.8	3.0	16.4	98.7
				NEARFIELD				
128.9	5.4	5.9	0.7	5.4	14.9	4.7	16.3	84.4
129.1	6.9	5.8	4.1	5.3	18.1	4.2	16.2	95.2
137.7	10.0	3.8	0.1	3.7	22.3	7.5	15.5	105.1
141.5	6.8	4.2	0.0	4.2	14.7	9.7	13.7	102.2
141.7	12.1	4.0	0.0	4.9	12.2	10.1	14.9	110.2
150.4	8.7	2.5	1.3	4.3	12.9	1.7	5.5	54.0
150.8	8.9	3.6	0.1	4.9	11.1	0.9	7.8	53.2
152.0	7.8	1.9	2.4	6.9	12.1	1.7	5.9	62.1
152.2	10.5	2.5	10.2	8.0	14.7	1.1	6.1	90.3
155.2	11.9	1.9	5.1	9.5	12.2	0.3	4.3	65.4
155.3[d]	0.8	6.5	0.0	33.1	5.9	1.1	9.3	76.8
155.4	10.5	2.6	5.9	11.9	19.2	0.2	6.0	82.3
157.0	12.9	2.9	0.0	8.7	8.3	0.5	6.1	61.5
157.1[d]	1.0	7.9	0.1	23.7	4.4	1.9	11.9	71.5
157.3	17.8	1.7	0.0	9.6	12.1	1.0	5.4	73.6
				UPPER FARFIELD				
166.6	25.6	2.4	6.3	24.7	11.8	2.0	3.7	96.6
176.0	8.9	1.3	0.1	12.8	11.7	1.0	2.9	52.5
187.1	1.6	0.3	0.0	25.2	4.9	0.9	0.7	47.7

a. Source: DOE, 1987.
b. Gizzard and/or threadfin shad.
c. Totals include taxa shown plus taxa not shown.
d. Intake canals.

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river (Tables C-15b and C-15c), and is more likely related to variations in spawning stock abundance or the availability of spawning sites. Low river water levels, especially during the 1985 spawning season, likely reduced access to swamp and backwater spawning sites used by blueback herring (Paller et al., 1986). The sharp increase in American shad ichthyoplankton abundance from 1983 to 1985 may be related to variations in spawning stock abundance.

Striped bass spawning in the upper reaches of the Savannah River had not been documented prior to 1982 (ECS, 1982). Dudley et al. (1977) reported that striped bass spawning was restricted to the lower reaches of the river and McFarlane et al. (1978) collected no striped bass ichthyoplankton during their sampling in 1977. However, striped bass eggs and/or larvae were collected during each year of the Comprehensive Cooling Water Study (Table C-14), and the highest densities occurred between approximately RM 166 to RM 120 during 1983-1985 (Tables C-15a, C-15b and C-15c). Although total striped bass ichthyoplankton abundance was substantially lower than found for American shad, striped bass showed a similar trend in abundance with a substantial increase from 1983 to 1985.

Ichthyoplankton relative abundance and densities for many of the abundant resident fish taxa (e.g., gizzard and/or threadfin shad, pirate perch, crappie and minnows) declined from 1983 to 1985 (Tables C-14, C-15a, C-15b, and C-15c). Suckers exhibited a slight increase and sunfish ichthyoplankton relative abundance was somewhat higher in 1984 than in either 1983 or 1985.

Sturgeon larvae were collected from the Savannah River in the vicinity of the SRP during 1982. Examination of these specimens indicated that both Atlantic sturgeon and the endangered shortnose sturgeon were present (Table C-16). Both sturgeon species have been collected in all subsequent years. Although total sturgeon larvae collections (number of specimens) were highest in 1982, sampling intensity was lowest (Table C-13). Generally, it appears that both species spawn upstream or near the SRP and that shortnose sturgeon spawn earlier and at cooler water temperature than Atlantic sturgeon.

Atlantic and shortnose sturgeon are demersal in nature. Consequently, most larvae were collected in samples near the river bottom. The National Marine Fisheries Service had previously concurred with DOE's determination that the population of shortnose sturgeon in the Savannah River would not be adversely affected by SRP operations (Oravetz, 1983).

Ichthyoplankton Abundance in the Mouths of Savannah River Tributaries - Twenty-seven creeks, ranging from small intermittent streams to major tributaries, were sampled for ichthyoplankton from February through July 1983. Five of these creeks - Beaver Dam Creek, Upper and Lower Three Runs Creeks, Four Mile Creek, and Steel Creek - drain portions of the Savannah River Plant. Researchers collected 5714 larvae and 1423 eggs from all the streams during 1983 (Table C-17).

TE Streams accounted for 8.8 and 14.4 percent of the fish eggs and larvae, respectively. Ninety-four percent of all eggs collected were from Spirit Creek (1230) and Steel Creek (103) (Table C-17). The high number of fish eggs collected at Spirit Creek were threadfin or gizzard shad, taken during May and June. Clupeids were the numerically dominant taxa in all streams; however, crappie, centrarchids, and yellow perch were also important.

Table C-15b. Mean Ichthyoplankton Densities (No./1000 m^3) at Savannah River Transects During February-July 1984.[a]

River mile	American shad	Blueback herring	Striped bass	Other shad[b]	Minnows	Sunfish	Crappie	Total Ichthyo-plankton[c]
				LOWER FARFIELD				
29.6	1.2	0.7	0.0	2.1	1.0	8.3	5.5	24.5
40.0	1.3	0.8	0.0	2.8	0.9	9.1	8.4	30.8
50.2	1.7	0.9	0.0	3.2	2.7	12.6	4.8	32.5
60.0	1.3	2.4	0.0	4.4	1.9	6.1	10.3	33.0
69.9	0.8	0.9	0.0	3.9	3.1	3.2	5.3	24.2
79.9	1.5	2.6	0.0	4.2	2.3	1.8	4.1	25.2
89.3	3.8	1.6	0.6	4.7	4.3	2.5	3.9	30.2
97.5	6.2	4.1	0.7	11.3	3.1	4.0	5.1	44.8
110.0	10.5	1.3	1.6	1.1	5.2	4.6	3.9	35.8
120.0	5.6	1.7	4.1	2.5	5.8	3.2	3.6	34.9
				NEARFIELD				
128.9	3.6	0.9	3.7	2.1	6.6	3.4	3.1	32.3
129.1	5.2	0.9	3.1	1.3	7.8	5.1	2.8	34.3
137.7	8.0	1.1	6.4	1.7	9.6	6.4	4.1	49.0
141.5	7.4	2.2	3.4	2.1	13.6	10.0	6.7	57.1
141.7	11.2	1.0	14.3	2.5	12.1	10.4	6.4	67.6
150.4	2.8	3.1	6.7	3.8	5.2	2.7	6.0	41.4
150.8	5.8	2.9	5.2	4.5	4.8	1.7	5.8	39.7
152.0	5.8	1.6	2.1	4.8	4.4	1.5	6.4	34.7
152.2	9.8	1.1	2.8	3.5	5.1	0.9	4.5	38.6
155.2	5.6	1.9	6.1	3.7	3.8	0.6	4.9	35.5
155.3[d]	0.2	6.6	1.6	4.9	3.0	0.8	10.9	43.1
155.4	4.0	1.1	6.1	3.8	4.2	1.0	5.9	36.8
157.0	9.9	1.5	4.0	3.5	4.6	1.9	6.1	45.3
157.1[d]	0.2	4.6	1.4	5.2	2.4	1.9	10.1	42.5
157.3	11.8	2.6	3.2	4.0	6.5	1.7	4.6	47.4
				UPPER FARFIELD				
166.6	3.3	2.5	0.0	8.2	5.6	0.4	1.1	28.7
176.0	4.0	0.8	0.0	7.0	6.1	1.1	0.3	26.2
187.1	3.6	0.2	0.1	4.0	5.7	0.9	0.4	23.6

a. Source: DOE, 1987.
b. Gizzard and/or threadfin shad.
c. Totals include taxa shown plus taxa not shown.
d. Intake canals.

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Table C-15c. Mean Ichthyoplankton Densities (No./1000 m^3) at Savannah River Transects During February-July 1985.[a]

River mile	American shad	Blueback herring	Striped bass	Other shad[b]	Minnows	Sunfish	Crappie	Total Ichthyo-plankton[c]
				LOWER FARFIELD				
89.3	47.4	0.9	2.0	2.2	2.5	1.4	0.1	67.8
97.5	26.6	1.7	1.2	4.7	1.6	0.2	0.1	44.1
110.0	39.6	0.6	1.5	1.2	3.2	0.2	0.1	55.6
120.0	35.3	0.8	1.3	1.7	2.2	0.7	0.4	51.7
				NEARFIELD				
128.9	41.7	1.4	5.3	2.2	4.1	1.0	0.2	64.2
129.1	31.3	0.8	6.3	1.9	2.9	1.4	0.2	54.7
137.7	34.1	1.8	0.4	2.9	1.9	1.4	0.1	55.2
141.5	30.0	1.4	0.1	3.4	1.5	1.1	0.1	50.9
141.7	54.6	0.9	0.5	3.7	1.8	1.8	0.3	83.2
145.7	63.2	0.7	0.6	3.0	1.6	1.5	0.5	84.3
150.4	22.0	1.0	2.4	2.1	0.8	0.2	0.3	44.7
150.8	12.6	1.9	0.3	3.0	1.0	0.1	0.0	31.8
152.0	10.6	1.4	3.7	3.2	1.6	0.1	0.1	28.7
152.2	14.2	2.2	3.3	3.6	2.0	0.1	0.1	43.1
155.2	18.2	2.6	16.0	3.1	1.0	0.0	0.2	67.1
155.3[d]	0.3	0.9	2.5	7.0	1.0	0.1	0.2	30.7
155.4	19.3	0.8	13.6	4.8	1.6	0.1	0.0	57.0
157.0	24.6	0.4	0.5	3.8	1.7	0.2	0.1	47.5
157.1[d]	0.8	1.1	0.1	3.0	0.7	0.2	0.1	22.2
157.3	36.0	0.5	2.1	3.8	1.6	0.2	0.2	81.6
				UPPER FARFIELD				
166.6	59.4	3.2	10.7	22.3	2.5	0.2	0.1	149.3
176.0	15.7	2.4	0.1	27.2	4.5	0.4	0.2	70.9
187.1	3.3	2.8	0.1	22.7	5.4	0.6	0.4	58.6

a. Source: DOE, 1987.
b. Gizzard and/or threadfin shad.
c. Totals include taxa shown plus taxa not shown.
d. Intake canals.

Table C-16. Larval Sturgeon Collected From the Savannah River During 1982, 1983, 1984, and 1985[a]

1982						1983					
Collection date	River mile	Sample location[b]	Identity[c]	River temp. (°C)	River Elev. (ft)[d]	Collection date	River mile	Sample location[b]	Identity[c]	River temp. (°C)	River elev. (ft)[d]
3/12	157.3	CT	Sh	12.5	85.9	3/09	79.9	WB	Sh	16.0	94.9
3/26	157.3	CB	Sh	13.2	84.2	3/22	155.4	CB	Sh	12.5	91.9
4/21	150.8	CB	Atl	17.8	83.5	3/22	157.1[e]	WT	Sh	11.5	92.5
4/22	155.2	EB	Atl	15.2	86.3	3/22	155.3[e]	ET	Sh	11.5	92.5
4/22	155.2	ET	Atl	15.2	86.3	3/22	155.2	ET	Sh	11.3	92.5
4/22	155.2	EB	Atl	15.2	86.3	3/23	97.5	WT	Sh	12.6	92.5
4/22	157.0	WB	Atl	15.2	86.3	3/29	155.2	CT	Atl	12.5	90.6
4/22	157.0	EB	Atl	15.3	86.3	4/26	129.1	CB	Atl	14.4	94.0
5/21	155.4	CB	Atl	20.3	83.2	5/03	157.0	WB	Atl	18.1	86.5
5/21	155.4	CB	Atl	20.3	83.2	5/10	155.4	CB	Atl	17.5	84.5
5/21	157.0	CB	Atl	20.2	83.2	5/17	150.4	EB	Atl	22.5	84.3
5/21	157.3	CT	Atl	20.2	83.2	5/18	69.9	EB	Atl	21.5	84.6
5/21	157.3	CB	Atl	20.2	83.2	6/14	150.8	CB	Atl	20.5	83.8
8/21	157.3	CT	Atl	21.0	84.7						

1984						1985					
Collection date	River mile	Sample location[b]	Identity[c]	River temp. (°C)	River Elev. (ft)[d]	Collection date	River mile	Sample location[b]	Identity[c]	River temp. (°C)	River elev. (ft)[d]
3/28	120.0	EB	Sh	15.0	89.3	3/19	155.4	WB	Sh	12.0	83.6
4/04	110.0	CB	Sh	15.5	88.6	3/26	166.6	EB	Sh	12.8	83.3
4/23	176.0	WB	Atl	14.0	92.9	4/09	157.3	EB	Atl	14.1	83.3
4/24	152.0	CB	Atl	14.5	93.3	4/16	141.7	EB	Atl	16.5	83.3
5/02	176.0	WB	Atl	15.8	94.5	4/16	157.0	WB	Atl	16.0	83.3
5/23	110.0	WB	Atl	20.5	86.6	4/24	120.0	CB	Atl	20.5	84.1
5/29	157.0	WB	Atl	20.4	86.1	4/30	176.0	WT	Atl	18.6	82.8
5/29	152.2	WB	Atl	20.5	86.1						
5/29	152.2	EB	Atl	20.5	86.1						

a. Source: DOE, 1987.
b. Samples were taken in mid-channel (C), near the South Carolina bank (E), and near the Georgia bank (W); samples were also taken near the top (T) and near the bottom (B) of the water column.
c. Sh = shortnose sturgeon; Atl = Atlantic sturgeon.
d. River elevation at Jackson, SC.
e. Intake canal.

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Table C-17. Ichthyoplankton Abundance in 27 Savannah River Tributaries Located Between RM 30 and 187.2. February - July 1983[a]

Creek, RM	Mean discharge (m^3/sec)	Number dates sampled	Larvae collected	Eggs collected	Taxa collected	Mean ichthyoplankton density (no./1000 m^3)	Maximum density (no./1000 m^3)	Date of maximum density	Dominant taxa on date of max. density	Number[b] ichthyoplankton transported x 10^6
Collin, 30.0	195.5	22	238	0	14	49	225	03/18	Blueback herring crappie	180.2
Meyers, 35.4	150.1	16	155	0	15	42	185	05/05	Unidentified clupeid	157.6
Coleman Lake, 40.3	237.9	22	309	1	13	62	266	03/18	Blueback herring crappie	341.9
Lockners, 43.2	24.8	20	238	0	14	126	500	07/08	Sunfish	81.1
Ebenezer, 44.8	36.9	23	502	5	15	105	802	03/18	Crappie	53.3
Seines Landing, 47.7	1.2	11	70	2	14	194	1145	05/12	Yellow perch	1.1
Plank, 51.1	8.7	6	86	0	8	105	195	06/30	Other shad	9.4
Lake Parachuchia, 64.2	79.6	18	653	9	14	263	738	03/24	Blueback herring	279.2
Black, 78.4	6.4	4	5	1	4	29	49	03/17	Blueback herring pirate perch	3.4
Pike, 84.1	30.1	17	112	0	11	77	377	07/27	Sunfish	30.8
Ware, 88.6	1.4	2	50	0	7	664	1093	05/25	Carp	4.5
Buck, 92.6	28.1	20	708	13	16	383	2669	05/11	Blueback herring	185.3
Briar, 97.6	86.4	23	760	3	15	140	938	04/13	Blueback herring unidentified clupeid	220.7
The Gaul, 109.0	6.7	3	34	0	9	75	100	04/26	Blueback herring	1.3
Smith Lake, 126.5	48.5	22	329	5	14	90	712	04/12	Crappie	148.1
Lower Three Runs, 129.0	2.7	10	72	0	12	187	1698	05/03	Crappie	2.1
Sweetwater, 133.5	33.4	13	102	4	14	51	194	05/03	Pirate perch	19.9
Lower Boggy Gut, 141.3	4.2	3	7	1	5	17	43	03/15	Crappie	0.1
Steel, 141.6	26.2	24	518	103	14	123	507	04/05	Blueback herring	77.2
Four Mile, 150.6	4.1	16	40	7	11	50	332	04/05	Blueback herring	2.7
Beaver Dam, 152.1	8.3	13	138	10	10	74	320	05/03	Yellow perch	7.4
Upper Three Runs, 157.2	15.8	19	56	5	10	25	334	05/03	Crappie, yellow perch	2.4
Upper Boggy Gut, 162.2	9.5	9	32	2	9	43	116	06/08	Sunfish	2.2
McBean, 164.2	5.1	5	78	1	11	93	186	07/07	Other shad	6.3
Hollow, 176.1	14.5	16	107	21	13	53	229	03/22	Crappie	34.4
Spirit (183.3)	8.6	19	300	1230	13	157	4412	06/02	Other shad	38.0
Butler, 187.2	13.3	9	15	0	4	37	185	05/12	Minnow	4.4

a. Source: Du Pont, 1985
b. Calculated as sum of ichthyoplankton density x creek discharge for each sampling data extrapolated to intervals between sampling dates.

The number of ichthyoplankters transported from creek to river ranged from approximately 0.1 x 10^6 from Lower Boggy Gut to 342 x 10^6 from Coleman Lake (Table C-17). Steel Creek and Beaver Dam Creek accounted for 77.2 x 10^6 and 7.5 x 10^6 ichthyoplankters, respectively, the greatest production of any of the SRP streams. Some creeks exhibited high densities but low transport numbers due to their low discharge rates.

Considerably more fish spawning occurred in Four Mile Creek in 1983 than in 1982, apparently due to unusually high river levels that reversed stream flow and lowered water temperatures enough to allow fish to enter the creek and from the transport of ichthyoplankton from nearby refuge areas into the creek when river levels receded. Centrarchids, blueback herring, and shad dominated the larval catch. Ichthyoplankton densities were low to moderate in March, peaked at 332 per 1000 cubic meters on April 4, and declined to zero by early June (Table C-17). Larvae collected during May were taken at temperatures between 35° and 37°C and represent larvae transported from refuge spawning areas in the Four Mile Creek watershed. Although more ichthyoplankton were collected in 1983, similar medium-sized streams had higher densities and longer spawning periods. The mean temperature in these creeks was often as much as 15°C lower than that in Four Mile Creek. Apparently, the elevated temperatures in this stream limited spawning. Transport of ichthyoplankton from Four Mile Creek was very low (2.7 x 10^6), ranking it as twenty-first of the 27 streams sampled (Table C-17).

During sampling trips, researchers collected 138 fish larvae and 10 fish eggs on Beaver Dam Creek (Table C-17). Sunfish, silversides, and yellow perch dominated species composition. Because of excessively high river levels, Beaver Dam Creek was not sampled during February, March, or most of April. Subsequent sampling indicated a peak density of 320 per 1000 cubic meters (primarily sunfish) in early May, which declined to low densities by July. Similar-sized streams had higher densities, mainly because of high shad concentrations. Temperatures in Beaver Dam Creek were generally 3° to 7°C higher than in similar-sized creeks. Although elevated temperatures might have reduced spawning later in the year in Beaver Dam Creek, the effect was not as pronounced as that in Four Mile Creek. The number of ichthyoplankters transported from Beaver Dam Creek (7.4 x 10^6) was equivalent to or greater than from other creeks that did not have large numbers of threadfin or gizzard shad.

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Effects of Cooling Water Intakes

The once-through cooling water systems for C- and K-Reactors each withdraw about 11 cubic meters of water per second from the Savannah River through the 1G and 3G pumphouses. An additional 1 cubic meter per second enters these intakes to provide makeup water for P-Area. The 5G pumphouse provides cooling water to the D-Area powerhouse at about 3 cubic meters per second. The current combined cooling water flow requirement for these facilities is about 26 cubic meters per second. This withdrawal of river water could affect the fishes inhabiting areas on or adjacent to the Savannah River Plant in two ways:

- Entrainment of fish eggs and larvae through the cooling water system
- Impingement of larger fishes on the intake screens

Estimates of the impacts of entrainment and impingement are based on field data collected during past and present sampling programs performed in the SRP vicinity (Du Pont, 1985; Paller, O'Hara, and Osteen, 1985; Paller and Osteen, 1985). The following sections discuss the results of these investigations as summarized in DOE (1987).

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Entrainment - The entrainment of fish eggs and larvae (ichthyoplankton) at intake structures is affected by a variety of factors including overall ichthyoplankton abundance in waters adjacent to the intake and percentage of river water withdrawn. The total magnitude and species composition of entrainment can also be influenced by aspects of intake design, the spatial distribution of ichthyoplankton relative to the intakes, and fish species behavioral and life history characteristics. The ultimate result of entrainment-related mortality on fish population persistence depends on the magnitude of species-specific mortality rates and the population level responses of the species to this added source of mortality.

Entrainment of ichthyoplankton into the SRP cooling water intake pumps removes them from the Savannah River population. Entrainment of ichthyoplankton is dependent on several factors including the density of organisms in the river, the amount of spawning in the intake canals, the volume of water withdrawn by each pump and, in the case of 1G intake, the density of organisms in Upper Three Runs Creek which enters the river immediately upstream of the 1G intake canal (Figure 2-1).

When fish larvae enter the intake canals from the river, they move from rapid currents to slow currents which may enable larger larvae to swim to protected shoreline areas. This behavior could reduce the mortality rate of larvae entrained from the river. However, there is evidence from the larval collections made during 1982 (ECS, 1983) that the intake canals are used as spawning sites by several species. Accordingly, loss of larvae for some species by entrainment may be greater than is indicated by the ichthyoplankton densities in the river water entering the canal. Consequently, larval entrainment at the 1G and 3G intakes was calculated using the larval density in the intake canals since these organisms are the ones most likely to be lost from the total Savannah River ichthyoplankton population, regardless of whether they were spawned in the canal or moved in on river currents. Larval densities in the Savannah River were used to calculate entrainment at the 5G intake because of the short length of this canal.

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The calculation of entrainment of fish eggs from the Savannah River into the three pumphouses was not as direct as the calculation of larval entrainment. Few eggs were actually collected in the canals. Generally, fish that spawn in freshwater have demersal rather than planktonic eggs. The only exceptions in the Savannah River drainage are the anadromous American shad and striped bass. The reduced current velocity in the intake canals allows the suspended eggs to settle out of the water column (McFarlane, 1982). Silt settles over these eggs and they die. The entrainment losses were calculated such that fish eggs that settle out of the water column and those actually entrained by the pumps are assumed to be lost. Consequently, the average egg densities used in the entrainment calculations were from the immediate upstream river transect. The egg densities for 3G and 5G are the same because they were calculated from the river transect immediately upstream of the 3G intake canal.

The density of eggs entering 1G canal was not calculated directly from the upstream river transect because a portion of the water entering 1G canal comes from Upper Three Runs Creek. The relative percent contribution of Upper Three Runs Creek and the river to the 1G intake canal water was estimated by measuring the sodium concentrations in the river upstream of the 1G canal, in Upper Three Runs Creek, and in the mixed water coming out of the pump. These percentages were multiplied by the density of eggs from each source to get an average density of fish eggs entering the 1G canal.

To estimate total entrainment of ichthyoplankton during a spawning season, the daily entrainment rates were multiplied by the number of days between samples, generally a week, and summed. Annual entrainment is considered to be equal to that which occurs during the February-July spawning season. There is generally very little ichthyoplankton in the river to be entrained from September to January.

A minimum of 17 species of larval fishes were entrained at the three intake structures at the SRP during 1983 (Table C-18). Because larval fish are difficult to identify, there were probably unidentified species in these collections. The most abundant family of fish collected was Clupeidae, the herring family, which comprised 59 percent of the total ichthyoplankton entrainment. The single most abundant taxon was the genus Dorosoma (gizzard shad and threadfin shad), with 10.5×10^6 larvae (37.4 percent). Other abundant taxa were crappie, blueback herring and minnows, which represented 14.1, 9.5 and 9.0 percent, respectively.

Total larval fish entrainment for the SRP from February-July 1983 was calculated to be 28.0×10^6, of which 12.9×10^6 larvae (46.2 percent) were from the 1G pumphouse, 13.2×10^6 larvae (47.3 percent) were from the 3G pumphouse and 1.8×10^6 (6.5 percent) were from the 5G pumphouse (Table C-19). BB-3 BD-5

At least 17 taxa of larval fish were entrained at the SRP pumphouses during the 1984 spawning season (Table C-20). As in 1983, the most common family found in the entrainment samples was Clupeidae, the herring and shad family, which comprised 50 percent of the larval fish that were entrained. The single most abundant taxon was crappie with 4.3×10^6 larvae (24.5 percent). Other abundant taxa were unidentified clupeids, blueback herring, and other shad (gizzard and/or threadfin shad), which comprised 23.9, 13.2 and 12.7 percent of the total larvae entrained, respectively. Generally, there were no differences in the species composition among the three pumphouses.

Total larval fish entrainment for the SRP from February to July 1984 was calculated to be 17.6×10^6. The 1G pumphouse entrained 7.7×10^6 larvae (44 percent), 8.8×10^6 larvae (50.3 percent) were entrained at the 3G pumphouse and 1.0×10^6 larvae (5.6 percent) at the 5G pumphouse (Table C-19).

At least 6 taxa of larvae were entrained at the SRP pumphouses in 1985 (Table C-21). The most common larval fish entrained were suckers, which comprised 43 percent of the larval fish entrained. The single most abundant taxon was spotted sucker with a total of 4.6×10^6 larvae (42.7 percent) entrained at the three pumphouses. Other abundant taxa were gizzard and/or

Table C-18. Estimated Number and Percent Composition of Larval Fish Entrained at 1G, 3G, and 5G Pumphouses, February-July 1983[a]

Taxa	Pumphouse 1G (x1000)	3G (x1000)	5G (x1000)	Total (x1000)	Percent Composition
Clupeidae					
American shad	90	80	4	174	0.6
Blueback herring	1434	1146	68	2648	9.5
Other shad	4315	5782	365	10,462	37.4
Unident. clupeids	1641	1572	90	3303	11.8
Esocidae					
Unident. pickerel	129	53	9	191	0.7
Cyprinidae					
Carp	26	80	17	123	0.4
Unident. cyprinids	814	1026	690	2530	9.0
Catostomidae					
Spotted sucker	853	573	237	1663	5.9
Other suckers	–	13	20	33	0.1
Ictaluridae					
Unident. catfish	–	13	–	13	<0.1
Aphredoderidae					
Pirate perch	388	400	28	816	2.9
Atherinidae					
Brook silverside	–	–	7	7	<0.1
Percichthyidae					
Striped bass	13	–	2	15	<0.1
Centrarchidae					
Unident. crappie	2170	1599	184	3953	14.1
Unident. sunfish	233	40	2	275	1.0
Other centrarchids	129	133	7	269	1.0
Percidae					
Yellow perch	142	320	33	495	1.8
Other percids	388	187	52	627	2.2
Other	129	213	26	368	1.3
Total	12,894	13,230	1,841	27,965	100.0

BB-3
BD-5

a. Source: DOE, 1987.

Table C-19. Estimated Entrainment of Larval Fish at SRP Intakes[a]

		1G	3G	5G	Total
1977[b]	Number ($x10^6$)	7.1	11.9	0.6	19.6
	Percent	36.2	60.7	3.1	
1982[c]	Number ($x10^6$)	5.2	12.0	0.7	17.9
	Percent	28.8	67.1	4.0	
1983[d]	Number ($x10^6$)	12.9	13.2	1.8	28.0
	Percent	46.2	47.3	6.5	
1984[e]	Number ($x10^6$)	7.7	8.8	1.0	17.6
	Percent	44.0	50.3	5.6	
1985[f]	Number ($x10^6$)	3.8	6.4	0.7	10.9
	Percent	34.9	58.7	6.4	
Average number ($x10^6$)		8.1	9.5	1.2	18.8
(1983-85) percent		43.4	50.3	6.3	

a. Source: DOE, 1987.
b. April-June, McFarlane et al. (1978).
c. March-August, ECS (1983).
d. February-July, Paller et al. (1984). BB-3
e. February-July, Paller et al. (1985). BD-5
f. February-July, Paller et al. (1986).

threadfin shad (22.0 percent), unidentified Clupeidae (11.4 percent), and carp (10.3 percent). Generally, there were no substantive differences in the species composition between the three pumphouses.

Total larval fish entrained due to SRP activities from February-July 1985 was calculated to be 10.9×10^6 (Table C-19). The 1G pumphouse entrained 3.8×10^6 larvae (35 percent); 6.4×10^6 larvae (59 percent) were entrained at the 3G pumphouse and 0.7×10^6 larvae (6 percent) at the 5G pumphouse.

For the five years for which data are available, estimated entrainment of larval fish was highest in 1983 when 28.0×10^6 larvae were entrained (Table C-19). Minimum larval entrainment (10.9×10^6 larvae) occurred in 1985. The 1983 estimated larval entrainment is almost 50 percent higher than the average entrainment (18.8×10^6 larvae) for the three year period (1983-85) during which sampling methodologies were consistent. The 1983-85 average entrainment is comparable to entrainment estimates for 1977 and 1982.

The highest percentage of larval entrainment occurred at the 3G intake during 1983-85 (9.5×10^6 larvae, 50.3 percent of total; Table C-19). Larval entrainment was substantially lower at the 1G intake (8.1×10^6 larvae, 43.4 percent of total). Larval entrainment at the 5G intake was consistently

Table C-20. Estimated Number and Percent Composition of Larval Fish Entrained at 1G, 3G, and 5G Pumphouses, February-July 1984[a]

Taxa	Pumphouse				
	1G (x1000)	3G (x1000)	5G (x1000)	Total (x1000)	Percent Composition
Clupeidae					
American shad	36	26	-	62	0.4
Blueback herring	891	1398	39	2328	13.2
Other shad	1010	1085	139	2234	12.7
Unident. clupeids	2102	1975	116	4193	23.9
Esocidae					
Unident. pickerel	23	7	-	30	0.2
Cyprinidae					
Carp	175	203	46	424	2.4
Unident. cyprinids	449	679	167	1295	7.4
Catostomidae					
Spotted sucker	495	506	118	1119	6.4
Other suckers	-	23	12	35	0.2
Aphredoderidae					
Pirate perch	-	-	3	3	<0.1
Percichthyidae					
Striped bass	33	73	17	123	0.7
Centrarchidae					
Unident. crappie	1908	2181	233	4322	24.5
Unident. sunfish	147	100	22	269	1.5
Other centrarchids	200	59	16	275	1.6
Percidae					
Yellow perch	77	218	5	300	1.7
Other percids	84	219	39	342	1.9
Lepisosteidae					
Gar	19	-	-	19	0.1
Other	99	87	19	205	1.2
Total	7,748	8,839	991	17,578	100.0

a. Source: DOE, 1987.

BB-3
BD-5

Table C-21. Estimated Number and Percent Composition of Larval Fish Entrained at 1G, 3G, and 5G Pumphouses, February-July 1985[a]

	Pumphouse				
Taxa	1G (x1000)	3G (x1000)	5G (x1000)	Total (x1000)	Percent Composition
Clupeidae					
American shad	46	9	5	60	0.6
Blueback herring	195	198	21	414	3.8
Other shad	563	1660	171	2394	22.0
Unident. clupeids	379	797	69	1245	11.4
Cyprinidae					
Carp	341	687	89	1117	10.3
Unident. cyprinids	122	225	61	408	3.8
Catostomidae					
Spotted sucker	1835	2585	223	4643	42.7
Unident. suckers	0	24	6	30	0.4
Others	341	195	39	575	5.1
Total	3,822	6,380	684	10,886	100.1

a. Source: DOE, 1987.

BB-3
BD-5

low (1.2 x 10^6 larvae, 6.3 percent), and never exceeded 6.5 percent of the total entrainment at the SRP river water intakes during 1983-85. Thus, the magnitude of larval entrainment at the SRP is primarily determined by losses at the 1G and 3G intakes.

The relative abundance of larval taxonomic groups entrained varies substantially from year-to-year. McFarlane et al. (1978) reported that clupeids (48 percent), primarily blueback herring (29.1 percent), were most abundant among entrained larvae in 1977. Cyprinid (10.0 percent) and catastomid (11.2 percent) larvae were relatively abundant. No striped bass eggs or larvae were collected during sampling in 1977.

Clupeid larvae also dominated entrainment collections during 1983-85. This group accounted for over 50 percent of larval entrainment in 1983 (Table C-18) and 1984 (Table C-20), but only approximately 38 percent in 1985 (Table C-21). Among the clupeids, gizzard and/or threadfin shad larvae were most abundant, representing 37.3, 12.7 and 22.0 percent of total larval entrainment in 1983, 1984, and 1985, respectively. Blueback herring represented 9.5, 13.2 and 3.8 percent of collections in those years. American shad larvae were a minor component of entrainment, ranging from 0.4 to 0.6 percent of entrainment from 1983-85.

Abundances of other larval taxa were also variable among years in entrainment. Cyprinids ranged from 9.4 to 14.1 percent of entrained larvae (Tables C-18, C-20, and C-21). However, the greatest change in relative composition occurred among catastomid larvae, with spotted sucker larvae increasing from 5.9 and 6.4 percent of larval entrainment in 1983 and 1984, to 42.7 percent in 1985.

The total egg entrainment during February-July 1983 was calculated to be 9.2×10^6 eggs of which 4.3×10^6 eggs were entrained at 1G, 4.2×10^6 eggs at 3G, and 0.7×10^6 eggs at 5G (Table C-22). The most abundant species was American shad which represented 55.0 percent of the total eggs entrained (Table C-23). The other abundant groups were other eggs and striped bass eggs, representing 28.0 and 14.2 percent of the total egg entrainment, respectively.

The total fish egg entrainment during February-July 1984 was estimated to be 5.8×10^6 eggs, of which 2.7×10^6 eggs (46.6 percent) were entrained at the 1G pumphouse, 2.6×10^6 eggs (45.4 percent) at the 3G pumphouse and 0.5×10^6 eggs (8.0 percent) at the 5G pumphouse (Table C-22). The most abundant egg species was American shad, representing 50.3 percent of the total eggs entrained (Table C-23). The other abundant groups of eggs entrained were striped bass and other eggs, representing 30.6 and 15.2 percent of the total eggs entrained, respectively.

The total fish egg entrainment during February-July 1985 was estimated to be 15.1×10^6, of which 7.8×10^6 eggs (51.4 percent) were entrained at the
BB-3 1G pumphouse, 6.2×10^6 (41.4 percent) at the 3G pumphouse, 1.1×10^6 eggs
BD-5 (7.3 percent) at the 5G pumphouse (Table C-22). American shad eggs were most abundant in entrainment and represented 46.7 percent of the total eggs entrained (Table C-23). The other abundant groups of eggs entrained were striped bass and other eggs, representing 26.2 percent and 24.8 percent of the total entrained, respectively.

Total fish egg entrainment varied considerably among the years for which data are available. Average total entrainment from 1983-85 was 10.0×10^6 eggs at the three SRP intakes (Table C-22). However, egg entrainment varied almost threefold during those years from 5.8×10^6 in 1984 to 15.1×10^6 in 1985. The highest estimated egg entrainment occurred in 1982 (18.1×10^6), while estimated entrainment in 1977 (6.9×10^6) was near the low end of the range of values.

The proportions of total eggs entrained at each of the three intakes remained relatively constant from year to year. Highest egg entrainment occurred at the 1G intake during all years except 1977 when entrainment was highest at the 3G intake (Table C-22). The 1G intake averaged 49.1 percent of the total eggs entrained from 1983 to 1985. The 3G intake averaged 43.3 percent of total egg entrainment from 1983 to 1985, while the 5G intake averaged 7.6 percent of egg entrainment during this period.

American shad eggs dominated entrainment collections from 1983 to 1985 and the percentage of total egg entrainment attributable to this species was relatively constant (Table C-23). American shad eggs averaged 50.0 percent of egg entrainment and ranged from 46.7 percent (1985) to 55.0 percent (1983) of all eggs entrained. The number of American shad eggs entrained annually varied

Table C-22. Estimated Egg Entrainment at SRP Intakes[a]

		1G	3G	5G	Total
1977[b]	Number (x10^6)	2.4	4.0	0.5	6.9
	Percent	34.8	58.0	7.2	
1982[c]	Number (x10^6)	8.7	8.2	1.2	18.1
	Percent	48.3	45.1	6.6	
1983[d]	Number (x10^6)	4.3	4.2	0.7	9.2
	Percent	46.7	45.7	7.6	
1984[e]	Number (x10^6)	2.7	2.6	0.5	5.8
	Percent	46.6	44.8	8.6	
1985[f]	Number (x10^6)	7.8	6.2	1.1	15.1
	Percent	51.1	41.1	7.3	
Average number (x10^6)		4.9	4.3	0.8	10.0
(1983-85) percent		48.3	43.8	7.8	

a. Source: DOE, 1987.
b. April-June, McFarlane et al. (1978).
c. March-August, ECS (1983).
d. February-July, Paller et al. (1984).
e. February-July, Paller et al. (1985).
f. February-July, Paller et al. (1986).

BB-3
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substantially, however, as total egg entrainment varied. The highest number of American shad eggs entrained was 7.1 x 10^6 in 1985. However, this species represented only 46.7 percent of total egg entrainment that year.

Striped bass eggs were less than half as abundant as American shad eggs in entrainment, averaging 23.4 percent (2.4 x 10^6 eggs/year) from 1983 to 1985 (Table C-23). However, striped bass eggs varied widely among years both as a percentage of total egg entrainment (14.2 - 30.6 percent) and as numbers of eggs entrained annually (1.3 x 10^6 - 4.0 x 10^6 eggs/year). Eggs of blueback herring, Dorosoma spp. (gizzard and/or threadfin shad) and percids were relatively minor components in entrainment. The undifferentiated component of other eggs represented a substantial component of egg entrainment, but likely included a wide variety of taxa, few of which represented substantial individual contributions to total egg entrainment.

Ichthyoplankton Withdrawal - The percentage of ichthyoplankton withdrawn from the Savannah River is determined by dividing the number of fish eggs and larvae entrained by the number of eggs and larvae transported past the intake canals in the Savannah River. The number of ichthyoplankton entrained at each intake is derived by summing the numbers of eggs and larvae that were entrained during each year (Table C-24). The number of ichthyoplankton that

Table C-23. Estimated Entrainment and Taxonomic Composition of Fish Eggs at SRP Intakes, 1983-85[a]

Taxa		1983[b]	1984[c]	1985[d]	Average
American shad	Number ($x10^6$)	5.07	2.91	7.06	5.01
	Percent	55.0	50.3	46.7	50.0
Blueback herring	Number ($x10^6$)	0.09	0.07	0.14	0.10
	Percent	1.0	1.2	0.9	1.0
Dorosoma spp.	Number ($x10^6$)	-[e]	0.13	0.21	-[f]
	Percent	-[e]	2.2	1.4	-[f]
Striped bass	Number ($x10^6$)	1.31	1.77	3.96	2.35
	Percent	14.2	30.6	26.2	23.4
Unident. percids	Number ($x10^6$)	0.16	0.02	-[e]	-[f]
	Percent	1.7	0.3	-[e]	-[f]
Other eggs	Number ($x10^6$)	2.58	0.88	3.74	2.4[g]
	Percent	28.0	15.2	24.8	25.6[g]
Total number ($x10^6$)		9.21	5.78	15.11	10.03

BB-3
BD-5

a. Source: DOE, 1987.
b. Paller et al. (1984).
c. Paller et al. (1985).
d. Paller et al. (1986).
e. Not provided in source document.
f. Not calculated because of partial data.
g. Includes Dorosoma spp. and unident. percids.

were vulnerable to entrainment was estimated by multiplying ichthyoplankton densities in the river near the canals times the river discharge on that date. Ichthyoplankton densities at RM 157.3 were used for entrainment at the 1G intake, and densities at RM 155.4 were used for estimates at the 3G and 5G intakes. Annual ichthyoplankton transport was derived by extrapolating the weekly measurements through the sampling season (February to July).

The total number of ichthyoplankton entrained was consistently highest at the 3G intake and ranged from 11.4×10^6 ichthyoplankton in 1984 to 17.4×10^6 in 1983 (Table C-24). Entrainment at the 1G intake was slightly less than at 3G, while a much smaller number of ichthyoplankton was entrained at the 5G intake.

Total number of ichthyoplankton entrained was highest in 1983, with substantially lower numbers of eggs and larvae entrained in 1984 and 1985 (Table C-24). Total numbers of ichthyoplankton entrained were similar in 1984 and 1985.

Table C-24. Percentage of Savannah River Ichthyoplankton Entrained at SRP Intakes, 1983-85[a]

		1983[b]	1984[c]	1985[d]
Number entrained ($x10^6$)	1G	17.2	10.4	11.6
	3G	17.4	11.4	12.6
	5G	2.5	1.5	1.8
	Total	37.1	23.3	26.0
Number transported in River ($x10^6$)	RM 157.3	388	282	212
	RM 155.4	405	216	133
Percent entrained	1G	4.4	3.7	5.5
	3G	4.3	5.3	9.5
	5G	0.6	0.7	1.4
	Total[e]	9.6	8.3	12.3
Percent river withdrawn[f]		7.7	7.0	12.2

a. Source: DOE, 1987.
b. Paller et al. (1984).
c. Paller et al. (1985).
d. Paller et al. (1986). BB-3
e. Based on transport at RM 157.3. BD-5
f. All intakes combined, February-July.

Estimates of ichthyoplankton transport varied among years and between transects at which transport was calculated (Table C-24). Highest ichthyoplankton transport occurred during 1983 when densities (Table C-15a) and river discharge (Table C-25) were both relatively high. Ichthyoplankton transport past the SRP intakes was substantially lower in 1984 and 1985. In 1984 ichthyoplankton densities were relatively low (Table C-15b), while river discharge was slightly below that observed in 1983 (Table C-25). Ichthyoplankton densities in 1985 (Table C-15c) were comparable to densities observed in 1983, but river discharge was extremely low as a result of low winter rainfall and relatively low releases of water from Clarks Hill Reservoir.

The combined effects of changes in ichthyoplankton density and river water discharge among years resulted in differences in estimates of the percentages of ichthyoplankton entrained from the river each year (Table C-24). The percentage of ichthyoplankton entrained at all intakes was lowest in 1984 (8.3 percent) and only slightly higher in 1983 (9.6 percent). The highest percentage of river ichthyoplankton entrained was in 1985 (12.3 percent) when Savannah River discharge was low during the spawning season (Table C-25).

The primary factor that appears to influence the percentage of river ichthyoplankton entrained in the SRP intakes is the percentage of river water withdrawn (Table C-24). Although the volume of river water withdrawn by the SRP remained relatively constant during the spawning season among the three

Table C-25. Monthly Average[a] Savannah River Discharge (m^3/sec) at the Jackson Gauge, Water Years[b], 1972-85[c]

	1972-82						
	Average	Maximum	Minimum	1983 Average	1984 Average	1985 Average[d]	1983-85 Average
October	208.7	247.7	143.6	190.1	173.8	184.1	182.7
November	249.7	410.2	129.2	170.4	164.2	182.7	172.4
December	285.7	395.7	162.4	247.9	258.5	172.3	226.3
January	359.1	461.6	190.8	418.6	366.8	183.6	323.0
February	412.6	533.6	221.9	493.4	403.2	375.5	424.0
March	332.9	529.2	195.4	513.3	469.3	211.8	398.1
BB-3 BD-5 April	338.3	561.0	188.1	503.3	412.3	177.9	364.5
May	300.5	394.5	160.9	257.0	396.5	157.7	270.4
June	305.7	560.8	190.0	297.3	250.9	151.5	266.6
July	231.7	391.5	154.8	196.9	234.1	164.8	198.8
August	204.5	241.5	161.1	187.7	343.8	162.1	231.2
September	199.5	232.0	241.5	189.8	216.8	155.4	187.3

a. Average discharge underestimated during high flow, maximum discharge reliably measured is approximately 625 m^3/sec, which was used in calculations when discharge exceeded that value.
b. Water Year is October-September, e.g., Water Year 1985 is October 1984-September 1985.
c. Source: DOE, 1987.
d. Source: USGS, 1986.

years (Table C-26), river discharge varied substantially and the percentage of river water withdrawn during the spawning season was higher in 1985 than in 1983 or 1984.

Impingement - Studies to measure and evaluate the loss of fish trapped on the traveling intake screens began in 1977 (McFarlane, Frietsche, and Miracle, 1978). They resumed in March 1982 and continued through 1985 (ECS, 1983; Paller et al., 1984; Paller and Osteen, 1985; Paller and Saul, 1986) as part
BB-3 of the expanded ongoing Savannah River aquatic ecology program. Results of
BD-5 these investigations indicate that several factors, including the number of pumps in operation, the volume of water pumped, the river water level, the

Table C-26. Monthly Volume and Percent of Savannah River Water Withdrawn at the 1G and 3G Intakes at the SRP, 1983-85[a]

		1983	1984	1985
January	Volume (m^3/sec)	23.7	25.3	23.0
	Percent of River[b]	5.8	5.6	12.9
February	Volume (m^3/sec)	22.5	15.2	22.8
	Percent of River	4.6	4.1	6.7
March	Volume (m^3/sec)	22.6	18.0	21.6
	Percent of River	4.4	4.4	10.5
April	Volume (m^3/sec)	22.8	23.7	21.8
	Percent of River	4.1	6.3	12.4
May	Volume (m^3/sec)	22.8	23.6	22.8
	Percent of River	9.3	6.4	14.6
June	Volume (m^3/sec)	16.9	22.0	18.7
	Percent of River	6.4	9.2	12.6
July	Volume (m^3/sec)	19.5	22.2	15.7
	Percent of River	10.2	9.8	9.5
August	Volume (m^3/sec)	23.4	23.1	15.3
	Percent of River	12.7	7.8	9.5
September	Volume (m^3/sec)	22.6	23.8	16.4
	Percent of River	12.1	11.3	10.7
October	Volume (m^3/sec)	23.1	18.8	19.9
	Percent of River	13.5	10.5	–[c]
November	Volume (m^3/sec)	22.9	14.4	21.3
	Percent of River	14.4	7.9	--
December	Volume (m^3/sec)	23.6	22.0	18.2
	Percent of River	9.8	13.1	--

BB-3
BD-5

a. Source: DOE, 1987.
b. Percentage overestimated during months of high river discharge.
c. River discharge volume not available.

water temperature, and the density and species of fish in the intake canal, influence the impingement rate to some degree.

Impingement data were summarized from the reports prepared on these investigations (DOE, 1987). Although impingement samples were collected from March 1982 to September 1985, the samples used in this evaluation are primarily from September 1982 through September 1985 because methodologies were consistent during this interval. Additional unpublished data from October to December 1985 were included as appropriate.

In a preliminary biological measurement program, collections of impinged fishes on the traveling screens at the 1G, 3G, and 5G intakes were made biweekly between April and August 1982. Between September 1982 and August 1985 collections were made on approximately 100 randomly selected sampling dates yearly. The data collected after August 1982 more accurately represent impingement over an annual cycle because the frequency of collection was higher and more consistent.

Impingement at 1G and 3G intakes varied substantially each year. The maximum annual impingement collections occurred at the 1G intake in 1983 (1462 fish, Table C-27). By extrapolating the estimated daily impingement for 1983, it is estimated that 5336 fish were impinged at the 1G intake per year. The highest annual impingement collections at the 3G (1150 fish) and 5G (1282 fish) intakes also occurred in 1983 with an estimated annual impingement of 4198 and 4679 fish per year, respectively. Although the sampling effort remained constant from 1983 through 1985, both the actual (measured) impingement and the estimated annual impingement declined at the 1G and 3G intakes. The minimum estimated annual impingement occurred in 1985 at the 1G (1670 fish) and 3G (1316 fish) intakes; minimum annual impingement occurred in 1984 at the 5G intake (213 fish). Average estimated annual impingement for the three year period was 3124 fish (8.56 fish/day) at the 1G intake, 2761 fish (7.56 fish/day) at the 3G intake, and 1718 fish (4.70 fish/day) at the 5G intake.

BB-3 Impingement at the SRP intakes is strongly seasonal. Approximately 60 percent
BD-5 of the fish impingement at 1G and 3G during 1983-1985 occurred from March through May (63.3 percent at 1G; 58.4 percent at 3G: Figure C-7). Almost 93 percent of impingement at the 5G intake occurred during these months. The largest number of impinged fish were collected in May, when approximately one-third of the annual impingement occurred over the three-year period at 1G and 3G. However, 65 percent of annual impingement at the 5G intake occurred during April. No month other than March, April, and May exhibited greater than ten percent of the annual average impingement at the 1G intake. However, substantial impingement occurred during January (11.1 percent) and December (12.3 percent) at the 3G intake. Impingement was low during the late summer and fall months at all intakes.

At least 62 species of fish, representing 17 families, were impinged at SRP intakes from March 1982 to December 1985 (Tables C-28 and C-29). Twenty species were collected in such abundance that the species collection represented more than one percent of the total collections between September 1982 and September 1985 (Table C-28). Blue-spotted sunfish (23.29 percent) and threadfin shad (11.39 percent) were the most abundant species in impingement samples at all intakes during this three-year period. Among the remaining species only gizzard shad (6.31), redbreast sunfish (5.49 percent), and warmouth (5.30 percent) exceeded five percent of the total collections. Thus, overall impingement losses from the Savannah River were fish identified as forage species with little commercial or recreational value.

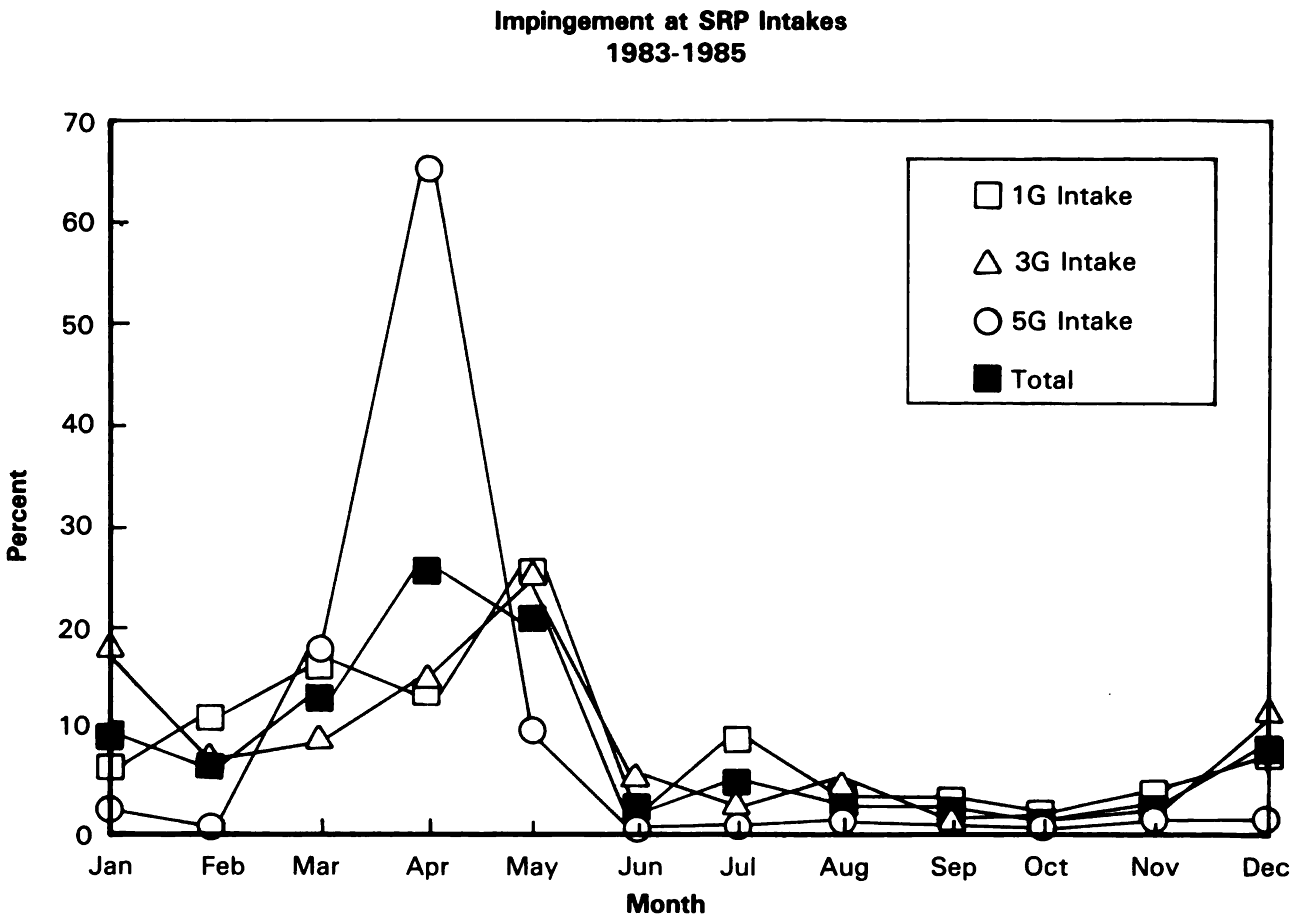
However, species specific impingement varied substantially among the three intakes and among years. For the period from September 1982 through August 1983, blue-spotted sunfish dominated impingement collections at the 1G and 5G

Table C-27. Total Annual Impingement at 1G, 3G and 5G Intakes[a]

Year		Intake 1G	3G	5G
1982	Total fish collected	73	284	84
	Number of days sampled	43	43	43
	Average impingement/day	1.70	6.60	1.95
	Estimated annual impingement	619.7	2410.7	713.0
1983	Total fish collected	1462	1150	1282
	Number of days sampled	100	100	100
	Average impingement/day	14.62	11.50	12.82
	Estimated annual impingement	5336.3	4197.5	4679.3
1984	Total fish collected	655	766	59
	Number of days sampled	101	101	101
	Average impingement/day	6.48	7.58	0.58
	Estimated annual impingement	2367.0	2768.2	213.2
1985[b]	Total fish collected	430	339	67
	Number of days sampled	94	94	94
	Average impingement/day	4.57	3.61	0.71
	Estimated annual impingement	1669.7	1316.3	260.2
1983-85[c] average	Total fish collected	849.0	751.7	469.3
	Number of days sampled	98.3	98.3	98.3
	Average impingement/day	8.56	7.56	4.70
	Estimated annual impingement	3124.3	2760.7	1717.6

a. Source: DOE, 1987.
b. Includes unpublished data from October-December 1985.
c. Only 1983-85 data were used for these calculations because sampling was limited in 1982. BB-3 BD-5

intakes while threadfin shad dominated collections at 3G (Figure C-8a). From September 1983 through August 1984 threadfin shad dominated collections at the 1G intake and blue-spotted sunfish were a relatively minor component of the 1G collections (Figure C-8b). Blue-spotted sunfish dominated collections at the 3G and 5G intakes during this latter period. From September 1984 through September 1985 impingement collections were relatively low at all intakes and gizzard shad were most abundant in 1G intake collections, threadfin shad dominated collections at 3G, and American shad were most abundant at the 5G intake (Figure C-8c). Centrarchids did not dominate the collections at any of the three intakes during this last period.



Source: DOE, 1987

Figure C-7. Monthly Percentage of Total Annual Impingement at 1G, 3G, and 5G Intakes. Average Values for 1983-85.

Table C-28. Number and Percentages of Fish Species Representing Greater Than One Percent of Impingement Collections at the 1G, 3G and 5G Intakes, September 1982-September 1985[a]

Species	Number	Percent
Bluespotted sunfish	1465	23.30
Threadfin shad	716	11.39
Gizzard shad	397	6.31
Redbreast sunfish	345	5.49
Warmouth	333	5.30
Flier	313	4.98
Hogchoker	252	4.01
Spotted sunfish	218	3.47
Bluegill	179	2.85
Black crappie	171	2.72
Bowfin	162	2.58
Blueback herring	141	2.24
Spottail shiner	122	1.94
Pirate perch	119	1.89
Dollar sunfish	112	1.78
Pumpkinseed	85	1.35
White catfish	82	1.30
Redfin pickerel	77	1.22
Flat bullhead	70	1.11
Mud sunfish	69	1.10
Total of minor species	860	13.68
Total	6288	100.00

a. Source: DOE, 1987.

The impingement of fish at SRP intakes appears to be strongly selective and relative to the abundance of fish in the intake canals. Quarterly electrofishing of the intake canals revealed that the fish community in the canals is strongly dominated by centrarchids (Figures C-8a, C-8b, and C-8c). During the sampling period September 1982 through September 1985, the electrofishing collections were dominated by a mixture of bluegill, redbreast, and dollar sunfish at all intake areas. Chain pickerel were collected routinely, while yellow perch, suckers, largemouth bass, and spotted sunfish appeared less routinely in collections, but occasionally in substantial numbers. The most notable exception to this pattern is the dominance of flat bullhead, white catfish, and channel catfish in collections near the 5G intake during September 1984 through September 1985. Generally, those species that were dominant in electrofishing collections were not abundant in impingement collections.

BB-3
BD-5

The findings on the relative abundance of fish in the Savannah River near the SRP intakes and in the impingement collections were analyzed relative to the

Table C-29. Species of Fish Collected at the 1G, 3G, and 5G Intakes Representing Less Than One Percent of Total Collections, September 1982-September 1985[a]

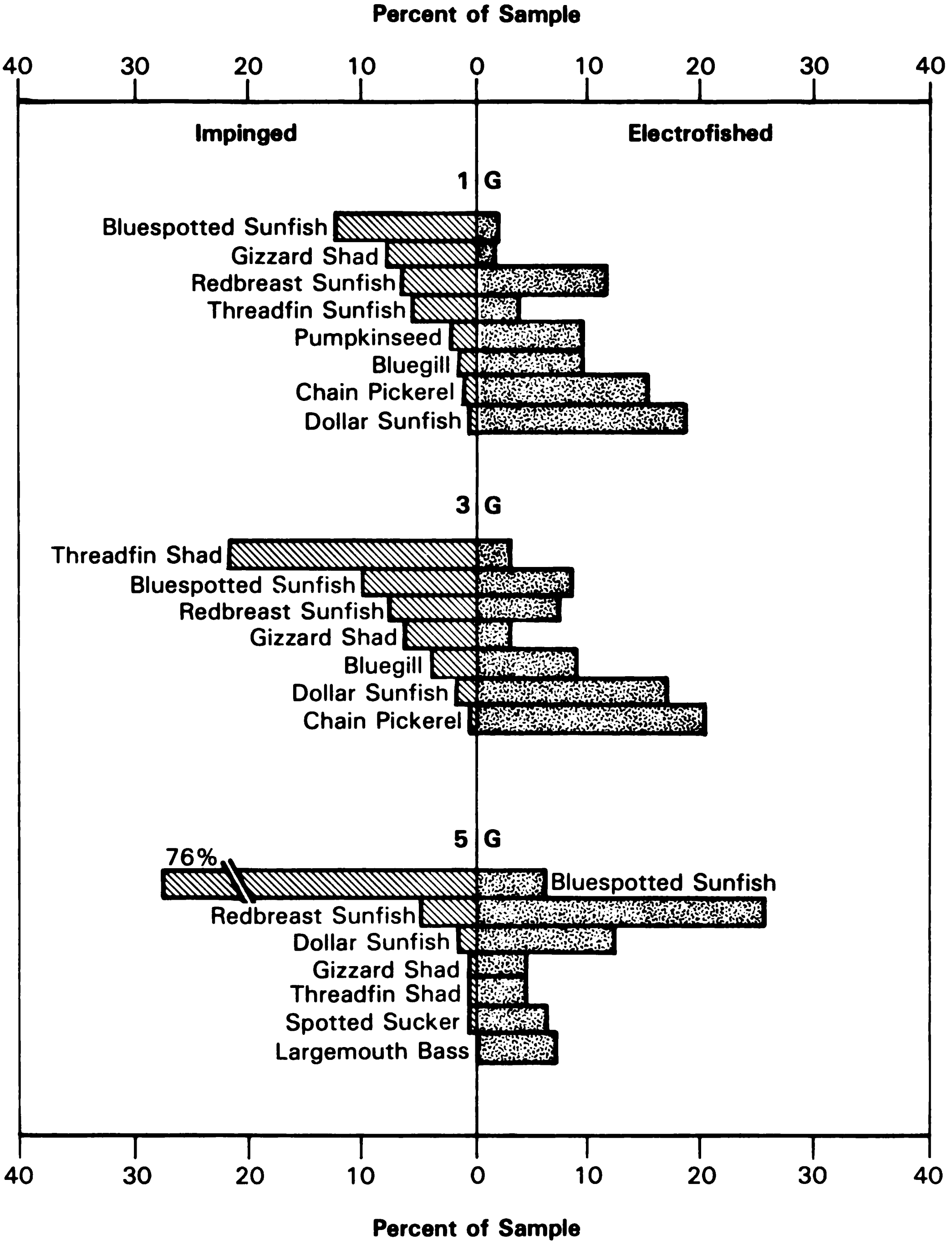
Hickory shad	Speckled madtom
American shad	Margined madtom
Chain pickerel	Redear sunfish
Golden shiner	Blackbanded sunfish
Pugnose minnow	Largemouth bass
Ohoopee shiner	Banded sunfish
Coastal shiner	White crappie
Bannerfin shiner	Green sunfish
BB-3 Carp	Yellow perch
Whitefin shiner	Blackbanded darter
Eastern silvery minnow	Tesselated darter
Spotted sucker	Swamp darter
Creek chubsucker	Mudminnow
Lake chubsucker	Eastern mudminnow
Chubsucker	Atlantic sturgeon
Silver redhorse	American eel
Channel catfish	Unidentified killifish
Snail bullhead	Mosquitofish
Brown bullhead	Brook silverside
Yellow bullhead	Striped bass
Tadpole madtom	Atlantic needlefish

a. Source: DOE, 1987.

angler catches in freshwater sections of the Savannah River. Fish species caught by anglers in the Savannah River represent an extremely limited set of available species. Electrofishing collections made during 1980-1982
BB-3 throughout the freshwater sections of the lower Savannah River have indicated
BD-5 that the taxa caught by anglers represented only 33.1 percent of the numerical abundance collected in electrofishing. Similarly, those species that constitute 95.8 percent of the angler catch constitute only 27.8 percent of total impingement at the SRP intakes. The species caught by anglers represent 59.8 percent of the fish caught by electrofishing and 86.9 percent of hoop-net sampling from the Savannah River near the SRP intakes. However, Paller and Osteen (1985) noted that the electrofishing collections near SRP do not accurately reflect the abundance of minnows and other small species. The same caution undoubtedly applies to hoop-net collections because the hoop-nets used for the SRP collections had a maximum mesh size of 37 millimeters.

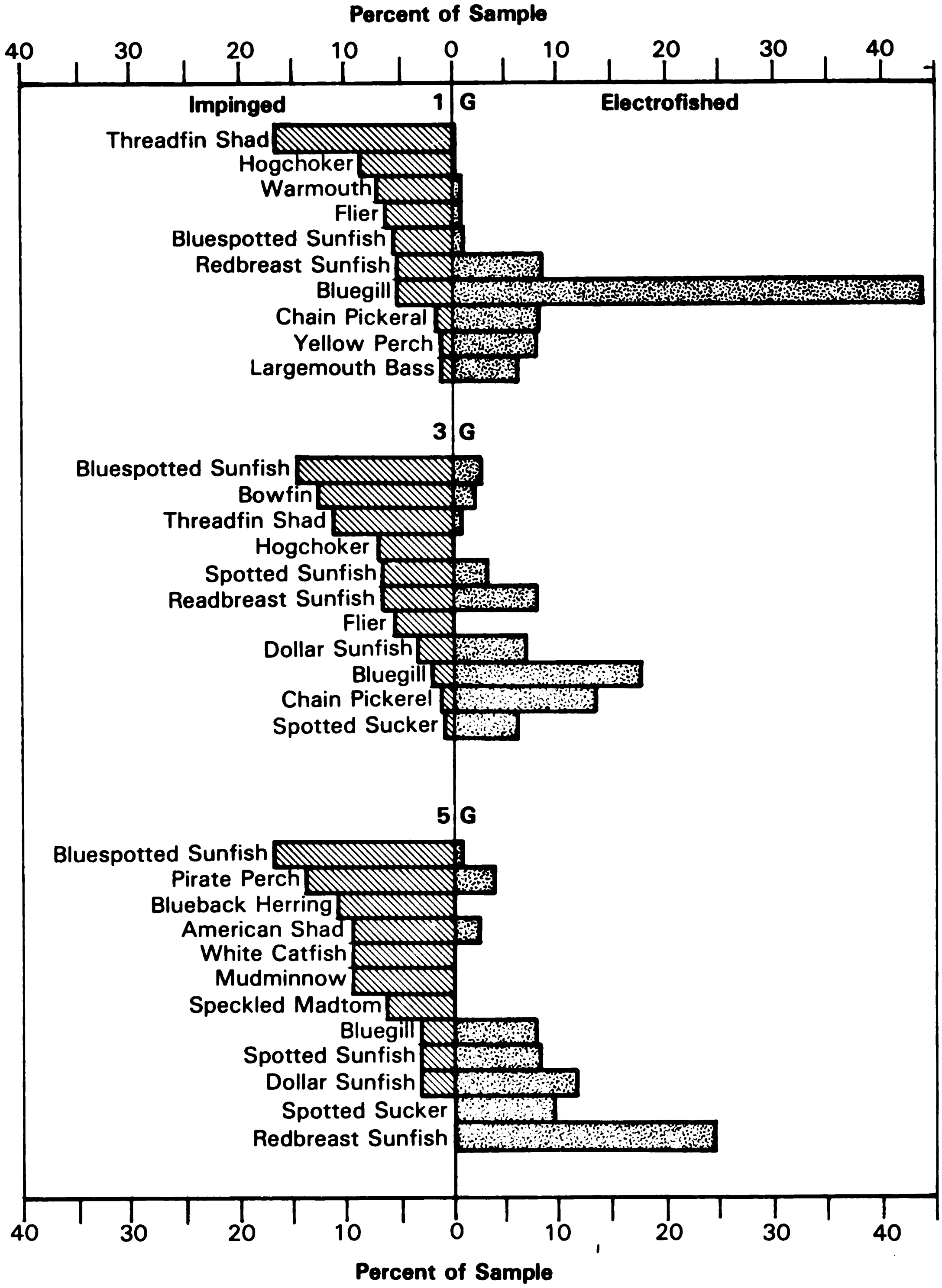
BB-3

Bream represent the largest component of the anglers' catch in the Savannah River. Although centrarchids were a substantial component of SRP impingement collections, the species impinged were not predominantly those caught by anglers (Figure C-9). Although redbreast sunfish are abundant in the creel (27.1 percent and in the river near the intakes (26.7 percent), they represented only 5.5 percent of impingement. Bluegill show much higher



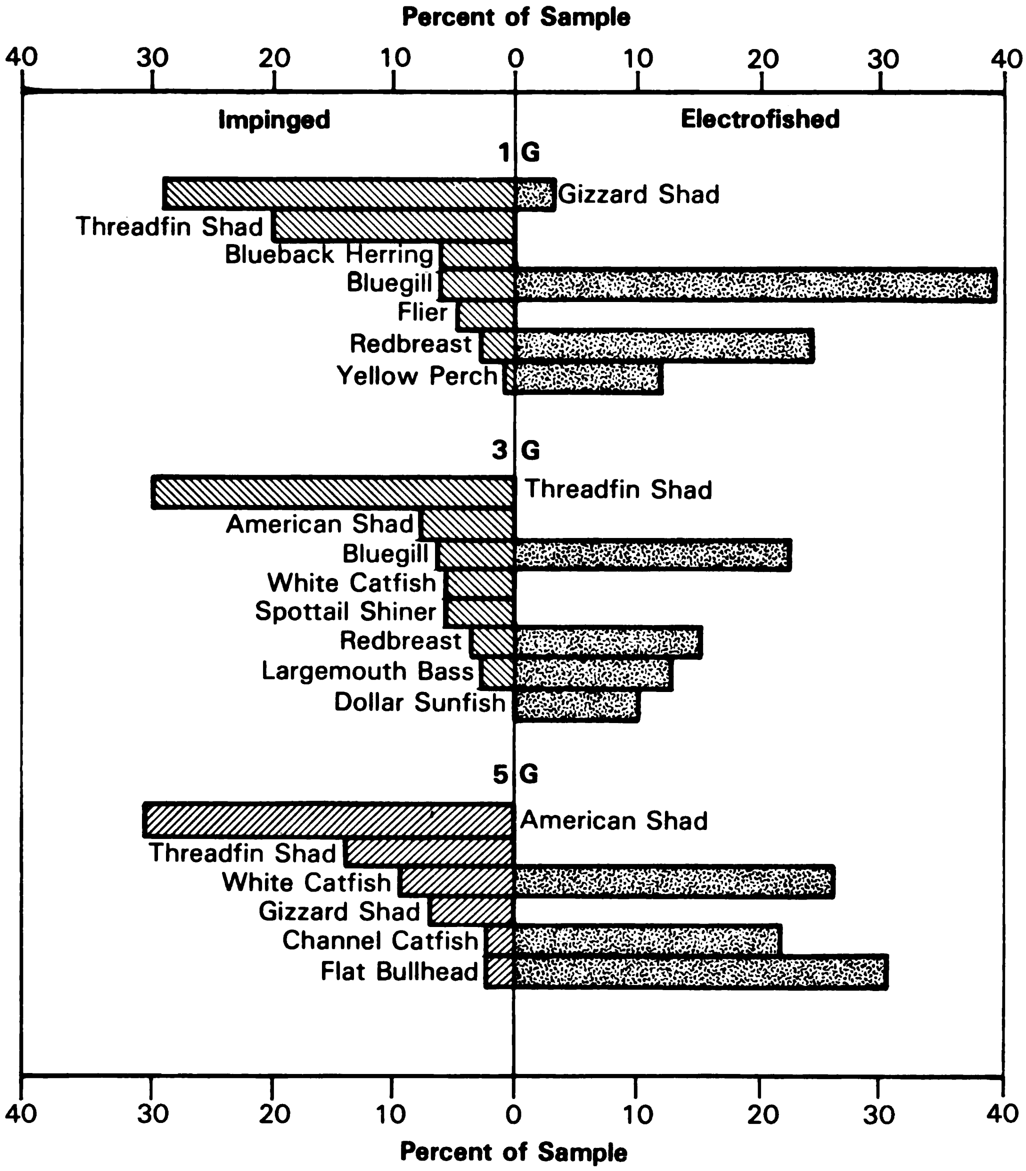
Source: DOE, 1987 from Paller et al. 1984

Figure C-8a. Percent Composition of Selected Fish Species Impinged at the 1G, 3G, and 5G Pumphouses and Collected Near the Pumphouse by Electrofishing. September 1982-August 1983



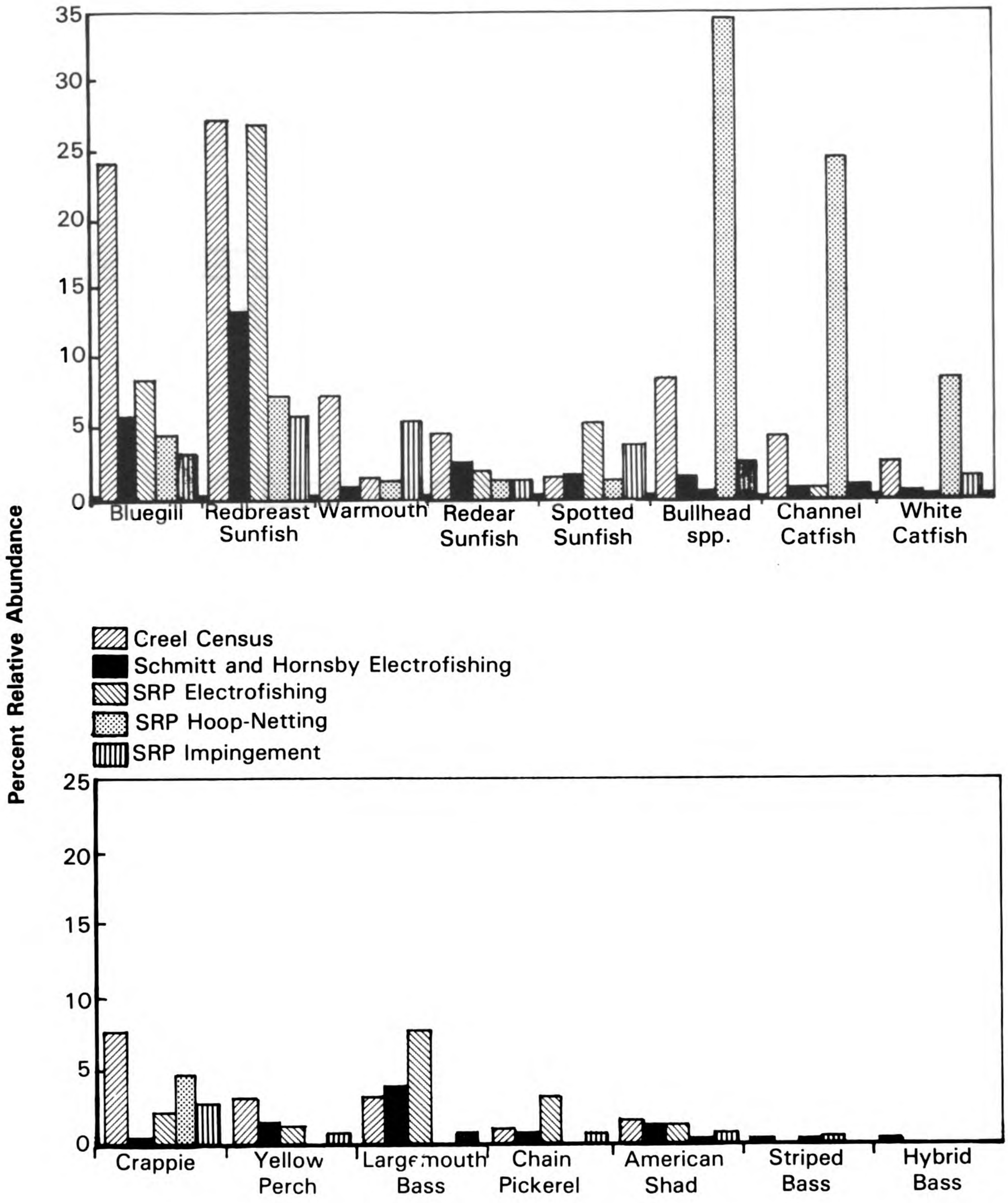
Source: DOE, 1987 from Paller and Osteen, 1985

Figure C-8b. Percent of Composition of Selected Fish Species Impinged at the 1G, 3G, and 5G Pumphouses and Collected Near the Pumphouse by Electrofishing. September 1983-August 1984



Source: DOE, 1987 from Paller and Saul, 1986

Figure C-8c. Percent Composition of Selected Fish Species Impinged at the 1G, 3G, and 5G Pumphouses and Collected in the Vicinity of the Pumphouses by Electrofishing. September 1984-September 1985



Source: DOE, 1987

Figure C-9. Relative Abundance of Fish Taxa in Creel, Electrofishing and Hoop-Net Collections, and SRP Impingement

relative abundance in the anglers' catch than in the river (all methods) and impingement. Among the bream caught by anglers, only the spotted sunfish represents a higher relative abundance in impingement (3.5 percent) than in the creel (1.1 percent), but the species relative abundance in impingement is less than the relative abundance in electrofishing collections (5.2 percent).

Crappie, yellow perch, and largemouth bass all exhibit higher relative abundances in the creek (8.0 percent, 3.0 percent, and 3.2 percent, respectively) than in impingement (2.9 percent, 0.8 percent, and 0.5 percent, respectively, Figure C-9). All three species exhibit higher relative abundance in the river (by at least one collection method) than in impingement. Largemouth bass exhibits higher abundance in the river (by at least one collection method) than in impingement, and exhibits higher relative abundance in the river than in the creel. Chain pickerel is a minor component of the creel (0.9 percent) and has comparable abundance in impingement (0.7 percent).

Relative abundances of all taxa of catfish [bullhead spp. (2.1 percent), channel catfish (0.8 percent), and white catfish (1.3 percent)] taken in impingement samples were lower than relative abundances for those taxa in the creel (8.2 percent, 4.2 percent, and 2.1 percent, respectively, Figure C-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 a poor estimate of the abundance of these taxa. BB-3

American shad, striped bass and hybrid bass were minor components with all of the collection methods (angling, electrofishing, hoop-netting, impingement, Figure C-9). The abundance of the migratory American shad and striped bass in the Savannah River near SRP was undoubtedly underestimated during the quarterly sampling program. Nevertheless, the low frequency of these species in impingement collections (taken in 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 SRP operations.

Status of Savannah River Fish Populations

The primary source documents containing the data used in this section are referenced in DOE (1987). TE

Relatively little is known about the current status of fishery stocks in the Savannah River and the overall levels of mortality sustained by individual species populations. The creel survey in DOE (1987) represents a significant addition to the knowledge of sports fishing pressure on individual species in freshwater and estuarine areas of the lower Savannah River. Concurrent sampling of the creel census areas using electrofishing and rotenone provided additional information on abundance and species composition of resident species. BB-3

American shad stocks appear to be healthy and productive in the Savannah River. Reports on commercial catches by Georgia shad fishermen in 1980 indicated that the Savannah River produced the greatest catches (in pounds of fish and income) in the state, representing 51 percent of Georgia shad landings in that year, while only 13 percent of Georgia's commercial shad fishermen operated in the river during that year. Thus, American shad stocks in the Savannah River may be less heavily exploited and relatively more abundant than stocks in other Georgia rivers. Additionally, researchers have reported on the development of a previously undocumented sport fishery for American shad in the vicinity of the New Savannah Bluff Lock and Dam, and have recommended that the magnitude of this fishery be evaluated.

Less is known about the status of striped bass in the Savannah River. Only recently has spawning upstream of tidally influenced regions of the river been documented (ECS, 1983, Paller et al., 1984, Paller et al., 1985, Paller et al., 1986). Nevertheless, it has been 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 re-establishment 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.

BB-3

Although relatively little is known concerning fish stocks, the quality of fish habitat in the river near the SRP has likely improved. The recent improvement of the sewage treatment facilities in Aiken County, South Carolina, have undoubtedly resulted in improvement of water quality in Horse Creek, which enters the Savannah River at RM 197.4. The continuing upgrading of sewage treatment facilities for the Augusta, Georgia, area will result in improved water quality in Butler Creek (RM 187.2) which enters the river near the New Savannah Bluff Lock and Dam. The river section from the New Savannah Bluff Lock and Dam to downstream of Spirit Creek (RM 182.2) has been identified as an area of degraded water quality.

Overall, there is currently no basis for concluding that fish stocks in the Savannah River are adversely affected by SRP operations. Although direct assessment of recent changes in fish stocks is currently not feasible, the losses of fish resulting from SRP operations are small and localized. Such small losses should not result in a significant risk to the abundance or persistence of fish stocks in the lower Savannah River.

Thermal Effects on Larval Fish

Studies of the thermal tolerance of early life stages of largemouth bass, bluegill, and channel catfish indicated that these species can tolerate higher (several degrees) temperature than the highest observed spawning temperature (Du Pont, 1985). The optimal temperatures for largemouth bass and channel catfish larvae were found to be 24°C and 28°C, respectively. The 24-hour median lethal temperature for largemouth bass larvae was found to range from 32°C to 36°C, while that for bluegill larvae was 36°C to 38°C. The incipient lethal temperature for channel catfish larvae was determined to be 33°C to 36°C. Studies on cold shock conducted on early life stages of largemouth bass and channel catfish indicated that neither species would be likely to suffer mortality if stream temperatures returned to ambient levels during the late spring spawning season.

TE

Fish kills from cold shock can be equally important in environments such as Four Mile Creek and Pen Branch that are thermally constant for long periods of time during extended reactor operation, and then cool rapidly when reactor operations stop (Du Pont, 1985).

Chlorination/Dechlorination Effects

Experimental studies were conducted to evaluate the potential effects of chlorination and dechlorination of K- and C-Reactor cooling water (Wilde, 1987). Chlorination is expected to be necessary to prevent biofouling of the proposed cooling tower systems for these reactors and dechlorination may be necessary to meet expected NPDES permit limitations on residual chlorine in the receiving streams.

Testing of chlorine demand and dissipation rates in April and May 1986 using K-Reactor cooling water effluent determined that a chlorine dose of approximately 3 mg/l is required to obtain a free residual chlorine (FRC) concentration of 1 mg/l in reactor cooling water (the FRC concentration typically required to prevent biofouling in cooling tower systems). The average total residual chlorine (TRC) concentration resulting from this chlorine dose was 1.7 mg/l.

Reduction of TRC to approximately background levels was usually achieved with a sodium sulfite dose of 1.5 times the calculated stoichiometric concentration. However, 2 times the stoichiometric amount of sodium sulfite produced slightly better dechlorination effectiveness. Therefore, based on the results of this study, with a chlorine dosage (ca. 3 mg/L) providing FRC and TRC concentrations of 1.0 and 1.7 mg/l, respectively, a sodium sulfite dose of approximately 6 mg/l would reduce TRC in the effluent to near background levels. BB-1 BC-16

Static 48-hour bioassays with bluegill collected from Par Pond showed no toxicity for cooling water containing up to 64 times the stoichiometric concentration of sodium sulfite calculated to remove residual chlorine.

In flow-through 96-hour bioassays with young-of-the-year largemouth bass and bluegill, no mortality occurred with chlorination at peak doses as high as 1.3 mg/L TRC at 20°C. At 30°C, LC 50 values for peak chlorine dosages ranged from 0.8 to 1.1 mg/l TRC. In the flow-through tests no mortality occurred with either species in chlorinated cooling water dechlorinated with 6 mg/l of sodium sulfite.

A sodium sulfite dose of as much as 25 mg/l resulted in no significant reduction in dissolved oxygen or change in pH with a contact time of 150 minutes. The concentration dosages required for substantial dissolved oxygen depletion were found to be more than an order of magnitude greater than the concentration (6 mg/l) proven to effectively dechlorinate SRP cooling water effluent chlorinated to an FRC concentration of 1 mg/l.

C.6 ENDANGERED AND THREATENED SPECIES

The Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.), 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 (FWS) and the National Marine Fisheries Service

(NMFS) jointly administer this Act. The Act affords protection to some 300 species of native American plants and animals. A species can be listed Federally under either 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 means 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 various species to ensure against excessive taking and to continue necessary protection to similar appearing species which are still classified as threatened. When a species is proposed for either the endangered or the threatened status, areas essential to its survival or conservation are proposed as "critical habitat," when appropriate. Compliance with the Endangered Species Act requires Federal agencies to consult with FWS and/or the NMFS regarding the implementation of a proposed action. If FWS or NMFS indicate that an endangered or threatened species (or one proposed as such) or critical habitat could be present in the area of the 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.

The State of South Carolina has a Nongame and Endangered Species Conservation Act (Section 50-15, 1976, S.C. Code of Laws). Rules established to implement the act protect Federally protected 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 and Strigiformes (R.123-160). The State does not afford protection to flora other than Federally protected species (DOE, 1982). Additions to the State protection listings can be made by the South Carolina Wildlife and Marine Resources Commission.

Table C-30 lists species of flora and fauna that have been documented at the Savannah River Plant (Dukes, 1984) and have been listed by the Federal Government (50 CFR 17.11 and 17.12, "Endangered and Threatened Wildlife and Plants") or State of South Carolina as endangered, threatened, or of special concern. The Savannah River Plant contains no areas that have been designated as critical habitat for any species.

TC Formal consultations were held between DOE and the U.S. Fish and Wildlife Service to comply with the Endangered Species Act of 1973. Based on these consultations, the FWS issued a biological opinion that the preferred alternative cooling systems should have no effect on endangered and threatened species (Parker, 1986; Henry, 1986).

C.6.1 AMERICAN ALLIGATORS

TE Sections 6.1 through 6.5 address the threatened and endangered species that occur on the Savannah River Plant. Much of the information presented in these sections is summarized from the <u>Comprehensive Cooling Water Study</u> (Du Pont, 1985). Additional information concerning other species listed in Table C-30 is in DOE, 1984.

Formerly high alligator population levels in the United States were greatly reduced by habitat alteration, indiscriminate killing, and legal, as well as

Table C-30. Species on the Federal List of Endangered Species or the South Carolina List of "Endangered," "Threatened," or "Of Special Concern" Species That Might Occur on the Savannah River Plant[a]

TC

Species	Status: Federal[b] Threatened	Status: Federal[b] Endangered	Status: State Threatened	Status: State Special concern	Observations on or near SRP
Mammals					
Ursus a. americana (Black bear)			X		No resident population on SRP, observation infrequent in past
Lynx rufus (Bobcat)				X	Common on SRP
Lutra canadensis (River otter)				X	Observed along ambient streams of SRP
Spilogale p. putorius (Eastern spotted skunk)				X	Common on SRP
Condylura cristata parva (Star-nosed mole)				X	Collected infrequently near Risher Pond, Ellenton Bay, Rainbow Bay, and Steel Creek floodplain
Birds					
Picoides borealis (Red-cockaded woodpecker)		X			A few scattered colonies in pine stands of SRP; see text for more details
Haliaeetus l. leucocephalus (Bald eagle)		X			Thirty-six birds have been observed on the SRP, most of which have occurred on Par Pond and L-Lake. A single active nest containing two juveniles was located below Par Pond dam in the Lower Three Runs Creek drainage area in 1986.
Mycteria americana (Wood Stork)		X	X		Individuals have been observed foraging in the Savannah River swamp; see text for more details

Table C-30. Species on the Federal List of Endangered Species or the South Carolina List of "Endangered," "Threatened," or "Of Special Concern" Species That Might Occur on the Savannah River Plant[a] (continued)

Species	Status: Federal[b] Threatened	Federal Endangered	State Threatened	State Special concern	Observations on or near SRP
Birds (continued)					
Pandion haliaetus (American osprey)			X		A few individuals have been observed as migrants over SRP
Accipiter cooperii (Cooper's hawk)			X		A few individuals have been observed near Sun Bay and Rainbow Bay
Bubo virginianus (Great horned owl)				X	A few individuals have been observed near Rainbow Bay
Melanerpes erythrocephalus (Red-headed woodpecker)				X	Common on SRP
Picoides villosus (Hairy woodpecker)				X	Common on SRP
Lanius ludovicianus (Loggerhead shrike)				X	Infrequently observed on SRP
Aythya valisineria (Canvasback)				X	
Ictinia mississippiensis (Mississippi kite)				X	
Reptiles					
Alligator mississippiensis (American alligator)	X[c]		X		Common on Par Pond, Beaver Dam Creek, and in the SRP Savannah River Swamp; see text for more details
Clemmys guttata (Spotted turtle)				X	Uncommon

TC

TC

Table C-30. Species on the Federal List of Endangered Species or the South Carolina List of "Endangered," "Threatened," or "Of Special Concern" Species That Might Occur on the Savannah River Plant[a] (continued)

TC

Species	Status				Observations on or near SRP
	Federal[b]		State		
	Threatened	Endangered	Threatened	Special concern	
Reptiles (continued)					
Natrix cyclopion (Green water snake)				X	Collected commonly from Ellenton Bay
Seminatrix pygaea (Carolina swamp snake)				X	Uncommon; collected from Ellenton Bay
Virginia valeriae (Smooth earth snake)				X	Collected from deciduous forests mixed with older pines; found near Pond C or Par Pond, Lost Lake, and Rainbow Bay
Pituophis m. melanoleucus (Pine snake)				X	Uncommon
Micrurus f. fulvius (Eastern coral snake)				X	Uncommon
Ophisaurus attenatus longicaudus (Eastern slender glass lizard)				X	Uncommon; has been collected near Risher Pond, Rainbow Bay, Sun Bay, and Steel Creek floodplain
Amphibians					
Ambystoma t. tigrinum (Eastern tiger salamander)				X	Found throughout SRP
Pseudacris triseriata feriarum (Upland chorus frog)				X	Locally common
Hyla avivoca ogechiensis (Bird-voiced treefrog)				X	Locally common in the Savannah River swamp

Table C-30. Species on the Federal List of Endangered Species or the South Carolina List of "Endangered," "Threatened," or "Of Special Concern" Species That Might Occur on the Savannah River Plant[a] (continued)

Species	Status: Federal[b] Threatened	Status: Federal[b] Endangered	Status: State Threatened	Status: State Special concern	Observations on or near SRP
Amphibians (continued)					
Rana grylio (Pig frog)				X	Observed near Steel Creek Bay and Steel Creek delta
Rana palustris (Pickerel frog)				X	Rare; a few have been captured from Risher Pond
Fish					
Acipenser brevirostrum (Shortnose sturgeon)		X			Rare; a few larvae (5) have been collected in the Savannah River near the SRP pumphouses and two larvae were collected in the intake canals; see Section C.5.2.2 for more details
Acipenser oxyrhynchus (Atlantic sturgeon)			X		Rare; a few larvae (17) have been collected in the Savannah River near the SRP pumphouses; see Section C.5.2.2 for more details
Alosa aestivalis (Blueback herring)				X	Common in the Savannah River; present in Par Pond
Alosa mediocris (Hickory shad)				X	Collected downstream of SRP in the Savannah River
Invertebrates					
Elliptio fraterna (Brother spike mussel)		X			Collected from Savannah River below Lower Three Runs Creek
Elliptio lanceolata (Yellow lance mussel)				X	Collected from ambient streams of SRP and the Savannah River
Alasmidonta triangulata (Triangle floater mussel)			X		Collected from Savannah River below SRP

TC

TC

Table C-30. Species on the Federal List of Endangered Species or the South Carolina List of "Endangered," "Threatened," or "Of Special Concern" Species That Might Occur on the Savannah River Plant[a] (continued)

TC

Species	Status: Federal[b] Threatened	Status: Federal[b] Endangered	Status: State Threatened	Status: State Special concern	Observations on or near SRP
Invertebrates (continued)					
Carunculina pulla (Savannah shore mussel)			X		Collected from Savannah River near Lower Three Runs Creek
Anodonta couperiana (Barrel floater mussel)				X	Collected from Savannah River and Lower Three Runs Creek at Donora Station
Strophitus undulatus (Strange floater mussel)				X	Collected from Savannah River downstream of Steel Creek
Lampsilis cariosa (Yellow mucket mussel)				X	Collected from Savannah River and Lower Three Runs Creek
Lampsilis radiata splendida (Red mucket mussel)				X	Collected from Savannah River, Lower Three Runs Creek, and Tinker Creek
Procambarus hirsutus (Crayfish)				X	Collected from ambient streams of SRP
Tortopus incertus (Mayfly)				X	Collected from clay banks in the Savannah River near Upper Three Runs Creek and Steel Creek mouth
Plants					
Echinacea laevigata (Smooth coneflower)		X			Along Burma Road
Nestronia umbrellula (North American sandlewood)				X	Dry wood bluffs along Upper Three Runs Creek
Habenaria lacera (Green fringed-orchid)				X	Rainbow Bay, Sun Bay, and Mill Creek Reserve Site areas

Table C-30. Species on the Federal List of Endangered Species or the South Carolina List of "Endangered," "Threatened," or "Of Special Concern" Species That Might Occur on the Savannah River Plant[a] (continued)

Species	Status: Federal[b] Threatened	Federal Endangered	State Threatened	State Special concern	Observations on or near SRP
Plants (continued)					
Ludwigia spathulata (Spathulate seedbox)			X		Sun Bay and transplanted to Rainbow Bay area
Enchinodorus parvulus (Little burhead)			X		Lost Lake and Sun Bay
Rhexia aristosa (Ann-petaled meadow-beauty)			X		Craig Pond
Ipomopsis rubra (Standing cypress)			X		On roadbank of Highway 125 just east of SRP boundary in Barnwell County, SC
Coreopsis rosea (Pine tickseed)			X		Karen's Pond and Flamingo Bay

a. Source: Dukes, 1984.
b. Source: 50 CFR 17.11 and 17.12.
c. Threatened due to similarity of appearance.

TC

TC

illegal commercial harvest (Du Pont, 1985). By the 1950s, alligator populations were at an all-time low. Since that time, State and Federal law enforcement and management, as well as public education, have allowed the alligator to recover throughout much of its range. On June 4, 1987, FWS reclassified the American alligator from endangered to threatened due to similarity of appearance because the species is no longer biologically endangered or threatened throughout its range (FR 52 No. 107: 21059-21064). The threatened due to similarity of appearance status was retained to ensure against excessive taking and to continue necessary protection to the American crocodile, a morphologically similar species.

Alligators will feed on most aquatic and semiaquatic vertebrates and some terrestrial animals. Limited data suggest that fish make up the bulk of the alligator diet on the Savannah River Plant (Du Pont, 1985). American alligators have relatively broad temperature tolerances; the critical thermal maximum is estimated to be 38°C and animals have survived exposure to temperatures as low as 2°C to 4°C (Colbert, Cowles, and Bogert, 1946; Hagan, Smithson, and Doerr, 1983).

The American alligator occupies most major aquatic habitats at the Plant where water temperatures are suitable and food supplies are adequate (Du Pont, 1985). Large alligator populations occupy Par Pond and Beaver Dam Creek, areas that receive cooling water but have only moderately elevated temperatures. The Par Pond population has been studied most intensively; historically it has shown population parameters that indicated reduced reproduction in relation to more southerly populations. However, recent surveys indicated more extensive reproduction and a normalization of the age and sex structures (Du Pont, 1985). Recent surveys also indicate that Beaver Dam Creek might represent the most dense population of American alligators (Du Pont, 1985). At least 40 individuals were documented in less than 6 kilometers of the stream; clear evidence (i.e., two "pods" of hatchlings located 100 meters apart) indicated recent and successful reproduction (Du Pont, 1985).

Reproducing populations of alligators are known to occur in both post-thermal SRP stream systems, Steel Creek and Lower Three Runs Creek (Du Pont, 1985). A few alligators have been observed to move upstream in the reactor effluent streams when the reactors are not operating. Experimental studies confirm that alligators avoid lethal water temperatures associated with reactor start-up, even in winter when the animals' metabolic rates are low (Du Pont, 1985).

SRP operations have impacted the alligator population in many different ways. The creation of manmade reservoirs has dramatically increased the amount of aquatic habitat available to alligators. Therefore, it has increased the carrying capacity of the Plant for this species (Du Pont, 1985).

The thermal alteration of aquatic habitats has also impacted the resident alligator population (Du Pont, 1985). Temperature elevations greater than 38°C result in the loss of this habitat to alligators. Alligators respond to moderate thermal increases by moving to other locations. Observations suggest that alligators might utilize vertical and horizontal temperature profiles established by thermal loading to maintain their body temperatures at a preferred level; definitive data have not been collected (Murphy, 1981). Alligators around areas of thermal loading might also profit from extended breeding seasons or increased productivity by prey species. A serious negative influence of moderate levels of thermal loading appears to result from the induction of a premature reproductive season combined with differential use of thermal areas by adult male and female alligators (Murphy, 1981).

The current information available on the alligators of the Savannah River Plant suggests the following predicted trend: low density populations distant from thermally altered areas will continue at a low density with the exception of localized increases. The alligators inhabiting Par Pond should continue a trend toward a more normal size distribution and sex ratio as the reservoir matures and the older adults are replaced by the young (Du Pont, 1985).

C.6.2 WOOD STORKS

During the last 50 years the wood stork population declined from an estimated 20,000 breeding pairs in the early 1930s to approximately 4800 pairs in 1980 and 3650 pairs in 1983 (Ogden and Nesbitt, 1979; Odgen and Patty, 1981; DOI, 1983). FWS has listed the wood stork as an endangered species (DOI, 1984; 50
TC CFR 17.11 and 17.12).

The most northern and inland wood stork colony is located at Big Dukes Pond, a cypress swamp 12.6 kilometers northwest of Millen, Jenkins County, Georgia (Du Pont, 1985). This colony, referred to as the Birdsville colony, is the source of the birds foraging at SRP. The Plant is 45 kilometers from the Birdsville colony, a distance within the 60- to 70-kilometer radius that wood storks can travel during daily feeding flights (Du Pont, 1985).

The wood stork method of feeding is highly specialized. Wood storks wade in shallow pools, 15 to 30 centimeters deep, with their bills extended slightly forward and submerged as far as the external nares and opened about 8 centimeters at the tips. When a stork touches fish or other prey with its bill, the bird snaps the bill shut, capturing the prey. This method has been termed tactolocation. This feeding technique allows wood storks to forage in muddy or turbid water where birds that hunt visually cannot feed. To feed efficiently, storks forage in ponds where prey are concentrated. It is important that the birds feed in areas where prey are densely concentrated during the breeding season because food requirements are greatest when adults are caring for chicks (Kahl, 1964; Du Pont, 1985).

Wood storks are colonial nesters. They build large nests in trees, usually over standing water. Nest heights range from a few meters above water in mangrove swamps to the tops of the tallest cypress trees (Taxodium sp.) (Ogden and Nesbitt, 1979). Storks use cypress trees for nesting habitat most often; however, in southern Florida they use red mangrove, Rhizophoro mangle (Kahl, 1964).

Wood storks breed during the dry season when evaporation in shallow ponds concentrates the prey (Du Pont, 1985). Breeding lasts about 120 days, including time for courtship and nest-building. Two to five white eggs are incubated for 28 to 30 days. During the first 30 days after hatching, the young are attended by one parent while the other parent forages. During this period the chicks gain the ability to thermoregulate and grow to a size at which they are no longer vulnerable to their major predators, crows and vultures. As the food demand of the chicks exceeds the level that one parent can provide, the young are left alone at the nest while both parents forage. The young leave the rookery after about 65 days (Kahl, 1964).

Kahl (1964) estimated that during the breeding season the minimum fish biomass needed by a nesting pair of storks and an average of 2.25 fledge young was 201 kilograms. Feeding habitat, including cypress swamps and domes, scrub cypress, freshwater marshes, and mixed hardwood swamp, must be available within 60 to 70 kilometers of the stork colony. These habitats must also be productive enough to maintain fish populations at levels sufficient to allow an annual take by the colony equal to about 201 kilograms times the number of nesting pairs (Meyers, 1984).

Wood stork feeding sites for the Birdsville colony were studied during the second half of the nesting season in 1983 and for most of the 1984 and 1985 nesting season (Meyers, 1984; Coulter, 1986a,b). Feeding sites were located by following storks from the nesting colony and by surveying the SRP Savannah River swamp and other habitats near the colony. The following information was gathered from this research:

- Wood storks at Birdsville produced an average of 2.2 fledglings per active nest during 1983. About the same number of young were observed in 1984 (2.4 fledglings) and 1985 (2.5 fledglings). When the loss of entire nests is considered, the mean number of young per nest declined from 2.04 in 1984 to 0.33 in 1985.

- Wood storks forage up to 80 kilometers from the colony, but a majority (91 percent) of feeding flights during 1983 were less than 50 kilometers. During 1984, more than 80 percent of the foraging sites were within 20 kilometers and 55 percent were within 10 kilometers of the colony. During 1985, most sites (89 percent) were within 20 kilometers of the colony, and 46 percent were within 10 kilometers of the rookery.

- Of the 50 feeding sites located during 1983, 18 percent were located in SRP swamps (3 sites at the Steel Creek delta, 5 sites at Beaver Dam Creek, and 1 site near the Pen Branch delta) in 1983. Similar areas at SRP were used in 1984, along with additional foraging sites in the swamp between Pen Branch and Four Mile Creek. Two wood storks were observed feeding in Kathwood Lake on August 5, 1984; no other sitings were recorded during the surveys. In 1985, 58 percent of the feeding sites were in swamps and 23 percent were in Carolina bays and ponds. BB-3

- Before fledging (when young birds leave the nest) in 1984, 33 percent of the feeding sites were located at SRP. However, of the total number of adult storks observed feeding at that time, 64 percent were at SRP sites and 36 percent were not. During 1985, no wood storks were observed feeding at SRP prior to fledging.

- After fledging, juvenile wood storks did not feed at SRP sites in 1983.

- In 1983, storks fed in shallow pools with an average of 6.2 acres and depths between 10 and 32 centimeters. In 1984 and 1985, the median water depth was 22 and 21 centimeters, respectively. Habitat types for 1983-1985 included black gum swamp, cypress swamp, shrub swamp, open marsh, manmade ponds, and Carolina bays used as feeding sites.

BB-3 • Habitat use varied markedly from 1983 to 1985. The Steel Creek delta was heavily used in 1983 and 1984, but was infrequently used in 1985. Beaver Dam Creek was important to wood storks in 1983 and 1984, but none were observed there in 1985. The greatest use in 1985 was recorded on the Four Mile Creek delta and in the area between this delta and the Pen Branch delta.

• Direct and indirect effects from thermal effluent discharge from SRP facilities probably limit the potential use of the Savannah River swamp by foraging adult wood storks.

TE • If the Florida colonies continue to decline, the Birdsville colony will become relatively more important to the wood stork.

C.6.3 SHORTNOSE STURGEON

The shortnose sturgeon is listed by the National Marine Fisheries Service (NMFS) as an endangered species in the United States (Du Pont, 1985; 50 CFR 17.11 and 17.12). [TC] This species is found only on the east coast of North America in tidal rivers and estuaries. Until recently, the presence of shortnose sturgeon had not been documented in the middle reaches of the Savannah River. However, from 1982 to 1985, shortnose sturgeon larvae were collected near the Savannah River Plant as part of the SRP aquatic ecology program (see Section C.5.2.2; DOE, 1987). [TC] Because the shortnose sturgeon is anadromous, protection of this species is under jurisdiction of the NMFS. Critical habitat for this species has not been designated by the NMFS (Du Pont, 1985).

Breeding populations of shortnose sturgeon are normally associated with estuary-river complexes that have a strong flow of fresh water. 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).

Shortnose sturgeon have been found in rivers, estuaries, and the ocean with their greatest abundance occurring in the estuary of their respective rivers (Dadswell et al., 1982). The few fish that have been captured at sea were found within a few miles of the mouth of an estuarine system. [TE] 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,b) and the Lake Marion-Moultrie system in South Carolina (Marchette and Smiley, 1982).

Spawning of shortnose sturgeon occurs between February and May, depending on the latitude. 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 to occur between 9°C and 19°C (Heidt and Gilbert, 1978; Dadswell, 1979; Taubert, 1980a; Buckley and Kynard, 1981). Specific spawning grounds for populations in southeastern rivers have not been described. The shortnose sturgeon exhibits a migration pattern between spawning grounds, feeding grounds, and overwintering areas.

Although a segment of the Savannah River shortnose sturgeon population spawns upstream of SRP cooling water intake canals, entrainment of eggs is unlikely

(Du Pont, 1985). Sturgeon eggs are demersal and are usually deposited on rubble and gravel substrate (Buckley, 1982; Taubert, 1980b). Whether this substrate is utilized or available to the Savannah River population is not known. However, the negative buoyancy and strongly adhesive, gelatinous nature of the eggs preclude significant downstream transport or dispersion of eggs through the water column (Pottle and Dadswell, 1979).

Collections made near SRP indicate that some shortnose sturgeon larvae might be entrained (see Section C.5.2.2). However, it is not possible to accurately estimate entrainment losses due to the low number of specimens collected. Given the small number of shortnose sturgeon larvae collected and the relatively extensive ichthyoplankton sampling effort in the vicinity of the SRP site, the number of larvae entrained probably is small and their loss does not represent an adverse effect on the Savannah River shortnose sturgeon population (Du Pont, 1985). TC

In January 1983, one 147-millimeter juvenile Atlantic sturgeon was impinged on the intake screens (Du Pont, 1985). Thus, shortnose sturgeon might be impinged. However, there is no evidence that Atlantic or shortnose sturgeon commonly inhabit the intake canals. Shortnose sturgeon, unless injured, should be able to avoid the intake screens because their swim speed exceeds the pumphouse intake velocity (Du Pont, 1985).

Potential direct thermal effects on the shortnose sturgeon are limited to existing and any future thermal plumes in the Savannah River. Thermal plumes should not affect adults because they can avoid these areas; at present, a large zone of passage exists in the Savannah River for all migratory species (Du Pont, 1985). Eggs are not planktonic and should not drift through the plumes; however, newly hatched larvae could be swept into the plume under conditions of high water flow or drift downstream as part of a normal dispersion process. Although there are no temperature tolerance data on larval shortnose sturgeon, larvae drifting through the plume near the mouth of Four Mile Creek might not survive. This potential effect is expected to be limited because only adults spawning immediately above the thermal plume and larvae drifting through the hottest part of the thermal plume would be affected (Du Pont, 1985).

The NMFS had previously concurred in DOE's determination that the population of shortnose sturgeon in the Savannah River would not be adversely affected by SRP operations (Oravetz, 1983).

C.6.4 RED-COCKADED WOODPECKER

The red-cockaded woodpecker was once a common bird in the mature pine forests of the Southeast. Today its range and population have been reduced through loss of habitat. It is unique among North American woodpeckers in its selection of mature, living pines for cavity excavation (Jackson, 1978). The disappearance of mature pine forests (Whalenberg, 1946, 1960; Lennartz et al., 1983) has resulted in fragmentation of the required habitat. As a result, many red-cockaded woodpecker populations exist in isolated mature pine reserves (Jackson, 1977).

The red-cockaded woodpecker has a complex cooperative breeding system (Lennartz and Harlow, 1979). These birds live in groups called clans, are nonmigratory, and maintain large year-round territories (Ligon, 1970). The clan can consist of from two to nine birds, but there is never more than one breeding pair. The other adults are usually males called helpers. Some clans have no helpers, but others might have as many as three. The helpers assist in incubating eggs, making new cavities, feeding the young, and defending the clan's territory. A breeding male can live for several years. When he dies, one of the helpers usually inherits the status of breeding male (Lennartz and Harlow, 1979).

A clan nests and roosts in a group of cavity trees called a colony. Cavities are made in live pine trees. Each clan member tries to have a cavity for
TE roosting. Birds without cavities in live trees often roost in forks between limbs or in cavities of dead trees. A cavity is seldom excavated in one year, and most take several years of work (Jackson, Lennartz, and Hooper, 1979).

The red-cockaded woodpecker nests between late April and July. Only the breeding male courts and mates with the female. The female usually lays two to four eggs in the breeding male's roost cavity. The breeding male stays with the eggs at night and the clan members take turns incubating during the day. The eggs hatch in 10 to 12 days. Young birds leave the nest in about 25 days (Ligon, 1970). The clan spends a great deal of time looking for food. Most of the foraging is concentrated on the trunks of live pine trees. The birds will scale the bark and dig into dead limbs for spiders, ants, cockroaches, centipedes, and the eggs and larvae of various insects.

The clan defends year-round a territory surrounding the colony. Territories range from less than 100 acres to more than 250 acres. The total area used by the clan can be as large as 1000 acres.

The Savannah River Forest Station's wildlife management program has concentrated on red-cockaded woodpecker habitat improvement since 1979. In July 1980, an intensive program was started to reduce encroaching hardwood understory in several colonies. The objective was to provide the open, park-like mature pine stands that are required. This type of habitat is scarce at SRP. About one-third of the forest area has been planted since 1951 and will require 30 or more years to provide suitable habitat. Much of the remaining area is either scrub oak or bottomland hardwoods.

The Forest Service is in the process of evaluating inventoried colonies of red-cockaded woodpeckers and their habitats and determining which habitats should be improved. No active colonies are located near the areas of proposed
TC alternative cooling water system construction. In 1987, the Plant had three active breeding colonies, and the Southeastern Forest Experiment Station successfully cross-fostered two chicks from the Francis Marion National Forest to stabilize and increase the genetic diversity of the colonies.

C.6.5 BALD EAGLE

The federally endangered bald eagle is a fairly common permanent breeding resident in South Carolina and is most abundant in the coastal region (Sprunt
TC and Chamberlain, 1970). The presence of this species on Par Pond was first recorded in May 1959 (Norris 1963), and has been frequently sighted since 1978 (Mayer et al., 1986). From September 1984 through August 1985, Mayer et al. (1986) reported 36 bald eagles, 92 percent of which were observed on the Par

Pond reservoir system; no active nests, however, were found. From September 1985 to January 1986, a total of 22 birds was observed, some of which were seen in the vicinity of the newly constructed L-Lake reservoir system. TC

Bald eagles migrate from southeastern to northern states and Canada in mid-summer; they return south in the fall and early winter to nest and rear their young (Sprunt and Chamberlain, 1970). TC

The first sighting of an active bald eagle nest occurred on June 5, 1986, below Par Pond dam in the Lower Three Runs Creek drainage area, and two eaglets fledged from the nest in 1987. Because this nest is outside the preferred alternative cooling impact zones and because of the implementation of management practices in accordance with the guidelines of the 1984 bald eagle recovery plan, the FWS issued a finding of no effect to this species in 1986 (Henry, 1986). TC

C.7 COMMERCIALLY AND RECREATIONALLY VALUABLE BIOTA

Commercially valuable plant biota on the Savannah River Plant include approximately 175,000 acres of timber that are managed by the Forest Service. The commercial value of SRP timber that was managed and sold by the Forest Service in 1982 was $1.7 million; this included pine and hardwood sawtimber, pine pulpwood, and cordwood hardwoods. Approximately 71 percent of the timber sales consisted of pine pulpwood. The longterm trend in planting activities has been an increase in the number of loblolly pine and a decrease in slash pine. The latter is more susceptible to injury from ice glazing and has not been planted since 1970. More than 1,530,000 loblolly pine seedlings and 160,000 longleaf pine seedlings were planted in 1980 (USDA, 1983). TE

Public hunts of deer and feral hogs, managed by the Forest Service, began in 1965. These hunts minimize deer-car accidents and maintain habitat quality. Since 1981, Du Pont personnel have planned and managed these hunts. TE

The annual number of hunter-days increased from 700 in 1966 to 6325 in 1980; paralleling this trend was an increase from 198 deer harvested in 1966 to 961 in 1980. The harvest of feral hogs ranged from 10 in 1972 to 32 in 1980. Additionally, there has been a relatively consistent decline in the number of deer-car accidents. In the late 1960s and early 1970s, there were more than 50 deer-car accidents; only 11 incidents were reported in 1980. TE

Other game species that have commercial and recreational value but have protection from hunting include the bobcat, fox, mink, muskrat, opossum, otter, rabbit, raccoon, skunk, squirrel, migratory waterfowl, bobwhite quail, mourning dove, wild turkey, Wilson's snipe, and woodcock. TE

The Savannah River supports both commercial and sports fisheries. Table C-31 lists the species and catches of fish taken commercially from the river from 1970 to 1979. Many of these fisheries are confined to the marine and brackish waters of the coastal regions of South Carolina and Georgia.

The only commercial fishes of significance near SRP are the American shad, the channel catfish, and the Atlantic sturgeon. These species, except for the

Table C-31. Commercial Landing Data for Fish Taken from Savannah River, 1970-1979[a]

	Combined catches in Georgia and South Carolina (kg)									
Species	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Carp	0	250	252	1,503	590	998	136	453	136	363
Catfish	544	157	222	518	726	1,814	1,043	1,043	363	1,043
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	2,500	1,800	181	181	0
American shad	43,591	25,568	25,439	33,912	26,263	20,412	8,618	20,820	54,432	57,607
Sturgeon	726	23	1,967	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	1,013	1,071	0	. 0	0	0	0	0

a. Source: Du Pont, 1982.

sturgeon, are exploited to a limited degree by nonprofessional local fishermen. There is no fishery specifically for hickory shad in South Carolina or Georgia; however, many are taken each year incidental to the catch of American shad (Ulrich et al., 1978).

Sport fishermen are the principal consumers of river fishes, primarily sunfish and crappie. Striped bass, which is classified as a game fish in South Carolina and Georgia (Ulrich et al., 1978), is a favorite quarry of fishermen in the Augusta area.

Commercial and recreational fisheries for blueback herring exist in South Carolina (Ulrich et al., 1978), but none are taken commercially in Georgia because of state netting restrictions.

Although species of commercial or sport fishing importance in the Savannah River might use SRP streams, DOE does not allow fishing or other exploitation of commercial species.

The Fisheries Section of the Georgia Department of Natural Resources published the results of a creel survey in the estuarine and fresh-water sections of the Savannah River from December 29, 1979 to December 26, 1980 (Georgia Game and Fish Division, 1982). The most abundant species harvested in the fresh-water section were bluegills (29.1 percent), redbreast sunfish (27.5 percent), warmouth (10.6 percent), bullheads (7.1 percent), and crappie (6.2 percent). Those fish species comprising the greatest weight were bluegills (19.8 percent), redbreast sunfish (21.1 percent), warmouth (8.2 percent), largemouth bass (7.3 percent), and crappie (7.0 percent). Based on electrofishing studies conducted by the Georgia Game and Fish Division, the relative abundance of sunfish in the freshwater section of the river is high, as is the actual angler success rate. The success rate for largemouth bass (0.04 percent fish per hour) was low. The average-size striped bass (5.21 kilograms) creeled in fresh water was over four times greater than the average-size striped bass (1.19 kilograms) creeled in the estuary.

The most abundant species harvested in the estuarine section were croakers and spots (24.5 percent), white catfish (17.4 percent), silver perch (11.3 percent), and other species (26.3 percent). Species comprising the greatest weight were white catfish (23.9 percent), red drum (16.0 percent), and sea trout (12.9 percent). Angler success rates for all species were very low.

The greatest fishing effort in the estuary was expended for sea trout (42.1 percent), striped bass (29.9 percent), and red drum (17.3 percent). The five most sought-after species in fresh water were largemouth bass (38.0 percent), sunfish (30.5 percent), redbreast sunfish (12.7 percent), crappie (7.7 percent), and catfish (5.4 percent).

DOE (1987) cites evaluations made of the fishery resources in the Savannah River downstream of the New Savannah Bluff Lock and Dam during 1980-1982. Average annual sport fishing harvest from the freshwater portions of the river (approximately RM 21-187) was estimated to range from 171,561 fish/year in BB-3
1982 to 550,282 fish/year in 1980 (3 year averages = 305,778 fish/year). BD-5
Dominant species in the sport harvest were redbreast sunfish (27.2 percent) and bluegill (24.1 percent, Table C-28). The composite category of bream accounted for 64.0 percent of the total angler catch. The composite category

of catfish also represented a substantial portion of the sport harvest (14.6 percent), with bullhead spp. (8.2 percent) as the major reported taxon within this category. Crappie (8.0 percent) represented a substantial component of the sport harvest and was comparable to warmouth (7.3 percent). No other species (or species group) represented greater than five percent of the sport harvest. Notably, anadromous species (striped bass, 0.2 percent; American shad, 1.7 percent) did not contribute substantially to the angler's harvest. However, 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.

The proportions of fish species caught by anglers were frequently in sharp contrast to angler preferences. Approximately 35 percent of angler fishing effort was directed toward bream (composite reporting category plus individual species), while 64 percent of the harvest was from this category (Table C-32). The relationship between effort and harvest was even more disparate for largemouth bass; 25.7 percent of the fishing effort was targeted toward this species, while it constituted only 3.2 percent of the catch. Overall, catfish were not highly desired (approximately 7 percent of effort), but were caught in slightly greater proportion (14.6 percent). American shad (7.8 percent of effort) and striped bass (4.7 percent of effort) were caught in substantially
BB-3 lower abundances than desired by sport fishermen, the disparity being
BD-5 comparable to that exhibited for largemouth bass.

Impingement relative abundances for all taxa of catfish [bullhead spp. (2.1 percent), channel catfish (0.8 percent) and white catfish (1.3 percent)] were lower than relative abundances for those taxa in the creel (8.2 percent, 4.2 percent, and 2.1 percent, respectively Figure C-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 were minor components in all the collection methods (angling, electrofishing, hoop-netting, impingement, Figure C-9). The abundance of the migratory American shad and striped bass in the Savannah River near SRP 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 SRP operations.

C.8 HABITAT EVALUATION PROCEDURES ANALYSIS

The potential effects on wildlife of the implementation of thermal mitigation alternatives for C- and K-Reactors were evaluated using Habitat Evaluation
BD-4 Procedures (HEP) developed by the U.S. Fish and Wildlife Service (FWS) and modified by the Savannah River Laboratory for the Savannah River Plant (SRP) environment (Mackey et al., 1987). These procedures allow for the relative

Table C-32. Fishes Preferred and Caught by Savannah River Sport Fishermen[a]

Taxon	Percent Angler Effort	Percent Angler Catch
Bream	24.9	64.0[b]
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[b]
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. Source: DOE, 1987.
b. Sum of taxa within category.

BB-3
BD-5

ranking of project alternatives and/or mitigation with respect to representative wildlife species over the life of the project or for selected time periods in the future. The Department of Energy-Savannah River was requested by the FWS to provide an HEP analysis for the cooling water alternative for these reactors during the comment period on the Draft EIS.

For C- and K-Reactors the potential wildlife impacts and/or benefits of once-through and recirculating cooling towers were evaluated for both near-term (30-year) and long-term (100-year) time periods. These options were evaluated against the projected effects of the current operations, i.e., release of once-through cooling water effluent directly to Four Mile Creek and Pen Branch from C- and K-Reactors, respectively. Those species that were selected as representative of potential project effects in terrestrial environments included the pine warbler, downy woodpecker, cottontail rabbit, gray squirrel, white-tailed deer, and eastern wild turkey. Those species selected to represent aquatic and/or semi-aquatic environments included the creek chub, redbreast sunfish, black bullhead catfish, blueback herring, great egret, wood duck, mallard, and yellow-bellied slider. The land cover data base for the habitat cover maps for the HEP assessment was developed using Geographic Information System (GIS) methods and remote sensing aerial photography and multispectral scanner data. Much of the data to predict future changes in Four Mile Creek, Pen Branch, and the SRP Savannah River swamp was BD-6 developed from previous remote sensing studies and from the Comprehensive Cooling Water Study (CCWS) and L-Reactor restart studies.

For the various cooling water alternatives, the following relative rankings of future wildlife effects were determined. Effects on terrestrial wildlife from construction of the once-through and recirculation cooling towers are essentially equal since in both cases either type of tower would be constructed at the same location and pipeline and other support facilities would affect essentially the same locations. Small stream species, such as the creek chub, benefit more from the recirculation alternative in the upper reaches of the creeks. In the middle and lower reaches, species such as the catfish and
BD-4 sunfish benefit more from the once-through alternative. In the deep swamp environment, those fish which are more likely to use the swamp during the spawning period benefit more from the recirculation alternative. In the Savannah River swamp, wading birds such as the great egret benefit more from the recirculation alternative. Overwintering waterfowl such as the mallard benefit more either from the present SRP operations or from the once-through cooling tower. These alternatives either maintain the existing "marsh" type environment in the swamp for wintering waterfowl or permit expansion of this type of habitat as deep swamp wetlands (cypress/tupelo) are reduced and converted to more open wetlands by the future release of high flows of cooling water effluent. Similar trends were noted for both C- and K-Reactors for both the short-term 30-year and long-term 100-year analyses.

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APPENDIX D

RADIOCESIUM INVENTORY AND TRANSPORT AND ATMOSPHERIC TRITIUM RELEASES

This appendix discusses the existing releases of radionuclides, principally radiocesium, to the Beaver Dam Creek, Four Mile Creek, and Indian Grave Branch/Pen Branch systems; describes the estimated distribution and inventory of radiocesium in the sediments, fish, and water of the creeks, swamp, and Savannah River; examines the transport of radiocesium offsite; and predicts the concentrations in the Savannah River and downstream water-treatment plants as a result of implementation of the alternative cooling water systems. This appendix also describes the atmospheric releases of tritium associated with the discharge of cooling water from existing and alternative cooling water systems.

D.1 RELEASES OF RADIOCESIUM

The principal sources of radiocesium in the environment at the Savannah River Plant have been reactor effluent discharges to onsite streams and releases from the chemical separations facilities in F- and H-Areas. From 1955 through 1980, about 560 curies of radiocesium were discharged to all onsite streams (DOE, 1984a).

From 1960 through 1980, approximately 21.9 and 16.2 (both decay corrected to 1980) curies of cesium-137 were discharged to Indian Grave Branch/Pen Branch and Four Mile Creek from K- and C-Reactors, respectively (Table D-1). These discharges resulted from leaching of reactor fuel elements with cladding failures that exposed the underlying fuel to water. The direct sources of these releases were heat-exchanger cooling water, spent-fuel storage and disassembly-basin effluents, and process water from K- and C-Reactor areas. In addition to these reactor effluent discharges, approximately 0.7 curies of cesium-137 (decay corrected to 1980) was released to Four Mile Creek from the chemical separations facilities in F- and H-Areas, and 21.9 curies (decay corrected to 1980) of cesium-137 was released to Four Mile Creek as a result of an overflow of high-level waste in 1967. Generally, the longer lived cesium-137 will be of greater interest than cesium-134. A cesium-134 to cesium-137 ratio of 1:20 is expected (DOE, 1984a) in creek sediments. Further, special low-level analyses of water samples from the Savannah River have not detected cesium-134 attributable to Plant releases since the program was initiated in March 1983 (Hayes, 1986). When the change in radionuclide transport due to operation of the alternative cooling water systems is considered, both forms of cesium are identified.

Through 1980, releases of radiocesium to Beaver Dam Creek amounted to only 0.004 curie (decay corrected). These small releases occurred from the D-Area heavy-water production facility (Du Pont, 1985a). A summary of releases through 1980 to Beaver Dam Creek is also presented in Table D-1.

Table D-1. Radiocesium Releases (Ci) 1960 Through 1980[a,b]

Creek	Radionuclide	Source	Total release	Total release, decay corrected to 1980
Indian Grave Branch/ Pen Branch	Cs-134	K	0.19	0.03
	Cs-137	K	24.442	16.2
			Total: 24.63	Total: 16.23
Beaver Dam Creek	Cs-134	D	-	-
	Cs-137	D	-	0.004
				Total: 0.004
Four Mile Creek	Cs-134	C	0.063	0.01
	Cs-137	C	31.092	21.9
	Cs-137	F	0.632	0.53
	Cs-137	H	0.206	0.18
	Cs-137	H[c]	41.160	30.8
			Total: 73.15	Total: 53.42

a. Du Pont, 1985a.
b. All releases are direct liquid releases to onsite streams.
c. In 1967, overflow of high-level waste to ground and nearby storm sewer occurred when flow from 242-H evaporator to Tank 9 was restricted by formation of crystals.

D.2 DISTRIBUTION OF RADIOCESIUM

D.2.1 SEDIMENTS

Most of the cesium-137 that has been discharged to onsite creeks by SRP operations and fallout from offsite weapons testing became associated with the silts and clays found in the streambed and suspended solids. The principal mechanisms for this association were (1) cation and sorption processes exchange with kaolinite and gibbsite clay minerals, and (2) chelation with naturally occurring organic material. Table D-2 shows the variation in sand, silt, and clay content; total carbon content; and ion exchange capacity in sediment depth increments of 0-5 and 5-10 centimeters in floodplain soils of the three creeks (Du Pont, 1985a). A distribution coefficient of K_d = 3960, measured for sediments from Four Mile Creek and Steel Creek (Kiser, 1979), and the work by Prout (1958) demonstrate the affinity of cesium-137 for the sediments and suspended solids in the creek systems.

As a result of these affinities, sedimentation and sorption processes control the distribution of cesium-137 within the creeks and deltas and the adjoining Savannah River swamp. The resuspension, transport, and deposition of sediment are governed by the hydraulic properties of the sediment and streambeds and by the creeks' flow regimes.

Table D-2. Results of Floodplain Sediment-Characterization Analysis for Beaver Dam Creek, Four Mile Creek, and Indian Grave Branch/Pen Branch[a]

Creek	Location/ depth increment	Composition (%) Sand	Silt	Clay	Total organic carbon (%C)	Cation-exchange capacity (meq/100g)
Indian Grave Branch/ Pen Branch	Road 3					
	0-5 cm	61	20	19	7.4	3.8
	5-10 cm	75	14	11	6.2	3.8
	Indian Grave Branch at Road B					
	0-5 cm	19	60	21	1.3	5.8
	5-10 cm	19	60	21	0.9	4.1
	Swamp between Four Mile Creek and Pen Branch					
	0-5 cm	23	43	34	7.1	13.4
	5-10 cm	17	37	46	5.0	11.9
	Delta					
	0-5 cm	15	48	37	4.7	13.2
	5-10 cm	49	28	23	3.3	9.7
	Stave Island					
	0-5 cm	72	6	22	24.1	17.3
	5-10 cm	68	11	21	18.0	15.6
Beaver Dam Creek	Downstream of D-Area effluent					
	0-5 cm	39	42	19	8.7	7.5
	5-10 cm	51	36	13	10.4	2.3
	Road A-12.2 South					
	0-5 cm	40	24	36	11.4	7.6
	5-10 cm	17	26	57	5.9	8.0
	Mouth					
	0-5 cm	17	53	30	2.1	11.7
	5-10 cm	41	32	27	1.2	7.7
Four Mile Creek	Road 3					
	0-5 cm	79	12	9	7.1	7.8
	5-10 cm	90	4	6	2.4	2.5

Table D-2. Results of Floodplain Sediment-Characterization Analysis for Beaver Dam Creek, Four Mile Creek, and Indian Grave Branch/ Pen Branch[a] (continued)

Creek	Location/ depth increment	Composition (%) Sand	Silt	Clay	Total organic carbon (%C)	Cation-exchange capacity (meq/100g)
Four Mile Creek (continued)	Road A					
	0-5 cm	33	42	25	0.1	10.1
	5-10 cm	33	29	38	0.3	11.2
	Delta					
	0-5 cm	34	42	24	5.5	10.9
	5-10 cm	46	28	26	2.6	6.2
	Mouth					
	0-5 cm	52	29	19	1.9	15.9
	5-10 cm	51	28	21	1.2	13.5

a. Du Pont (1985a).

Almost all sediment redistribution occurred between 1955 and 1968, the period of major reactor discharges. Since 1968, little change has occurred in the sedimentation patterns or in the channel-delta configurations (Ruby, Reinhart, and Reel, 1981).

D.2.1.1 Beaver Dam Creek Sediments

Concentrations of cesium-137 in Beaver Dam Creek sediments are presented in Table D-3. Cesium-137 concentrations ranged from 0.20 picocurie per gram at the south arm near Road A-12.2 to 1.13 picocurie at the mouth. These concentrations are very low compared to data from the other onsite streams.

D.2.1.2 Four Mile Creek Sediments

Cesium-137 has been monitored routinely in Four Mile Creek sediments since 1977. These data are presented in Table D-4 (Du Pont, 1985a,b). Sediment cesium-137 concentrations along Four Mile Creek ranged from 0.4 to 20.3 (mean = 8.6) picocuries per gram, dry weight, at the creek-swamp confluence and from 11 to 80.3 (mean = 35.3) picocuries per gram, dry weight, at Road A-7 upstream of thermal influence. In general, concentrations at both Four Mile Creek stations clearly reflected SRP releases, while Savannah River floodplain sediment concentrations downstream of Four Mile Creek were within ranges associated with global fallout as high as 1.0 picocurie per gram.

Table D-3. Concentrations of Cesium-137 (pCi/g, Dry Weight) in Beaver Dam Creek Sediments[a]

Core location	Concentration
Below 400-D	(b)
South Arm Road A-12.2	0.20
Mouth	1.13

a. Du Pont, 1985a.
b. Not detectable above background.

D.2.1.3 Pen Branch/Indian Grave Branch Sediments

Cesium-137 has been monitored routinely in Pen Branch/Indian Grave Branch sediments since 1977. Table D-5 presents these data (Du Pont, 1985a,b). Because the Pen Branch flow joins the flow of Steel Creek before its entry into the Savannah River, the routine floodplain sediment-monitoring stations at the Steel Creek mouth and in the Savannah River downstream of Little Hell Landing were used for data analysis for both the Pen Branch and Steel Creek systems (Du Pont, 1985a).

D.2.1.4 Swamp and Savannah River Sediments

Beginning in 1974, comprehensive radiological surveys were made of the Savannah River swamp, including the 1235-acre, uninhabited, privately owned Creek Plantation Swamp (Figure D-1), and of the soil and the vegetation. Soil cores collected in 1974 showed that about 70 percent of the cesium-137 was confined to the upper 6 to 7 centimeters but that cesium was detectable at depths of 25 centimeters (Ashley and Zeigler, 1975). The 1982 values were appreciably less than those for 1974, but slightly lower on the average than those for 1977. Mean values at comparable locations averaged 33.3 (1982), 39.8 (1977), and 75.9 picocuries per gram (1974) (Du Pont, 1983b).

D.2.1.5 Savannah River Sediments

In 1974, riverbed sediments from downstream of the Savannah River Plant contained average radiocesium concentrations from about 2 picocuries per gram at the U.S. Highway 301 bridge (River Mile 118.7) near Millhaven, Georgia, to 6.5 picocuries per gram at the Georgia Highway 119 bridge (River Mile 61.5) near Clyo, Georgia. Table D-6 summarizes more recent monitoring data for Savannah River sediments.

D.2.1.6 Beaufort-Jasper Water Treatment Plant Sediments

A radiological survey of the raw-water and backwash holding-pond sediments at the Beaufort-Jasper water treatment plant was performed in November 1982

Table D-4. Concentrations of Cesium-137 (pCi/g, Dry Weight) in Four Mile Creek Sediments

Source	Location (sampling year)	Concentrations
Du Pont, 1985a[a]	Road A-7 (1984)	70.6
	Road 3 (1984)	43.3
	C-Reactor effluent (1984)	0.26
	Road A (1984)	28.8
	Road A-12.21 (1984)	24.1
	Road A-12.2 (1984)	6.9
	Swamp entrance (1984)	10.5
	Swamp entrance (1984)	10.4
	Swamp entrance (1984)	10.3
	Swamp entrance (1984)	29.0
	Mouth (1984)	0.53
	Mouth (1984)	0.79
	Road A-7 (1977-1983)	35.2 ± 55.0[b]
	Four Mile Creek Swamp (1977-1983)	8.6 ± 15.9
	Savannah River downstream of Four Mile Creek (1977-1983)	0.4 ± 0.5
Du Pont, 1985b	Road A-7 (1984)	18 ± 0.18[c]
	A-7A, Beaver Pond (1984)	49 ± 0.60
	Discharge at swamp (1984)	0.5 ± 0.02

a. Du Pont, 1985a; these data are grouped into two categories. The first 12 entries are one-time samples, each 7.6 centimeters deep and 15.2 centimeters wide, collected in 1984. The last six entries are 7-year averages of floodplain sediment samples. These are 7.6-centimeter-deep multiple samples composited for analysis that were collected between 1977 and 1983.

b. Error term is 2 standard deviations of 7-year mean.

c. Error term is 2-sigma counting error.

(Du Pont, 1985a). Cesium-137 concentrations in the sediment from the raw-water holding pond are about one-tenth those from the backwash pond sediment, which is principally floc. Backwash floc from the North Augusta water treatment plant, which is upriver from the Plant, has cesium-137 concentrations similar to those at the Beaufort-Jasper plant. These cesium-137 concentrations are low, generally less than 1 picocurie per gram, and within the concentration range of cesium-137 in sediments from other locations in South Carolina not influenced by the Savannah River Plant (Hayes, 1983a).

Table D-5. Concentrations of Cesium-137 (pCi/g, Dry Weight) in Indian Grave Branch/Pen Branch Sediments

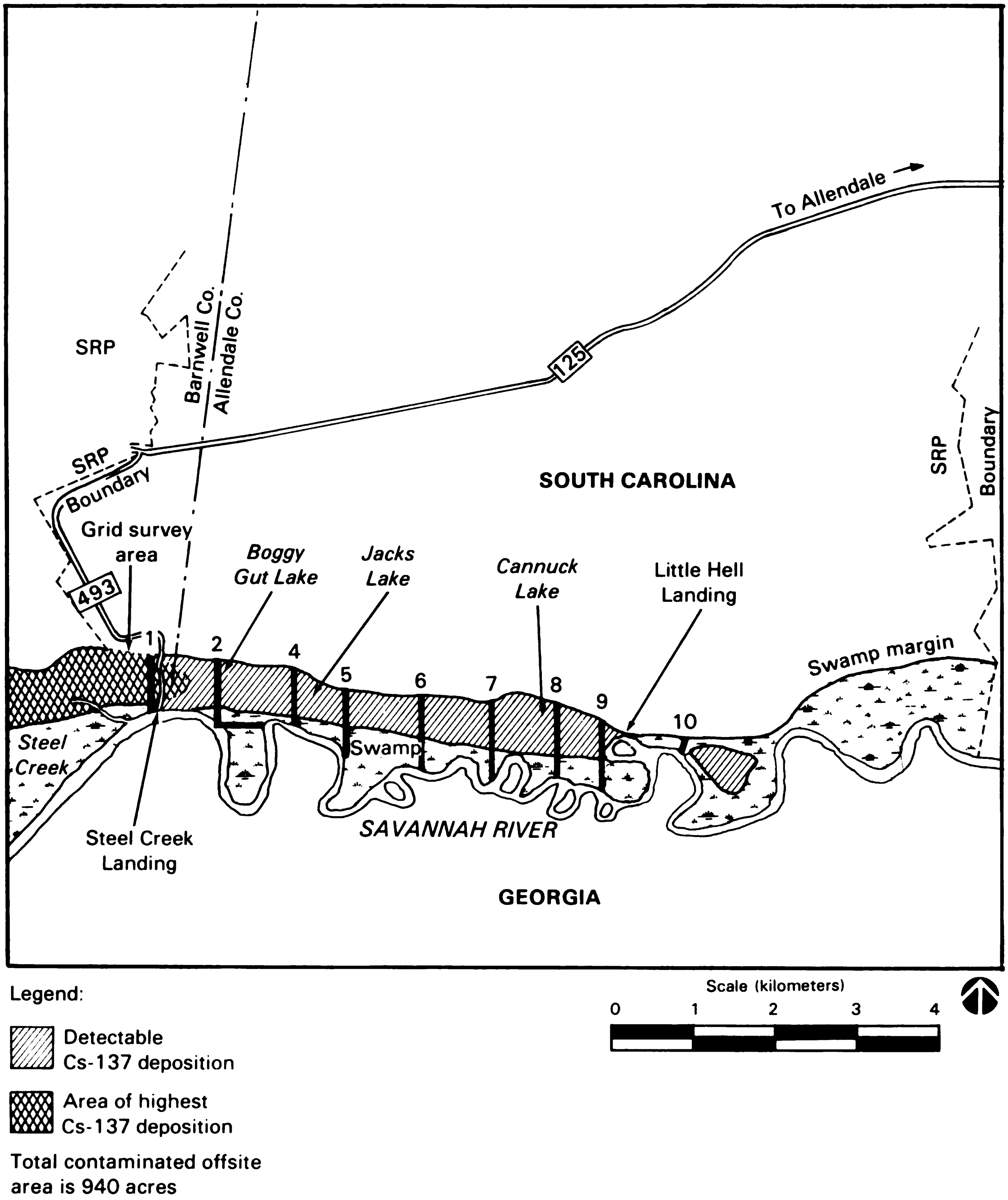
Source	Location (sampling year)	Concentrations
Du Pont 1985a[a]	Road B-3 (1984)	0.10
	K effluent at Road B on Indian Grave Branch (1984)	0.6
	Road A-13.1 (1984)	7.7
	Road A-13.2 (1984)	0.10
	Swamp along Road A-13 (1984)	2.2
	Swamp along Road A-13 (1984)	5.0
	Swamp entrance (1984)	0.31
	Swamp entrance (1984)	0.57
	Swamp entrance (1984)	0.72
	Swamp entrance (1984)	0.31
	Swamp near Stave Island (1984)	1.3
	Swamp near Stave Island (1984)	0.43
	Pen Branch discharge at swamp (1977-1983)	4.2 ± 6.5[b]
	Steel Creek-Pen Branch Mouth (1977-1983)	14.4 ± 46.3
	Savannah River downstream of Little Hell Landing (1977-1983)	2.7 ± 7.9
Du Pont, 1985b	Pen Branch discharge at swamp (1984)	0.3 ± 0.02[c]

a. Du Pont, 1985a; these data are grouped into two categories. The first 12 entries are one-time samples, each 7.6 centimeters deep and 15.2 centimeters wide, collected in 1984. The last six entries are 7-year averages of floodplain sediment samples. These are 7.6-centimeter-deep multiple samples composited for analysis that were collected between 1977 and 1983.
b. Error term is 2 standard deviations of 7-year mean.
c. Error term is 2-sigma counting error.

D.2.2 BIOTA

When K- and C-Reactors are not operating, the Pen Branch and Four Mile Creek delta areas provide roosting and feeding habitat for migratory ducks. The cesium-137 concentration in flesh from these ducks is expected to reflect their cesium-contaminated environment (Marter, 1974; Fendley, 1978).

Whole-body bioaccumulation factors for fish taken from the river at the U.S. Highway 301 bridge from 1965 to 1970 average about 2903 picocuries per gram



Source: Du Pont, 1983a

Figure D-1. Locations of Transects Used for Collecting Soil Cores and Vegetation Samples in Savannah River Swamp, Including 1235-acre Creek Plantation Swamp

Table D-6. Cesium-137 Concentrations (pCi/g, Dry Weight) in Savannah River Sediments (0-8cm depth)[a]

Location	River mile	Average, 1975-1979	1980	1981	1982	1983	1984
Demier's Landing[b]	160.5	0.5	0.2	0.07	0.03	0.13	0.21
Downriver of Four Mile Creek	150.2	0.7	0.2	0.4	0.25	0.20	(d)
Upriver of Little Hell Landing	136.6	0.8	0.2	0.7	0.7	0.25	0.34
Downriver of Little Hell Landing	134.0	3.9	0.4	0.5	0.1	0.39	0.37
Upriver of Lower Three Runs Creek	129.5	0.8	0.4	0.5	(d)	0.32	0.76
U.S. Highway 301 bridge	118.7	1.7	1.1	0.07	0.5	0.50	(d)
GA Highway 119 bridge	61.5	6.5[c]	(d)	(d)	(d)	(d)	(d)

a. Sources: Ashley and Zeigler, 1976, 1978a,b, 1981; DOE, 1984a.
b. Control above plant.
c. Based on 1975 data only.
d. No analysis performed.

(Table D-7). The mean bioaccumulation factor for 20 species of fish (527 specimens) from Steel Creek was found to be 2019 whole-body and 3029 flesh (Smith, Sharitz, and Gladden, 1982a,b; Ribble and Smith, 1983). A fish flesh bioaccumulation factor of 3000, 1.5 times the value recommended in the NRC LADTAP-II computer code (Simpson and McGill, 1980), was chosen for dose-assessment analyses in this document.

D.2.3 WATER

D.2.3.1 Beaver Dam Creek

Based on the low concentration of cesium-137 in Beaver Dam Creek sediment and the nature of operations in D-Area, which do not involve cesium-137, the concentration in water is expected to be negligible.

D.2.3.2 Four Mile Creek

Annual mean cesium-134 and cesium-137 concentrations in Four Mile Creek water (nominally based on 12 measurements per year at Road A) are presented in Table D-8. From 1978 to 1986 the annual mean concentrations remained low, ranging from 0.45 to 2.4 picocuries per liter and from 0.30 to 1.6 picocuries per liter for cesium-134 and cesium-137, respectively. However, the individual measurements exhibit considerable variability, with standard deviations typically ranging from about 1 to 2 times their respective annual mean value. In addition, the 95 percent confidence limit for the counting error was usually several times the reported value. BC-22

Table D-7. Radiocesium Whole-Body Bioaccumulation Factors for Fish from Steel Creek and Savannah River[a]

	Steel Creek (Road A)		Savannah River[b]	
Year	Maximum	Average	Downriver of Steel Creek	Hwy 301 bridge
1965	--[c]	--	1626	3902
1966	--	--	1975	1111
1967	--	--	5528	1707
1968	2385	1355	4058	2174
1969	5490	2353	4848	7273
1970	3958	1639	1111	1250
1981	3792[d]	2019[e]	--	--
Arithmetic mean		1842	3191	2903
Geometric mean		1802	2700	2295

a. Adapted from Marter, 1970a,b; Du Pont, 1982; and Smith, Sharitz, and Gladden, 1982a,b.
b. Values are averages.
c. Data not available.
d. Mean of 53 specimens of largemouth bass, for which maximum whole-body bioaccumulation factors were measured in 1981. Maximum bioaccumulation factor measured for largemouth bass was 4780. One specimen of American eel had a bioaccumulation factor of 8300.
e. Mean of 527 specimens representing 20 species.

The cesium-134 data are suspect because the reported concentrations of cesium-134 are greater than the cesium-137 concentrations. A cesium-134 to cesium-137 ratio of 1:20 is expected (DOE, 1984a). Further, special low-level analyses of water samples from the Savannah River have not detected cesium-134 attributable to Plant releases since the program was initiated in March 1983 (Hayes, 1986).

BC-22

D.2.3.3 Pen Branch/Indian Grave Branch

Table D-8 also lists the cesium-134 and cesium-137 concentrations for Pen Branch/Indian Grave Branch. Ranges similar to those for Four Mile Creek were observed. From 1978 to 1986, annual mean concentrations ranged from 1.0 to 2.0 picocuries per liter and from 0.12 to 1.6 picocuries per liter for cesium-134 and cesium-137, respectively. As noted in Section D.2.3.2, the data exhibit considerable variability and the 95-percent confidence limits for the counting error were typically several times the measured values. The cesium-134 data are suspect for the reasons stated in Section D.2.3.2.

Table D-8. Annual Mean Concentrations of Cesium-134 and Cesium-137 (pCi/liter) in Water of Four Mile Creek and Indian Grave Branch/Pen Branch[a]

		Annual Mean Concentration (pCi/L)[b]								
Creek	Location	1978	1979	1980	1981	1982	1983	1984	1985	1986
Pen Branch	Road A									
Cesium-134		1.4	(c)	(c)	1.2	1.0	2.0	1.4	1.7	(c)
Cesium-137		0.26	(c)	(c)	0.40	0.53	1.6	0.12	0.42	(d)
Four Mile Creek	Road A									
Cesium-134		0.78	(c)	(c)	0.77	0.45	1.3	1.4	2.4	(c)
Cesium-137		0.48	(c)	(c)	0.58	0.30	1.6	0.65	0.43	(d)

a. Sources: Ashley et al., 1982; Zeigler, Culp, and Smith, 1983; Ashley, Padezanin, and Zeigler, 1984a; Du Pont, 1985b; Ashley and Zeigler, 1981, 1984; Zeigler, Lawrimore, and Heath, 1986; Zeigler, et al., 1987.
b. Mean values were below the minimum detectable concentration for cesium, using standard techniques.
c. No value reported.
d. Not detected.

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D.2.3.4 Savannah River

The concentrations of cesium-137 in the Savannah River have been monitored routinely since 1960. The highest concentrations were measured in the early 1960s as a result of SRP releases and nuclear weapons test fallout (Figure D-2). Radiocesium concentrations are diluted as the flow of the Savannah River increases downriver from the Savannah River Plant, and as these radionuclides are deposited in the river channel and floodplain (Hayes and Boni, 1983).

Results of recent special low-level cesium-137 measurements of Savannah River water samples are presented in Table D-9. In 1983, prior to the restart of L-Reactor, the concentration of cesium-137 in the river attributable to the Savannah River Plant was 0.046 picocurie per liter (difference between upriver and downriver average values). With a total river flow at the Highway 301 Bridge (the downriver monitoring station) of 1.189 x 10^{13} liters during 1983 (Du Pont, 1984a), the annual release of cesium-137 to the river from the Plant was calculated to be about 0.55 curie. In 1984 the releases totaled about 0.57 curie, following the same calculation methodology (Table D-9 and Du Pont, 1985b). BC-22

D.2.3.5 Water-Treatment Plants

The North Augusta, South Carolina, water-treatment plant is about 20 River Miles above the Savannah River Plant. There are no known individuals who consume Savannah River water for a distance of about 120 River Miles downriver of

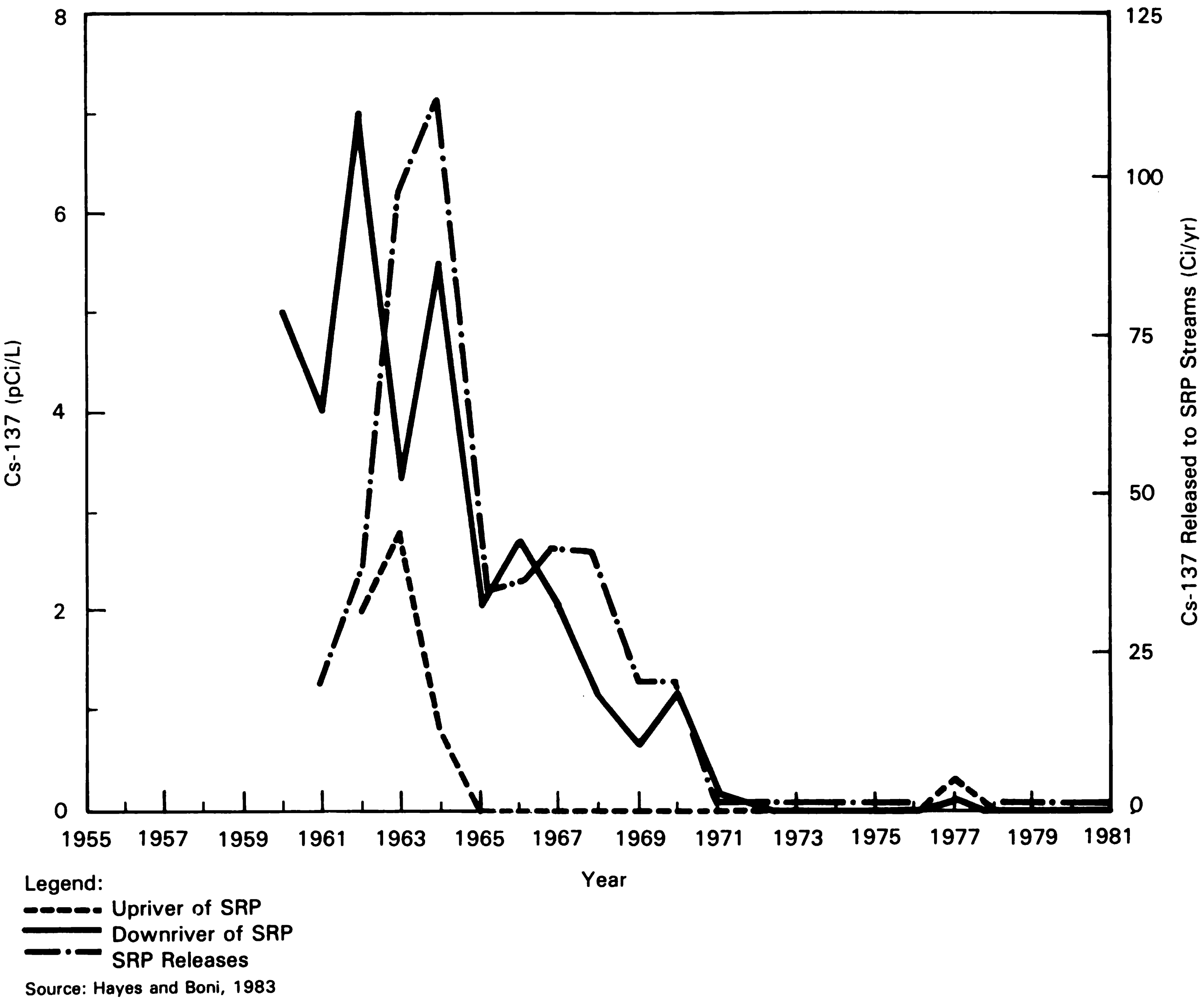

Figure D-2. Cesium-137 Concentrations in the Savannah River, 1960-1980

Table D-9. Special Low-Level Cesium-137 Measurements in Water[a]

Location	Year	No. of Analyses[b]	Maximum[c]	Minimum[c]	Average[d]
			Concentration, pCi/L		
Savannah River					
Shell Bluff (Upriver)	1983	11	0.024 ± 0.005	0.012 ± 0.006	0.017 ± 0.008
	1984	37	0.029 ± 0.003	0.004 ± 0.001	0.012 ± 0.011
	1985	28	0.032 ± 0.004	0.007 ± 0.002	0.015 ± 0.007
	1986	23	0.035 ± 0.002	0.007 ± 0.001	0.021 ± 0.007
Highway 301 (Downriver)	1983	13	0.113 ± 0.016	0.035 ± 0.010	0.063 ± 0.042
	1984	51	0.106 ± 0.007	0.031 ± 0.002	0.065 ± 0.037
	1985	28	0.211 ± 0.010[e]	0.023 ± 0.006	0.071 ± 0.038
	1986	46	0.213 ± 0.004	0.057 ± 0.002	0.114 ± 0.038
Water Treatment Facility					
Port Wentworth, GA Raw	1983	21	0.057 ± 0.008	0.023 ± 0.006	0.045 ± 0.017
	1984	28	0.037 ± 0.005	0.022 ± 0.004	0.032 ± 0.010
	1985	15	0.069 ± 0.003	0.016 ± 0.003	0.049 ± 0.031
	1986	19	0.098 ± 0.003	0.022 ± 0.002	0.064 ± 0.016
Port Wentworth, GA Finished	1983	33	0.048 ± 0.009	0.020 ± 0.004	0.036 ± 0.019
	1984	31	0.035 ± 0.006	0.017 ± 0.020	0.026 ± 0.011
	1985	18	0.060 ± 0.003	0.013 ± 0.005	0.036 ± 0.022
	1986	23	0.089 ± 0.006	0.023 ± 0.002	0.051 ± 0.015
Beaufort-Jasper, SC Raw	1983	19	0.066 ± 0.014	0.019 ± 0.007	0.042 ± 0.027
	1984	31	0.052 ± 0.001	0.020 ± 0.004	0.031 ± 0.022
	1985	14	0.144 ± 0.025[f]	0.018 ± 0.005	0.043 ± 0.063
	1986	22	0.080 ± 0.003	0.040 ± 0.005	0.063 ± 0.011
Beaufort-Jasper, SC Finished	1983	33	0.039 ± 0.006	0.013 ± 0.005	0.024 ± 0.015
	1984	28	0.024 ± 0.006	0.009 ± 0.002	0.016 ± 0.010
	1985	15	0.022 ± 0.002	0.008 ± 0.002	0.013 ± 0.009
	1986	21	0.044 ± 0.004	0.006 ± 0.002	0.020 ± 0.010

a. Adapted from DOE 1987.
b. Represents number of times analyses were performed on samples obtained from continuous samplers.
c. ± value is the 2 sigma counting uncertainty.
d. ± value is the 2 sigma standard deviation about the mean.
e. These slightly higher Cs-137 concentrations occurred the first month after L-Reactor restart on October 31, 1985.
f. Occurred in April during construction activities in the canal between the river and water treatment plant.

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the Plant. At this distance (River Mile 39.2) and beyond (River Mile 29.0) are the Beaufort-Jasper and Cherokee Hill water-treatment plants, respectively. The Beaufort-Jasper water-treatment plant pumps water from the river through a 2.4-kilometer-long inlet canal that connects to an open canal. This open, unlined canal flows 29 kilometers to the water-treatment plant (Du Pont, 1983a). The Cherokee Hill water-treatment plant pumps water from the Savannah River above the U.S. Interstate Highway 95 bridge; the water is piped about 11 kilometers to the plant (Du Pont, 1983a).

BC-22 A special program was initiated in March 1983 to measure the effect of L-Reactor restart on the cesium-137 and cobalt-60 concentrations in the raw and finished water in the downriver water treatment plants (Beaufort-Jasper and Cherokee Hill). The concentrations of these two radionuclides are so low in the raw and finished water that samples of 300-400 liters were required. A special resin was used to concentrate the radionuclides. Analysis was performed in an ultra low-level counting facility; counting was performed for about 16 hours (Hayes, 1987). Results of these studies for cesium-137 are presented in Table D-9.

D.3 INVENTORY OF CESIUM-137

The decay-corrected inventory of cesium-137 releases to onsite streams from 1960 through 1980 totaled 414.18 curies (Du Pont, 1985a). Most cesium-137 releases to onsite streams during this period originated from L- and P-Reactor areas (to Steel Creek) and R-Reactor area (to Lower Three Runs Creek). Two methods (Table D-10) were used to estimate the inventory of cesium-137 remaining in the onsite streams. The first method (Method 1, Table D-10) is based on the extensive sampling of Steel Creek. Studies of cesium-137 in Steel Creek based on core samples up to 1 meter in length and categorized by soil type, sample depth interval, and creek section identified 67.1 curies (decay corrected to 1981) between the area above L-Reactor and the delta (Smith, Sharitz, and Gladden, 1982a,b). This value is about 33 percent of the amount of cesium-137 released to Steel Creek (201.23 curies). To calculate the estimated inventory of cesium-137 remaining in the other streams, the release values were multiplied by 0.33, assuming that the Steel Creek ratio of remaining cesium-137 to the total amount released is the same for all streams. The second method (Method 2, Table D-10), from the Comprehensive Cooling Water Study (Du Pont, 1985a), uses a mass-balance approach. Using this approach, the amount of cesium-137 (decay corrected to 1980) remaining in an onsite stream was calculated by multiplying the total cesium-137 released to the stream between 1960 and 1980 by about 76 percent, or the ratio of total cesium-137 released to all SRP streams (about 414 curies, decay corrected to 1980) minus the total cesium-137 in transport (about 100 curies, decay corrected to 1980) to the total cesium-137 released to all SRP streams.

The three creeks of concern - Four Mile Creek, Beaver Dam Creek, and Pen Branch/Indian Grave Branch - contain only about 17 percent of the total cesium-137 remaining onsite. This amounts to 23.22 curies if Method 1 is used to derive the estimate.

Table D-10. Cesium-137 Inventory Remaining in Onsite Streams as Estimated by Two Methods[a]

Stream	Total release 1960 through 1980[b] (Ci)	Percent of total release[c]	Method 1 (using Steel Creek sampling data)[d] (Ci)	Method 2 (mass balance approach)[e] (Ci)
Four Mile Creek	53.42	12.9	17.81	40.59
Beaver Dam Creek	0.0	0.0	0.0	0.0
Indian Grave/ Pen Branch	16.23	3.9	5.41	12.27
Total of all SRP streams	414.18	100	138.10	314.65

a. Sources: DOE, 1984a; Du Pont, 1985a.
b. Sum of cesium-134 and cesium-137 activities (Du Pont, 1985a). All values decay corrected to 1980.
c. Total decay-corrected (to 1980) cesium-137 releases from 1960 through 1980.
d. L-Reactor EIS (DOE, 1984a) uses 67.1 curies as the estimate of cesium-137 remaining in Steel Creek. This value is about 33 percent of amount of cesium-137 released to Steel Creek (201.23 curies). Values for other streams were calculated by multiplying release value by 0.33, assuming that the ratio of remaining cesium-137 to the total released for Steel Creek is the same for the other onsite creeks. All values decay corrected to 1980.
e. Values calculated by multiplying percentage of total releases by 314.65 (414.18 - 99.53) curies. All values decay corrected to 1980.

D.4 REMOBILIZATION OF RADIOCESIUM

The amount of cesium-137 transported from onsite streams to the Savannah River resulting from the implementation of the alternative cooling water systems for K- and C-Reactors was estimated on the basis of data from routine monitoring in Four Mile Creek and Pen Branch (Sections D.2.3.2 and D.2.3.3) and detailed monitoring in Steel Creek (Hayes, 1983c; DOE, 1984a; Zeigler et al., 1987). Special low-level monitoring techniques have shown that the Plant is not releasing cesium-134 to the Savannah River. Therefore, the remobilization of cesium-134 is not considered here.

Measurements in Steel Creek at stream flows of about 3.5 cubic meters per second showed that concentrations of cesium-137 in Steel Creek water appeared to be governed by a reequilibriation process between the water and the cesium in the creekbed and floodplain sediments. Hence, transport was found to be proportional to creek flow (Hayes, 1983c).

To estimate the remobilization of cesium-137 from Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek as the result of the existing cooling water systems, the annual flow volume from each creek was multiplied by the appropriate mean concentration of cesium-137. Because these cesium-137 concentrations were determined by standard techniques and are less than the limits of detection, the cesium transported by the individual creeks and assumed to reach the Savannah River was adjusted so the sum of the creek
BC-22 contributions matched the total contribution from the Plant, as estimated in Section D.2.3.4. As indicated in Table D-11, the transport from the Plant creeks in 1983, based on standard counting techniques, is calculated to total 1.25 curies, with 0.54 curie from Four Mile Creek. However, the total Plant contribution to the River, based on special low-level counting methods, is estimated to be 0.55 curie. Thus, the contribution from Four Mile Creek was reduced to 44 percent [(0.55/1.25) x 100 = 44 percent) of the calculated value of 1.25 curies, or 0.24 curie of cesium-137.

As indicated in Table D-11, the average total stream flows below Road A for Pen Branch and Four Mile Creek are about equal, approximately 3.0×10^{11} liters per year, or 9.75 cubic meters per second. This flow for the existing cooling water systems for K- and C-Reactors is assumed to be the same as that for the once-through cooling-tower alternatives. The recirculating cooling-tower alternatives would have substantially less flow, 1.08 and 1.35 cubic meters per second for K- and C-Reactors, respectively. Thus, cesium-137 remobilization under these alternatives would be approximately 13.8 and 11.1 percent, respectively, of the "full-flow" alternatives.

For K-Reactor, the recirculating cooling-tower alternative would result in a decrease in the release of cesium-137 of about 0.12 curie per year. For C-Reactor, it would result in a decrease in the release of approximately 0.21 curie per year.

BC-22 Table D-12 lists the estimated amounts of cesium-137 remobilized for each alternative cooling water system, calculated as outlined above.

Table D-11. Parameter Values for Cesium-137 Remobilization Estimates[a]

Condition	Year	Four Mile Creek[b]	Pen Branch[b]	Steel Creek[b]	Lower Three Runs Creek[b]	Total Calculated releases	Savannah River[c]	Adjustment factor
Total flow (10^{11} liters)	1983	3.34	2.43	0.57	0.59		118.900	
Annual mean Cs-137 (pCi/l)		1.60	1.60	3.00	2.50		0.046	
Calculated transport (curies Cs-137)		0.54	0.39	0.17	0.15	1.25	0.550	0.44
Adjusted transport (curies Cs-137)		0.24	0.17	0.07	0.07	0.55		
Total flow (10" liters)	1984	3.31	3.41	0.73	0.70		107.100	
Annual mean Cs-137 (pCi/l)		0.65	0.12	1.40	1.10		0.053	
Calculated transport (curies Cs-137)		0.22	0.04	0.10	0.08	0.44	0.570	1.30
Adjusted transport (curies Cs-137)		0.29	0.05	0.13	0.10	0.57		
Total flow (10" liters)	1985	2.59	3.19	0.41	0.56		80.220	
Annual mean Cs-137 (pCi/l)		0.43	0.42	0.28	0.56		0.056	
Calculated transport (curies Cs-137)		0.11	0.13	0.01	0.03	0.28	0.450	1.61
Adjusted transport (curies Cs-137)		0.18	0.21	0.02	0.05	0.46		
Estimated releases to SR, existing system (curies Cs-137)	Mean 1983-1985	0.24	0.14					
Annual total flow (10^{11} liters)		3.08	3.01					

a. Annual flow (below Road A) and cesium-137 concentration data from Ashley, Padezanin, and Zeigler (1984b); Bennett et al. (1983, 1984, and 1985); Du Pont (1985b); Zeigler, Lawrimore, and Heath (1986); and Zeigler et al. (1987).
b. Cesium-137 concentrations in SRP streams measured by standard techniques; reported values less than the limits of detection.
c. Cesium-137 concentrations in Savannah River measured by special low-level techniques; annual average concentrations attributable to SRP operations determined by subtracting downriver average from the upriver average (see Table D-9).

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Table D-12. Estimated Cesium-137 Releases to Savannah River from C- and K-Reactors in First Year for Each Cooling Water Alternative

Alternative	Reactor	Release to River (Ci)	Change in release (Ci)
Recirculating cooling towers	K[a]	0.02	-0.12
Once-through cooling tower,[b] existing system to Indian Grave Branch	K	0.14	0.0
Recirculating cooling tower	C[c]	0.03	-0.21
Once-through cooling tower,[b] existing system to Four Mile Creek	C	0.24	0.0

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a. Discharges from K-Reactor flow into Indian Grave Branch/Pen Branch.
b. Either a mechanical- or a natural-draft once-through cooling-tower that receives its water by pumping or gravity feed.
c. Discharges from C-Reactor flow into Four Mile Creek.

D.5 TRITIUM AND OTHER RADIONUCLIDE RELEASES

D.5.1 TRITIUM RELEASES AND INVENTORY

Tritium accounts for more than 99 percent of the radioactivity in the Savannah River. From 1960 through 1978, about 1.4×10^6 curies of tritium of SRP origin were in transport in the Savannah River. The peak tritium concentration in river water downstream of the Plant was 14 picocuries per milliliter, recorded in 1961 and 1963. A summary of tritium concentration data appears in Table D-13.

The sources of tritium in liquid effluents include direct release from SRP facilities (42 percent) and migration of tritium from the burial ground, F- and H-Area seepage basins, and the K-Area containment basin (58 percent) (Du Pont, 1984a). Migration occurs when tritium that has been released to the basin in previous years reaches SRP streams via groundwater that outcrops into the streams. Tritium migrating from the C-Area seepage basins has not been detected.

Table D-14 presents the tritium releases through 1980 for individual streams. Tritium monitoring data indicate that essentially all tritium released from the Plant in liquid effluents moves down SRP streams to the Savannah River (Du Pont, 1984a, 1985b).

Table D-13. Average Tritium Concentrations (pCi/ml) in Four Mile Creek, Beaver Dam Creek, Indian Grave Branch/Pen Branch, and Savannah River[a]

Location	Concentration								
	1953-1981	1978	1979	1980	1981	1982	1983	1984	Average
Beaver Dam Creek									
effluent		47	28	34	38	73	69	50	48.4
Four Mile Creek									
Road A		200	96	80	61	61	58	61	88.1
Indian Grave Branch/ Pen Branch									
K effluent		2.1	23	7.1	3.6	7.8	19	7.6	10.0
Road A		38	46	31	35	32	29	32	34.7
Savannah River									
Above Plant	1.04	0.39	0.38	0.39	0.21	0.36	0.31	0.33	0.34
Above Four Mile Creek	(b)	1.9	1.6	1.4	2.9	3.2	2.5	2.5	2.3
Highway 301	7.55	3.9	3.1	3.2	4.1	4.3	3.3	3.3	3.6

a. Sources: Ashley and Zeigler, 1981; Zeigler, Culp, and Smith, 1983; Ashley, Padezanin, and Zeigler, 1984a,b; Du Pont, 1985a,b; Ashley et al., 1982.
b. Not analyzed.

Table D-14. Tritium Releases to Four Mile Creek, Beaver Dam Creek, and Indian Grave Branch/Pen Branch Through 1980[a]

Creek	Source[b]		Release (Ci)
Four Mile Creek	C		249,380
	F		260
	F sbm		39,324
	H		1,172
	H sbm		98,432
		Total	388,568
Beaver Dam Creek	D[c]		124,090
Indian Grave Branch/ Pen Branch	K		212,180
	K sbm		145,390
		Total	357,570

a. Du Pont, 1985a.
b. sbm = seepage basin migration. Entries not so labeled represent areas of direct liquid releases.
c. Releases were from D-Area heavy-water production facility.

Tritium releases to the Savannah River have decreased significantly since the early 1960s when the maximum tritium releases occurred (Du Pont, 1985a,b). The following process control improvements have caused the reduction:

- The elimination of a continuous purge from the reactor-area disassembly basins in the late 1960s, which allowed longer holdup time for tritium decay (the half-life of tritium is 12 years) and some evaporation.

- The development of equipment and techniques to flush and contain the tritium-bearing moderator present on fuel and target housings during disassembly-basin discharge.

- The diversion of disassembly-basin purges from streams to seepage basins in P- and C-Areas in 1978, which allowed a longer holdup time for radioactive decay before migration to streams via groundwater.

In addition, total tritium releases were reduced by the shutdown of R-Reactor in June 1964 and of L-Reactor from February 1968 until October 1985.

D.5.2 EFFECTS OF ALTERNATIVE COOLING WATER SYSTEMS ON TRITIUM RELEASES

Source terms used to calculate the current cumulative impact from liquid releases to the Savannah River are presented in Table D-15. Changes in releases of tritium as a result of alternative cooling water systems are presented in Table D-16.

Table D-15. Tritium and other Radionuclide Releases Used for Calculating Changes in Release Rates (Ci/yr)[a]

Nuclide	Beaver Dam Creek	Four Mile Creek	Indian Grave Branch/ Pen Branch	Total release[b]
H-3	2.80×10^{3}	1.35×10^{4}	1.18×10^{4}	3.08×10^{4}
Co-58,60	-	2.64×10^{-5}	2.94×10^{-4}	7.41×10^{-4}
Sr-89,90	1.42×10^{-2}	5.49×10^{-1}	1.32×10^{-3}	5.72×10^{-1}
Pu-239	3.25×10^{-4}	1.13×10^{-2}	7.86×10^{-5}	1.19×10^{-2}
U-235,238	-	-	-	6.23×10^{-2}

a. Values are 5-year averages, 1980 through 1984, provided by Du Pont.
b. Total releases also include Tims Branch/Upper Three Runs Creek, Par Pond/ Lower Three Runs Creek, and Steel Creek.

Table D-16. Changes in Release of Tritium to Savannah River from K- and C-Reactors in First Year for Each Cooling Water Alternative[a]

Alternative cooling water system	Reactor	Change in release (Ci)
Recirculating cooling towers	K	-425
Once-through cooling tower,[b] discharge to Indian Grave Branch	K	-50.0
Recirculating cooling towers	C	-425
Once-through cooling tower,[b] discharge to Four Mile Creek	C	-50.0

a. DOE, 1984b.
b. Either a mechanical or a natural-draft once-through cooling-tower that receives its water by pumping or gravity feed.

The release of tritium to the Savannah River for the K- and C-Reactor once-through cooling-tower alternatives (pumped or gravity feed and mechanical or natural draft) is expected to be reduced by about 50 curies per year because of increased evaporation and a corresponding increase in the tritium released to the atmosphere. Similarly, the tritium released to the Savannah River from the K- and C-Reactor recirculating cooling-tower alternatives would also be reduced by about 425 curies and a correspondingly greater increase in the tritium released to the atmosphere. The difference between the release rates of the recirculating cooling towers and once-through cooling tower is based on the differences in cooling-tower evaporation and blowdown rates.

D.5.3 OTHER RADIONUCLIDE RELEASES TO ONSITE STREAMS

Source terms for other radionuclides are presented in Table D-15.

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APPENDIX E

ARCHAEOLOGICAL AND HISTORIC RESOURCES

In accordance with the National Environmental Policy Act of 1969, Executive Order 11593, the National Historic Preservation Act of 1966 (as amended in 1986), and the Archaeological and Historic Preservation Act of 1974, archaeological and historic surveys were conducted for the analysis of the environmental consequences of the cooling water alternatives proposed for K- and C-Reactors and the D-Area powerhouse. These surveys focused on the watersheds of Pen Branch, Four Mile Creek, and Beaver Dam Creek, into which cooling water is discharged from these facilities.

This appendix describes the results of these surveys. In addition, it contains a list of sites in the six-county area near the Savannah River Plant (SRP) that are included in the National Register of Historic Places.

E.1 PEN BRANCH AND FOUR MILE CREEK ARCHAEOLOGICAL AND HISTORIC RESOURCES

An intensive archaeological survey of the Pen Branch and Four Mile Creek areas was conducted by the Savannah River Plant Archaeological Research Program, South Carolina Institute of Archaeology and Anthropology, from May 16 through August 17, 1984, at the request of the DOE Savannah River Operations Office (Martin, Hanson, and Brooks, 1984). At the time the survey was performed, cooling lakes were among the potential cooling water alternatives under consideration. Consequently, the survey focused on the proposed impoundment areas. Additionally, the areas that might be disturbed by the alternatives addressed in this environmental impact statement were encompassed by the survey. Table E-1 lists the sites included in this survey.

The survey located 65 discrete archaeological resources in the Pen Branch and Four Mile Creek watersheds. Analysis of the data recovered during the survey revealed human occupation from the Early Archaic through the Mississippian Period and from the 1780s through the 1950s. Table E-1 lists each of the sites by identification number, and presents information regarding periods of site occupation, site type, National Register eligibility, and recommended future activities at the site. Figure E-1 shows the location of these sites.

The sites located during the survey were divided into three groups to evaluate nomination eligibility for the National Register (36 CFR 63.3). The groups are (1) those sites that are not significant, (2) those that are potentially significant, and (3) those that are significant. Sites characterized as significant have sufficient content, integrity, and scientific importance to warrant their eligibility for the National Register. These sites would suffer adverse effects from any human activity that altered or destroyed the immediate environment.

Of the 65 sites, 42 are considered not significant because of low site integrity and the limited research potential. Factors contributing to the

Table E-1. Archaeological Resource Summary for Sites Recovered During Survey of Pen Branch and Four Mile Creek

Site	Period of occupation[a]	Type of site[b]	Eligible for nomination to National Register	Recommended site preservation plan if ground disturbance occurs
38BR54	19th century	Prehistoric: habitation Historic: scatter	No	None
38BR58/59	2,4,5,6	Habitation	No	None
38BR62	1,2,5,6	Habitation	No	None
38BR63	4,5	Intrusive	No	None
38BR65	(?)	Intrusive	No	None
38BR71	1,2	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR76	4,5	Limited activity	No	None
38BR77	(?)	Habitation	No	None
38BR78	4	Limited activity	No	None
38BR96	(?)	Limited activity	No	None
38BR97	4,5,6	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR98	4	Limited activity	Yes	Data recovery: sample excavations; intensive excavations
38BR99	(?)	Limited activity	No	None

Table E-1. Archaeological Resource Summary for Sites Recovered During Survey of Pen Branch and Four Mile Creek (continued)

Site	Period of occupation[a]	Type of site[b]	Eligible for nomination to National Register	Recommended site preservation plan if ground disturbance occurs
38BR100	(?)	Limited activity	No	None
38BR280	8 (1880-1950)	Historic: dwelling	Yes	Data recovery: documentary search; intensive excavations
38BR282	8 (1880-1950) 4,5	Historic: dwelling Prehistoric: habitation	Yes	Data recovery: documentary search; sample excavations; intensive excavations
38BR289	8 (19th-20th century)	Mill dam	Yes	Data recovery: documentary search
38BR292	8 (19th-20th century)	Mill dam	Yes	Data recovery: documentary search
38BR297	3,4,5,6	Limited activity	Yes	Data recovery: sample excavations; intensive excavations
38BR298	(?)	Limited activity	No	None
38BR299	2,3,4,5 6,7	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR305	8 (19th-20th century)	Mill and dam	Yes	Data recovery: documentary search; intensive excavations
38BR310	4,5,8 (19th-20th century)	Prehistoric: limited activity Historic: dwelling	Yes	Data recovery: sample excavations; intensive excavations

Table E-1. Archaeological Resource Summary for Sites Recovered During Survey of Pen Branch and Four Mile Creek (continued)

Site	Period of occupation[a]	Type of site[b]	Eligible for nomination to National Register	Recommended site preservation plan if ground disturbance occurs
38BR316	(?)	Intrusive	No	None
38BR318	3,4,5,6	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR319	(?)	Limited activity	No	None
38BR322	(?)	Limited activity	No	None
38BR323	(?)	Limited activity	No	None
38BR335	(?)	Limited activity	No	None
38BR339	(?)	Intrusive	No	None
38BR345	4,5,6	Limited activity	No	None
38BR352	(?)	Limited activity	Yes	Data recovery: sample excavations; intensive excavations
38BR353	(?)	Limited activity	No	None
38BR355	3,4,5,6	Habitation	No	None
38BR357	1,2,3	Limited activity	No	None
38BR530	(?)	Limited activity	No	None
38BR531	2,3,4,5,6	Habitation	Yes	Data recovery: intensive excavations

Table E-1. Archaeological Resource Summary for Sites Recovered During Survey of Pen Branch and Four Mile Creek (continued)

Site	Period of occupation[a]	Type of site[b]	Eligible for nomination to National Register	Recommended site preservation plan if ground disturbance occurs
38BR532	4	Limited activity	Yes	Data recovery: sample excavations; intensive excavations
38BR533	(?)	Limited activity	No	None
38BR534	(?)	Limited activity	No	None
38BR535	4,5,6	Habitation	Yes	Data recovery: intensive excavations
38BR536	(?)	Limited activity	No	None
38BR537	6	Limited activity	No	None
38BR538	4,5	Limited activity	No	None
38BR539	4,5,6	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR540	3,4,5,6	Habitation	Yes	Data recovery: intensive excavations
38BR541	1,4,6	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR542	3,4,5,6	Habitation	Yes	Data recovery: intensive excavations
38BR543	(?)	Limited activity	No	None

Table E-1. Archaeological Resource Summary for Sites Recovered During Survey of Pen Branch and Four Mile Creek (continued)

Site	Period of occupation[a]	Type of site[b]	Eligible for nomination to National Register	Recommended site preservation plan if ground disturbance occurs
38BR544	(?)	Limited activity	No	None
38BR545	4,5,6	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38BR547	(?)	Limited activity	No	None
38BR548	(?)	Limited activity	No	None
38BR549	(?)	Limited activity	No	None
38BR550	5	Limited activity	No	None
38BR551	8 (20th century)	Historic dump	No	None
38BR552	5,6	Limited activity	No	None
38BR555	4,5,6	Limited activity	No	None
38AK148	5,6	Limited activity	No	None
38AK149	4,5,6	Limited activity	No	None
38AK163	2,5	Limited activity	No	None
38AK414	(?)	Limited activity	No	None

Table E-1. Archaeological Resource Summary for Sites Recovered During Survey of Pen Branch and Four Mile Creek (continued)

Site	Period of occupation[a]	Type of site[b]	Eligible for nomination to National Register	Recommended site preservation plan if ground disturbance occurs
38AK415	5	Limited activity	No	None
38AK417	4,5,6	Habitation	Yes	Data recovery: sample excavations; intensive excavations
38AK418	5	Limited activity	Yes	Data recovery: sample excavations; intensive excavations

a. 1 = Early Archaic Period (9500-7500 B.C.)
2 = Middle Archaic Period (7500-3000 B.C.)
3 = Late Archaic Period (3000-1000 B.C.)
4 = Early Woodland Period (1000 B.C.-A.D. 1)
5 = Middle Woodland Period (A.D. 1-700)
6 = Late Woodland Period (A.D. 700-1000)
7 = Mississippian Period (A.D. 1000-1700)
8 = Historic Period (A.D. 1700-Present)
? = prehistoric lithic or ceramic debris--no specific time period

b. Determined by the type and function of the artifact assemblage present at a site and its strategic location. A habitation site is defined as a base camp or area of long-term use where artifacts would be curated and manufactured and not necessarily taken along during food forays. Limited activity sites are defined as temporary, specialized, extractive sites (utilizing a specific local resource) with scarcity and lack of diversity within the artifact assemblage. Intrusive sites are those where artifacts located in the locale are the result of soil borrowing from another unknown area for pre-SRP construction activities. A historic dwelling is defined as the structural remains of a 19th-20th century building.

problem of low site integrity, include pre-1950s agricultural practices, pre-SRP construction activities, road construction and maintenance, and pine-plantation management practices.

Site 38BR548 is the only site that is potentially affected by the construction of cooling towers. It is one of the 42 sites. Site 38BR548 is a small, prehistoric lithic and ceramic scatter located on a terrace edge adjacent to the bank of the northern branch of Four Mile Creek. Sixteen systematic shovel tests were conducted at this site. Further research is not recommended for | TE

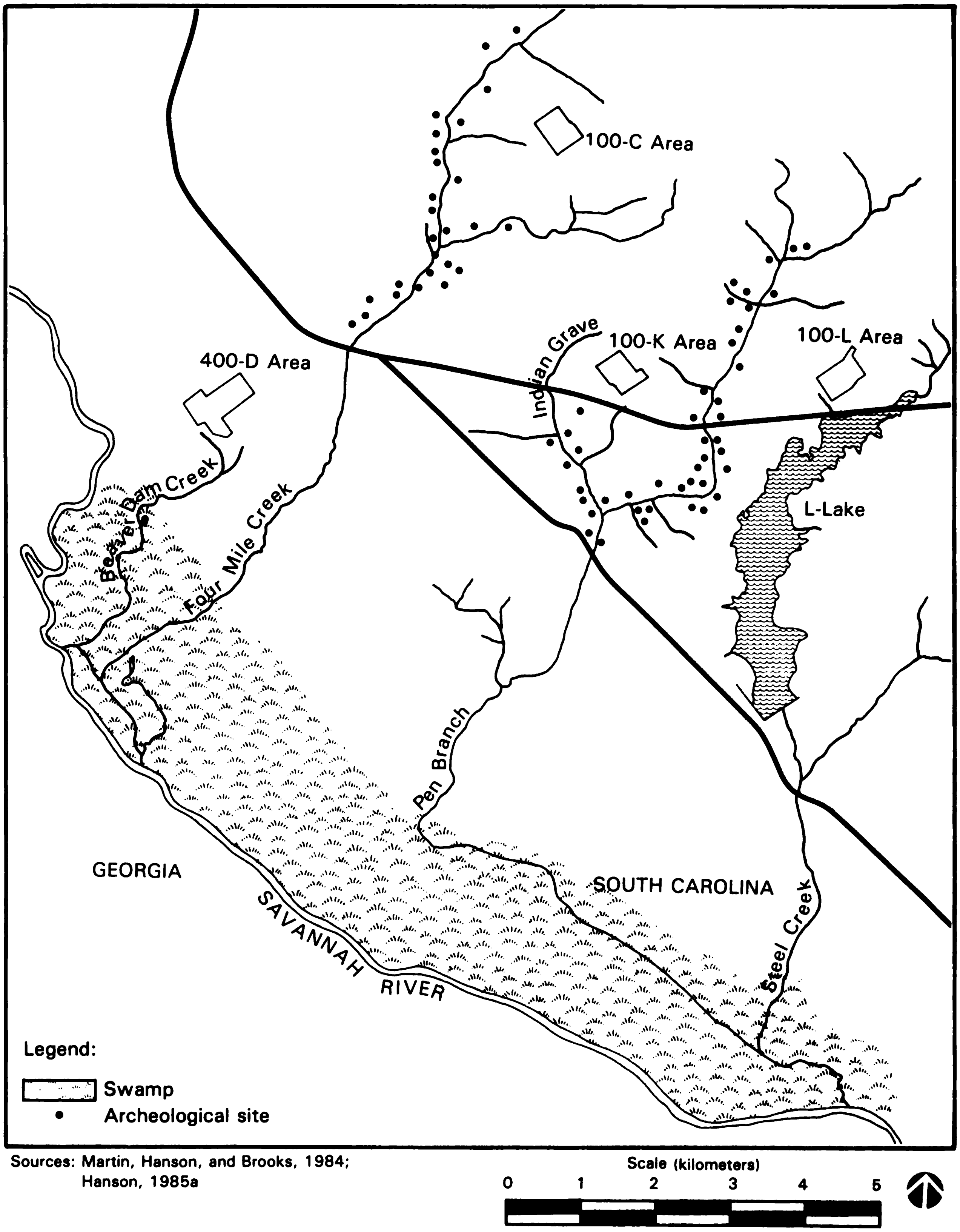

Figure E-1. General Map of the Survey Area Indicating Site Location

this site because the potential yield of additional information is negligible. A concurrence with the determination of "no effect," based on the absence of significant archaeological resources in the prepared construction areas, was issued by the State Historic Preservation Officer (Lee, 1986). AT-1 AT-2 AZ-1

E.2 BEAVER DAM CREEK ARCHAEOLOGICAL AND HISTORIC RESOURCES

During October and November of 1985, an intensive archaeological survey was conducted along Beaver Dam Creek and in an area west of the creek near D-Area. The survey purpose was to locate and evaluate any archaeological resources that could be affected by implementation of cooling water alternatives in the D-Area, such as increased flow with mixing or direct discharge to the Savannah River via pipeline (Hansen, 1985a).

Shovel testing was conducted along the stream near the edge of the terrace because this area may be disturbed by increases in water flow in the creek. TE Testing revealed site 38BR450 along the stream. Site 38BR450, known as the Pie Site, is a large, multicomponent, prehistoric base camp/village at the junction of Beaver Dam Creek and the Savannah River swamp (Figure E-1). Originally recorded in 1982 as part of the general survey of the Savannah River Plant, this site has been tested extensively to determine its extent, depth, and composition. The site has a high level of archaeological integrity and significance for addressing contemporary research problems in the region.

Based on these findings, site 38BR450 has been recommended for nomination TE eligibility to the National Register of Historic Places. Field examination of the site with respect to its proximity to the creek and the possible increase in water flow of 10 centimeters above normal levels indicates that no inundation of the location will occur. The site is buffered by a dense growth of natural vegetation which serves to protect it from the projected minor flow changes. The implementation of cooling water alternatives in D-Area would result in neither erosive action nor inundation of the prehistoric property. Concurrent with the request for determination of National Register eligibility for the site, a request for a determination of "no effect" was submitted to, AT-1 then issued by the State Historic Preservation Officer (Lee, 1986 and Klima, AT-2 1986). AZ-1

A field survey was conducted in the area west of Beaver Dam Creek that may be disturbed by pipeline construction activities associated with the direct-discharge alternative for D-Area. The survey documented that the area had been extensively disturbed during initial SRP construction in the early 1950s, and no further evidence of intact archaeological resources was found. A review of the National Register of Historic Places also indicated that no sites are located in the area west of Beaver Dam Creek (Hansen, 1985b).

E.3 REGIONAL ARCHAEOLOGICAL AND HISTORIC RESOURCES

In 1986, 69 sites in the six-county area near SRP had been listed in the National Register (Table E-2). Richmond County, Georgia, has the largest TC number of sites (27), most being in and around the City of Augusta. Aiken County, South Carolina, has 18 sites.

Table E-2. National Register Sites in the Six-County Area Near the Savannah River Plant[a]

Name	Location
AIKEN COUNTY, SOUTH CAROLINA	
Chancellor James Carrol House	Aiken
Coker Springs	Aiken
Legare-Morgan House	Aiken
Phelps House	Aiken
Dawson-Vanderhorst House	Northeast of Aiken
Fort Moore-Savano Town site	Beech Island vicinity
Redcliffe	Northeast of Beech Island
Graniteville Historic District	Graniteville
Silver Bluff	West of Jackson
Charles Hammond House	North Augusta
Rosemary Hall	North Augusta
Joye Cottage	Aiken
Chinaberry (Williams-Converse House)	Aiken
St. Mary Help of Christians Church	Aiken
Willcox's	Aiken
Pickens House	Aiken
Georgia Avenue-Butler Avenue Historic District	North Augusta
White Hall (Aiken Winter Colony)	Aiken
ALLENDALE COUNTY, SOUTH CAROLINA	
Antioch Christian Church	Southwest of Allendale
Erwin House	Southwest of Allendale
Gravel Hill Plantation	Southwest of Allendale
Red Bluff Flint Quarries	Allendale vicinity
Roselawn	Southwest of Allendale
Smyrna Baptist Church	South of Allendale
Lawton Mounds	Johnsons Landing vicinity
Fennell Hill	Peeples vicinity
Virginia Durant Young House	Fairfax
BAMBERG COUNTY, SOUTH CAROLINA	
General Francis Marion Bamberg House	Bamberg
Woodlands	Southeast of Bamberg
Rivers Bridge State Park	Ehrhardt vicinity
Voorhees College Historic District	Denmark vicinity
Bamberg Historic District	Bamberg
Cal Smoak Site	8 miles east of Bamberg

Table E-2. National Register Sites in the Six-County Area Near the Savannah River Plant[a] (continued)

Name	Location
BARNWELL COUNTY, SOUTH CAROLINA	
Banksia Hall	Barnwell
Church of the Holy Apostles	Barnwell
Church of the Holy Apostles Rectory	Barnwell
Old Presbyterian Church	Barnwell
Bethlehem Baptist Church	Barnwell
COLUMBIA COUNTY, GEORGIA	
Kiokee Baptist Church	Appling
Stallings Island	Northwest of Augusta
Woodville	Winfield vicinity
Columbia County Courthouse	Appling
RICHMOND COUNTY, GEORGIA	
Academy of Richmond County	Augusta
Augusta Canal Industrial Historic District	Augusta
Augusta Cotton Exchange	Augusta
Stephen Vincent Benet House	Augusta
Brahe House	Augusta
First Baptist Church of Augusta	Augusta
Fitzsimons-Hampton House	Augusta
Gertrude Herbert Art Institute	Augusta
Harris-Pearson-Walker House	Augusta
Meadow Garden	Augusta
Old Medical College Building	Augusta
Old Richmond County Courthouse	Augusta
Sacred Heart Catholic Church	Augusta
St. Paul's Episcopal Church	Augusta
Augusta National Golf Club	Augusta
Gould-Weed House	Augusta
Laney-Walker Historic District	Augusta
Lamar Building	Augusta
Reid-Jones-Carpenter House	Augusta
Woodrow Wilson Boyhood Home	Augusta
College Hill	Augusta vicinity
Broad Street Historic District	Augusta
Pinched Gut Historic District	Augusta
Summerville Historic District	Augusta
Greene Street Historic District	Augusta
Springfield Baptist Church	Augusta
Meadow Garden-George Walton House	Augusta

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