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COMPREHENSIVE COOLING WATER STUDY FINAL REPORT

VOLUME I
SUMMARY OF ENVIRONMENTAL EFFECTS

SAVANNAH RIVER PLANT

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ABSTRACT

The Comprehensive Cooling Water Study (CCWS) was initiated in 1983 to evaluate the environmental effects of the intake and release of cooling water on the structure and function of aquatic ecosystems at the Savannah River Plant. The initial report (Gladden et al., 1985) described the results from the first year of the study. This document is the final report and concludes the program. The report comprises eight volumes. The first is a summary of environmental effects. The other seven volumes address water quality, radionuclide and heavy metal transport, wetlands, aquatic ecology, Federally endangered species, ecology of Par Pond, and waterfowl.

FOREWORD

This study was initiated in response to a commitment by the U.S. Department of Energy (DOE) Savannah River Plant Operations Office to the U.S. Senate Armed Services Committee and the State of South Carolina. The study was a joint effort undertaken by DOE, Du Pont, and the Savannah River Ecology Laboratory of the University of Georgia.

The broad scope of this project and size of the report necessitated that it be subdivided into smaller, coherent subject areas. The resulting document contains eight volumes:

Volume Number	DP Number	
I	1739-1	Summary of Environmental Effects
II	1739-2	Water Quality
III	1739-3	Radionuclide and Heavy Metal Transport
IV	1739-4	Wetlands
V	1739-5	Aquatic Ecology
VI	1739-6	Federally Endangered Species
VII	1739-7	Ecology of Par Pond
VIII	1739-8	Waterfowl

Only Volume I is being generally distributed. Readers desiring to obtain additional volumes may do so by writing to the National Technical Information Service.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS FOR ALL VOLUMES

TABLE OF CONTENTS, Contd

TABLE OF CONTENTS, Contd

EXECUTIVE SUMMARY

The Savannah River Plant (SRP), a U.S. Government nuclear materials production facility, was established in the early 1950's to produce plutonium and tritium for the United States weapons program. The SRP has been continuously operated for the government (now the Department of Energy (DOE)) by E. I. du Pont de Nemours and Company. SRP facilities related to the production of nuclear materials include a fuel and target fabrication facility (in M Area), five production reactors (in C, K, L, P, and R Areas) which utilize recirculating heavy water (D_2O) for moderating and primary cooling, two chemical separations facilities (F and H Areas), a heavy water production facility (in D Area), and a coal-fired power plant (Figure 1) (also in D Area). These facilities, primarily the reactors, utilize Savannah River water and onsite surface water for secondary cooling. Heat exchangers in the reactors transfer heat from the primary coolant, D_2O, to the secondary cooling water. The heated secondary cooling water is discharged into SRP streams or other onsite surface waters. These streams return the thermal effluent to the Savannah River.

The intake and thermal discharge of cooling water for SRP operations have physically, chemically, and biologically modified the SRP streams and other onsite surface waters. In 1983, DOE, Savannah River Operations, initiated a two-year Comprehensive Cooling Water Study (CCWS) to determine the environmental impacts associated with SRP cooling water withdrawals and discharges, and to determine the significance of those impacts on the onsite and downriver environments. The onsite environments studied included the Par Pond system, the SRP onsite streams, the SRP Savannah River swamp, and the Savannah River bordering the SRP site. Streams and river segments both upriver and downriver from the plant were studied for baseline and comparison purposes. The study was a necessary step toward evaluating mitigation alternatives for SRP thermal discharges.

The CCWS represents a joint effort by DOE, E. I. du Pont de Nemours and Company, and the Savannah River Ecology Laboratory (SREL) of the University of Georgia. The study was initiated in response to a commitment made by DOE to the State of South Carolina and the U.S. Senate Committee on Armed Services.

This eight volume report summarizes the historical information and the results of the two-year CCWS program. The laboratory and field data collected for the program were supplemented by results of several previously initiated studies to define current cooling water impacts on SRP surface waters and ecosystems. Much of the relevant literature available for SRP aquatic ecosystems was summarized, and results of several long-term monitoring programs on the SRP were included to provide historical perspective on environmental conditions of SRP surface waters. Volume I discusses the

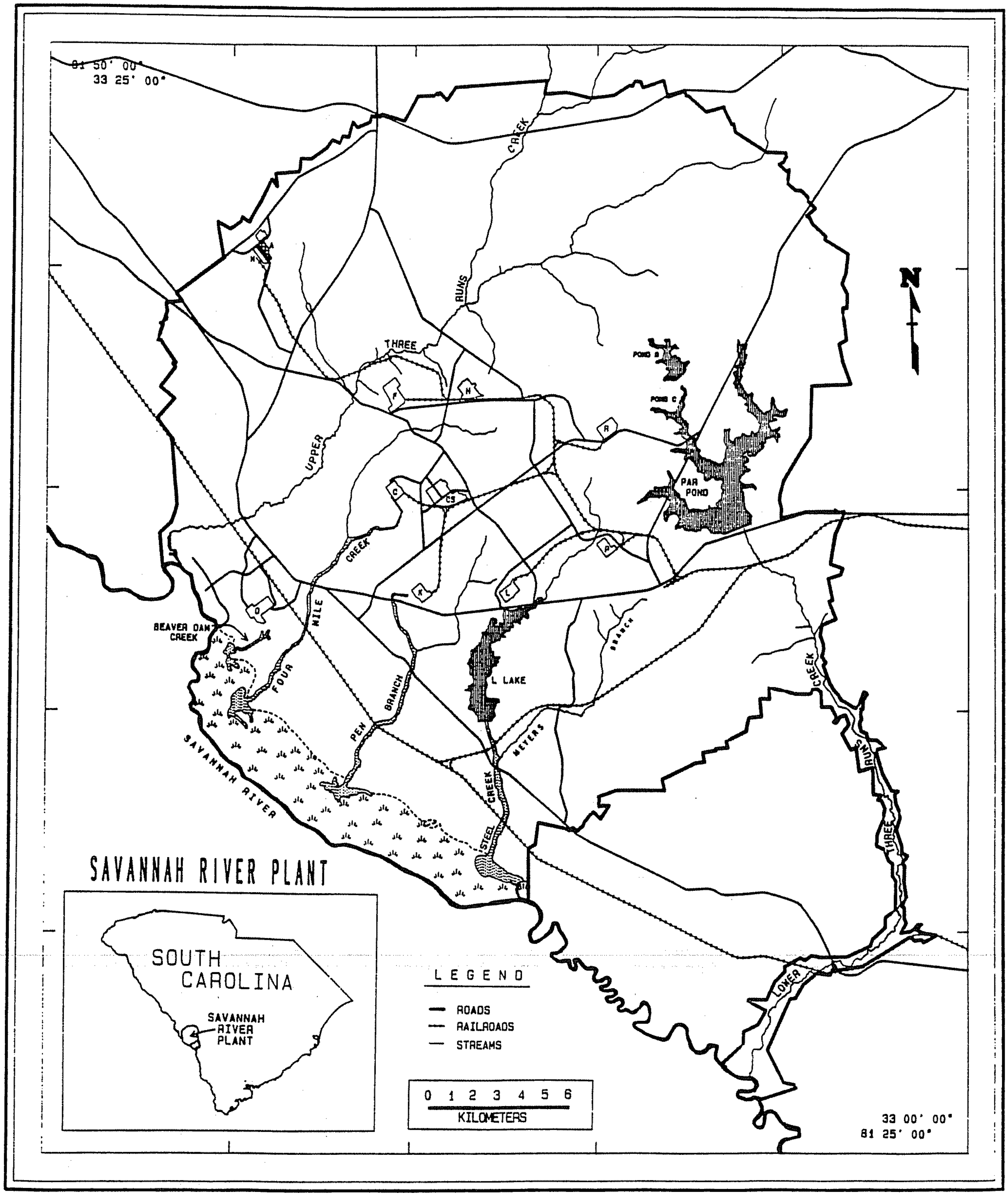

FIGURE 1. The Savannah River Plant Site

objectives and design of the CCWS, as well as the history of the SRP site. Volume II addresses the quality of SRP surface waters, and Volume III covers the radionuclide and heavy metal transport studies. Results of studies on the wetland plant communities are reported in Volume IV. The SRP aquatic habitats, especially the lower food chain and fisheries communities, are discussed in Volume V. Volume VI presents the status of four threatened or endangered species utilizing the SRP site. Volume VII is devoted to the Par Pond ecosystem studies. Finally, Volume VIII covers waterfowl utilization of SRP habitats.

Of the approximately 770 square kilometers comprising the SRP site, about 20% are classified as wetlands, including open water. Bottomland hardwood forest, occurring mostly along the stream corridors and in the SRP Savannah River swamp, and cypress-tupelo forest, found predominantly in the swamp, account for about 78% of the site wetlands. Surface waters on the SRP include more than 50 artificial impoundments, six tributaries of the Savannah River, and the Savannah River swamp. Par Pond and L Lake are the largest of the artificial impoundments. The tributaries are Upper Three Runs Creek, Beaver Dam Creek, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek (Figure 1). Pen Branch flow joins Steel Creek in the Savannah River swamp prior to discharging into the Savannah River. Beaver Dam Creek and Four Mile Creek also discharge into the Savannah River via the SRP Savannah River swamp, a 3,800-hectare (ha) riverine swamp bordering the Savannah River and separated from it by a natural levee. The swamp is contained within the plant boundaries.

Initially all five reactors, the heavy water production facility, and the power plant operated with a once-through cooling water system, using water pumped from the Savannah River and discharged into the nearest surface stream. However, numerous changes have occurred in the plant cooling water systems since the start-up of SRP operations. The Par Pond system (Figure 2) was constructed in 1958 to provide a recirculating secondary cooling water system for R Reactor, originally, and later for P Reactor. Since R Reactor was placed on standby in 1964, P Reactor is the only reactor currently using Par Pond for cooling water. In 1982 the heavy water production facility was placed on standby, reducing the volume and temperature of cooling water released to Beaver Dam Creek. Then in June 1985, C Reactor was placed in standby condition. Also in 1985, L Lake, a 405-hectare cooling pond, was formed by damming the headwaters of Steel Creek. L Reactor, which had been on standby since 1968, was restarted in the fall of 1985 and began releasing once-through cooling water to L Lake.

The average surface water use by the plant has varied depending on the number of reactors operating and the corresponding reactor power levels. Withdrawal generally constitutes approximately 9% of the average annual Savannah River flow. The maximum

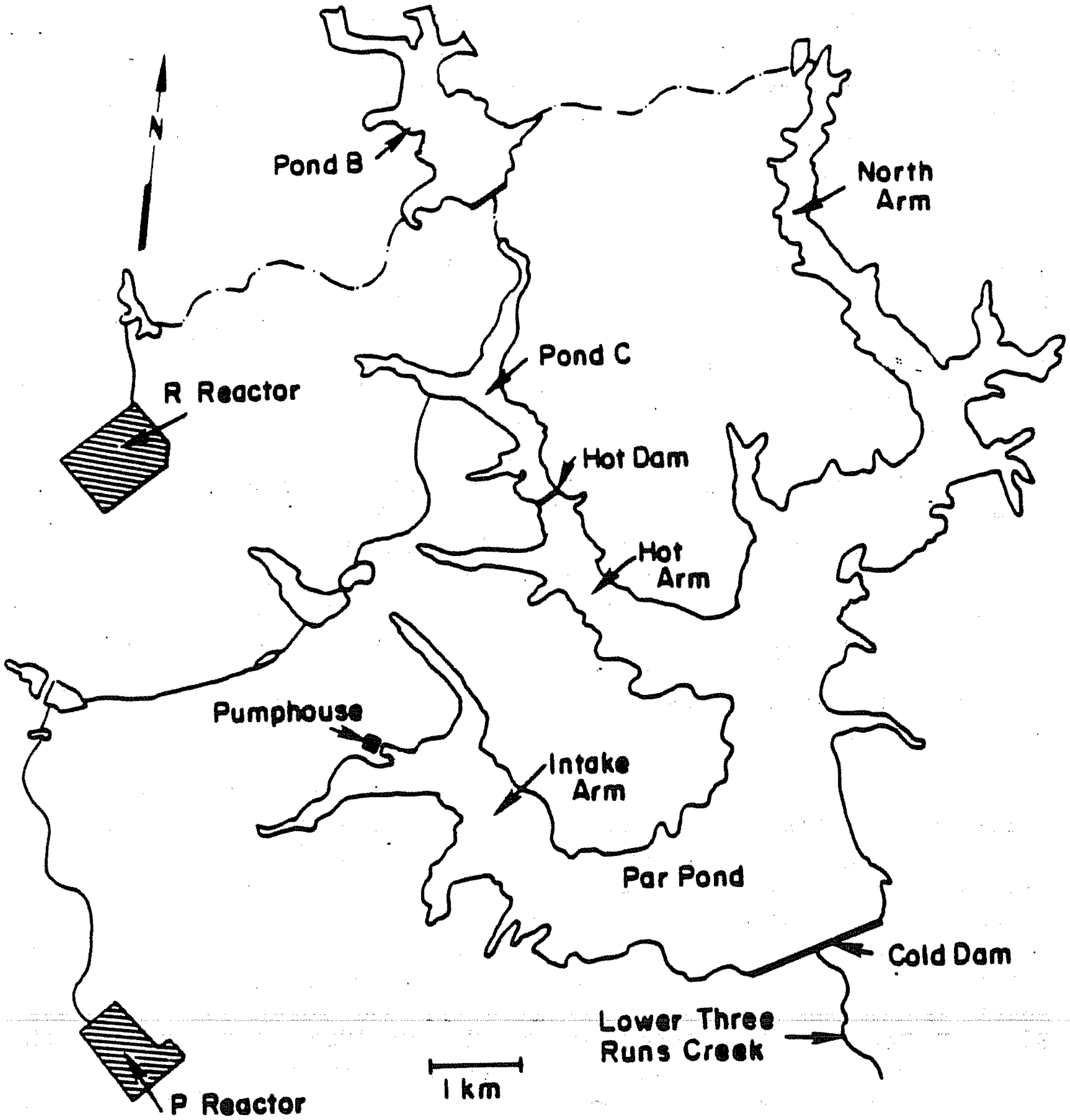

FIGURE 2. The Par Pond System

amount of water withdrawn from the river during the period of the CCWS was about 37 m^3/sec. This included approximately 11 m^3/sec to each of two reactors (C and K), 0.6 m^3/sec pumped to Par Pond to compensate for seepage and evaporation, 2.8 m^3/sec to the D-Area power plant, and additional pumpage required for L-Reactor cold flow testing prior to L-Reactor startup.

After use, heated cooling water returns to the river via onsite streams. During the period of the CCWS only Four Mile Creek (with C Reactor on standby, Four Mile Creek no longer receives reactor cooling water) and Pen Branch directly received cooling water. Steel Creek and Lower Three Runs Creek received the overflow from the L-Lake cooling pond (although L Reactor was not operating, yet) and the Par Pond system, respectively. Beaver Dam Creek, a lesser drainage system, received power plant cooling water from D Area.

The intake and discharge of cooling water are the principal SRP activities affecting SRP surface water quality. The CCWS water quality program which supplemented existing Du Pont Health Protection Department and SREL routine and nonroutine data, focused on the physical and chemical parameters of each component of the cooling water cycle: the intake at the Savannah River, the discharge to the stream channel, and the flow through the river swamp to the river channel. The 34 sampling stations covered nonthermal, post-thermal, and thermal sites along the SRP streams and the river swamp, as well as upriver and downriver locations on the Savannah River. These stations were sampled biweekly for 20 parameters. Special nonroutine studies addressed diel changes in thermally impacted and unimpacted streams, changes in water quality attributable to differing reactor operating conditions, swamp flow patterns and water residence times during different stages of river flooding, and thermal plume characteristics of the Savannah River.

Evaluation of the CCWS water quality data and previously gathered data indicated that the SRP surface waters complied generally with applicable water quality standards, with the exception of temperature regulations. The waters in nonthermal and post-thermal onsite streams and the Savannah River remained in compliance with Class B Water Classification Standards of the State of South Carolina. Excursions in pH and dissolved oxygen measurements were attributed to natural stream fluctuations rather than to impacts associated with SRP operations. Streams thermally altered by reactor cooling water complied with Class B pH standards, but compliance with dissolved oxygen standards ranged from 48 to 56%. Water temperatures in thermal streams exhibited 26 to 52% compliance with Class B standards, exceeding the temperature standard by as much as 40°C at the reactor cooling water discharge outfall. When all SRP streams were considered, stream temperatures complied with the Class B standards with 88% frequency. The water quality data demonstrated 100% compliance with water quality limits established by the Environmental Protection Agency (EPA) for chlorides, sulfates, nitrate-nitrogen, ammonia-nitrogen, total nickel, total zinc, total arsenic, and total mercury. Concentrations of priority organic contaminants such as volatile, acid, and base/neutral organics were below minimum detection limits using EPA-approved analytical regimes. In contrast, mean site-wide compliance with the EPA alkalinity criterion was 22%. However, ambient stream waters exhibited alkalinity concentrations naturally lower than the EPA criterion, complying with the standard with only 0 to 13% frequency. Thermal plumes downriver of the Beaver Dam Creek, Four Mile Creek, and Steel Creek mouths generally complied with the allowable plume cross-sectional and surface area requirements during the period of the CCWS.

The CCWS also focused on the identification and evaluation of radionuclide and heavy metal deposition and transport in the onsite streams, the SRP Savannah River swamp, and the Savannah River. The data collected through the routine radiological monitoring and water quality programs at SRP, including inventories of radioactive releases to onsite surface streams, was supplemented with additional water quality studies initiated by the CCWS, plus extensive collections and analyses of sediments in depositional areas of the SRP streams and swamp, Par Pond, and the Savannah River.

Historically, the effluents discharged from the reactor areas to onsite streams have been the principal sources of tritium, radiocesium, and radiocobalt in the SRP area. Data on radionuclide releases were compiled and compared with routine radiological monitoring data to determine the contributions by the SRP to downstream heavy metal and radionuclide concentrations. With the exception of tritium releases, the decay corrected releases during the 1981-1984 period were very small compared to total releases during the 1954-1984 period. During all years, however, SRP liquid radioactive releases to onsite streams resulted in stream and river concentrations well within regulatory concentration guidelines. Samples of raw and finished water collected at a water treatment plant downriver from SRP indicted that SRP operations had no measurable impact on downriver ^{137}Cs and ^{60}Co concentrations. The average SRP contribution of ^{137}Cs to finished water concentrations at downriver water treatment plants was 0.032 pCi/L, less than 0.02% of the EPA drinking water standard for ^{137}Cs (200 pCi/L). ^{60}Co concentrations were below minimum detection limits in raw and finished water. In addition, alpha concentrations in raw and finished water were near or below the minimum detectable concentration of 0.5 pCi/L. Nonvolatile beta concentrations upstream and downstream from SRP exhibited no significant differences. Tritium was the only radionuclide attributable to SRP operations that was routinely detected downriver of the plant; however, tritium concentrations averaged about 3.0 pCi/L, only 15% of the EPA limit.

Sediment analyses were used to determine the locations and concentrations of radionuclide and heavy metal deposits. Although radionuclides associated with reactor area effluent discharges have contributed to above-ambient concentration levels in onsite floodplains, data indicated that these releases did not have significant offsite impacts.

Onsite thermal floodplain concentrations of the metals aluminum, barium, beryllium, calcium, copper, iron, magnesium, manganese, nickel, sodium, and zinc, were higher than onsite nonthermal and post-thermal floodplain concentrations, but lower than upriver floodplain concentrations. Since the river water was rich in these elements compared to the nonthermal streams, the river water that was used as secondary coolant and discharged to the thermal streams contributed to the elevated concentrations of these metals in the thermal floodplains. All concentrations, however, remained within typical soil abundance levels. Concentrations of cadmium, chromium, lead, mercury, and silver in the sediments of streams receiving cooling water discharges reflected upriver concentrations, but were not significantly different from concentrations in nonthermal and post-thermal stream sediments. Thus the cooling water did not impact the sediment levels of these five trace elements. All concentrations of these elements also remained within typical soil abundance levels.

Physical factors associated with the release of cooling water effluents to onsite streams, such as flooding, elevated water temperatures, erosion, and sedimentation have caused substantial canopy loss along the effluent stream corridors and in the swamp forests of the affected areas. River flow conditions and local topography contributed to the relationship between swamp canopy loss and reactor activities by affecting the water movement patterns in the swamp.

Although a precise relationship is unclear, variations in reactor cooling water discharges and volumes have affected canopy loss rates. In general, increased flows and temperatures have resulted in increased canopy loss. Canopy defoliation in the bottomland hardwood forests along the stream corridors became apparent one or two years after the reactors and D Area began discharging heated effluent. In 1961, aerial photographs showed increased canopy losses throughout the length of the corridors, and the beginnings of cypress-tupelo canopy losses in the Savannah River swamp. Over the next several years, canopy loss stabilized in the corridors, but swamp forest defoliation increased and swamp deltas continued to expand. By 1985, 1020 ha of forested wetlands had been impacted by the thermal discharges.

Following the shutdown of L Reactor early in 1968, wetland communities reinvaded Steel Creek. Succession proceeded from herbaceous dominated to shrub dominated wetland communities. A few woody species such as willow and buttonbush, which are typically found in the elevated or cooler regions of the thermal deltas, formed the basis for revegetation. Cypress-tupelo revegetation was minimal and appeared to be mainly stump and root sprouts. In general, plant community productivity recovered more rapidly than community biomass or species composition.

Results from the Steel Creek studies can be applied to post-thermal wetland areas, in general. Reductions in thermal effluent flow and temperature result in recolonization of stream and delta areas by various herbaceous and scrub-shrub species. These reductions may also reverse the trend of canopy loss. However, the deposition of sediments and altered flow paths in the swamp delta areas, products of the former thermal discharges, might retard or prevent recovery of the original cypress-tupelo dominated swamp forest. Although the types of vegetation might differ, food production for stream and swamp populations in post-thermal areas is likely to be comparable to food production in unimpacted areas.

Factors affecting aquatic food chains, including the plants and invertebrates, can ultimately affect fish populations. Consequently, the aquatic ecology component of the CCWS focused not only on the distribution and abundance of fish in the SRP surface waters, but also on the abundance, composition, and dynamics of organisms in the lower trophic levels. The CCWS examined and compared components of ecosystem structure and function in nonthermal, thermal, and post-thermal streams on the SRP, as well as in the Savannah River.

Nonthermal streams on the Savannah River Plant include Upper Three Runs Creek, Meyers Branch, Lower Three Runs Creek, and the headwater reaches of Pen Branch and Four Mile Creek. These streams are all coastal plain blackwater streams, with sand, silt, or clay substrates. Water temperatures in the streams vary seasonally, but usually remain below 33°C. Large numbers of fallen logs and woody debris in the stream channels produce a structurally complex environment that provides a diversity of habitat types and increases the retention time of leaves and other organic matter upon which many stream organisms feed. The streams have closed canopies, which limit the amount of light that reaches the stream channel and result in sparse periphyton growth that is dominated by diatoms. Leaf litter inputs from terrestrial vegetation are high, and these inputs and other suspended organic material in the streams constitute the primary base of the food web in these streams. During the period of the CCWS, macroinvertebrate communities were diverse (56 to 70 taxa) and included pollution-sensitive taxa. Fish communities in the upper reaches of the nonthermal streams were dominated by minnows and darters, while centrarchids, suckers, and catfish were dominant in the lower reaches. The taxonomic composition of the fish larvae and egg (ichthyoplankton) collections differed among the nonthermal streams. In Meyers Branch, darters and centrarchids were the dominant taxa collected; in Upper Three Runs Creek, spotted sucker, crappie, and darters were dominant, while in Lower Three Runs Creek, centrarchids, crappie, darters, and brook silverside predominated. Ichthyoplankton of anadromous species (primarily blueback herring and American shad) were collected only in the creek mouths at the Savannah River. Species dominance among the ichthyoplankton varied somewhat from year to year. Ichthyoplankton densities in the nonthermal streams were low, except for Lower Three Runs Creek, where high numbers of ichthyoplankton occurred just below the Par Pond dam, probably as a result of transport over the spillway from Par Pond.

The thermal streams which received reactor effluent during the CCWS included Four Mile Creek and Pen Branch. Temperatures in these streams could reach nearly 70°C at the reactor outfalls, gradually cooling as the water flowed to the river. Temperatures at the mouth of Four Mile Creek were generally 10 to 20°C above ambient. The stream channels had been greatly altered by the thermal discharge. Increased flow had enlarged and scoured the stream channels and removed much of the smaller woody debris, but large stumps and logs were more abundant than in the nonthermal streams. Particulate matter transport was high, but the seston had a lower organic content than in the nonthermal streams and was largely comprised of silt and sand particles. Suspended solids particles (sand and silt from the river and eroded sediment from the stream channel) in the reactor effluent had been deposited where the streams enter the Savannah River swamp, forming large open deltas that were largely devoid of woody vegetation. Periphyton biomass was low at the hottest stream sites, while at the cooler thermal sites, biomass was high and was dominated by blue-green algae. Macroinvertebrate communities in the thermal streams had greatly reduced species richness, low biomass, and low densities of organisms, except for a few heat-tolerant taxa, such as oligochaetes, nematodes, and some chironomids. During reactor outages, however, the streams were rapidly recolonized by many species of macroinvertebrates. During reactor operation, the streams were largely devoid of fish, except for mosquitofish, which inhabited some of the cooler backwater areas and side channels. Fish entered the mouth of Four Mile Creek when temperatures permitted (during reactor outages and during the winter months). Redbreast sunfish, channel catfish, longnose and spotted gar, white catfish, and gizzard shad congregated in the mouths of the thermal creeks and in the river just below the creek mouths during the winter months. Fish densities, for all species combined, were approximately twice as high in thermal habitats as in the nonthermal habitats during the winter, which indicated an overall

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attraction to the thermal areas during the winter. Limited spawning took place in the thermal creeks. Spawning in the mouth of Four Mile Creek occurred earlier than in the nonthermal creeks.

95°F

During the CCWS, Beaver Dam Creek received thermal effluent from a coal-fired power plant, but temperatures in the creek were much cooler than in the reactor streams (usually <35°C). Beaver Dam Creek also received overflow from a coal ash settling basin, as well as other minor effluents from the power plant. Stream characteristics varied considerably from headwaters to mouth, with high water velocity and evidence of scouring near the effluent outfall. The stream broadened and water velocity decreased in the midreaches of the stream, permitting the development of lush macrophyte beds and periphyton. In the lower reaches, the channel narrowed, with resultant increases in water velocity and scouring. The stream canopy was closed in the upper and lower reaches of the stream, but open in the midreaches. Although macroinvertebrate density in Beaver Dam Creek was comparable to densities in the nonthermal streams, biomass and taxa richness was somewhat lower, except in areas containing macrophyte beds. These differences appeared to be due more to differences in stream structure and habitat availability than to thermal effects. The adult fish community was reasonably diverse. Ichthyoplankton in Beaver Dam Creek exhibited low to moderate densities throughout the creek and showed no evidence of thermal impact.

Steel Creek, a post-thermal stream during the study period, still showed some effects of reactor effluent more than 15 years after the cessation of thermal discharges. Vegetation along the edges of the stream was altered from that of the nonthermal streams, in that large trees were absent, and most of the vegetation consisted of small trees and shrubs. The canopy was relatively open, and periphyton biomass and macrophyte development were greater than in the nonthermal streams. Steel Creek contained less wood in the stream channel than the nonthermal streams, and most of the stream structure was provided by less permanent features, such as sticks and macrophytes. In general, the higher water velocity in Steel Creek and the lack of retention structures resulted in a higher inorganic silt load. Macroinvertebrate densities and taxa richness were similar to the nonthermal streams, indicating a recovery of the macroinvertebrate community. The fish community of Steel Creek was dominated by redbreast sunfish and other centrarchids, spotted sucker, channel catfish, and flat bullhead. High ichthyoplankton densities occurred in the Steel Creek swamp and in the creek mouth, but densities were low upstream of the swamp. The dominant ichthyoplankton taxa in the upper reaches of the creek were minnows and darters, while in the swamp, species composition was more diverse and was dominated by centrarchids, minnows, and darters. Ichthyoplankton of anadromous species (blueback herring, American shad, and striped bass) occurred in varying densities in the mouth of Steel Creek at the Savannah River.

The Savannah River in the vicinity of the SRP contained an abundant and diverse fish community, with 75 species collected to date. Shiners and brook silverside were the most abundant small forage fish, while redbreast sunfish and other centrarchids, spotted sucker, channel catfish, and flat bullhead were the dominant large species. Fish spawning began earlier in the lower reaches of the river, and gradually increased in an upstream direction, as the upper reaches of the river reached suitable temperatures for spawning. Substantial differences were noted in the abundances of numerous ichthyoplankton taxa between the 1984 and 1985 collections. These differences appeared to be related to differences in the magnitude and duration of river flooding. Ichthyoplankton collections from the mouths of 33 streams, including the five SRP streams and all major tributaries of the Savannah River between Augusta and Savannah, Georgia indicated that Steel Creek was a major contributor of ichthyoplankton to the Savannah River. Steel Creek appeared to be an important producer of yellow perch and minnows, both of which were relatively scarce in the ichthyoplankton collections of the other creeks.

Studies conducted in the Savannah River in the vicinity of the SRP to determine the effects of SRP discharges on the river ecosystem indicated no evidence of adverse impacts. The only measurable differences that could be attributed to SRP discharges were higher periphyton biomass immediately below Four Mile Creek and congregation of some species of fish during the winter months in the thermal plumes immediately downstream of Beaver Dam and Four Mile Creeks.

Impingement rates of adult and juvenile fish at SRP pumphouses were very low, averaging less than 18 fish per day. Although at least 50 species of fish had been impinged, the majority of the fish were clupeids (blueback herring, threadfin shad, and gizzard shad) and sunfish. The average combined weight of the fish impinged daily was approximately 0.5 kg.

The SRP entrained an estimated 23.4 million ichthyoplankton during 1984 and an estimated 25.9 million in 1985. These totals represented approximately 8.3% and 12.1% of the total number of ichthyoplankton that drifted past the SRP pumphouses during 1984 and 1985, respectively. Ichthyoplankton typically have extremely high rates of natural mortality and there was no evidence that entrainment losses adversely affected the Savannah River fishery.

Since Par Pond is the only recirculating cooling water system at SRP, the CCWS addressed the Par Pond ecosystem separately from other surface water ecosystems. The major effects of P-Reactor operation on the aquatic ecology of Par Pond resulted from the thermal discharge into the Hot Arm of the pond, the introduction of Savannah River makeup water into the pond, and the pumping at the intake structure in the south arm of Par Pond (Figure 2).

Most thermal effects noted in the CCWS were restricted to the Hot Arm of Par Pond. In the winter, the warmer temperatures in the Hot Arm attracted some species of fish more than others, thereby locally reducing species diversity. The mean Shannon-Weaver diversity index was 1.11 at the sampling location in the Hot Arm, and ranged from 1.81 to 2.24 at the other Par Pond sampling locations. The elevated temperatures (4 to 6°C higher near the Hot Dam than in the rest of Par Pond) also caused early spawning in some species in the Hot Arm. The increased temperature in conjunction with the chemical enrichment introduced into the Par Pond system by the Savannah River makeup water, appeared to be responsible for increased primary productivity in the Hot Arm (1.3 to 1.7 times greater than in other Par Pond sites). As a result, more food was available for each level of the food chain. Because of the greater availability of food, largemouth bass, black crappie, and bluegill congregated near the Hot Dam even during the summer, when water temperatures exceeded those preferred by these species.

In relation to lakewide populations, the estimated entrainment losses associated with the pumping of Par Pond water to P Reactor were minimal for phytoplankton (1.3%), zooplankton (1.3%), macroinvertebrate meroplankton (generally less than 5%), and ichthyoplankton (an estimated total of 1975.2 x 10^5 larvae and eggs over the entire study period). Impingement losses were negligible.

Overall, the CCWS determined that the P-Reactor cooling water system had no significant adverse impact on the Par Pond system. The floral and faunal communities in Par Pond continued to flourish, remaining diverse, balanced, and representative of the region.

For the past 15 years, waterfowl research and surveys at SRP have focused on the following three elements: the extent to which waterfowl use the SRP site, wood duck reproductive biology, and waterfowl wintering ecology. During that time, 31 species of waterfowl were observed and documented on the SRP. From January 1982 to January 1985, midwinter waterfowl numbers increased 73% on the SRP, while numbers decreased 33% in the Atlantic flyway and 70% in South Carolina. These trends indicated the importance of SRP as a waterfowl wintering refuge area.

Almost every body of water on the SRP site serves habitat for waterfowl. Throughout the study period, 1981 to 1985, mallards and wood ducks were the most abundant waterfowl species in the SRP Savannah River swamp. The highest waterfowl count obtained during any single aerial survey of the swamp in the winter of 1984-1985 was 1,444 in January 1985. In decreasing order of abundance, lesser scaup, ringneck ducks, ruddy ducks, and buffleheads were the most common of the 20 species observed during aerial surveys of Par Pond. Ruddy ducks were more common in the Hot Arm, while the other three species were more abundant in the West Arm. On Pond B, however, buffleheads were most frequently sighted, followed by ruddy ducks, lesser scaups, and ringneck ducks. Waterfowl used Pond C primarily when P Reactor was not operating. L Lake provided additional wintering habitat for five species, lesser scaup, ruddy ducks, buffleheads, American coots, and piedbilled grebes, without decreasing waterfowl use of Par Pond.

Nest box surveys indicated that the wood duck was the only waterfowl species to breed commonly on the SRP site. The population size was estimated to be 29 to 63 breeding females, with a recruitment rate of 10 to 37 females per year. Currently, nest box surveys are being used to determine how restarting L Reactor affected and will continue to affect wood duck nesting along Steel Creek. Although increased water temperatures along the nesting sites do not appear to be a problem, the concurrent increased flow rates and water depths might affect nesting habitat, and reduce forage and cover species in the Steel Creek Delta and corridor.

As a whole, SRP probably will become an increasingly important refuge for waterfowl in the future, with the continued drainage of wetlands and concurrent decline of waterfowl in the plains regions of western Canada and the United States. While overall waterfowl numbers may decrease at SRP, also, the decrease should be less severe than in other areas because of the reduced human disturbance of waterfowl at the SRP site. In addition, waterfowl use of L Lake is likely to increase and become more diversified as the lake's floral and invertebrate faunal species increase.

The SRP site also acts as a refuge for certain Federally endangered species. The endangered species act requires that federal agencies, such as DOE, ensure that their own actions do not jeopardize, destroy, or adversely affect endangered or threatened species. Federally endangered species that occur on the SRP site include the wood stork, the shortnose sturgeon, the bald eagle, and the red-cockaded woodpecker. The American alligator, also found on the SRP site, was previously classified as "endangered," but recently has been reclassified as "threatened by similarity of appearance." Because the red-cockaded woodpecker nests and forages in old age upland pine forests, it is not likely to be affected directly or indirectly by SRP cooling water systems, and it was not included in the CCWS. The effects of SRP activities on the other four threatened or endangered species were addressed in this study.

The Birdsville Colony, located approximately 45 km southwest from the SRP Savannah River swamp, is the source of the wood storks that have been observed in the Steel Creek, Beaver Dam Creek, Four Mile Creek, and Pen Branch Deltas. Numbers of wood storks observed during CCWS aerial surveys were greatest in July 1983, when an average of 30 storks were observed per survey. Studies initiated in 1983 determined that high cooling water effluent discharges from

SRP facilities probably limited woodstork use of the SRP Savannah River swamp by reducing forage fish availability. Some habitat temporarily became available during reactor shutdowns, as evidenced by the wood storks observed foraging in the Pen Branch and Four Mile Creek Deltas during K- and C-Reactor shutdowns. Additional foraging sites were available near the Beaver Dam Creek Delta. But the replacement foraging sites constructed at Kathwood Lake provided substantial new habitat and more than compensated for any loss of foraging habitat due to restarting L Reactor. As many as 72 wood storks have been observed in Kathwood Lake on a single day.

Shortnose sturgeon were not documented in the Savannah River until 1982 and 1983, when a few larvae of this species were collected near the SRP site. Based on information from the literature and fisheries data for the Savannah River, SRP cooling water systems had low potential for effects on the shortnose sturgeon. Spawning, rearing, and foraging habitats of the species were not affected by the SRP operations. Entrainment was unlikely due to the demersal, adhesive nature of the eggs, and the low density of larvae in the intake canals. Previous studies showed no evidence of shortnose sturgeon juveniles or adults inhabiting the canals. This information in conjunction with a comparison of swimming speed versus intake velocity indicated that impingement was unlikely. Temperature-related effects also were considered minimal because the localized nature of the thermal plumes provided an adequate zone of passage for migration.

In contrast with the shortnose sturgeon, bald eagles have been sighted in the SRP area as far back as 1904. Bald eagle observations at SRP have been increasing over the last decade. During the period from September 1984 through August 1985, 36 bald eagles were sighted. Par Pond, L Lake, and the SRP Savannah River swamp constituted inland foraging and roosting habitat for bald eagles, and were the primary locations of the sightings. In 1986, a pair of bald eagles established a nest south of Par Pond. The abundance of fish in Par Pond and the increase in the South Carolina bald eagle population indicated the potential for increased foraging and nesting of bald eagles on the SRP.

The SRP supports a low to moderate alligator population, estimated by T. M. Murphy (1981) to be 150 adults, primarily in the Beaver Dam Creek Delta, Par Pond, and the Steel Creek area. SRP operations have affected the alligator population in various ways. Moderately thermal habitats, such as Beaver Dam Creek Delta, might have promoted alligator usage during the winter months. Studies indicated that alligators could avoid the stream areas warmed to above the critical thermal maximum temperature for American alligators. Although elevated temperatures restricted alligator use of stream areas nearest the cooling water outfalls, the man-made reservoirs substantially augmented the amount of naturally available alligator habitat on the SRP site. In addition, the SRP site offered the alligator refuge from indiscriminate killing and direct human disturbance.

The outlook for endangered and threatened species on the SRP is good. The SRP should continue to provide refuge for, and should not have significant adverse impact on indigenous endangered and threatened species. The alligator population at SRP should remain stable or increase with continuing cooling water operations. Because of the abundance of fish in large impoundments on SRP, and the increase in the South Carolina bald eagle population, the potential exists for increased foraging and nesting of bald eagles on the SRP. Although wood stork foraging is likely to continue to be limited in the SRP Savannah River swamp by high effluent discharges, the replacement habitat at Kathwood Lake should continue to compensate for the loss of natural habitat.

Overall, the CCWS studies indicated that the cooling water systems at the SRP had no significant adverse impacts on downriver water quality or radionuclide and heavy metal deposition. Wetlands on the SRP site, however, bore signs of cooling water impacts. The combined effects of thermal stress and sedimentation altered the physical and biological environment in the former creeks and floodplain swamp. Canopy losses along the stream corridors have stabilized, but the "swamp impact areas" continue to expand at a rate of 10 to 11 ha/yr. Cessation of thermal discharges has resulted in revegetation of disturbed areas, although the new shrub dominated wetlands communities do not resemble the former cypress-tupelo forests. In addition, cooling water discharges have reduced the diversity and species richness of aquatic autotroph communities in thermal streams. Autotroph communities in Par Pond, however, were balanced, diverse, and representative of the region.

In general, fish communities showed similar responses to cooling water discharges. Par Pond fish communities were balanced, diverse, and representative of the region. The SRP Savannah River swamp supported feeding and growth of adult fish, and provided suitable habitat for spawning and early growth. In thermally altered streams, below reactor outfalls, fish communities exhibited reduced species density, abundance, and richness, and had different relative abundances than in ambient streams. Nonthermal tributaries to thermal streams, however, supported self-maintaining fish populations representative of the region.

In addition, waterfowl and endangered species benefitted from the protection offered by the restricted-access site. The SRP should be an increasingly important resource for waterfowl and endangered species in the future.

TABLE OF CONTENTS FOR VOLUME I

I. SUMMARY OF ENVIRONMENTAL EFFECTS

TABLE OF CONTENTS FOR VOLUME I, Contd

LIST OF TABLES

LIST OF FIGURES

I.1 INTRODUCTION

The U.S. Department of Energy, Savannah River Operations Office, initiated a Comprehensive Cooling Water Study of Savannah River Plant (SRP) operations in 1983. A public hearing was held in North Augusta, South Carolina on February 9, 1983 before the U.S. Senate Armed Services Committee to assess the environmental consequences of the proposed restart of the L Reactor at the Savannah River Plant (SRP). In testimony presented at the meeting, Robert L. Morgan, Manager of the Savannah River Operations Office of the U.S. Department of Energy (DOE), indicated that a comprehensive study would be conducted to evaluate environmental impacts from the intake and discharge of cooling water at SRP. Subsequent correspondence between U.S. Senators Strom Thurmond and Mack Mattingly with Energy Secretary Donald P. Hodel reaffirmed the cooling water study commitment.

Accordingly, beginning July 1, 1983, DOE-SR initiated a two-year comprehensive cooling-water study to determine the environmental effects and significance as a result of operation of the SRP production reactors (C, K, L, and P) and the 400-D Area coal-fired power plant. Appropriate existing studies (e.g., historic water quality; radioactivity in floodplain sediment; physiochemical characteristics of floodplain and swamp sediments; fisheries) were incorporated into the Comprehensive Cooling Water Study. Information from this environmental study is being used with existing data to assist in the evaluation and selection of alternative methods for cooling the thermal effluents from the SRP production reactors and the D-Area power house.

An internal technical coordinating committee directed and coordinated the cooling water study. This committee was composed of representatives of the Department of Energy (Savannah River Operations Office), E. I. du Pont de Nemours and Company (Savannah River Laboratory), the University of Georgia's Savannah River Ecology Laboratory, the U.S. Forest Service, and NUS Corporation (Savannah River Center). The State of South Carolina, the State of Georgia, the U.S. Environmental Protection Agency (Region IV), the U.S. Fish and Wildlife Service (Region IV), and the U.S. Army Corps of Engineers (South Atlantic Division) participated in the study in a review and advisory capacity.

The area encompassed by the cooling water study included Par Pond, the SRP onsite streams, the Savannah River swamp, and the Savannah River (Figure I-1.1). Onsite streams studied were Four Mile Creek, Beaver Dam Creek, Pen Branch, Indian Grave Branch, Steel Creek, Meyers Branch, Upper Three Runs Creek, and Lower Three Runs Creek. Offsite streams upstream and downstream from the SRP site also were being studied for baseline and comparison purposes. Wetland areas studied include the onsite stream corridors and swamp

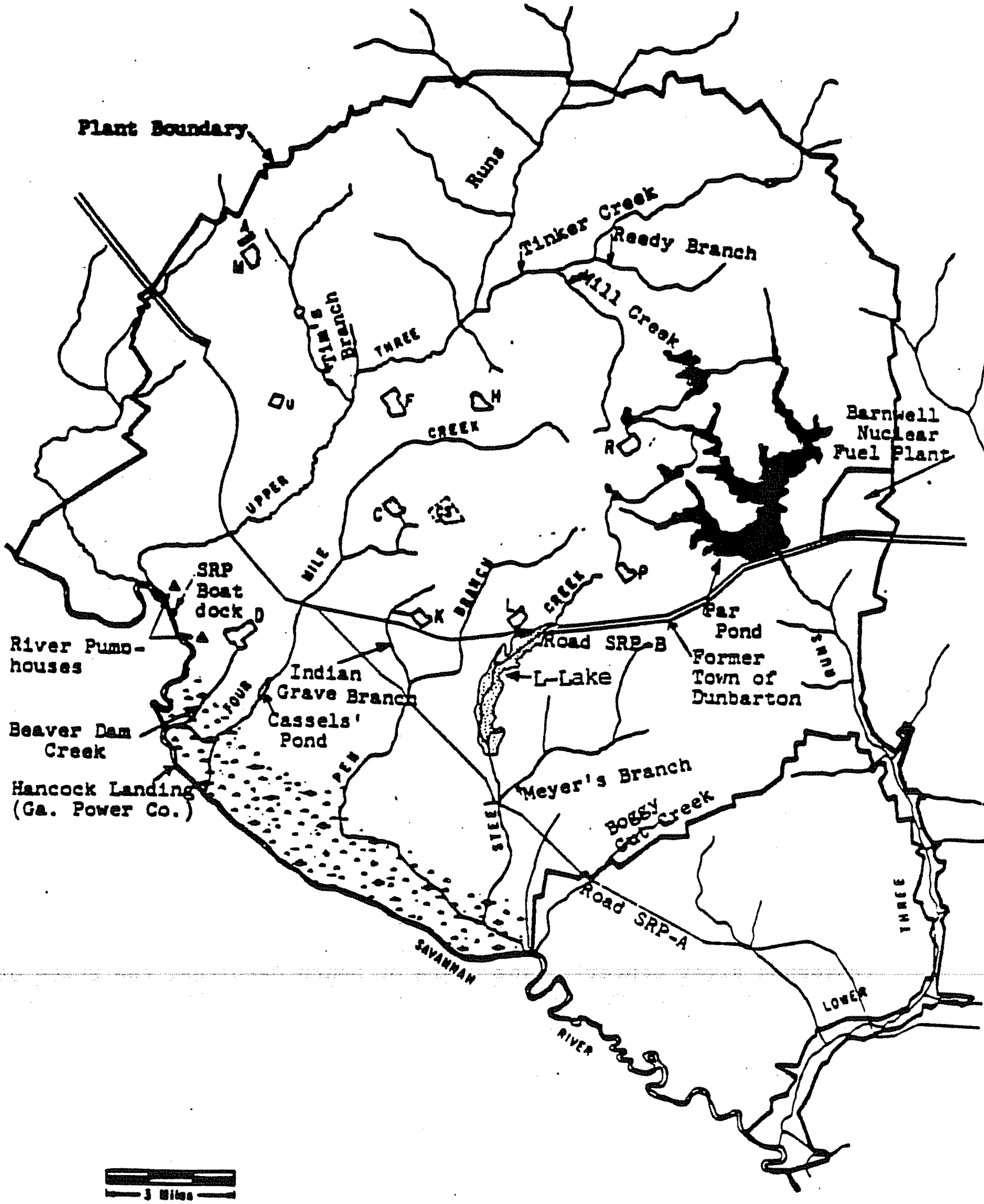

FIGURE I-1.1. Cooling Water Intakes, Onsite Thermal Streams and Cooling Water Reservoir at the Savannah River Plant adjoining the Savannah River on the SRP site. While most of the efforts of this program were directed toward studying the various environmental components of onsite streams and wetlands, certain studies extend into farfield reaches of the Savannah River from River Mile 187.4 near Augusta, Georgia to about River Mile 30 near Savannah, Georgia, in order to evaluate potential effects of SRP operations in downstream areas.

I.2 PROGRAM ELEMENTS OF THE COMPREHENSIVE COOLING WATER STUDY

I.2.1 Introduction

The CCWS had two primary objectives. The first objective was to determine the environmental effects of SRP cooling water withdrawals and discharges. This objective was accomplished by evaluating the specific effects of SRP operations on water quality, wetlands, aquatic ecology, endangered species, and radionuclide and heavy-metal transport. The second objective was to determine the significance of the cooling-water impacts on the onsite and down-river environments as a necessary step toward evaluating mitigation alternatives for SRP thermal effluents.

The cooling water study initially contained the following program elements:

- Water Quality,
- Radionuclide and Heavy Metal Transport,
- Wetlands,
- Aquatic Ecology, and
- Endangered Species.

Two additional categories, Par Pond and Waterfowl, were added later.

The schedule for the study allowed for two years of field and laboratory studies to develop sufficient technical data to define existing cooling water impacts. The scope and plan of study for each of the original program elements is discussed below.

I.2.2 Water Quality

I.2.2.1 Introduction

The Federal Water Pollution Control Act of 1972 (PL 92-500) and Amendments of 1977 (Clean Water Act) codified the national concern for the commitment to maintain national waterways in a clean and healthy state. While much of the impetus for this and previous water-related legislation was to prevent the degradation of waterways by high organic loadings, high organic loadings from reactor effluents are not considered a problem at the SRP. Rather, the operation of production reactors that release large volumes of heated water (30 to 70°C) is the primary activity affecting the water chemistry of onsite surface waters.

The cycle of reactor cooling water at SRP is generally divisible into three limnologically distinct components with potential changes in water quality attributable to each component. The first component is the pumping of water from the Savannah River or from Par Pond to holding basins in each of the reactor areas where this water is chlorinated. The cooling water is then passed through reactor heat exchangers where waste heat is removed from the primary cooling water and where the potential for leaching of metals from pipes is present and small amounts of radioactivity can be picked up. In the second limnological component, water from C and K Reactors and the D Area power plant is released into surface streams that have been substantially altered over the past 30 years of operations (Gibbons and Sharitz, 1974; Smith et al., 1981, 1982; Mackey et al., 1983). Water passes several kilometers down these open, well-defined stream channels and then enters the third limnological component, the SRP Savannah River swamp. The river swamp is dominated by cypress-tupelo and bottomland hardwood forest except at the points of entry for the thermal effluent streams where sedimentary deltas have formed. Reactor effluent water travels through the river swamp before returning to the Savannah River. Effluents from P Reactor are recycled through Par Pond with a small volume of overflow into Lower Three Runs Creek.

Upper Three Runs Creek is the only major stream system on the SRP that has never received thermal effluents. Monitoring data from this stream and headwater tributaries of thermally impacted streams provide baseline information from which ecological changes occurring in thermally affected onsite streams can be evaluated and compared.

Details and results of the CCWS Water Quality sampling program are addressed in Volume II of the CCWS report.

I.2.2.2 Plan of Work

Ongoing environmental and ecological monitoring programs over the last 30 years resulted in the collection of a substantial amount of water quality data pertaining to the Savannah River, onsite streams, and Par Pond. These data were reviewed and a historical water quality data base developed. This data base was used to provide a perspective and to identify information needs so that additional data collections under the CCWS could be defined.

The existing program for monitoring water quality was supplemented with the current program in order to provide information for evaluating changes in the physical and chemical parameters occurring in each component of the cooling water cycle (i.e., pumping and reactor cooling system, stream channel, river swamp). Thirty-one sampling locations representing thermal, nonthermal, and post-thermal surface waters, were designated for this program. Sampling locations were designated at the reactor water intakes, as near as is practicable to the point of entry of effluents into the receiving water body, at downstream locations prior to the confluence of onsite streams with the river swamp, and at stream exit points from the river swamp into the Savannah River. Where applicable, sampling stations were selected upstream of the point of reactor effluent input and on major undisturbed tributaries to facilitiate comparisons of reactor effluent effects with parameters in nonthermally impacted zones of onsite streams. Additional sampling locations were established on the thermally unimpacted Upper Three Runs Creek, and upriver and downriver of the SRP. These locations were sampled every two weeks (biweekly) for 20 parameters, including flow and temperature, standard water quality parameters, major ions, and nutrients. Concentrations of 9 metals were measured in water samples collected at each station on a monthly basis. Approximately half of these stations were monitored on a limited basis since early 1983. The full program was implemented at all locations in late 1983.

Data derived from fixed-location, fixed-time sampling designs have definite limitations in the evaluation of the status, functioning, and health of surface water systems (Sanders et al., 1983). Therefore, special studies addressed the following:

- Diel changes in water quality parameters in reactor effluent and unimpacted streams,
- Effects of differing reactor operational conditions on stream water quality, particularly relating to problems of organic and inorganic sediment transport,
- Patterns of water flow through the river swamp and changes in flow patterns and water residence times during different levels of flooding of the river swamp, and
- Thermal plume characteristics in the Savannah River and Par Pond.

Many of these studies were conducted parallel to efforts associated with the Radionuclide and Heavy Metal Transport Program Element of the CCWS (Volume III).

All sample collection, processing and analysis procedures conformed to Environmental Protection Agency (USEPA, 1979) and/or South Carolina Department of Health and Environmental Control (SCDHEC) approved techniques for certified laboratories. Where such procedures are not specified by EPA, analytical procedures were taken from Standard Methods (APHA, 1980) or subsequently amended EPA procedures. Quality control and data handling procedures were adopted according to EPA and SCDHEC guidelines (USEPA, 1979).

Water quality data collected in this program were analyzed in a manner to facilitate direct comparisons between water bodies that are affected by cooling water releases and those that are not.

I.2.3 Radionuclide and Heavy Metal Transport

I.2.3.1 Introduction

The Savannah River Plant has maintained an inventory of radionuclide quantities released to onsite surface streams and transported to the Savannah River by means of a routine radiological monitoring program established prior to plant startup. Radionuclide releases are within the limits of applicable regulatory guides. Work performed in this study assisted in the identification and evaluation of radionuclide and heavy metal deposition sites in sediments in SRP onsite streams, SRP wetlands areas and swamp, and the Savannah River as a consequence of SRP cooling water discharges.

The analysis and evaluation of integrated heavy metal and radionuclide deposition in SRP streams and the Savannah River was supported by data collected from the SRP routine radiological monitoring program and from water quality data collected from two separate water quality programs, one routine and one conducted under the CCWS. Extensive collections of sediment in depositional areas of SRP stream-swamp sites, Par Pond, and the Savannah River were conducted for analysis of radionuclide and heavy metal concentrations. Results of this program are reported in Volume III. Transport models were developed to aid in evaluating the potential for, and significance of remobilization and transport that might occur as a result of current or projected SRP operations.

I.2.3.2 Plan of Work

The Radionuclide and Heavy Metal Transport program element encompassed simultaneous study in three areas: (1) SRP onsite sediment core collection and analyses; (2) offsite Savannah River sediment core collection and analyses; and (3) sediment and finished water collection and analyses from downriver water treatment plant facilities.

The SRP onsite sediment collection and analysis program began in Autumn 1983. Sample site selection was based on the use of previous radiological overflight data produced by EG&G of SRP streams to determine areas of maximum radionuclide deposition (Gladden, et al., 1985)). Following final site selection of more than 60 onsite sampling locations, two sediment cores of about one meter in length were collected in parallel at each site. Cores were collected from each of the SRP streams which has received cooling water discharges from SRP operations.

Collection of sediment cores from the Savannah River floodplain upriver of SRP were undertaken later in 1984. Upriver cores provided a baseline comparison of river sediments unaffected by SRP cooling water operations. Analysis of the river sediment cores followed arrangements outlined for onsite cores described below.

Beginning in April 1983, weekly low-level analyses for radionuclides in raw and finished water collected at the downriver Beaufort-Jasper and Port Wentworth water treatment facilities were performed to determine Cs-137 concentrations. These analyses were continued for about 12 months after the L-Reactor restart. Samplers and rain gauges were placed at the Beaufort-Jasper intake canal in May 1983 to quantify the dilution effect on radionuclide concentrations in the canal water.

Each of the sediment cores removed from onsite stream and swamp floodplain areas was sectioned prior to analysis in order to maximize information of previous cooling water discharge impacts. Cores were prepared for analysis of SRP-released radionuclides and naturally occurring radionuclides. All sediment core subsamples were counted for gamma activity. Samples containing the greatest amount of gamma activity were selected to undergo radiochemical analyses to quantify the levels of the more difficult to detect radionuclides (e.g., Pu, Cm, I-129, Tc-99).

Initial characterization of all sectioned onsite floodplain samples included: (1) textural analyses (sand, silt, and clay fractions); (2) cation exchange capacity using EPA approved methods and an appropriate tracer; and (3) total carbon content using an EPA-approved induction furnace technique. These three preliminary analyses supported the development of an elemental transport model.

Sediment subsamples were analyzed by a certified offsite vendor for about 16 metals using EPA-approved methods by means of atomic absorption and inductively coupled argon plasma spectrometer techniques. Metals of interest for analysis included Cd, Cr, Fe, Hg, and Ni. Uranium concentrations were determined at SRL using lasor fluorescence techniques.

Data collected from this program element and related program elements were used:

- To determine SRP-released radionuclide and heavy metal concentrations in stream, swamp, river, and river drinking water in order to assess the potential effects to human and biological communities;

- To identify sites and concentrations at which radionuclides and/or metals were deposited and identify how these sites now contribute or may contribute to future transport of these materials; and

- To develop a transport model that will optimize the accurate prediction of elemental transport under a variety of stream and river flow rates.

I.2.4 Wetlands

I.2.4.1 Introduction

Wetlands of the southeastern United States have been studied for the past several decades. Previous studies provided data on the community structure and species composition of swamp forests (Monk, 1966, 1968; Wharton et al., 1976; Dabel and Day, 1977; Carter et al., 1973; Conner et al., 1981) and on the function of these wetland systems (Schlesinger, 1978; Odum et al., 1974; Odum and Ewel, 1975; Nessel, 1978). Increasing industrialization in the Southeast has resulted in increased disturbance and contamination of these wetland systems. Therefore, recent research focused on the responses of stream and swamp communities to associated perturbation (Christy and Sharitz, 1980; Dickson et al., 1965; Kennedy, 1970) and corresponding swampland ability to regenerate following perturbation (Sharitz et al., 1974a; Sherrod et al., 1980).

Initial studies of the SRP Savannah River swamp (Sharitz et al., 1974a, 1974b) revealed major differences in species composition and diversity between areas receiving thermal effluents from reactor operations (Pen Branch and Four Mile Creek), areas recovering following the cessation of thermal effluent (Steel Creek), and relatively unaffected portions of the SRP swamp (Upper Three Runs Creek). Changes in plant community structure were reflected in the changes in the utilization by various animals such as aquatic insects (Howell & Gentry, 1975) and birds (Straney et al., 1975). Recent studies of the Savannah River swamp on the SRP indicated continued degradation of the swamp forest canopy in areas receiving heated reactor effluents (Repaske, 1981). Repaske (1981) suggested that changes in the hydrologic regime of the swamp as a result of cooling water input, as well as alterations of the flood pattern in the Savannah River due to construction of upstream reservoirs, perhaps had a long-term, chronic effect by limiting the regeneration of bald cypress (Taxodium distichum), one of the dominant forest tree species in the swamp. Studies evaluating the recovery of the swamp forest following reactor shutdown (Smith et al., 1981, 1982) indicated that 14 years after cessation of reactor effluent input, the Steel Creek swamp supported freshwater herbaceous marsh communities and scrub-shrub wetlands dominated by willow (*Salix* spp.) and buttonbush (*Cephalanthus occidentalis*). Although these previous studies provided information on the responses of specific SRP swamp areas to reactor input, they do not provide a comprehensive evaluation of the long-term effects of SRP cooling waters on the extensive onsite wetland ecosystem.

This program element was designed to provide ecological and environmental data for assessing the effects of operating the SRP reactors and the D Area, coal-fired power plant on the SRP wetland ecosystem, including the swamp forest and its tributary streams. Details and results of CCWS wetlands vegetation are addressed in Volume IV of the CCWS report. Waterfowl studies are covered in Volume VIII.

I.2.4.2 Plan of Work

A program was initiated in 1981 to examine the potential effects of L-Reactor restart on the Steel Creek floodplain, delta, and surrounding swamp. The CCWS expanded that program to include the stream and swamp areas influenced by C and K Reactors and the D-Area discharges.

The four major components of this program element were cooling water effects on plant community structure and diversity, cooling water effects on community primary productivity, vegetation mapping of the SRP thermal areas including SRP swamp, stream floodplains and deltas, and studies of waterfowl habitat use. Appropriate data gathering and analysis techniques were used for each of these program components. Data were analyzed to facilitate comparison between swamp wetland and floodplain areas which are directly affected by cooling water releases, and those that are not. Details of the four major areas of study in the wetlands program follow.

I.2.4.2.1 Wetlands Community Structure and Diversity

Because of the heterogeneous array of plant community types within the SRP Savannah River swamp and associated wetlands (swamp forests to herbaceous marsh), the sampling design was tailored to the characteristics of the particular community type. A nested quadrat sampling technique (Mueller-Dombois & Ellenberg, 1974), was used to provide data on community composition and structure. Line-intercept transects and quadrats provided information on changes in community composition, as necessary for verifying the accuracy of vegetation maps via field measurements.

Species-area analyses were completed for each major community type to determine optimum plot size to adequately sample the vegetation. Similar analyses were also used to determine the adequacy of sampling in each community type. Major sampling locations were determined from aerial photographs that discriminate between thermally affected, post-thermal recovery, and natural sections of the swamp. Within each site, randomly located nested quadrats were used to sample trees, shrubs, and herbaceous species. Sampling data included density and diameter at breast height (dbh) of trees, density and diameter at one meter of shrubs, and presence or absence of herbaceous species.

Mathematical ordination techniques (Hill & Gauch, 1980) were employed to discriminate major community types and examine their distributional relationships. Correlations between ordination patterns and environmental measurements provided information on the major environmental factors along which the community types are distributed.

Long-term study was accomplished by the establishment of permanent quadrats in variously affected areas of the SRP swamp. Individuals of the dominant swamp forest species were measured, marked, and outfitted with dendrometer bands to provide data on mortality and growth rate. Standing crop values were estimated from dbh and height, and these data were compared with existing regressions of dbh, height, and standing crop for individual swamp forest species. Selected individuals were harvested, dried, and weighed as necessary to verify the accuracy of existing regression analyses for selected species. Community reproduction was evaluated by determining annual seed fall per individual species.

I.2.4.2.2 Primary Productivity

Community productivity was investigated by estimating standing crop values determined in the community structure analysis combined with data on annual growth and litter production. Permanent quadrats in unimpacted and impacted areas of the SRP swamp were selected for this study. Litterfall traps were used to determine litter production. Selected individuals were harvested or subsampled to determine nutrient concentrations and to estimate the nutrient inventory in above-ground components of the wetland communities. Soil cores have been taken for nutrient analysis. These data were combined with water quality data and nutrient levels of surface and groundwaters to provide a model of nutrient turnover and cycling in natural and impacted wetland areas. Continuous monitoring of water levels at several sites, combined with measurements of flow rates, permitted estimation of water flow rates in floodplains.

I.2.4.2.3 Vegetation Mapping

High-resolution multi-spectral scanner data were used to map the distribution of wetland communities throughout the SRP Savannah River swamp. Reflectance data from the swamp vegetation were collected in 11 regions of the electromagnetic spectrum. From a color infrared composite image, areas of known vegetative composition were selected as training fields to calibrate the digital data. A minimum distance classification algorithm was then applied to the swamp data set to map the distribution of these vegetation units (Jensen et al., 1983). Ground truth surveys utilizing line intercept sampling techniques and quadrats (Mueller-Dombois & Ellenberg, 1974) were employed to verify the accuracy of the vegetation mapping.

The pattern and rate of historic changes in wetlands vegetation were determined by examining previous aerial photographs of the swamp delta regions. Repaske (1981) provided preliminary data suggesting that the thermal delta areas are expanding at rates between 2 and 6.5 hectares per year. Series of photographs taken at intervals since the inception of the SRP were digitized into a GIS data base, and analyzed to determine the rate at which canopy degradation occurred. Data analyses included:

- Quantitative comparisons of plant community composition, structure, and diversity between thermal and nonthermal areas,
- The distribution of wetland communities along water depth and temperature (perturbation) gradients to provide an evaluation of the relative influence of these environmental components on community structure, and
- The pattern and rate of historical changes in the vegetation of the thermal deltas in the SRP Savannah River swamp.

I.2.4.2.4 Waterfowl Use

Standard sampling techniques were used to determine the waterfowl use of wetland communities within the SRP Savannah River swamp so that general faunal responses to habitat changes could be assessed. Resident and migratory waterfowl species were censused throughout the swamp as they were in the Steel Creek Delta (Smith et al., 1981, 1982). Fixed wing aircraft were used for weekly or biweekly flights over the entire swamp to estimate the relative abundance of major waterfowl species. A wood duck nest box research program included areas outside of the Steel Creek area.

Data analyses included quantitative comparisons of habitat use and relative abundances of waterfowl in thermal and nonthermal wetlands.

I.2.5 Aquatic Ecology

I.2.5.1 Introduction

The direct and indirect effects of cooling water intake and thermal discharge on resident aquatic communities were assessed in this program element. Aquatic ecology of the SRP streams, wetlands, and the Savannah River are discussed in detail in Volume V of this report. Aquatic ecology of Par Pond is covered in Volume VII. Data were gathered regarding icthyoplankton entrainment and impingement of adult fishes at the cooling water intakes; thermal plume effects on anadromous and resident fishes, including overwintering effects, in the SRP swamp; locations of nursery grounds in onsite streams and swamps by spawning fish from the Savannah River; and thermal impacts of cooling water discharges on other aquatic communities, including periphyton, macrophytes, phytoplankton, zooplankton, and macroinvertebrates.

Impacts from cooling water usage may be in the form of direct thermal impacts on organisms, such as fish kills due to thermally related physiological stress, or may be indirect, such as the effects resulting from increased disease and parasitism, habitat loss, or disruption of the aquatic food chain.

I.2.5.2 Plan of Work

The emphasis in this study, was placed on the monitoring of impingement and entrainment at the cooling water intakes on fish and icthyoplankton, and on quantifying the effects of SRP thermal discharges on aquatic communities in three study areas: the Savannah River, SRP streams and wetlands, and Par Pond. Standard sampling methodologies were used, and information gleaned from previous Savannah River Laboratory and Savannah River Ecology Laboratory aquatic studies (Wilde and Tilly, 1985; Smith et al., 1982) were incorporated.

Initially, studies in the onsite SRP streams and wetlands were concentrated in the Steel Creek/Meyers Branch system. Steel Creek system studies were conducted in 1981 and 1982 to evaluate the effects of the L-Reactor restart on aquatic communities in the Steel Creek/Meyers Branch system. Subsequently, these studies were expanded to include all SRP thermal and nonthermal streams.

As a result of numerous existing aquatic studies conducted since construction of Par Pond, an extensive data base already existed for Par Pond (Wilde & Tilly, 1985). The first phase of the Par Pond cooling water assessment was to evaluate the existing data base and draw conclusions on thermal effects in Par Pond. From this initial review, supplemental studies were developed to provide the additional data necessary to complete the evaluation of the effects of cooling water usage on the Par Pond system.

I.2.5.2.1 Icthyoplankton

Savannah River. Weekly icthyoplankton collections, using paired 505 µm mesh nets were from February through July 1984 and 1985 between the New Savannah River Bluff Lock and Dam and approximately river mile 30 (river km 48). Sampling locations included the following:

	1984	1985
• Onsite SRP river transects	13	14
• Onsite SRP intake canal transects	2	2
• Onsite SRP creek mouth stations	5	5
• Offsite river transects	13	7
• Offsite river oxbows	6	5
• Offsite creek stations	28	10

SRP Streams and Wetlands. Icthyoplankton collections were made at a total of 35 locations in Upper Three Runs Creek, Beaver Dam Creek, Four Mile Creek, Pen Branch, Steel Creek, Meyers Branch, and Lower Three Runs Creek in 1984. In 1985, the program was expanded to include an additional 7 sampling stations. Routine collections were made throughout the spawning season of both years (February - July).

Par Pond. Icthyoplankton collections in Par Pond were made in the intake area, the thermal plume, and at other reference stations in Par Pond and Pond B. Samples were collected biweekly throughout the 18-month study period.

I.2.5.2.2 Adult Fish Populations

Savannah River/SRP Creek Mouths. Adult fish were collected quarterly at 12 locations in the Savannah River in 1984, and 13 locations in the river in 1985, as well as in the two intake canals, and in the mouth of the five SRP creeks using electrofishing and hoopnetting techniques. Fish were identified, weighed, measured, tagged, and released in order to determine the community structure of the fish communities. In addition, overwintering studies were conducted in the Savannah River and in the mouths of selected SRP streams using electrofishing, hoopnetting, and mark/recapture methods to determine the effects of thermal discharges during the winter months on fish distribution, species composition, maturation, condition, parasitism, and disease incidence.

SRP Streams and Wetlands. Adult fishes were collected quarterly by electrofishing at 15 onsite SRP stream and swamp sites in 1985 to determine species composition, relative abundance of fish within different habitat areas.

Par Pond. Adult fish studies have been conducted at Par Pond for over 20 years (Wilde & Tilly, 1985). These studies addressed many of the questions concerning thermal effects on adult fish populations in Par Pond, including fish abundance, species composition, movements, body temperatures, thermal tolerance limits, feeding habitats, growth, reproduction, and red-sore disease (*Aeromonas*). Supplemental studies were initiated January 1, 1984. Adult fish collections in Par Pond and Pond B were made monthly for 18 months using four collection techniques: electrofishing, gillnetting, hoopnetting, and angling.

I.2.5.2.3 Macroinvertebrates, Periphyton, Macrophytes, Phytoplankton, and Zooplankton

Savannah River. Macroinvertebrates were sampled monthly in the Savannah River and in the mouths of the five SRP creeks, using multiplate (Hester-Dendy type) samplers. Ten river transects in the vicinity of the SRP were sampled during the 1983-1984 sampling year, while eight were sampled in 1984-1985. Macroinvertebrate drift was collected quarterly at the same stations using 505-µm mesh nets. The studies were conducted to assess differences in macroinvertebrate community structure, density, biomass, and functional group composition attributable to SRP operations.

SRP Streams and Wetlands. Macroinvertebrates were collected monthly at 12 locations in 1983-1984 and 29 locations in 1984-1985 in SRP streams, using Hester Dendy multiplate samplers to assess differences in community structure and function of macroinvertebrates in thermal, post-thermal, and ambient temperature streams. Macroinvertebrate drift collections were made quarterly using drift nets in order to determine differences in drift density and species composition attributable to differences in habitat and to SRP operations. Studies were also conducted to evaluate differences in primary producers (macrophytes and periphyton) and organic matter processing in nonthermal, thermal, and post-thermal streams.

Par Pond. Existing Par Pond studies, which include 20 years of thermal effects research, discuss cooling water effects on macroinvertebrates, macrophytes, periphyton, phytoplankton, and zooplankton in Par Pond. Supplemental studies identified by the initial Par Pond literature review were incorporated into the Par Pond study starting January 1, 1984 and ending in June 1985.

I.2.5.2.4 Impingement/Entrainment

Savannah River. Impinged fishes were collected at the SRP 1G, 3G, and 5G pumphouse trash removal pipes on 100 random dates each year. Impinged fishes at the river pumphouse intakes were identified, weighed and measured, and the sex and reproductive condition determined. Icthyoplankton collections were made at the SRP pumphouse stations using paired 505-μm mesh nets. Samples were sorted and the fish eggs and larvae counted and identified. Where possible, samples were collected just below the water surface and just above the bottom of the body of water. The data were analyzed to provide estimates of annual entrainment rates.

Par Pond. Assessments were made to evaluate meroplankton entrainment and the impingement of fishes at the Par Pond intake structure.

I.2.6 Endangered Species

I.2.6.1 Introduction

This study addressed the impacts of cooling water discharges to SRP surface waters on the persistence of endangered species. The four endangered or threatened species that potentially could be affected by SRP cooling water operations are the American alligator, the wood stork, the shortnose sturgeon, and the bald eagle.

Because extensive research has been conducted on the American alligator on the SRP site (Jenkins and Provost, 1964; Murphy and Brisbin, 1975; Murphy and Fendley, 1975; Adams, Smith and Baccus, 1980; Murphy, 1981; Gibbons and Patterson, 1978; Murphy, 1977), considerable information is available on alligator population ecology, distribution pattern, and behavior for SRP. Alligators are abundant in the SRP reservoir system of Par Pond, but are less common in the swamp and streams.

Wood stork studies have been conducted in other regions (Ogden et al., 1978; Ogden et al., 1976; Kahl, 1964; Ogden and Nesbitt, 1979; Ogden and Patty, 1981), but only limited research on this particular species had been carried out on the SRP prior to 1983 (Smith et al., 1981, 1982). Wood storks nest in rookeries in southern Florida in December and January, and in northern Florida from February through March. Reproductive success is controlled by water level fluctuations which have a major influence on the population dynamics of the species. Wood storks do not show clear migration patterns but do disperse throughout the southeast. This species primarily inhabits coastal areas where shallow freshwater pools high in fish concentration are readily available for foraging.

The shortnose sturgeon is found on the east coast of North America in tidal rivers and estuaries. Prior to 1982, this species had not been reported in the middle reaches of the Savannah River. However, shortnose sturgeon larvae were found in icthyoplankton samples taken from the Savannah River in the vicinity of SRP (ECS, 1983), and from the pumphouse intake canals (Matthews and Muska, 1983) as part of the Savannah River Biological Measurement Program. Although little is known about the Savannah River shortnose populations, extensive studies have been conducted on northern populations (Dadswell, 1979; Taubert, 1980), and to a lesser degree on populations in South Carolina (Marchette & Smiley, 1983), and Georgia (Heidt & Gilbert, 1978). Only a small number of larvae of the shortnose sturgeon have been collected from the Savannah River. Likewise, shortnose sturgeon research was conducted in SRP waters, although publications of regional and general work are available (Dadswell et al., 1983; Heidt and Gilbert, 1978; Rulifson and Huish, 1982; Marchette and Smiley, 1983).

Information on the bald eagle, although not included in the original CCWS design, has been included in this report for completeness.

The CCWS builds upon existing information regarding these species and expands the work into stream, swamp, and river areas presently or formerly potentially influenced by cooling water discharges in order to evaluate responses of these species to habitats impacted by thermal inputs.

I.2.6.2 Plan of Work

The American alligator inhabits certain wetlands of the SRP site. Extensive studies of the alligator populations in Par Pond and in the Steel Creek floodplain and adjacent swamp/wetland habitats have provided information on population size and distribution, sex ratios, reproduction, survivorship, and growth rates. Movements of alligators in and out of thermally affected areas have also been documented. These studies were expanded to additional swamp localities to provide the basis for comparisons of onsite stream, swamp and Par Pond populations and relative habitat value.

The wood stork, which has been listed as an endangered species, has been sighted in the delta area of the Steel Creek swamp system. These sightings have occurred during each summer since 1980, and indicate seasonal use of the Steel Creek Delta area for foraging. Studies during the summer of 1983 were enlarged to include the entire SRP Savannah River swamp. Evaluation of onsite and offsite habitat was performed using parameters, such as water depth, water quality, vegetation characteristics, and fish density to evaluate the attractiveness of the SRP wetlands relative to other local foraging sites.

Icthyoplankton samples collected from the Savannah River in the vicinity of SRP and the pumphouse intake canals during the 1982 to 1983 spawning seasons contained shortnose and Atlantic sturgeon larvae. From the location of the sampling stations, it was concluded that both species spawn upstream of the SRP site. To date, 13 shortnose sturgeon larvae have been collected. Prior to these collections, the shortnose sturgeon was not known to inhabit the upper reaches of the Savannah River.

Studies of all three species were expanded as indicated below.

I.2.6.2.1 American Alligator

Studies of the current status of the Par Pond alligator population were conducted in accordance with the study design and procedures used in previous studies (Murphy and Brisbin, 1974; Murphy, 1977). Alligator populations in thermal and nonthermal swamp habitats were surveyed in a manner similar to the ongoing surveys of the Steel Creek alligators (Smith et al., 1981, 1982). Minimum population estimates of alligators in the stream, delta and swamp areas were provided to compare the use of thermally affected and normal temperature areas. Survey methods included the following:

- Aerial and ground surveys were conducted regularly to estimate population size. Daytime searches were conducted to locate major habitat areas and potential nests. Surveys at night using eye-shining techniques were used to determine relative abundance of alligators in thermal and nonthermal portions of the reservoir. Shoreline areas were examined for nests using ground searches or low altitude overflights.

- Observations of alligator distributions around thermally affected areas were made using night-shining techniques.

- Alligators near Four Mile Creek, Pen Branch, and Steel Creek were outfitted and tracked with external and internal radio transmitters. Body temperatures were monitored. Changes in movement patterns upon release of thermal effluents in the areas were recorded.

I.2.6.2.2 Wood Stork

Extensive surveys determined wood stork use of SRP swamp wetlands and evaluated onsite and offsite feeding habitats. It is likely that most wood storks visiting the SRP are from a nesting colony near Millen, GA. Feeding flights of wood storks from the Millen Colony were monitored to identify local feeding habitats. For each feeding flight the following data were recorded: distance flown to first landing site, time of departure from the colony, duration of the flight, location of the feeding area, number of wood storks in the feeding flight, and association with other avian species. Ground crews measured the following parameters at the wood stork feeding locations: water quality (pH, dissolved oxygen, nitrogen, phosphorus, calcium, conductivity), physical attributes of the habitat (water depth, distance to shore, turbidity, area of feeding location), vegetative characteristics, and fish density (Kushlan, 1981). Data provided an evaluation of the extent to which wood storks feed in Steel Creek and the delta/swamp wetlands compared to other local areas.

I.2.6.2.3 Shortnose Sturgeon

The collection of samples for ichthyoplankton populations and impingement estimates were noted above. Icthyoplankton samples are important in identifying spawning seasons and spawning/nursery habitats. However, distinguishing shortnose larvae from Atlantic sturgeon larvae, which are also collected in Savannah River icthyoplankton samples, is difficult. Consequently, Mr. Darrel E. Snyder, Curator and Technical Director of the Colorado State University Larval Fish Laboratory, was contracted to prepare a diagnostic key to differentiate shortnose and Atlantic sturgeon larvae.

The conclusions of the Biological Assessment of the effects of SRP operations on the shortnose sturgeon collections have been summarized by Matthews and Muska (1983). Additional information on the shortnose sturgeon collections in the Savannah River is presented in Volume VI of the CCWS report.

I.2.6.2.4 Bald Eagle

Bald eagles have been reported from time to time on the SRP, especially near Par Pond. In 1986, a nest was established at a Carolina Bay south of the Par Pond dam. Although not included in the original CCWS design, information on the bald eagle was included in the CCWS report for completeness.

I.2.7 Summary

Studies implemented in the CCWS were designed to provide a comprehensive evaluation of the effects of cooling water utilization on biota and on physiochemical parameters of both the Savannah River and the receiving water bodies, predominantly tributary streams of the Savannah River. Generally, the questions addressed in the CCWS were the following.

- Water Quality. What changes in water quality occur as Savannah River water passes through the cooling cycle? In addition to temperature and flow, information was collected to determine changes in nutrient levels, major ions, and trace element concentrations. All major SRP aquatic systems including Par Pond, nonthermal, post-thermal and thermal streams, swamps, and the Savannah River were studied. The spatial distribution of thermal plumes in the Savannah River and onsite river swamp was evaluated under a variety of river discharge conditions.

- Radionuclide and Heavy Metal Transport. Does the release of large volumes of cooling water affect the distribution or redistribution of radionuclides and heavy metals released during SRP operations? Sediment cores were collected at many onsite and offsite floodplain areas to evaluate the distribution of heavy metals and radionuclides, while water at downstream water treatment facilities was analyzed to determine the magnitude of SRP contributions to radionuclide concentrations in domestic and industrial water supplies. A predictive model was developed and parameterized to aid in evaluating the potential for, and significance of remobilization and transport of heavy metals and radionuclides as a result of current or future SRP operations.

- Wetlands. How does the release of heated effluents affect the ecology of species inhabiting wetland habitats on the SRP? Remote sensing techniques were used to document the extent and general character of wetland habitats on the SRP, and determine the historical patterns of wetland change in relation to SRP activities. Ground truth studies were conducted to evaluate the structure and dynamics of wetland community types including the factors influencing plant community changes. Other studies evaluated the relationships between distributions of waterfowl and the various wetland types, so that more general models of faunal responses to habitat change could be evaluated.

- Aquatic Ecology. How do cooling water releases affect the structure and dynamics of aquatic communities? Integrated studies of primary producer populations, macroinvertebrate consumers, and fish populations were conducted to evaluate relationships between aquatic habitat structure and primary productivity, and the structure, distribution, and dynamics of consumer populations. These studies were conducted in Par Pond, onsite streams, the Savannah River swamp, and the Savannah River.

- Endangered Species. Does cooling water use affect the persistence of endangered species? Four endangered species use areas that are influenced by cooling water releases: the American alligator, the wood stork, the shortnose sturgeon, and the bald eagle. Studies of the ecology of these species on the SRP were conducted, especially with respect to potential impacts associated with the intake or release of cooling water.

I.3 SITE LOCATION AND HISTORY

I.3.1 Introduction

The Savannah River Plant (Figure I-3.1), operated for the U.S. Department of Energy by E. I. du Pont de Nemours and Company, was established in the early 1950s to produce nuclear materials for the national defense. Nuclear materials are produced at this site in large production reactors that are moderated and cooled by heavy water (D_2O). Support facilities fabricate nuclear fuel and targets, dissolve the irradiated materials, and separate nuclear products from the radioactive byproducts (Figure I-3.2). Chemical processing of irradiated materials produces high-level radioactive waste that is currently stored in waste tanks.

Other products are made in the SRP reactors. Plutonium-239 and tritium were the first nuclear products; the product list has since been expanded to include uranium-233, plutonium-238, curium-244, polonium-210, cobalt-60, and californium-252.

I.3.2 Site Location

The Savannah River Plant (SRP) is located in southcentral South Carolina. The plant occupies an almost circular area of about 770 square kilometers, bounded on its southwestern side by the Savannah River. Portions of the counties of Barnwell (121,503 acres), Aiken (66,665 acres), and Allendale (4,155 acres), South Carolina, lie within the SRP boundary. The location of the SRP site, relative to surrounding population centers within a 240-km radius, is shown in Figure I-3.3. The closest principal population centers near the SRP site are Augusta, Georgia, and Aiken and Barnwell, South Carolina.

The locations of the various plant areas are shown in Figure I-3.1, along with the five major stream systems that drain the site. Most of the plant areas drain toward the Savannah River, which is about 84 feet above sea level.

The SRP site is a controlled area with public access limited to US Highway 278, SRP Road 1, through traffic on SC Highway 125 (SRP Road A), the Seaboard Coastline Railroad, approved tour groups, forest management activities, and authorized environmental studies. Access to the site also is permitted for organized deer hunts which began in 1965 to help control the size of the deer population.

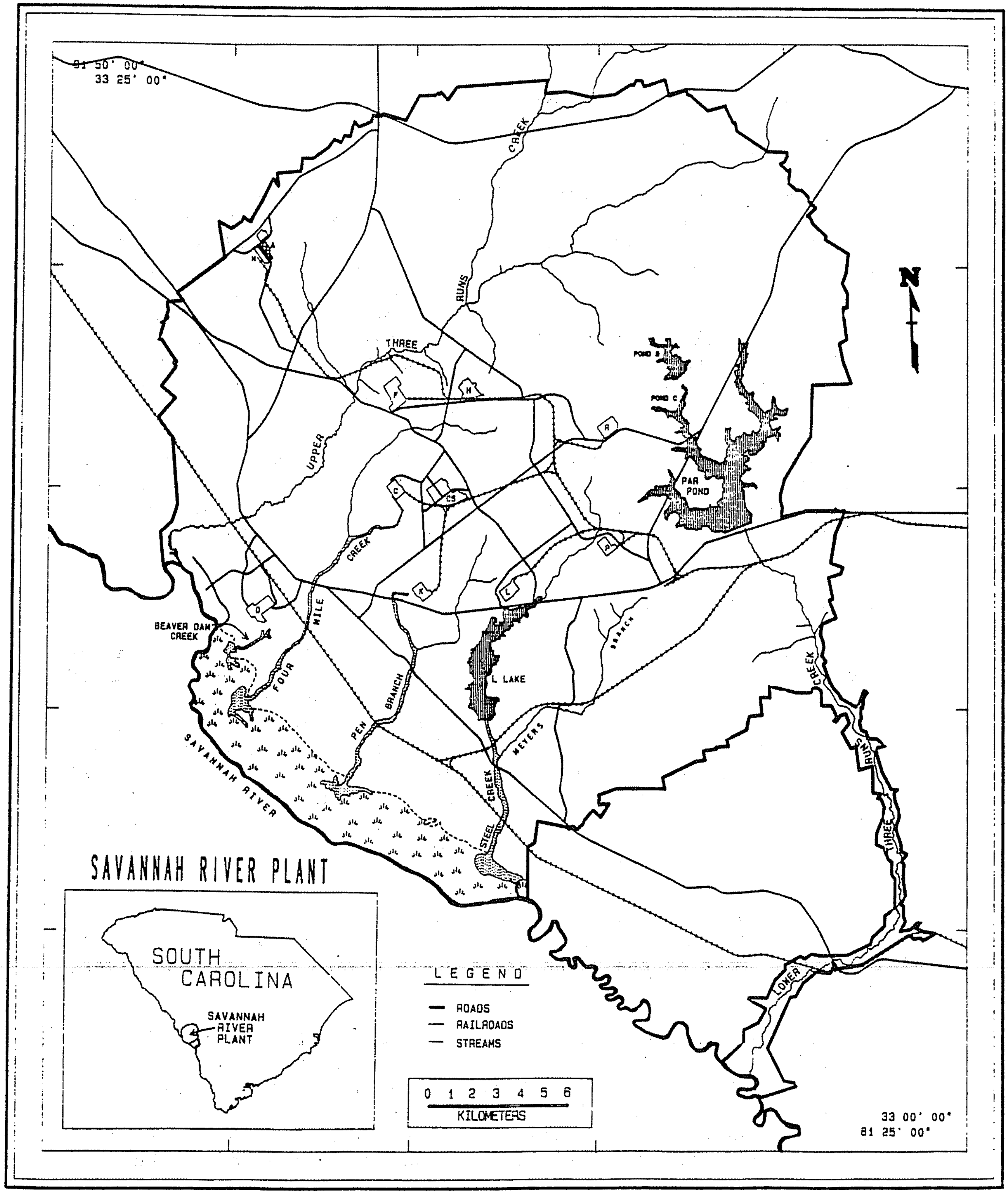

FIGURE I-3.1. The Savannah River Plant Site

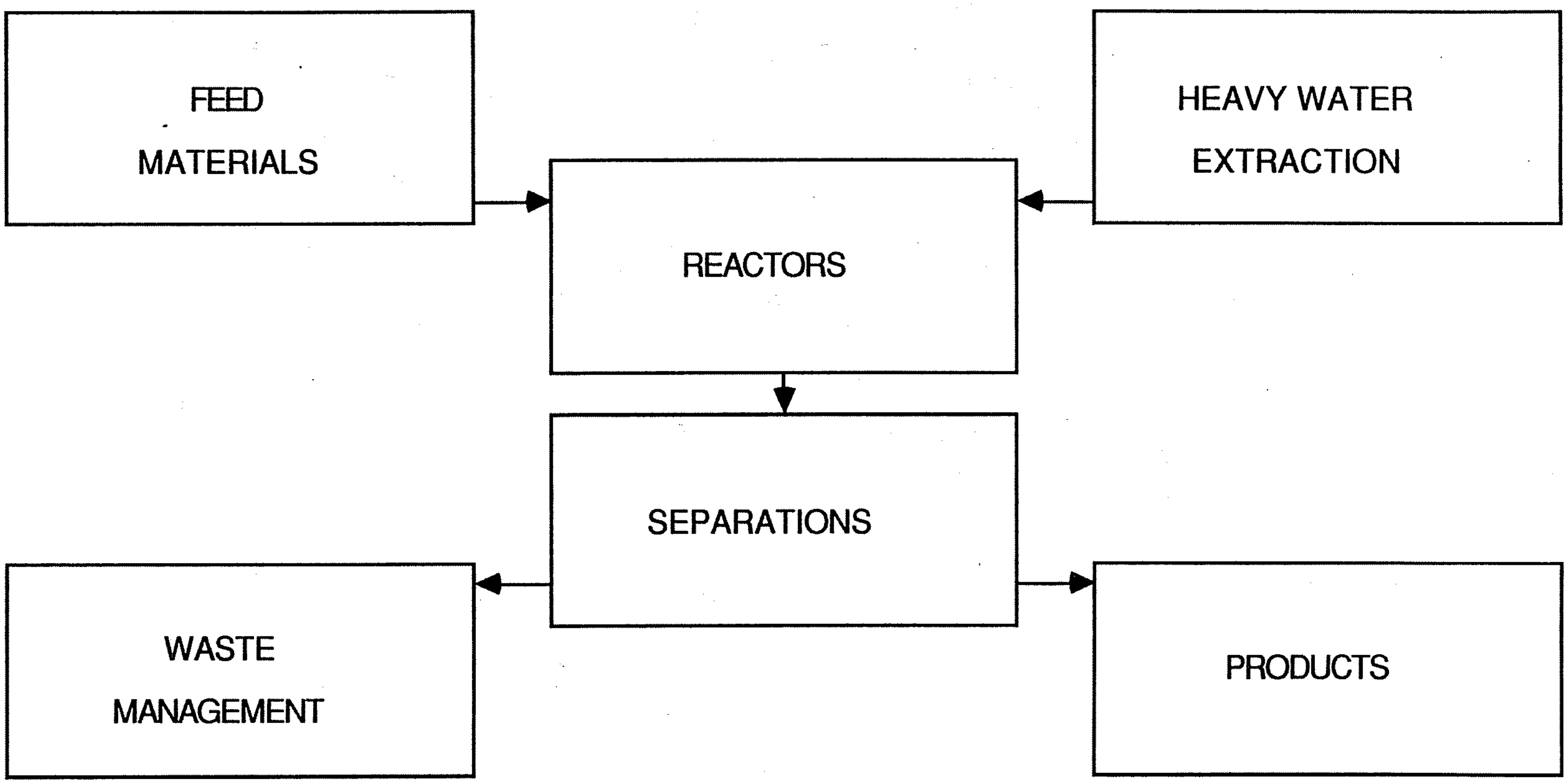

FIGURE I-3.2. The Savannah River Plant Production Complex

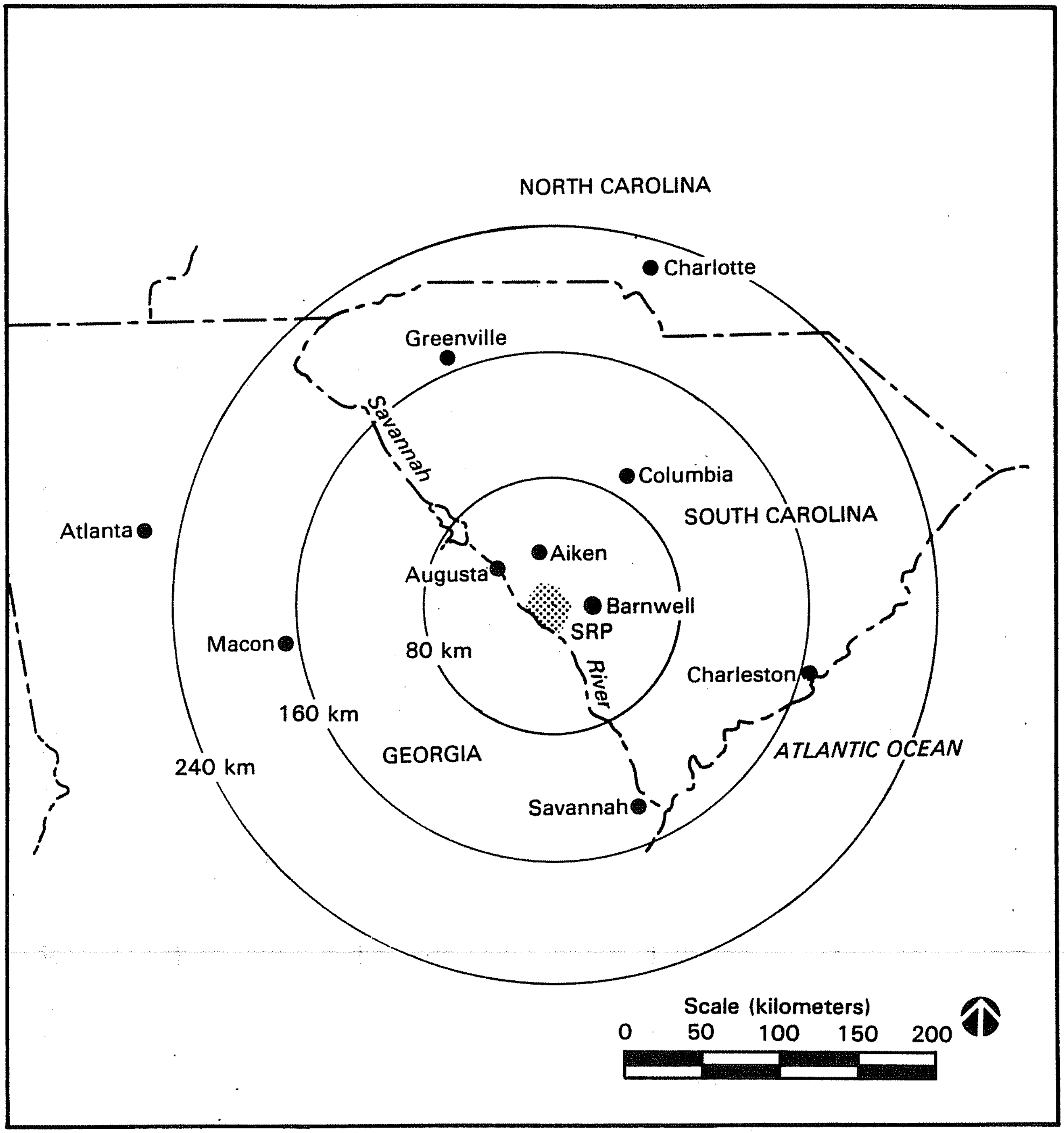

FIGURE I-3.3. Location of SRP Relative to Surrounding Population Centers

I.3.3 Geologic History and Physiographic Regions

I.3.3.1 Geologic Structure of South Carolina

South Carolina is divided into two main geologic provinces: (1) The Piedmont Plateau, which is underlain by igneous and metamorphic rock, and (2) the Atlantic Coastal Plain, which is characterized by flat, mostly unconsolidated sediments of Cretaceous age or younger. The relatively soft sediments of the Coastal Plain are more easily eroded than the hard crystalline rocks of the Piedmont Plateau, and for this reason, the boundary between the two provinces is called the Fall Line. The Fall Line is not a sharp line of contact but a zone of transition from the typical land forms of one province to those of the other. It is difficult to determine from the ground surface where the Piedmont Plateau ends and the Coastal Plain begins. However, in river beds the distinction is noticeable, as the change in rock formations causes waterfalls or rapids.

Studies have indicated that the Fall Line between these two provinces in South Carolina is located about 32 km northwest of the SRP near Augusta, Georgia (Dukes, 1984). In South Carolina, the Atlantic Coastal Plain sediments thicken southeastward from the Fall Line to the coast where the deposit thickness exceeds 945 m (Rankin, 1977). In the vicinity of the SRP, these sediments are approximately 320 m thick (Christl, 1964).

I.3.3.2 Topograpy of the SRP Site

The SRP is located on the upper Coastal Plain. On the site, two distinct physiographic subregions are represented (Figure I-3.4), the Pleistocene Coastal Terraces (below 82 m in elevation), and the Aiken Plateau (above 82 m and rising to 122 m on the northwest boundary). At least three terraces are recognizable within the Coastal Terraces subregion (Figure I-3.4). The lowest terrace (Wicomico, 30 m) is the floodplain of the Savannah River; it is covered with a dense swamp forest. The higher terraces (Sunderland, 52 m, and Brandywine, 82 m) have a level-to-gently rolling topography and were cultivated extensively before the establishment of SRP in those areas where soils and drainage were favorable.

The Aiken Plateau was once a relatively smooth, gently sloping area with a regional slope to the southeast. However, the plateau has been deeply eroded by numerous tributaries. Those interstream areas underlain exclusively by Cretaceous sediments are characterized by gently rolling hills and few undrained areas. Those interstream areas with a thin cover of Tertiary sediments are characterized by plateaus with steep ravines and numerous undrained "sinks" or "Carolina Bays."

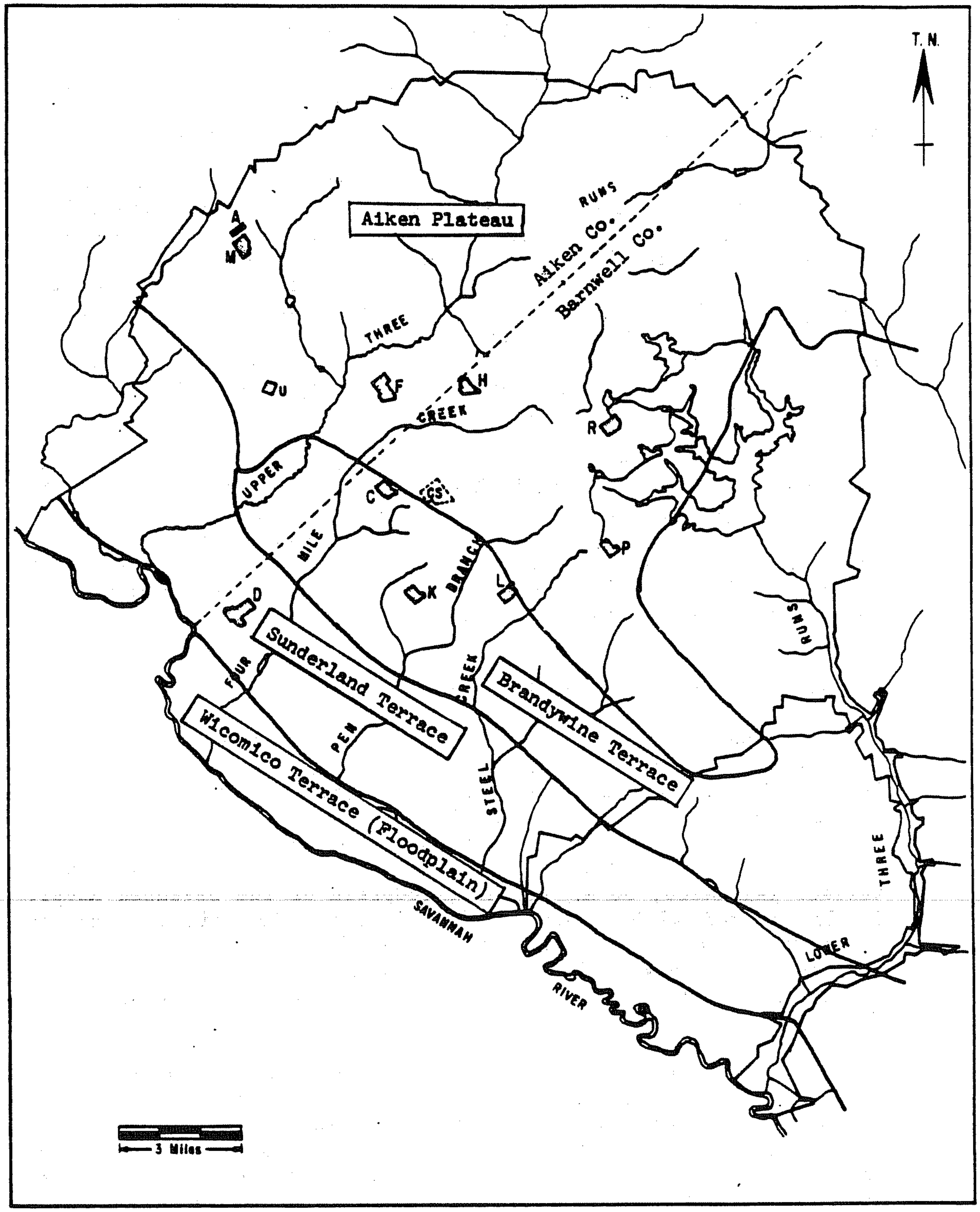

FIGURE I-3.4. Coastal Terraces on the Savannah River Plant

I.3.3.3 History of SRP Development

The Atomic Energy Commission (AEC), a predecessor agency to the U.S. Department of Energy (DOE), selected the location of the Savannah River Plant in November 1950, after studying more than 100 potential sites. Criteria used in the selection of the site included low population density, accessibility to a large supply of cooling water of good quality, and low frequency of major floods and destructive storms. The construction of most SRP facilities began in February 1951, and eventually involved more than $1 billion in expenditures with a peak construction force of 38,500 workers. The construction of most major SRP facilities was completed in 1954.

Uranium fuel fabrication began in M Area and extraction of heavy water (deuterium oxide, D_2O) began in D Area in 1952. The first production reactor (R) began operation in December 1953. Other production reactors began operation in February 1954 (P), July 1954 (L), October 1954 (K), and March 1955 (C). Reactors were placed in standby condition in June 1964 (R) and February 1968 (L). The locations of these production facilities are indicated in Figure I-3.1.

The separations areas began processing radioactive fuel assemblies from the reactor areas in November 1954 (F) and July 1955 (H). Low-level, radioactive waste was first sent to the onsite burial ground in the first half of 1955, when waste uranium from fuel fabrication in M Area was disposed of in this facility. The first high-level waste tank was completed in March 1954. Waste discharges to the seepage basins and waste tanks began shortly after startup of the separations areas.

I.3.3.4 Status of SRP Facilities

SRP activities in the production of nuclear materials to meet national defense needs include material production and processing, waste management operations, heavy water production, and additional related production tasks. SRP facilities include five production reactors (three in operation in C, K, and P Areas during the period of the CCWS, and two on standby in R and L Areas), two chemical separations facilities (F and H Areas), a fuel and target fabrication facility (M Area), a heavy water production facility (on standby in D Area), and various supporting facilities (Figure I-3.1). Onsite waste disposal facilities include waste tank farms near the chemical separations areas and a 195-acre burial ground for low-level solid radioactive waste. The primary products of the SRP reactors are plutonium (^{239}Pu) and tritium (T or ^{3}H). These are produced by absorption of neutrons in uranium (^{238}U) and lithium (^{6}Li), respectively.

During reactor operation, neutrons cause uranium-235 atoms to split into lighter atoms. In addition, each uranium-235 atom fissioned releases two to three neutrons. This surge of released neutrons, which split more uranium-235 atoms, results in a chain reaction that generates large amounts of heat. This controlled fissioning continues for a designated period. The fuel and target assemblies are then moved by remote control from the reactor core to a large pool of water in the reactor building to permit decay of short-lived fission products before the assemblies are delivered to a chemical separations plant (F and H Areas) on site.

The reactors are moderated and cooled with recirculating heavy water (D_2O). Secondary cooling is provided by a once-through flow of ordinary water (H_2O). The combination of high moderating ability and low neutron absorption provided by D_2O permits great flexibility in reactor-charge design, and full advantage of this is taken in designing different charges to produce a variety of products. The SRP reactors are production reactors. They are designed specifically to generate excess neutrons which can be used to make the desired isotopes. They are not designed to produce steam or electricity. Modification for such production is not practical or economical.

Water from the Savannah River or Par Pond (a man-made reservoir) is supplied to the reactor to cool D_2O from the reactor coolant system. The water is pumped into a 95-million-liter cooling water basin at the reactor area and pumped from the basin to the reactor building where it extracts heat from the D_2O circulating through primary heat exchangers. The effluent cooling water flows from the heat exchanger back to Par Pond by man-made channels and precooler ponds or to the Savannah River after flowing through onsite stream and swamp systems.

The river water is pumped to the C-, K-, and L-Reactor (L-Reactor was not operating during the CCWS) area cooling water basins through concrete lined steel pipes by two pumping stations located on the Savannah River (1G and 3G). Individual lines supply each reactor area, and alternative tie lines provide for emergency supply of cooling water should the primary line fail. A similar system supplies water from Par Pond to P Reactor which also receives some river water since natural supply to Par Pond requires supplementation to maintain pond water levels. Thermal discharges from L Reactor are released to L Lake on the Steel Creek. Nominal secondary cooling water flow of up to 11 m^3 (400 cfs) is established prior to reactor startup and is maintained during reactor operations.

Each of the two chemical separations plants (F and H Areas) has a large shielded "canyon" building for processing irradiated materials. The plants dissolve the irradiated fuel and target materials and produce solutions containing the various products which have been decontaminated from fission products by solvent extraction and ion exchange processes. Further processing is performed in unshielded facilities where the products can be converted from solution to solid form for shipment offplant.

The heavy water plant (which was located in D Area) extracted heavy water from river water by a hydrogen sulfide process, and further purified it by distillation. At present, only the rework unit is operating to purify reactor moderator. A coal-fired, power plant is also located in the D Area. Cooling water for facilities at the D Area is provided from the 5G pumping station on the Savannah River. Cooling water effluents from D Area are released into Beaver Dam Creek.

The facilities used in the production of defense nuclear materials occupy less than 5% of the total SRP land area. Reservoirs and ponds onsite occupy approximately 4,000 acres or about 2% of the total land area. The remainder of the SRP is comprised predominantly of pine plantations and natural vegetation, which are managed by the U.S. Forest Service under a cooperative agreement with the Department of Energy.

I.3.3.5 History of Water Use

The Savannah River forms the boundary between the States of Georgia and South Carolina (Figure C-3.3). Upstream of the SRP the river supplies water for Augusta, Georgia and North Augusta, South Carolina. The river receives treated waste water from these municipalities and from Horse Creek Valley (Aiken, South Carolina).

The Savannah River is a Class B waterway used for fishing, both commercial and sport, and pleasure boating downstream from the Savannah River Plant. Water withdrawn from the river is used for various SRP activities, but is used primarily to cool the production reactors. It is also used as a drinking water supply after treatment at Port Wentworth, GA (Cherokee Hill Water Treatment Plant) for a consumer population of about 20,000, and at Hardeeville, SC (Beaufort-Jasper Water Treatment Plant), for a consumer population of approximately 51,000.

I.3.3.5.1 River Water Use by the Savannah River Plant

The SRP is a major user of water from the Savannah River. SRP could remove 41 m^3/s if all 26 river water pumps are in simultaneous use at the three river pump stations. Under the worst conditions, the removal of the full 41 m^3/s would consume about 23% of the usual river minimum flow of about 181 m^3/s at SRP. The 7-day, 10-year low flow for the Savannah River is

159 m^3/s. Figure I-3.5 shows the cooling water pumped from the river from 1954 to 1980. During the period of the CCWS, the SRP withdrew a maximum of 37 m^3/s from the river; C and K Reactors each received about 11 m^3/s of cooling water, Par Pond received about 0.6 m^3/s to compensate for seepage and evaporation, and the coal-fired power plant received about 2.8 m^3/s. After the river water is used as secondary coolant in C, K, and L Reactors, it is discharged to Four Mile Creek, Pen Branch, and Steel Creek, respectively, which flow through an onsite swamp to the Savannah River. Present operations typically remove about 9% of the average annual Savannah River flow at SRP of 295 m^3/s. Nearly all water withdrawn from the river is returned to the river. The design and operation of the three Savannah River cooling water intake structures at the SRP is presented in Section I.3.3.5.5.

I.3.3.5.2 Surface Water Use by Nearby Industries

Two neighboring facilities use or plan to use Savannah River water for industrial cooling purposes. The South Carolina Electric and Gas Company's Urquhart Steam Station, located upstream of the SRP, uses about 7.4 m^3/s as once-through cooling water (DOE, 1984). The Alvin W. Vogtle Nuclear Power Plant, near Hancock Landing, Georgia, is now under construction. When completed, it will use up to 2.8 m^3/s of river water as make-up water for its recirculating cooling towers.

I.3.3.5.3 Surface Water Use by Downriver Consumers

Downstream from SRP, the Beaufort-Jasper Water Authority in South Carolina (River Mile 39.2) withdraws about 0.23 m^3/s to supply domestic water for a population of about 51,000 (Table I-3.1). The Cherokee Hill Water Treatment Plant at Port Wentworth, Georgia (River Mile 29.0), withdraws about 1.35 m^3/s the river to supply a business-industrial complex near Savannah which has an estimated consumer population of about 20,000 (Table I-3.2). The locations of both downriver water treatment plants prior to distribution to consumer populations are given in Figure I-3.6.

I.3.3.5.4 Commercial and Recreational Uses of Savannah River Water

Commercial fisheries in South Carolina and Georgia are important to the economy of the coastal region of both states. Shad, shrimp, blue crabs, and oysters are the most important commercial species. Most fishing is confined to the marine and brackish waters of the coastal regions of South Carolina and Georgia. The only commercial fish of significance near the SRP are the American shad, the channel catfish, and the Atlantic sturgeon (DOE, 1984).

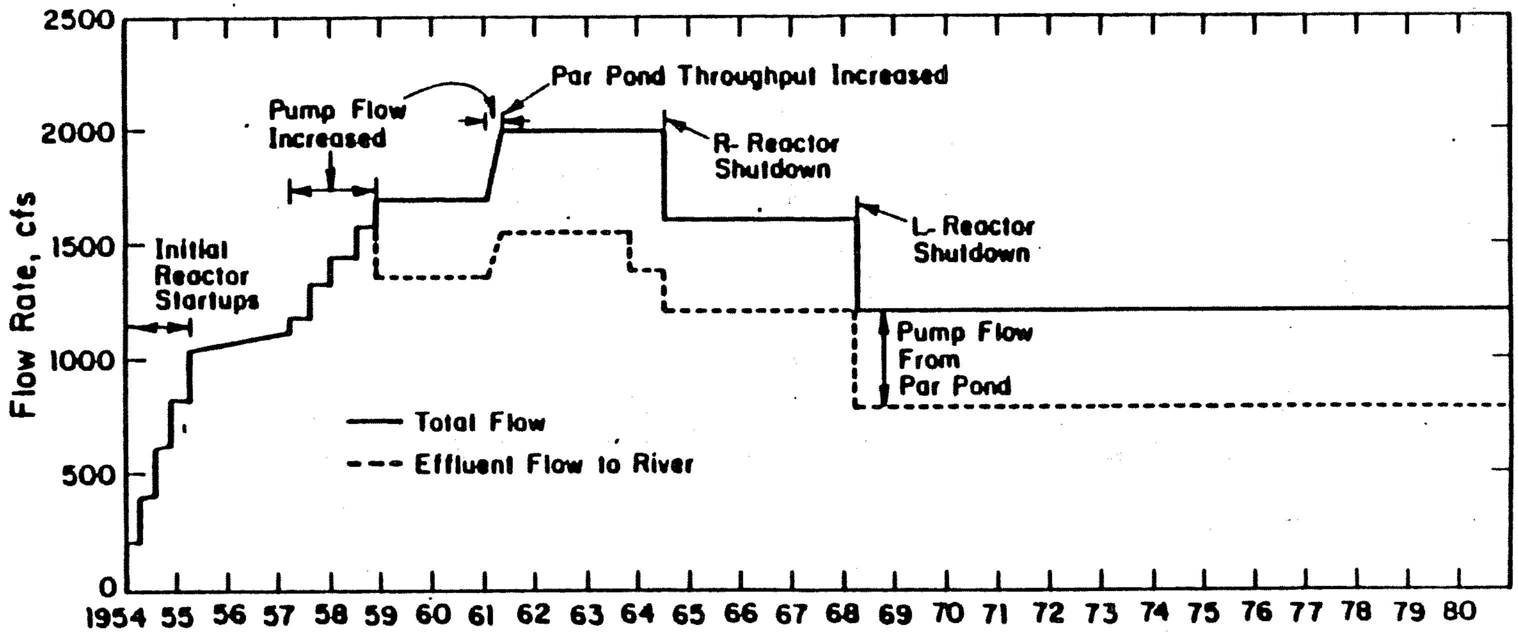

FIGURE I-3.5. SRP Reactor Cooling Water Flow, 1954-1980

TABLE I-3.1

Use of Water from the Beaufort-Jasper Water Authority

Water Treatment Capacity: 0.4 m^3/s
Average use: 0.23 m^3/s

South Carolina population served:

Group	Population
Beaufort-Port Royal	18,000
Naval installations	23,000
Rural areas	10,000
Total	51,000

Average Consumption Rates

Year	m^3/s	Month in 1980	m^3/s
1970	0.19	January	0.20
1971	0.19	February	0.19
1972	0.21	March	0.20
1973	0.24	April	0.19
1974	0.21	May	0.21
1975	0.20	June	0.27
1976	0.20	July	0.27
1977	0.21	August	0.27
1978	0.21	September	0.30
1979	0.22	October	0.23
1980	0.23	November	0.22
		December	0.19

TABLE I-3.2

Use of Water from the Cherokee Hill Water Treatment Plant

Water Treatment Capacity: 2 m^3/s

Customers (Primarily Industrial)	m^3/s
Continental Can Corp. (paper plant)	0.39
Union Camp (paper plant)	0.57
American Cyanamid	0.27
Kaiser Agricultural Chemical Co.	0.06
Savannah Electric Co.	0.005
American Oil Co.	0.004
Georgia Port Authority*	0.003
Coca Cola Bottling Co.**	0.002
Royal Crown Cola Bottling Co.	0.0005
Atlantic Creosoting Co.	0.002
Savannah Sugar Refinery	0.03
Continental Roofing Co.	0.001
Johns Manville Co.	0.001
Chevron Oil Co.	0.001
Koppers Co.	0.0006
Humson Battery Mfg. Co.	0.0001
Total	1.34

Estimated Number of Customers	Persons
Industrial workers	1,000
Seamen (effective person-year users)	2,000*
Beverages (effective person-year users)	17,000**
Total	20,000

* Fresh water for ships entering Savannah Harbor. One percent of water delivered is consumed by crewmen.

** Assumes 10% of water delivered is used for preparing bottled beverages.

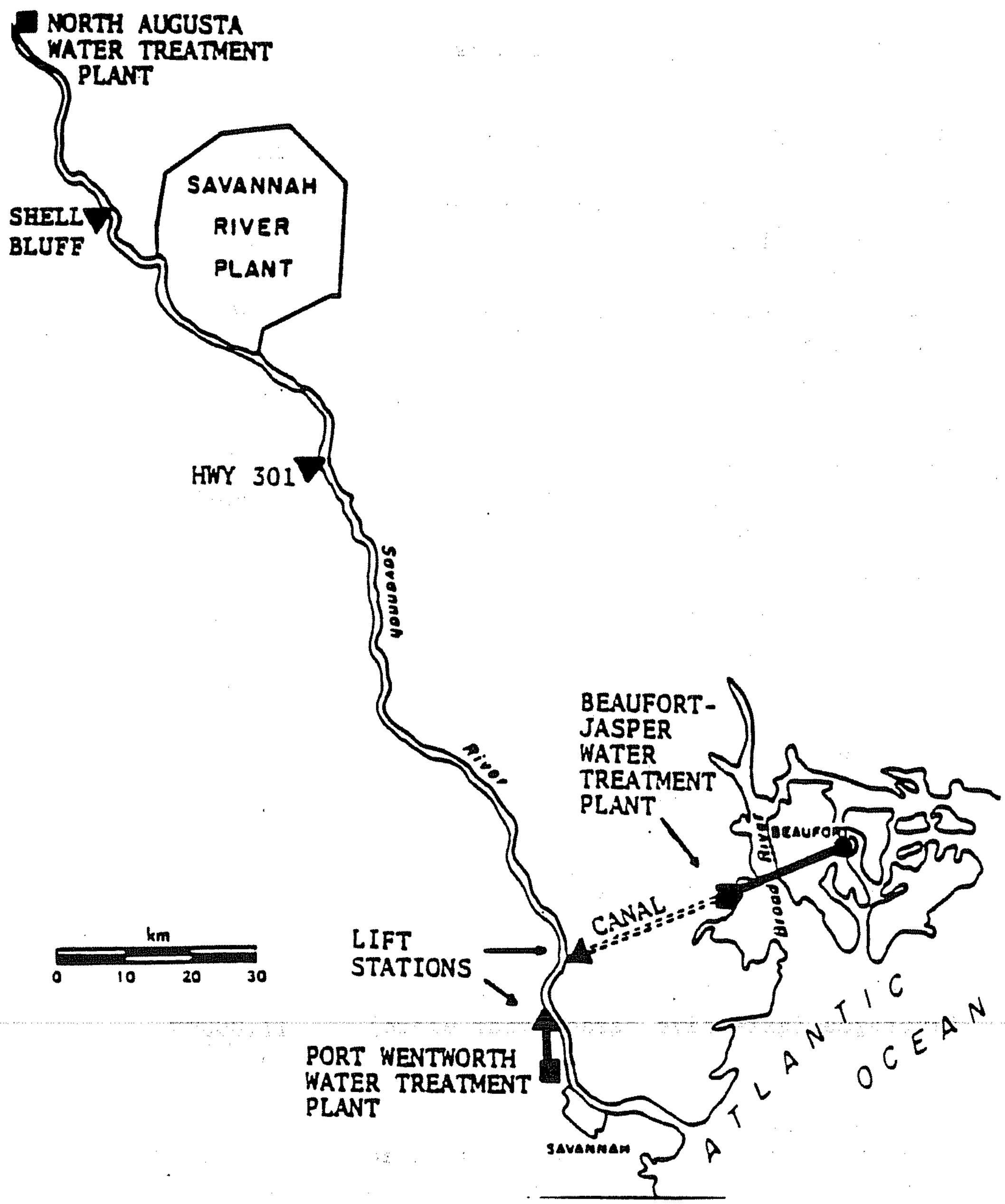

FIGURE I-3.6. Locations of Downriver Water Treatment Facilities

Recreational uses of the Savannah River are mostly upstream of SRP near Augusta or downstream of SRP near the coast. Recreational activities include sport fishing and limited water contact activities such as swimming or water skiing. No uses of the Savannah River for irrigation have been identified in either South Carolina or Georgia (DOE, 1984).

I.3.3.5.5 SRP Cooling Water Intake Structures on the Savannah River

SRP is on the middle reach of the Savannah River where it withdraws cooling water for production reactors, fossil fuel steam and electric generators, and other facilities. SRP operates three pumping stations on the Savannah River, as indicated in Figure I-3.7.

Two of the river intake structures, 1G and 3G, are identical ten-pump units, located at the end of intake canals. The third station 5G, operates six smaller pumps on a small inlet cove of the river. The rated capacities of the pumping stations are given in Table I-3.3. Sixteen to 18 pumps in the 1G and 3G pumping stations are needed to supply cooling water for C, K, L, and P Areas when all four reactors are operating. Historically, the U.S. Corps of Engineers has attempted to maintain a minimum flow of 181 m^3/s at SRP (DOE, 1984).

TABLE I-3.3

Savannah River Plant Pumping Station Capacities

River Pumping Station	Number of Pumps	Rated Pump Capacity, m^3/s	Maximum Sustained Station Flow m^3/sec
1G	10	2.05	20.5
3G	10	2.05	20.5
5G	6	0.8	4.7
Total SRP capacity			41.6

The 1G intake canal shown in Figure I-3.7 is about 549 m long and is located at River Kilometer 252.8. The Savannah River fluctuates about 4.3 m in elevation seasonally and the canal varies in width from 30 to 70 m in response to river level with a minimum depth of 2 m. The 3G canal is located at River Kilometer 250.0 and is 410 m long, with a width which varies from 26 to more than 90 m and a minimum depth of 2 m. The 5G intake is on a small cove about

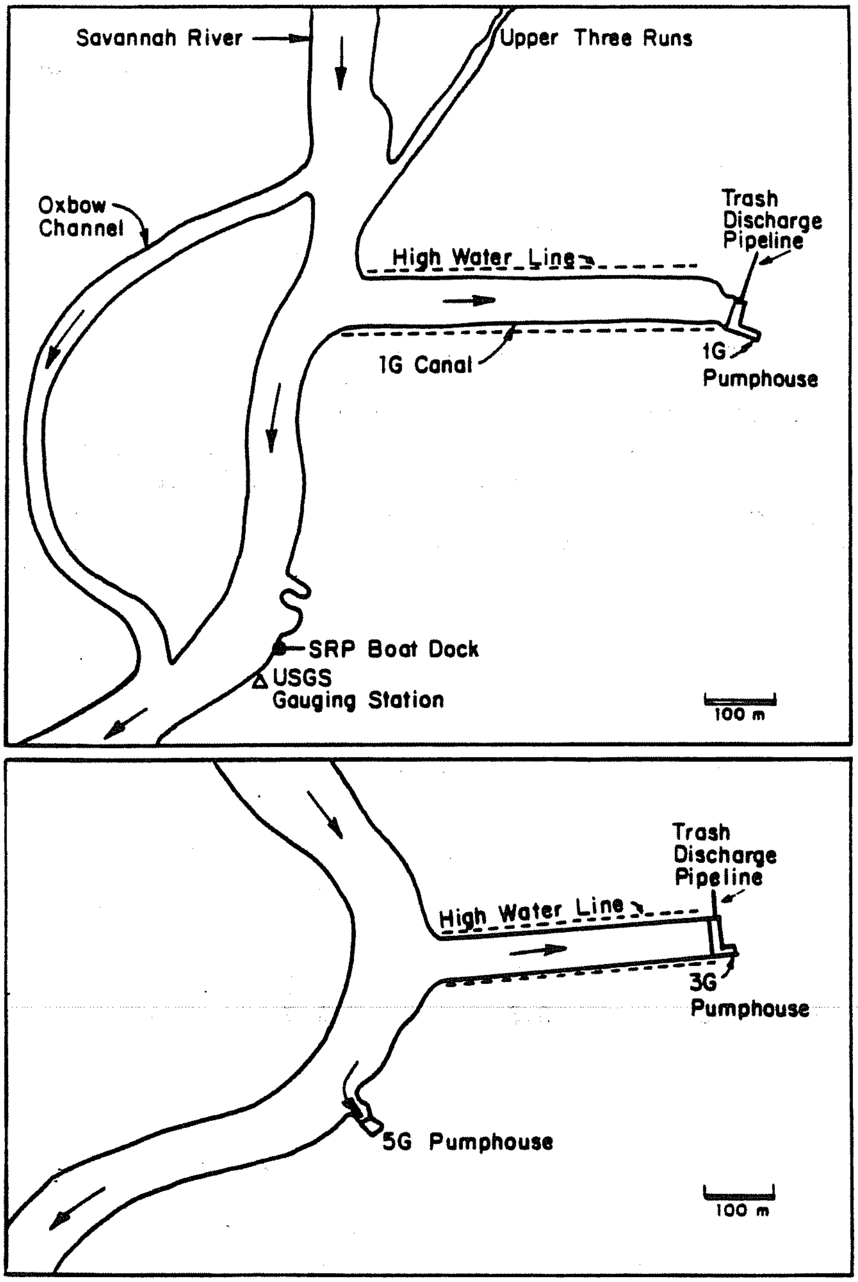

FIGURE I-3.7. SRP Pumping Stations and Nearby Reference Points on the Savannah River

12 m wide and 10 m from the river. The minimum depth of the cove is 2 m. Water enters the 1G and 3G pumphouses through individual bays for each pump. Water is drawn from each bay through a rectangular gate, through a vertical trash screen, and enters the conduit to the pump.

All of the SRP pumping stations use vertical traveling screens to remove trash from the cooling water. The screens are normally cleaned once per day, a procedure requiring 15 to 30 minutes. Water jets wash trash into a trough and to a 0.3-m-diameter pipe which empties into a swale. There is no opportunity for organisms impinged on the intake screens to return to the river (Matthews, 1982).

Intake velocities for typical low flow and high flow conditions for present operations are shown in Figures I-3.8 and I-3.9, and Table I-3.4. Higher velocity ranges would also occur as average river flow decreases below 295 m^3/s. Typically, six to eight pumps are operating in the 1G and 3G pumphouses at any given time, although a total of 12 pumps may be required at typical low river water flow (181 m^3/s).

TABLE I-3.4

Intake Canal High-Flow Water Velocity (m/sec)

Intake Canal	Near Inlet, Mean	Mid-Canal, Mean	At Pumphouse, Mean
1G	0.17	0.15	0.24
3G	0.22	0.15	0.28

The design of the 1G and 3G intake canals dictates that cooling water is withdrawn primarily from the upper layers of the river. Water is removed from the upper third of the water column at low river elevation, and from the upper two-thirds at high elevation. The proximity of Upper Three Runs Creek (Figure I-3.7) results in 45 to 95% of the creek discharge being drawn into the 1G canal, depending upon river flow rates.

The impingement and entrainment of fish and fish eggs/larvae at the river pumphouses is discussed in Volume V of the CCWS.

I.3.4 Surface Waters of SRP

Most of the surface water at the Savannah River Plant (SRP) results from rainfall or from the water which is pumped from the Savannah River and is used for secondary cooling for the plant

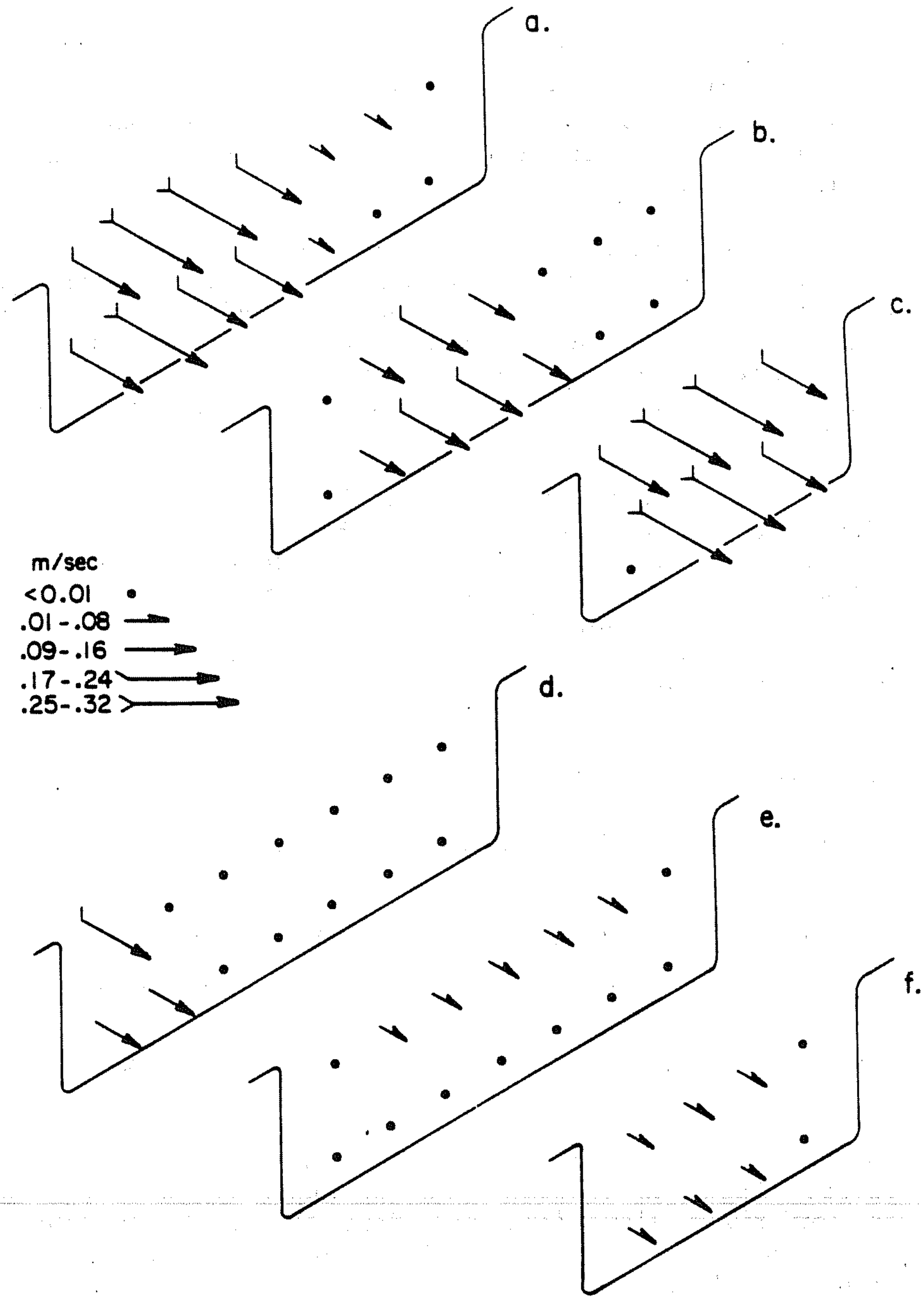

FIGURE I-3.8. Velocity Profile of 1G Canal

Velocity profile of 1G canal at 7 pump, high flow (a-c) and at 2 pump, low flow (d-f). Transects were located 100 m downstream from inlet (a,d) near canal midpoint (b,e) and immediately upstream of pumphouse training walls (c,f). Measurements were taken 0.5 m below the surface and 0.5 m above the bottom at 5-m intervals along the transect.

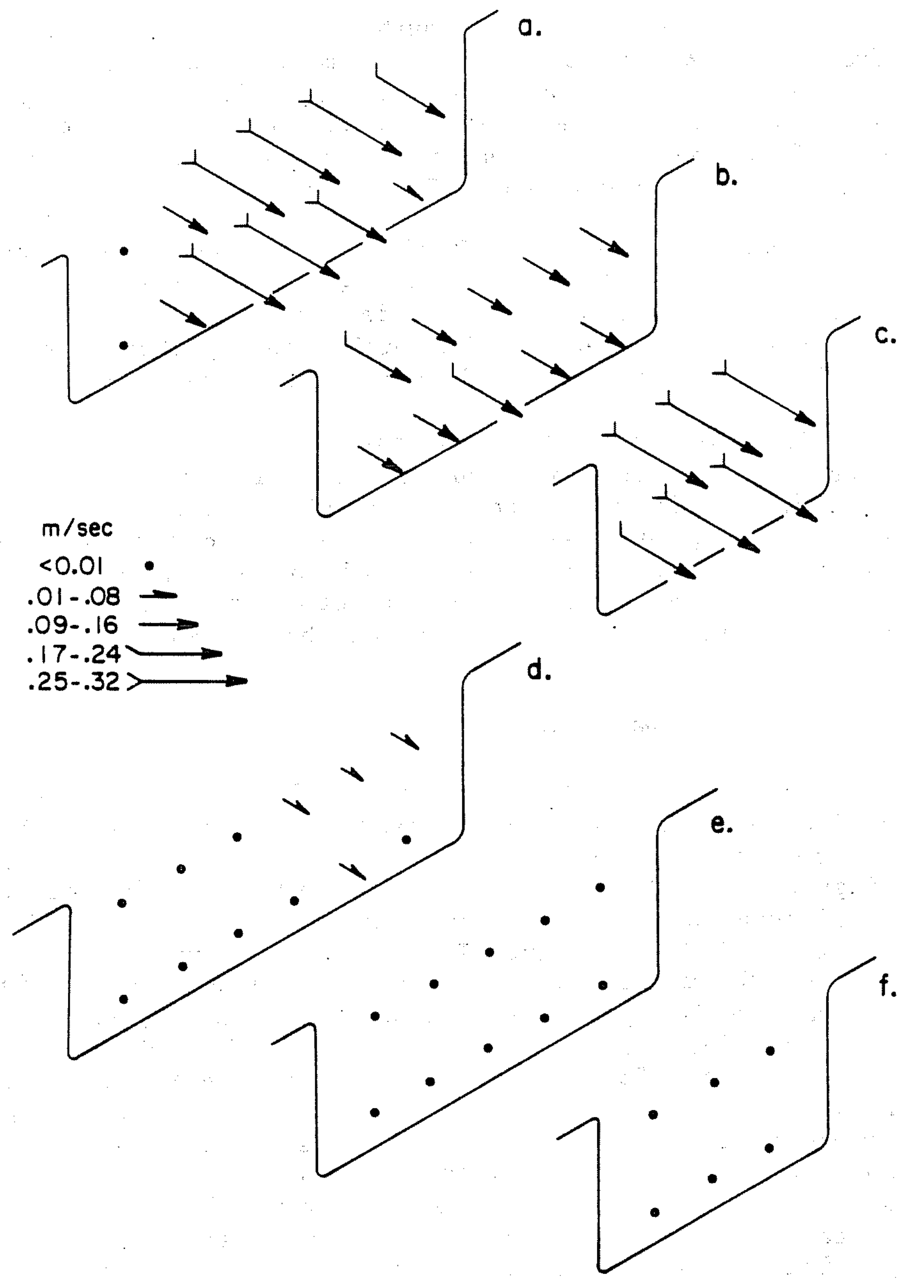

FIGURE I-3.9. Velocity Profile of 3G Canal

Velocity profile of 3G canal at 7 pump, high flow (a-c) and at 2 pump, low flow (d-f). Transects were located 100 m downstream from inlet (a,d) near canal midpoint (b,e) and immediately upstream of pumphouse training walls (c,f). Measurements were taken 0.5 m below the surface and 0.5 m above the bottom at 5-m intervals along the transect.

reactors. The rate of Savannah River water use by the SRP varies from about 8.5 m^3/s to about 26 m^3/s depending on the number of reactors operating and the corresponding reactor power levels. After use, the heated cooling water is discharged to the river via one of the onsite streams or discharged to recirculate through Par Pond with overflow to Lower Three Runs Creek.

Almost all of the SRP site is drained by tributaries of the Savannah River. Each tributary is fed by several small streams so that no location on the site is very far from a flowing stream. Only one small stream in the northeastern sector of the site drains to the Salkehatchie River instead of the Savannah River.

In addition to these streams, surface water is held in more than 50 artificial impoundments totaling over 4,000 acres. Par Pond is the largest with an area of about 2,700 acres and L Lake next with 1,000 acres. Water is retained intermittently in wetlands and in more than 200 natural basins, including some Carolina bays. A large swamp (about 10,000 acres) borders the Savannah River and is crossed by several of the streams.

I.3.4.1 Savannah River

The Savannah River drainage basin has a total area of 27,388 km^2 (10,579 square miles) and encompasses all or part of 41 counties in Georgia, South Carolina, and North Carolina (Figure I-3.10). The Savannah River Basin is located in three physiographic regions: the Mountain Province, the Piedmont, and the Coastal Plain (Figure I-3.11). The Mountain Province contains most of the major tributaries of the Savannah River, including the Seneca, Tugaloo, and Chattooga Rivers. The region is characterized by a relatively steep gradient, ranging from about 1,676 to 305 m, and includes 5,235 km^2 of the total drainage basin. The Mountain Province lies in the Blue Ridge Mountains, and has a bedrock composed of gneisses, granites, schists, and quartzites; the subsoil is composed of brown and red sandy clays. In this region the Savannah River and its tributaries have the character of mountain streams, with shallow riffles, clear creeks, and a fairly steep gradient. The stream bed is mainly sand and rubble, and the banks are sloping and grass-covered.

The Piedmont Region has an intermediate gradient, with elevations ranging from 305 to 61 m. This region includes 13,548 km^2 of the total drainage basin. Soils in the Piedmont are primarily red, sandy, or silty clays, with weathered bedrock consisting of ancient sediments containing granitic intrusions. The Piedmont is bordered by the Fall-Line, an area where the sandy soils of the Coastal Plain meet the rocky terrain of the Piedmont foothills. The city of Augusta, GA, is located near this line.

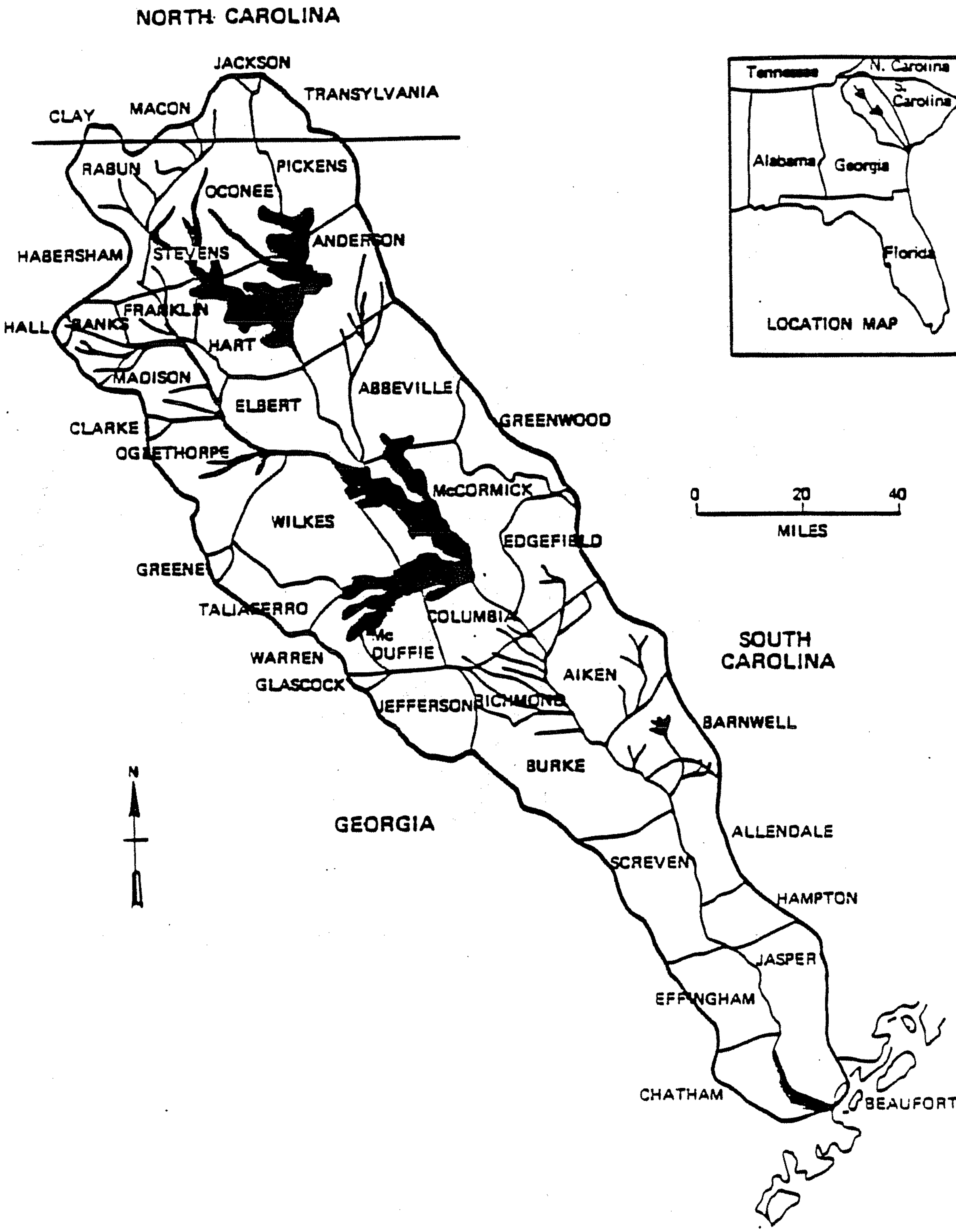

FIGURE I-3.10. Counties Included Within the Savannah River Drainage Basin

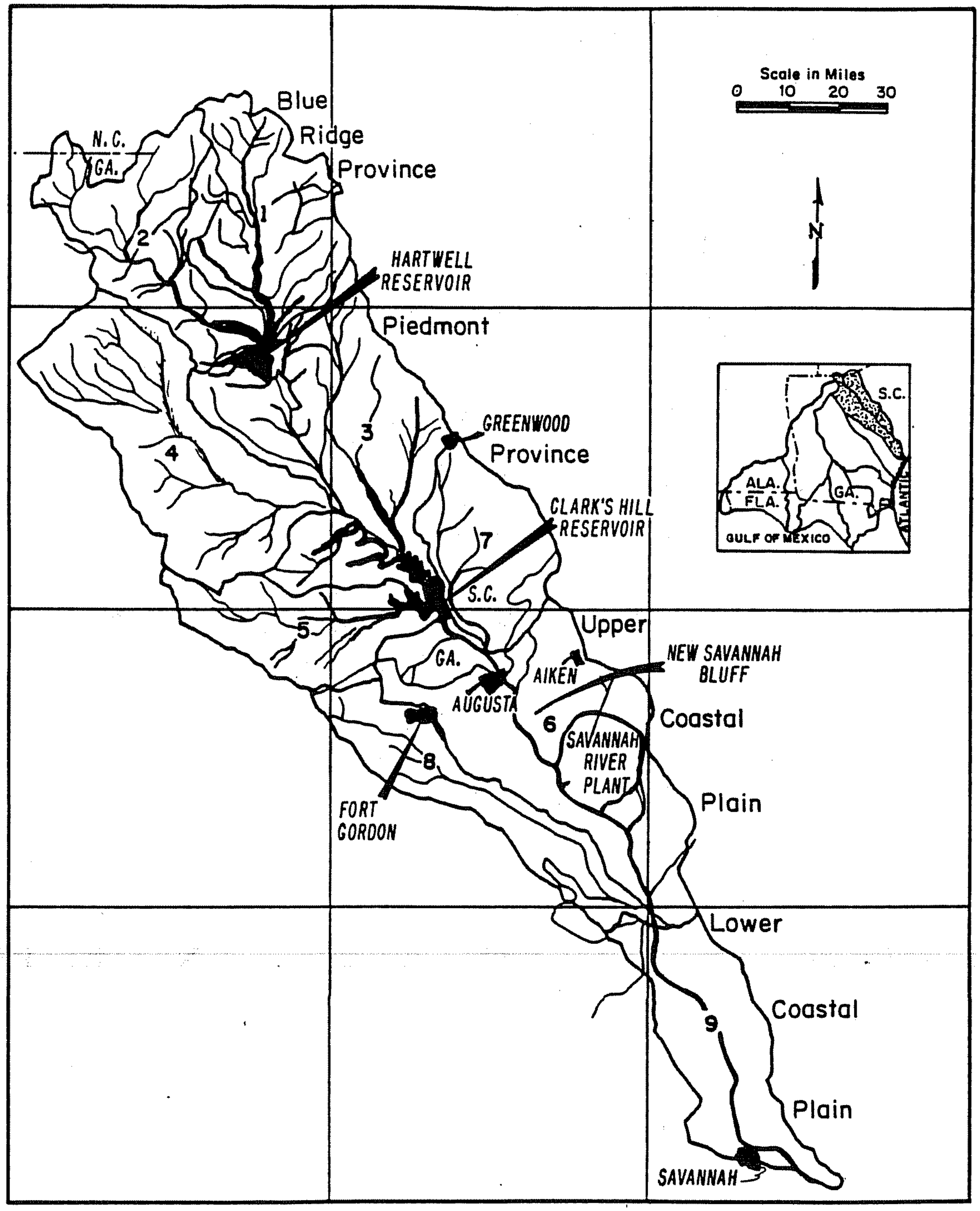

FIGURE I-3.11. Major Tributaries and Physiographic Regions Included in the Savannah River Drainage Basin

The Savannah River becomes more turbid in the Piedmont Region, picking up the majority of its silt load. The river often meanders, and, despite the stabilizing effect of Clarks Hill Dam, the outer banks on curves are relatively unstable. Sand bars are deposited downstream from many inside banks along the curves.

The Coastal Plain has a negligible gradient ranging from an elevation of 61 m to sea level. The soils of this region are primarily stratified silts, clays, and sands. The Coastal Plain contains 8,631 km^2 of the total Savannah River drainage area (27,388 km^2), and includes the city of Savannah, Georgia. In the Coastal Plain, the Savannah River is slow moving. Tidal effects may be observed near the mouth of the river, and a salt front extends upstream along the bottom of the riverbed. The riverbed is often muddy, and the river proper floods surrounding swamps.

Low flows in the Savannah River typically occur during the fall while high water occurs in late winter and early spring. Construction of upriver reservoirs and the new Savannah River Bluff Lock and Dam has stabilized the river flow at Augusta to a yearly average of 288.8 m^3/sec (DOE, 1984).

The water quality of the Savannah River and its tributaries varies considerably, ranging from clean to heavily contaminated with industrial and domestic effluents. Extensive discussion on river water quality is found in Volume II of this report.

Historically, the Augusta, North Augusta, and Aiken County areas have provided the major sources of pollution to the Savannah River in the area around the SRP. The city of Augusta did not have a secondary sewage treatment facility until 1975. Prior to that time most domestic and industrial wastes were discharged untreated or inadequately treated into the Savannah River, or into Hawks Gully, Butler Creek, and Spirit Creek, which flow into the Savannah River (Table I-3.5). In the North Augusta and Aiken County area, domestic and industrial effluents entered the Savannah River directly and via Horse Creek and Little Horse Creek (Table I-3.6). Treatment facilities for the North Augusta and Aiken County area were not in operation until 1979. The SRP also discharges waste water into the Savannah River. These discharges are primarily thermal effluents, but also include domestic and industrial wastes.

Hartwell Dam was completed in June 1962 and is located about 105 km upstream from the Clarks Hill Dam. A third large dam, the Richard B. Russell Dam lies between the Clarks Hill and Hartwell dams. Several other small dams are located along the river, including three near Augusta: New Savannah Bluff Lock and Dam (completed in 1937); Stevens Creek Dam (completed in 1914); and Augusta City Dam (rebuilt in 1863).

TABLE I-3.5

Partial List of the Savannah River Pollution Sources from the Augusta Area

Name of Industry	Const. Date	Type of Wastewater	Est. Vol. of Waste-water (m^3/s) Prior to 1970	Treatment prior to 1970*	Receiving Stream
Augusta Chemical Co.	NA	Organic, acidic, with sodium salts	0.006	Some neutral-ization	Camille St. ditch to Beaverdam ditch
Augusta Plating Co.	1966	Cd, Cr, Cu, Zn, cyanide plating wastes	0.004	None	Oates Creek
Augusta Waste Water Treatment Facility	1969	Domestic sewage, textile finishing wastes, chemical manufacturers wastes, slaughter-house wastes	0.35 (1.0 max. capicity)	Primary and chlorination	Butler Creek
Babcock & Wilcox	1928	Oil, kaolin, sawdust	0.006	Settling tank	Unnamed tributary to Rocky Creek
Buckeye Cotton Oil Div. of Buckeye Cellulose Corp.	1902	Suspended and floating organics, oils	0.01	None	Camille St. ditch to Beaverdam ditch
Burris Chemical, Inc.	1969	Cooling water & chloride solutions	0.005	Retention area	Savannah River
Castleberry's Food Co.	1926	Organic	NA	None	City sewer to Oates Creek
Columbia Nitrogen Corp. (Nitrogen Plant)	1963	Contaminated cooling water (ammonia), domestic wastes	NA	Containment and reuse, pH neutralization	Butler Creek
Columbia Nitrogen Corp. (Caprolactam Plant)	1963	Cooling water domestic wastes oil stripper bottoms	0.02	None (activated sludge in approx. 1975)	Savannah River
Continental Forest Industries	1960	Kraft pulp mill effluent	0.02	Settling ponds, aeration	Spirit Creek

* Most Augusta industries currently direct their wastewaters to the Augusta Waste Water Treatment Facility, which was improved in 1975 to provide secondary treatment. Columbia Nitrogen Corp. and Continental Forest Industries currently have their own secondary treatment facility.

NA = not available

TABLE I-3.5, Contd

Name of Industry	Const. Date	Type of Wastewater	Est. Vol. of Wastewater (m^3/s) Prior to 1970	Treatment prior to 1970*	Receiving Stream
E. I. du Pont de Nemours & Co.	1962	Inorganic caustics	NA	Settling ponds	Butler Creek
Graniteville Mills, Sibley Division	1870	Dye, slasher, and domestic	0.01	None	Water wheel tailrace to Savannah River
IMC (International Minerals & Chemicals)	1908	Cooling water and scrubber wastewater	0.00009	None	Oates Creek
J. P. King Mfg. Co.	1881	Dye, slasher, and domestic	0.001	None	Water wheel tailrace to Savannah River
Monsanto Company	1962	Cooling water, boiler blowdown	0.009	Cooling ditch	Ditch to Butler Creek
Olin Corp.	1964	Hg, chloride	0.11	Hg recovery and pH neutralization	Savannah River
Philadelphia Quartz Co.	NA	Inorganic caustics	0.0004	Two holding ponds	Savannah River
Riverside Mills	NA	Organic acidic	0.01	None	City sewer to Third Level Canal
Scott Meat Packers, Inc.	1939	Blood, washwater	0.005	None	Rocky Creek
Shapiro Packing Co., Inc.	1940	Organic	NA	Grease trap	Most of waste to sanitary sewers, small amount to Camille Street Ditch
Swift Fresh Meats Co.	1897	Organic	NA	Floor grates	Second Level Canal
Taylor-Piedmont Co.	NA	Creosote, oils	0.04	None	Rocky Creek

TABLE I-3.6

Partial List of the Savannah River Pollution Sources from the North Augusta and Aiken County Areas*

Name of Industry	Const. Date	Type of Wastewater	Est. Vol. of Wastewater (m^3/s) Prior to 1970	Treatment prior to 1970*	Receiving Stream
Aiken STP	1951 (improved 1963)	Domestic and industrial wastes	0.04	Secondary (trickling filter)	Kelly Creek
N. Augusta Sewer Outfall	NA	Domestic and industrial wastes	0.04	None	Savannah River
Bath Mill	1929	Domestic and industrial wastes	0.01	None	Horse Creek
Clearwater Finishing	1929	Finishing plant and domestic wastes	0.2	None	Little Horse Creek
Graniteville Mill	1890	Finishing plant wastes, chromium	0.2	None	Horse Creek
Kimberly Clark	1968	Domestic and industrial wastes	0.3	Retention lagoon	Savannah River
Seminole Mills	1924	Boiler blowdown air conditioning, wastewater, domestic wastes	0.002	None	Little Horse Creek
J. P. Stevens Co.	1966	Domestic and industrial wastes wool scouring wastes	0.02	None	Little Horse Creek
Valchem Chemical Co.	1947	Domestic and industrial wastes chromium, ammonia-N	0.07	None	Horse Creek
Warrenville STP	1946	Domestic and industrial wastes	0.01	Secondary (activated sludge)	Kelly Creek

* Most North Augusta and Aiken County industries currently direct their wastes to the Horse Creek Pollution Control Facility (constructed in 1979) for secondary treatment.

Dredging operations on the Savannah River have been conducted by the U.S. Corps of Engineers. This program, initiated in October 1958, was designed to dredge and maintain a 2.7 m navigation channel in the Savannah River from the city of Savannah to Augusta. A total of 61 sets of pile dikes were placed to constrict the river flow, thereby increasing flow rates, and a total of 11,477 linear meters of wood and stone revetment was laid to reduce erosion on banks opposite from the dikes. In addition, the channel was dredged, and 31 cutoffs were made, reducing the total river distance from Augusta to Savannah by about 24.1 km. The project was completed in July 1965; periodic dredging was continued to maintain the channel. A table of dredging dates and locations is included in Table I-3.7

I.3.4.2 Tributaries to the Savannah River on the SRP Site

The six principal streams on the SRP site are Savannah River tributaries. They arise on the Aiken Plateau and descend 30 to 61 m before discharging to the river. On the plateau, the streams are clear except during periods of high water. Rainfall soaks into the ground, and seepage from the sandy soil furnishes the streams with a rather constant supply (minimum 0.1 m^3/s) of water throughout the year. In addition, five of the onsite streams have historically received thermal discharges from cooling water operations. These discharges of thermal effluents, ranging from about 3 to 10 times the natural stream flows, have caused the streams to overflow their original banks along much of their length, cutting new and wider floodplains. The six principal tributaries are Upper Three Runs Creek, Beaver Dam Creek, Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek.

I.3.4.2.1 Upper Three Runs Creek

Upper Three Runs Creek, the longest of the plant streams, differs from the other five onsite streams in two respects: it is the only stream with headwaters arising outside the plant site, and it is the only stream that has never received heated discharges of cooling water from the production reactors or coal-fired powerhouse.

Upper Three Runs Creek drains an area of over 500 square kilometers (Figure I-3.12). Its significant tributaries are Tinker Creek, a rather lengthy headwater stream, and Tims Branch, which receives industrial wastes from the fuel fabrication facilities (M Area) and the Savannah River Laboratory. Typical surface discharges to Tims Branch from A and M Areas include nonprocess cooling water, steam condensates, process effluents, and treated groundwater effluents. In addition, three tributaries of Upper

TABLE I-3.7

Savannah River Dredging Activities, 1964 Through 1974 (Partial Listing)

Dates		River Miles Dredged
1964	Dec. 7-10	176.0 - 175.4
	Dec. 10-12	175.2 - 174.8
	Dec. 13	165.5
	Dec. 14-17	158.4 - 159.0
	Dec. 18-22	158.1 - 157.2
	Dec. 23-30	141.3 - 140.8
	Dec. 31	137.3 - 136.8
1965	Jan. 2-5	135.6 - 135.3
	Jan. 5	129.2
	Jan. 6	118.7 (Rt. 301 Bridge)
1966	April 22-25	173.8*
	April 26 - May 2	162.0*
	May 3-4	151.0*
	May 4-9	149.0*
	May 9-10	144.0*
	May 11-12	126.0*
	May 12-13	124.5*
1967	June 3-5	197.9 - 179.8
	June 6-16	179.8 - 175.0
	June 17-22	175.0 - 174.3
	June 22 - July 9	174.3 - 169.0
	July 10 - Aug. 4	169.0 - 135.0
	Aug. 4-10	135.0 - 134.4
	Aug. 10	128.4
	Aug. 11	59.4
1968	Sept. 8	Above 167.1
	Sept. 9	167.1
	Sept. 24-25	151.3 - 151.1
	Sept. 26	144.2 - 144.1
	Sept. 27	136.5 - 136.3
	Sept. 26 - Oct. 4	129.3 - 128.9
	Oct. 5-6	124.6 - 124.0
	Oct. 6-7	114.5 - 114.2

* Only average river mile values were available.

TABLE I-3.7, Contd

Dates		River Miles Dredged
1970	Aug. 21-27	179.7
	Aug. 28 - Sept. 9	151.3
	Sept. 10-23	150.8
	Sept. 24-29	149.6 - 149.4
	Sept. 30 - Oct. 8	149.3 - 149.0
	Oct. 9-14	148.5 - 148.3
	Oct. 15-22	146.6 - 146.2
	Oct. 23-29	145.7 - 145.4
	Oct. 30 - Nov. 12	128.4 - 128.2
	Nov. 13-19	124.4 - 124.2
	Nov. 20	78.6 - 78.4
1973	Oct. 22-30	187*
	Oct. 31 - Nov. 2	183.1*
	Nov. 3-6	151.3*
	Nov. 7-24	149.4*
	Nov. 25	148*
	Nov. 26 - Dec. 1	146*
	Dec. 2-4	144*
	Dec. 5-7	136*
	Dec. 8	117*

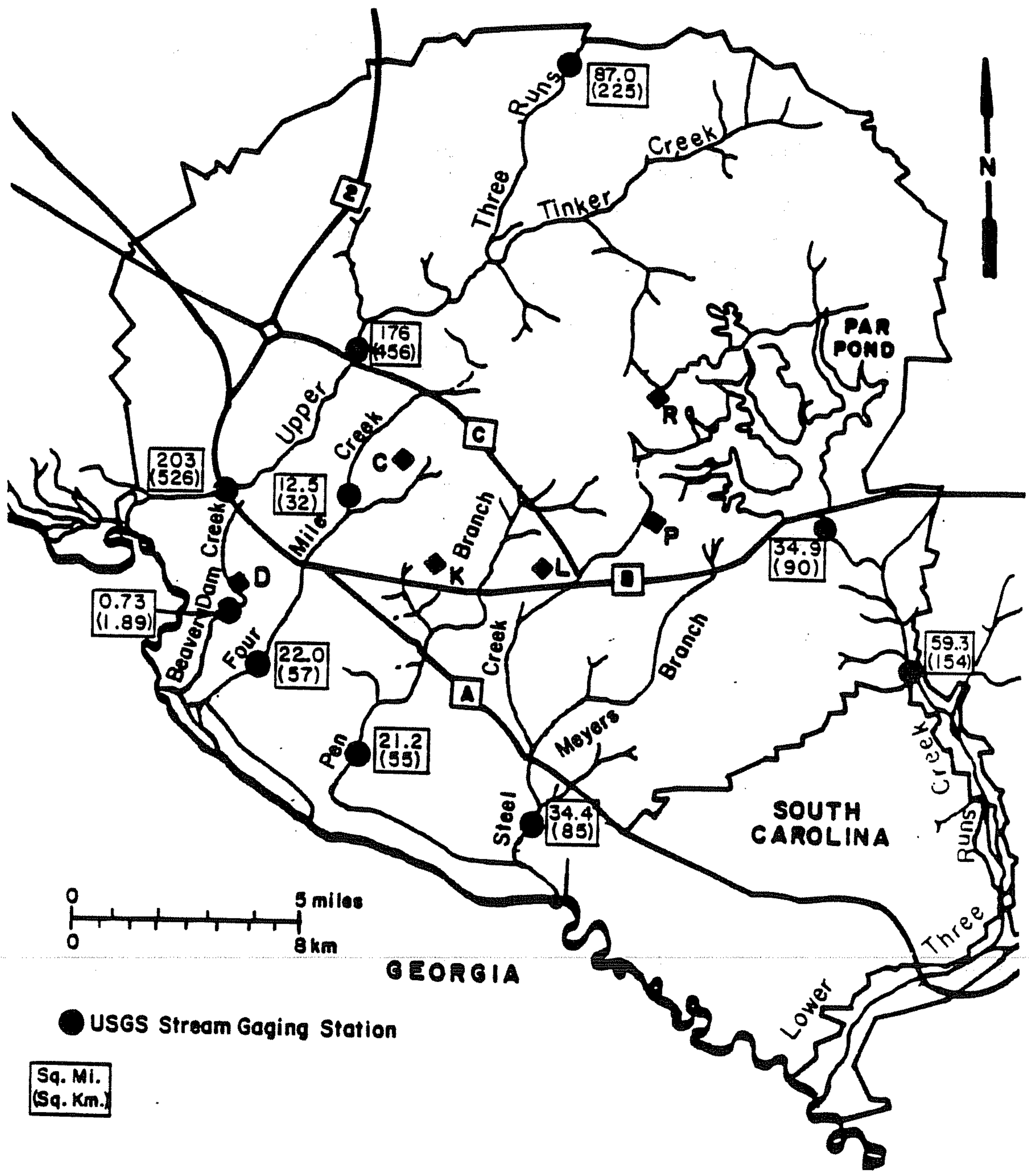

FIGURE I-3.12. USGS Flow Recorders and Drainage Areas on SRP Streams

Three Runs Creek from the F and H Separations Areas carry ambient temperature cooling water, steam condensate, powerhouse washdown waters and ash disposal basin effluents.

Upper Three Runs Creek is designated as a National Hydrologic Benchmark Stream by the United States Geological Survey (USGS) of the U.S. Department of the Interior. Mean flow rates generated by USGS flow recorders along Upper Three Runs Creek (Figure I-3.12) during the period 1972-1981 at US 278, SRP Road C, and SRP Road A were 3.2, 5.5, and 7.5 m^3/s, respectively. The minimum flow rates recorded at these sites during this ten-year period were 1.4, 3.2, and 3.7 m^3/s, respectively. The maximum flow rates associated with significant precipitation events during this ten-year period were 10.5, 19.9, and 25.7 m^3/s, respectively (Lower, 1982).

I.3.4.2.2 Beaver Dam Creek

Beaver Dam Creek was not identified in the 1951-1953 study of SRP streams by the University of South Carolina and may have been an intermittent flowing stream prior to SRP operation. The stream is located 1.6 to 3.2 km west of Four Mile Creek, flowing in a southwestern direction from the D Area through the swamp to the Savannah River. Beaver Dam Creek formerly was the receiving water body for the effluent from both the heavy water production plant and the coal-fired generating station which supplies D Area steam and a large fraction of SRP-generated electrical power. The heavy water production plant in D Area was placed on standby in 1982. Currently Beaver Dam Creek receives condenser cooling water from the coal-fired powerhouse, neutralization waste water, sanitary waste water, ash basin effluent waters, and various laboratory waste waters.

Since June 1974, a flow recorder located 1.6 km downstream from 400-D Area in Beaver Dam Creek (Figure I-3.12; drainage area 1.89 km^2) has recorded a mean discharge of 2.4 m^3/s and a range of flows of 1.2 to 5.6 m^3/s for the period 1974-1982 (Lower, 1982).

I.3.4.2.3 Four Mile Creek

Four Mile Creek follows a generally southwesterly path to the Savannah River for a distance of about 24 km. In the swamp along the river, part of the creek flow empties into Beaver Dam Creek, a much shorter stream that discharges into the river. The remainder of the Four Mile Creek flow discharges through an opening in the levee between the swamp and river, seeps through the levee into the river, or flows down the swamp and mixes with the flows from Steel Creek and Pen Branch.

Four Mile Creek and Beaver Dam Creek together drain about 90 square kilometers and receive discharges from five plant areas. From the Separations Areas, the upper reach of Four Mile Creek receives powerhouse waste water, cooling water, steam condensate, and sanitary treatment plant waste water discharges. Reactor cooling water from C Area is discharged to Four Mile Creek. Small quantities of ambient-temperature cooling water and automotive shop effluents are also discharged to Four Mile Creek from the Central Shops (CS) Area. The average flow upstream of any plant discharge is about 0.015 m^3/s and is increased by F, H, and Central Shops effluents and drainage to about 0.6 m^3/s just upstream from the confluence with the C-Reactor discharges. After the junction with the C-Reactor cooling water, the creek flows about 11 km before entering the river swamp at flow rates exceeding 11 m^3/s during periods of C-Reactor operation.

I.3.4.2.4 Pen Branch

Pen Branch follows a path roughly parallel to Four Mile Creek until it enters the river swamp (Figure C-12). The only significant tributary to Pen Branch is Indian Grave Branch, which flows into Pen Branch about 8 km upstream from the swamp. Pen Branch enters the swamp about 5 km from the river, flows directly toward the river for about 2.4 km, and then turns and runs parallel to the river for about 8 km before discharging into Steel Creek about 0.8 km from its mouth.

Pen Branch with Indian Grave Branch drains about 56 square kilometers of watershed upstream from the swamp. Indian Grave Branch receives the effluent cooling water from K Reactor. Upstream of K-Area discharges, Indian Grave Branch flow averages only about 0.03 m^3/s and Pen Branch proper is also a small stream averaging 0.1 to 0.3 m^3/s.

In addition to reactor cooling water effluents from K Area, discharges to Pen Branch proper and to Indian Grave Branch include nonprocess cooling water, ash basin effluent waters, powerhouse waste water, waste treatment plant overflow, reactor process waste water and sanitary waste water, all of which effluents are associated with K-Area operations. The only additional continuous surface discharge to Pen Branch is a small overflow from the sewage treatment basin at the Central Shops Area near the Pen Branch headwaters.

Since November 1976, a USGS flow recorder has been maintained at SRP Road A-13.2 on Pen Branch (Figure I-3.12; drainage area 55 km^2). During the period 1976-1982, the flow at this station ranged from a minimum of 0.6 m^3/s during a K-Reactor outage to a maximum of 26.9 m^3/s during simultaneous K-Reactor operation and a heavy precipitation event. During water-year 1982, the mean flow rate at this station was 10.8 m^3/s, which indicates the magnitude of reactor cooling water discharges on resulting Pen Branch flow rates.

I.3.4.2.5 Steel Creek

Steel Creek flows southwesterly for about 7.2 km, then turns to flow almost due south for about 8.8 km, and enters the river swamp 3 to 5 km from the river. In the swamp, it is joined by the flow from Pen Branch and part of the flow from the Four Mile Creek.

The drainage area of Steel Creek and its main tributary, Meyers Branch, is about 90 square kilometers. Steel Creek has received cooling water discharges from two reactors. It currently receives only about 0.4 m^3/s of process waste waters and sanitary treatment waste waters at about natural temperature from P Area. The discharge of cooling water effluent from P Reactor to Steel Creek was discontinued in 1963 when this reactor was switched to cooling with recirculated water from Par Pond; thermal discharge from L Reactor ceased in 1968 when the reactor was placed in standby condition. L Lake was constructed on Steel Creek in 1985 and thermal discharges from L Reactor were introduced into L Lake in the fall of 1985.

Discharges to Steel Creek at present result from P-Area, L-Area, and Railroad Yard (Y-Area) discharges. These effluents are discharged to Steel Creek proper or to Meyers Branch, the principal tributary of Steel Creek. Types of discharges to Steel Creek at present include ash basin effluent water, nonprocess cooling water, powerhouse waste water, reactor process effluents, sanitary treatment plant effluents, water treatment plant waste waters, and vehicle wash waters.

Since March 1974, the USGS has maintained a continuous flow recorder on Steel Creek at Old Hattiesville Bridge, which is located about 0.8 km of the confluence with the onsite swamp (Figure I-3.12; drainage area 85 km^2). During the period 1974-1982, the minimum recorded flow was 0.24 m^3/s and the maximum flow was 13 m^3/s. In water year 1982 the mean discharge at this station was 1.5 m^3/s (Lower, 1982).

I.3.4.2.6 Lower Three Runs Creek and Par Pond

Lower Three Runs Creek has the second largest watershed of these SRP streams (about 460 square kilometers). Near its headwaters a large impoundment, Par Pond, has been formed by the construction of an earthen dam. The three main arms of the pond follow the stream bed and drainage areas of the upper reaches of Lower Three Runs Creek and its tributaries, Poplar Branch and Joyce Branch. From the dam, Lower Three Runs Creek flows in a southerly, then southwesterly course for about 32 km to the Savannah River. Several small tributaries arising off the plantsite flow into the creek in its lower reaches.

Before construction of Par Pond, effluent cooling water from R Reactor was discharged via Joyce Branch to Lower Three Runs Creek. Following the completion of Par Pond construction in 1958, the overflow to Lower Three Runs Creek has varied, depending on the use of the pond cooling water system by R and P Reactors. In 1964, R Reactor was shut down and placed in standby condition. Even when both R and P Reactors were using the pond, the temperature of the pond overflow water was near ambient. During periods of no overflow, about 0.15 m^3/s seeps through and under the dam to enter Lower Three Runs Creek (Jacobsen et al., 1972). When the pond is thermally stratified (primarily during the warmer months) this seepage is usually several degrees cooler than the surface water in the pond.

The Par Pond impoundment covers 2,640 acres to an average depth of about 6 m. The maximum depth near the dam is about 17 m. A 140-acre portion is separated from the main body by a dam to form the Pond C "precooler", which is part of the P-Reactor effluent canal system. There are three major arms in Par Pond (Figure I-3.13): the north or upper arm; the middle arm; and the south or lower arm.

The canal systems for conducting the effluent cooling water from P and R Reactors to Par Pond are also shown in Figure I-3.13. The P canal system is currently in use, but the R system has not received thermal discharges since 1964. From P Reactor there are 6.8 km of canals and 5 small impoundments. The largest impoundment besides the 140-acre precooler covers 36 acres; the total surface area of the small impoundments and canals is 227 acres. The now-unused R canal system consists of about 5.6 km of canals and two impoundments, 7.4 and 260 acres in size, respectively. The total surface area of the system is 285 acres.

In addition to reactor cooling water effluents from P Reactor, Par Pond receives only minor effluents from the P-Area water treatment plant and the Par Pond Laboratories. Extensive discussion of Lower Three Runs Creek and Par Pond is found in Volumes II, III, and VII of this report.

Since May 1974, a USGS flow recorder has been maintained in Lower Three Runs Creek below the Par Pond overflow at SRP Road B. During the period 1974-1982, the average flow at this station was 0.9 m^3/s. The maximum flow recorded at this location was 4.3 m^3/s and the minimum flow was about 0.02 m^3/s (Lower, 1982).

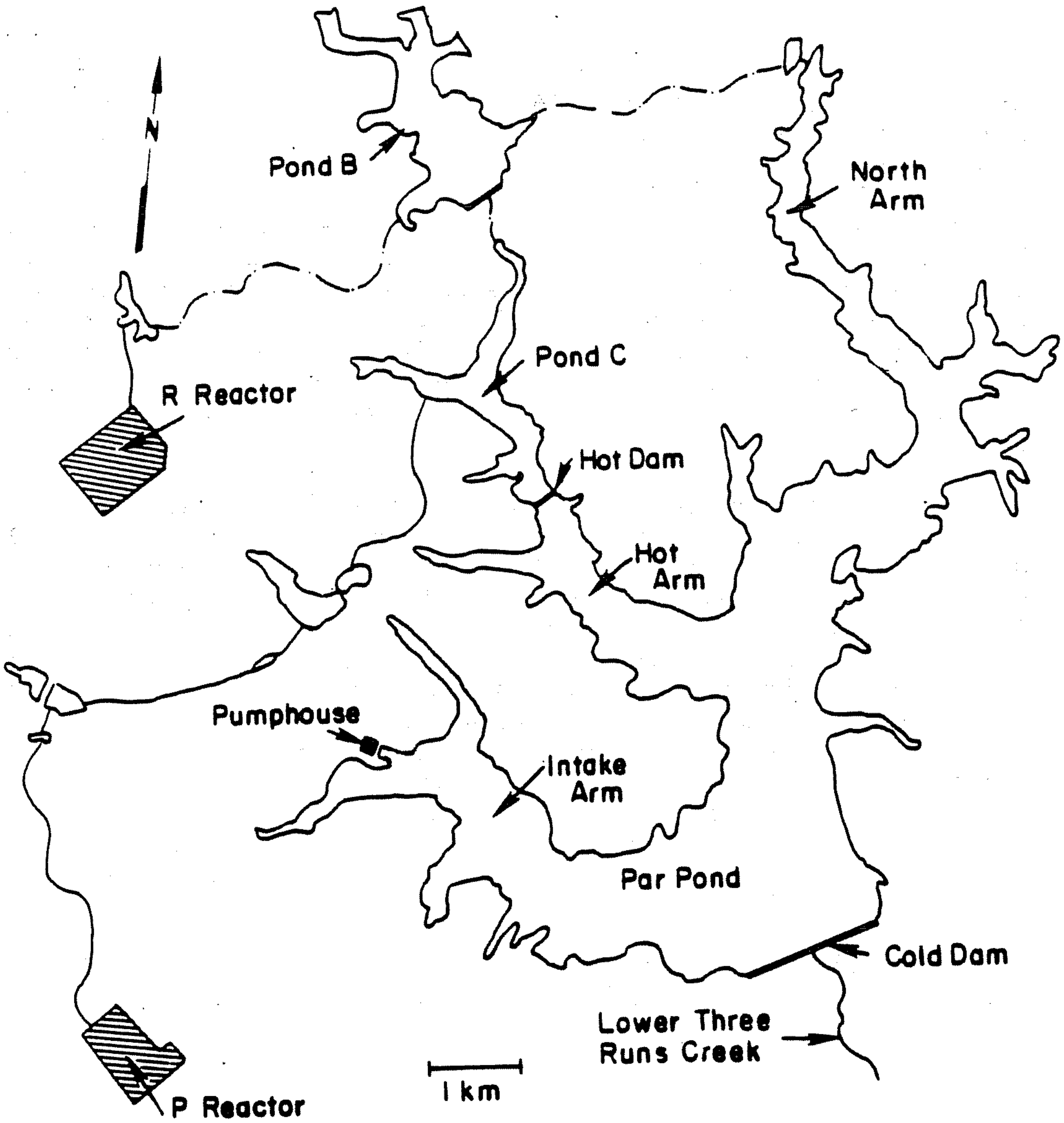

FIGURE I-3.13. The Par Pond System

A second USGS gaging station has been maintained near Pattersons Mill on Lower Three Runs Creek (Figure I-3.12) since March 1974. During the period 1974-1982, the average flow at this station was 2.6 m^3/s. The maximum flow recorded at this station was 20.8 m^3/s and the minimum flow was 0.4 m^3/s (Lower, 1982).

I.3.4.2.7 SRP Savannah River Swamp

On the SRP, a swamp lies in the floodplain along the Savannah River for a distance of about 16 km and averages about 2.4 km wide. A small embankment or natural levee has built up along the north side of the river from sediments deposited during periods of flooding. On the SRP site of the levee, the ground slopes downward, is marshy, and contains large stands of cypress-tupelo forest and bottomland hardwoods. During periods of high river level (about 27 m), river water overflows the levee and stream mouths and floods the entire swamp area, leaving only isolated islands that are also inundated during extremely high water levels. When flow subsides, stagnant pools of water remain, but even with the pools and meandering channels, much of the substrate in the swamp is inundated to shallow depths.

Three breaches in the natural levee allow discharge of creek water to the river - the mouths of Beaver Dam Creek, Four Mile Creek, and Steel Creek. The Beaver Dam Creek discharge contains the effluent from the D Area coal-fired powerhouse plus part of the Four Mile Creek flow. A second break in the levee forms the mouth of Four Mile Creek. During swamp flooding, the water from these streams flows through the swamp parallel to the river and combines with the Pen Branch flow. Pen Branch does not discharge directly to the river, but flows through the swamp and joins Steel Creek about 0.8 km above the Steel Creek mouth. However, during river flooding events, flows from Steel Creek and Pen Branch are also diverted parallel to the river, flow across the offsite Creek Plantation swamp and ultimately join the Savannah River flow near Little Hell Landing.

Each of the program elements of the Comprehensive Cooling Water Study places extensive focus on gathering ecological data from the onsite swamp system.

I.3.5 Summary

The Savannah River Plant (SRP) was acquired by the U.S. Government in the early 1950s to construct a facility for production of nuclear materials for United States weapons programs. Most major nuclear material production related facilities were completed and operational by 1954. These facilities included a fuel fabrication facility, five production reactors, two chemical separations facilities to remove and purify the required radioisotopes, a heavy water moderator production facility, and a coal-fired electricity/ steam generation facility. Administrative and support facilities were also constructed.

Initially, all five production reactors, the coal-fired power plant, and the heavy water facility were cooled in a once-through mode using water pumped through three intake structures located on the Savannah River. After passing through the reactor heat exchanger systems (where heat is passed from the primary coolant/ moderator systems to the secondary coolant), the heated secondary cooling water was released into the nearest surface stream through an engineered discharge canal. Both the volume of water pumped and the temperature of the discharged effluent tended to increase through the 1950s as reactor power levels were increased. At peak power levels, SRP reactors discharge approximately 11 m^3/sec of cooling water at 70 to 75°C.

Numerous changes in reactor operations occurred between 1958 and 1968 with respect to the withdrawal and release of Savannah River water for cooling purposes. Par Pond was constructed in 1958 to provide recirculating cooling for R and subsequently P Reactors. Previously, R Reactor had discharged cooling water into Joyce Branch, a tributary of Lower Three Runs Creek. An engineered canal system, including two precooler ponds, carried cooling water into the North Arm of Par Pond until 1964 when R Reactor was placed on standby.

P Reactor discharged cooling water into the upper portions of Steel Creek until 1963. Beginning in 1963, cooling water from P Reactor was discharged into the Middle Arm of Par Pond after passing through a series of canals and precooler ponds. Both reactors, when operating, received cooling water from an intake structure in the south arm of Par Pond. Currently, about 10% of total reactor cooling water requirements must be pumped from the Savannah River to replace losses by evaporation and seepage through the Par Pond Dam into Lower Three Runs Creek.

L Reactor discharged cooling water into Steel Creek from its initiation of operations in 1954 until it was placed on standby in 1968. Thus, from 1954 until 1963, Steel Creek received cooling water effluents from both L and P Reactors. Since the restart of L Reactor in October 1985, once-through cooling water is being discharged into a 405 hectare (ha) cooling pond (L Lake) constructed on the headwaters of Steel Creek. After passing through the lake, L-Reactor discharge water follows the Steel Creek channel to the Savannah River.

K Reactor (1954) and C Reactor (1955) have discharged cooling water into Pen Branch and Four Mile Creek, respectively, since their operations began. The upstream portions of Four Mile Creek also receive nonthermal effluents from the separations facilities in F and H Areas.

Cooling water for the coal-fired power plant and heavy water production facilities in D Area was discharged into Beaver Dam Creek. While the production reactors discharge approximately 11 m^3/sec (400 ft^3/sec) at 70°C, combined discharges from the D Area are approximately 3 m^3/sec (130 ft^3/sec) at approximately 30°C. Discharge volumes and temperatures were reduced somewhat in 1982 when the heavy water production facility was shut down. Beaver Dam Creek also receives surface runoff and possibly ground-water seepage from coal piles and fly ash basins associated with the power plant operation.

Four of the five major stream systems on the SRP have received reactor effluents. Beaver Dam Creek, a lesser drainage system, has received cooling water releases of a smaller magnitude than those creeks associated with reactor operations (Four Mile Creek, Pen Branch, Steel Creek, Lower Three Runs Creek). Only Upper Three Runs Creek has not received cooling water effluent. Four SRP streams that have received cooling water releases drain into the SRP Savannah River swamp, a 3,800 ha riverine swamp forest bordering the Savannah River and contained within the SRP boundaries. Flows from Upper Three Runs and Lower Three Runs Creeks discharge directly into the Savannah River, but these streams have relatively little swamp forest development near the creek mouths.

Water flow patterns through the SRP Savannah River swamp are complex and change depending on water levels in the Savannah River. Flows from Beaver Dam and Four Mile Creeks are each associated with distinct breaks in the river levee between the swamp and the Savannah River. Water temperatures are sometimes higher at the mouth of Beaver Dam Creek then they are upstream near D Area, suggesting that some of the flow from the nearby Four Mile Creek merges with Beaver Dam Creek flow.

Most of the flow from Four Mile Creek enters the swamp and travels in a generally southeast direction before entering the Savannah River after an approximately 3 kilometer (km) traverse through the swamp. As noted, a portion of this flow appears to enter the Savannah River along with Beaver Dam Creek water, and a portion of the Four Mile flow continues southeast through the swamp and exits through the next substantial break in the river levee near Steel Creek.

There is no break in the river levee associated with the flow of Pen Branch into the swamp. Rather, flows from Pen Branch enter the swamp and move southeasterly approximately 6-8 km to join with the flow from Steel Creek and exit the swamp.

Flow from Steel Creek enters the swamp and moves through numerous channels across the post-thermal delta for approximately 3 km before entering the Savannah River along with the flow from Pen Branch and part of the flow from Four Mile Creek.

These flow patterns for Beaver Dam Creek, Four Mile Creek, Pen Branch, and Steel Creek are substantially altered when the Savannah River is in flood stage (approximately 28 m above mean sea level). When the Savannah River floods, water entering the swamp from these four creeks is forced along the northeastern, upland margin of the swamp and enters the Savannah River main channel downstream from Steel Creek near Little Hell Landing.

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