Chapter 6

Wetlands and Carolina Bays of SRS

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

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6.1 Sitewide Wetland Resources

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Sitewide Wetland Resources

The SRS Savannah River swamp borders 16 km (10 mi) of SRS on the southwest. Bottomland hardwood forests border the six streams that drain SRS. Other SRS wetlands include Carolina bays, former cooling-water canals and reservoirs, former farm ponds, and freshwater marshes. The main streams on SRS are Upper Three Runs, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs. SRS cooling water discharges have influenced all of these streams except Upper Three Runs. The discharges, as much as 10 to 20 times the natural flows, overflowed the streams' original banks along much of their length, scouring upstream sediments and depositing them in deltaic fans where the streams enter the river swamp. This reduced or modified the original bottomland hardwood forests along much of Fourmile Branch, Pen Branch, and Steel Creek.

SRS wetlands support a variety of vegetation species and forms. Species that are characteristically dominant in a given wetland type may differ depending on whether the wetland is undisturbed, has received thermal effluents, or is undergoing successional revegetation following cessation of cooling-water releases. Also, in wetlands undergoing successional revegetation, species may differ depending on the stage of succession.

Recent Sitewide Wetland Inventory

Several inventories of SRS wetlands have been developed using aerial photography (Mackey et al. 1985; Shields et al. 1982; Schalles et al. 1989). Shields et al. (1982) reported that approximately 199 Carolina bays exist on SRS, and Mackey et al. (1985) indicated that wetlands cover more than 21% of the site. More recently, Kirkman et al. (1996) increased that count to 299 Carolina bays and bay-like depressional wetlands. The primary wetland cover types summarized in Mackey et al. (1985) are bottomland hardwood forest, cypress-tupelo swamp forest, scrub-shrub areas, emergent marsh, and open water. Most of the cypress-tupelo swamp forest is in a part of the Savannah River swamp. Scrub-shrub and emergent marsh areas are found in post-thermal areas of the SRS Savannah River swamp and in the post-thermal streams (Fourmile Branch, Pen Branch, and Steel Creek) along the shoreline of the former cooling reservoirs, and in Carolina bays.

Table 6-1 summarizes the estimated areas of wetland types on SRS as derived from a landcover and landuse geographic information system (GIS) database developed from multidate aerial photography taken in the late 1980s (Guber 1993). Most of the pond/reservoir class in Table 6-1 is from the Par Pond system and L Lake. Figure 6-1 is a map of the wetlands as derived from the landcover and landuse GIS database. As with all photographic surveys, these aerial estimates and maps provide guidance to locations and types of wetlands on SRS; however, field verification would be needed for detailed mapping and wetland delineation. Figure 6-2 identifies the USGS quadrangle sheets available for SRS. The GIS information has been plotted on these 7.5 in. maps and is used by scientists studying SRS wetlands.

Table 6-1. Estimate of Current SRS Wetlands Derived from Landcover and Landuse Geographic Information System (GIS) Database and of Historic SRS Wetlands Derived from 1943 and 1951 Black and White Aerial Photography[a]

Wetland Class[b]	Historic Area (ha)[c]	Recent Area (ha)
bottomland hardwood	15,077.1	13,823.7
swamp forest	2,340.7	2,331.7
scrub-shrub	1,548.1	843.1
emergent wetlands	407.7	519.4
aquatic beds		85.9
intermittent flooded		51.2
non-vegetated wetland		24.8
Carolina bay		15.0
open water	438.2	
pond/reservoirs		1,528.9
Savannah River		381.9
streams		138.4
canals		45.5
other waterways		29.7
drained wetlands	319.5	
total	20,131.3	19,819.2

[a]Landcover and landuse Geographic Information System recently derived wetland classes are those as described in Ezra and Tinney 1985, Guber 1993. Historic area based on estimates by Christel-Rose 1993.
[b]Direct comparisons are not possible because of the quality and resolution of the two data sets.
[c]To convert hectares to acres, multiply by 2.471.

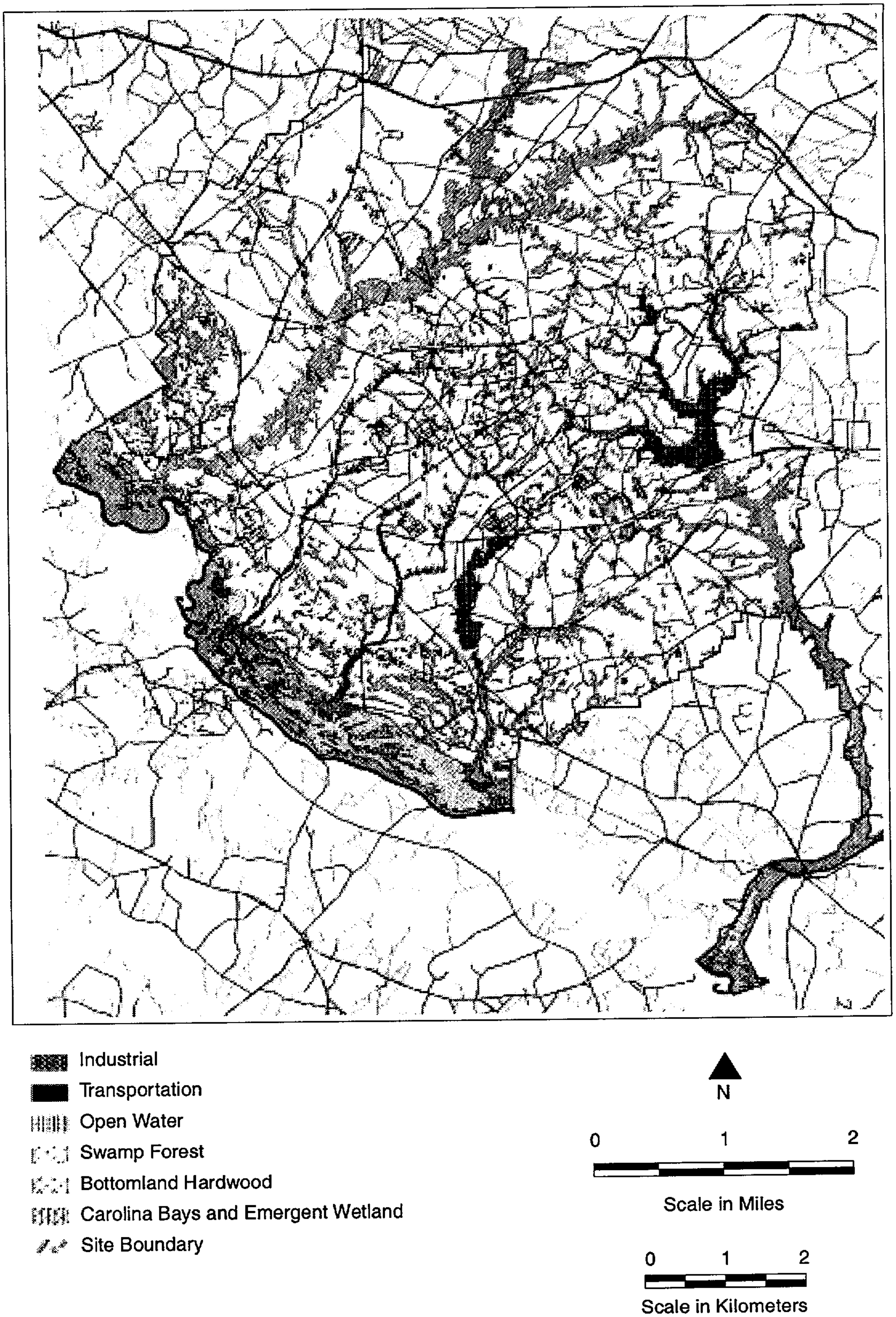

Figure 6-1. Sitewide Wetlands Map

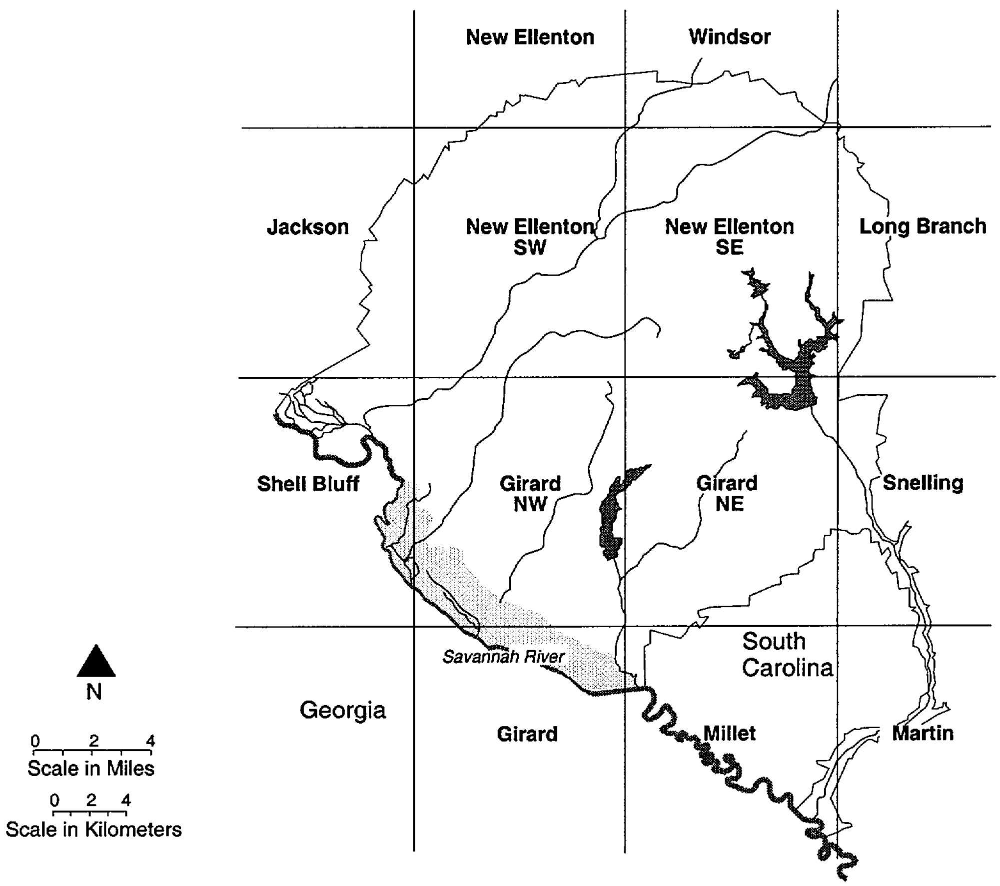

Figure 6-2. SRS Map Showing Names of USGS Quadrangles

Pre-SRS Wetland Distribution

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

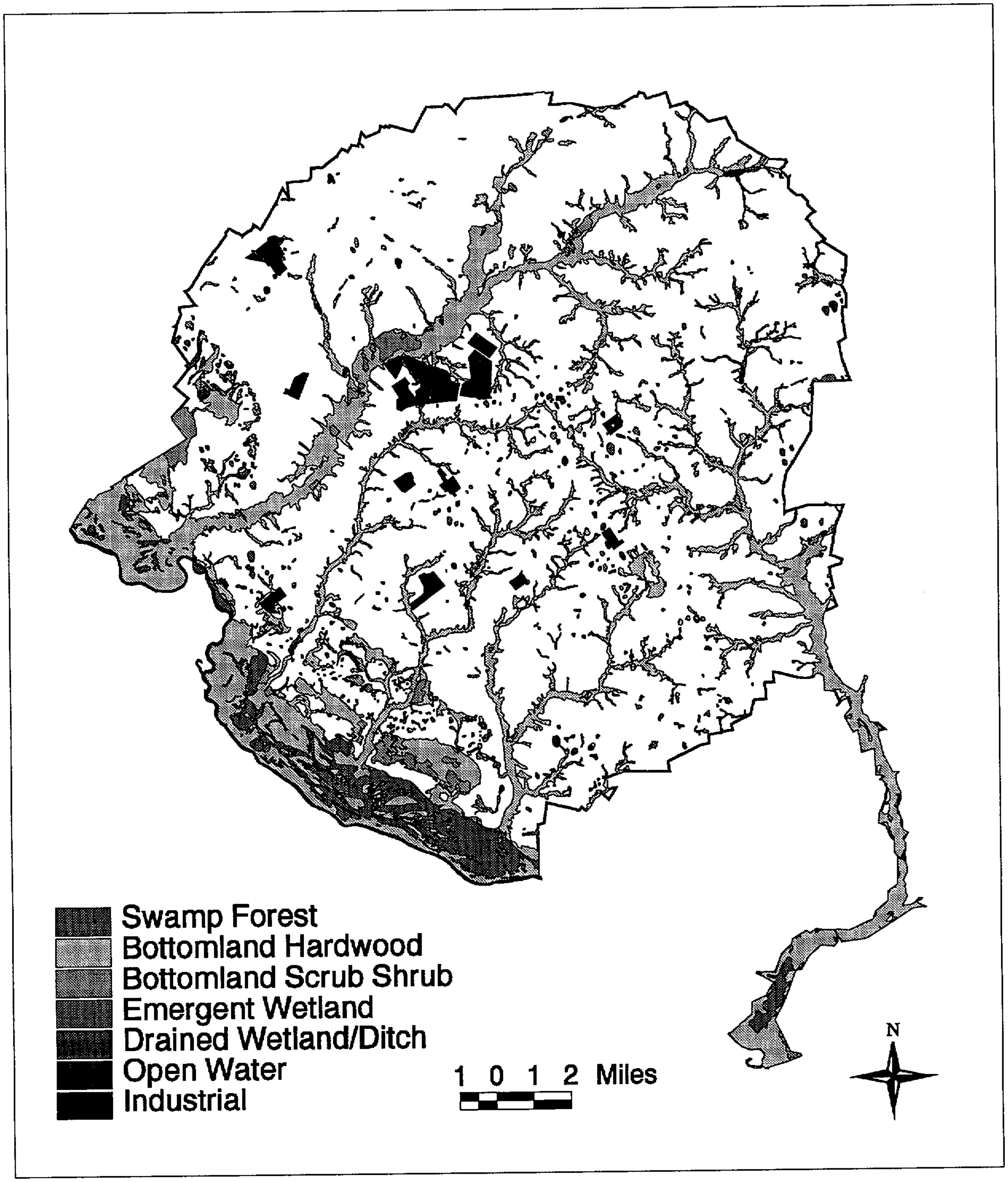

Figure 6-3. Area Wetlands Before Establishment of SRS

6.2 SRS Savannah River Swamp

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SRS Savannah River Swamp

Introduction

About 3800 ha (9390 acres) of the Savannah River swamp lie within SRS between Upper Three Runs Creek and Steel Creek; this area is referred to as the SRS Savannah River swamp. The SRS Savannah River swamp borders the Savannah River for approximately 16 km (10 mi) and has an average width of about 2.2 km (1.4 mi) (Figure 6-4). A levee and embankment run along the east side of the Savannah River. Breaches in the levee allow water from Beaver Dam Creek, Fourmile Branch, and Steel Creek to flow to the river. The combined discharges of Steel Creek and Pen Branch enter the river near the southeast edge of the SRS Savannah River swamp.

On the landward side of the levee, the Savannah River swamp contains stands of cypress (*Taxodium distichum*) and tupelo (*Nyssa aquatica*) trees, bottomland hardwoods, scrub-shrub, and open marsh areas. During periods of high water, river water overflows the levee and floods the swamp. The river begins to overflow into the swamp when river elevations reach between 27 and 28 m (88.5 and 92 ft) above mean sea level (MSL) or at flows of about 15,300 cfs. During flooding, the water from SRS streams flows through the swamp parallel to the river and enters the river downstream of Steel Creek.

A variety of environmental pertubations influence the wetlands community structure of the SRS Savannah River swamp. Like most riverine swamps of the southeastern United States, this forest was logged selectively. Virtually all of the swamp was dominated by second-growth timber in the early 1950s. When SRS initiated operations, the swamp was characterized primarily by a closed-canopy forest of bald cypress and water tupelo in the deep water

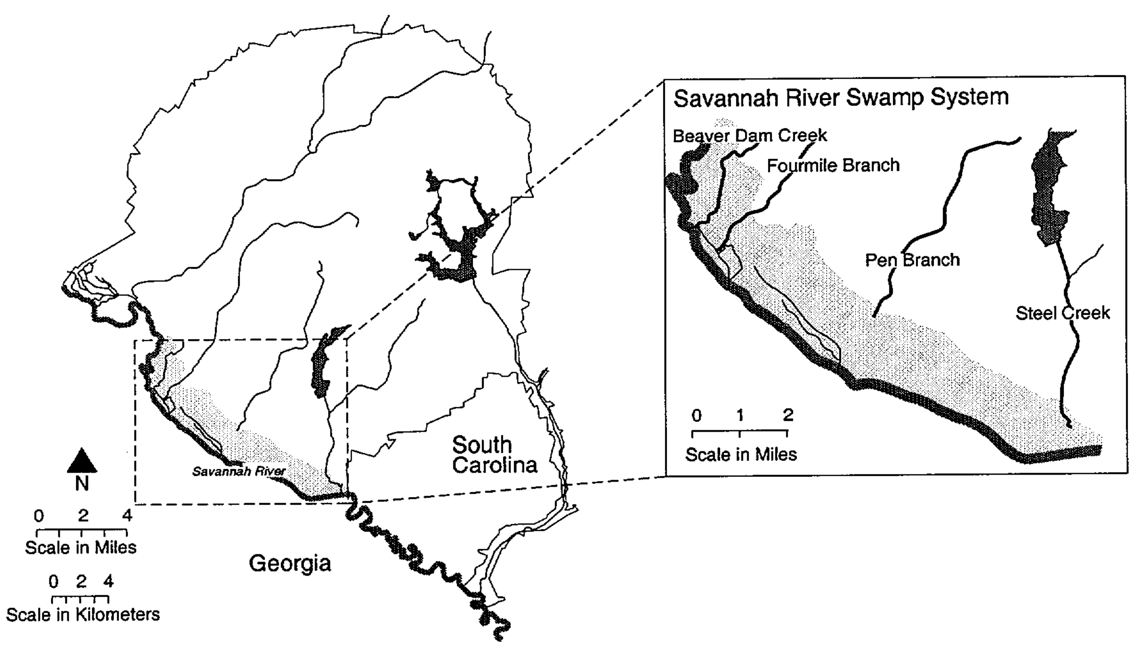


Figure 6-4. Location of the SRS Savannah River Swamp

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

The SRS Savannah River swamp currently receives thermal effluent from the D-Area power plant and formerly received thermal effluent from C Reactor (until late June 1985), K Reactor (until summer 1988), and L Reactor via L Lake (until summer 1988). The discharge of cooling-water effluents from the SRS reactors and the coal-fired power plant modified the SRS Savannah River swamp in several ways. Deposition of sediment from erosion associated with increased flow to creeks formed sedimentation deltas in the swamp (Figure 6-5) (Ruby et al. 1981). Water temperatures in those portions of the swamp near where thermal effluents entered the swamp exceeded the thermal tolerances of most vascular plant species and caused extensive forest mortality (Sharitz et al. 1974b; Tinney et al. 1986; Mackey 1987). Finally, the input of increased volumes of cooling water from the creeks into the SRS Savannah River swamp modified the hydrologic regime of the system. Flood-control activities on the Savannah River further influenced this change in hydrologic regime (Figure 6-6). Examination of long-term discharge fluctuations in the Savannah River revealed that following construction of Lake Strom Thurmond in the early 1950s, water levels in the river have been neither as high nor as low as they were prior to dam construction. SRS effluent discharges maintained relatively higher water levels in the SRS Savannah River swamp near the deltas throughout the year. Dry periods necessary for extensive regeneration of the dominant woody swamp-forest species seldom occurred under this modified hydrologic regime (Sharitz et al. 1986).

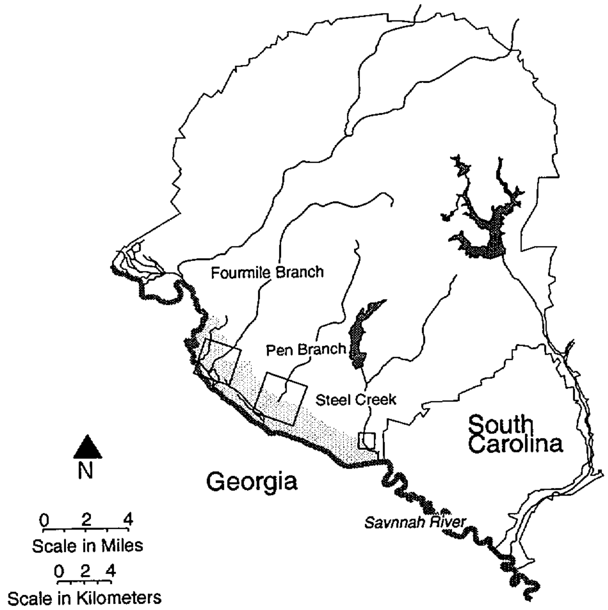
General Wetland Patterns of the SRS Savannah River Swamp

Pre-SRS Logging of the Swamp

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

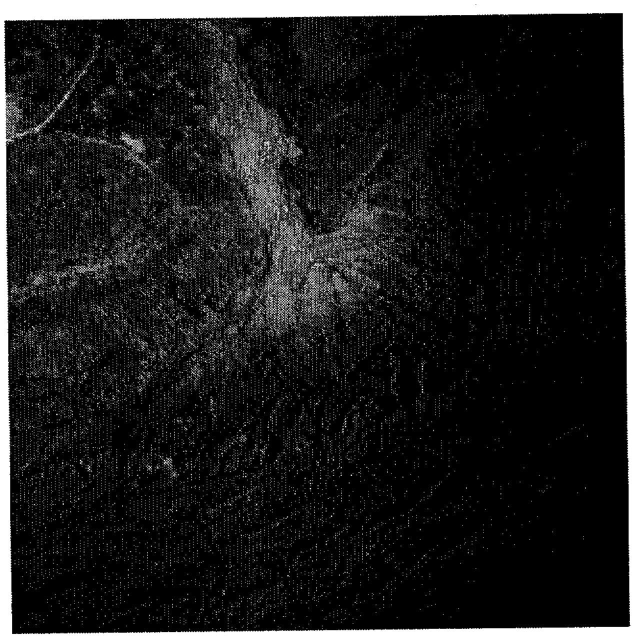
Lumbering was an important industry in early America and exploitation of the abundant swamp and bottomland-forest resources for export rendered barrel staves and heads from the oaks; shingles from the durable cypress wood; building lumber, turpentine, pitch, and tar from loblolly pine; and naval stores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

The swamp forests at SRS remained intact until the early part of this century due to the difficulty in accessing the swamp. The Leigh Banana Case Company was the primary company timbering the SRS Savannah River swamp. Located at Leigh, SC, south of the junction of South Carolina Highway 125 and Road B, the company produced veneer and vegetable crates. To access the best timber of the SRS Savannah River swamp, 14 miles of track, (two-thirds on trestles), were constructed (Fetters 1990). From these railroads, outriders on mules

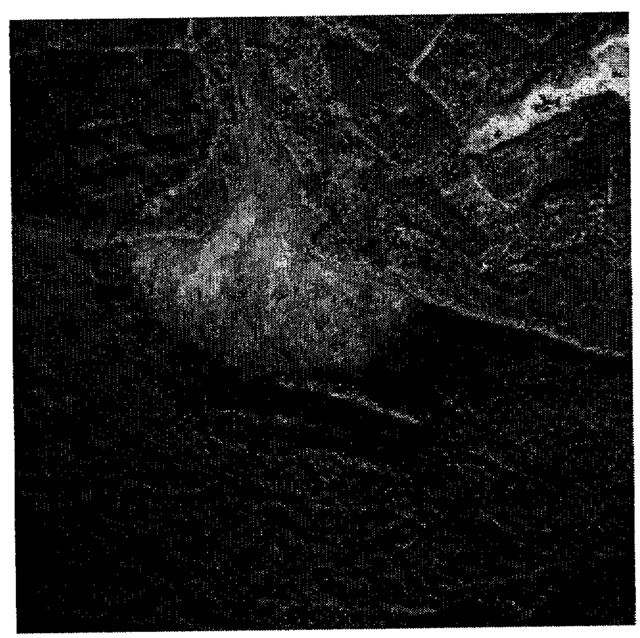


Approximate Locations of Photographs

Fourmile Branch Delta (1986)



Pen Branch Delta (1981)



Steel Creek Delta (1974)

Figure 6-5. Sediment Fans at the Fourmile Branch Delta Area (1986), the Pen Branch Delta Area (1981), and the Steel Creek Delta Area (1974)

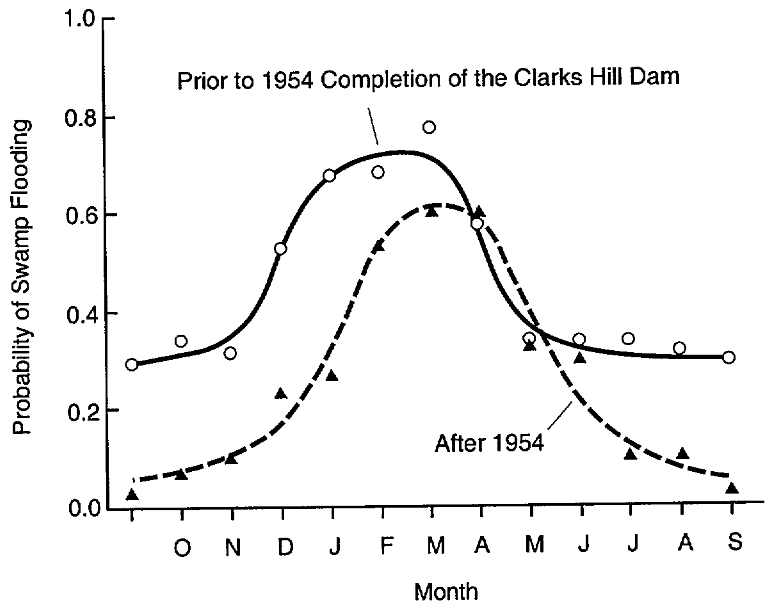


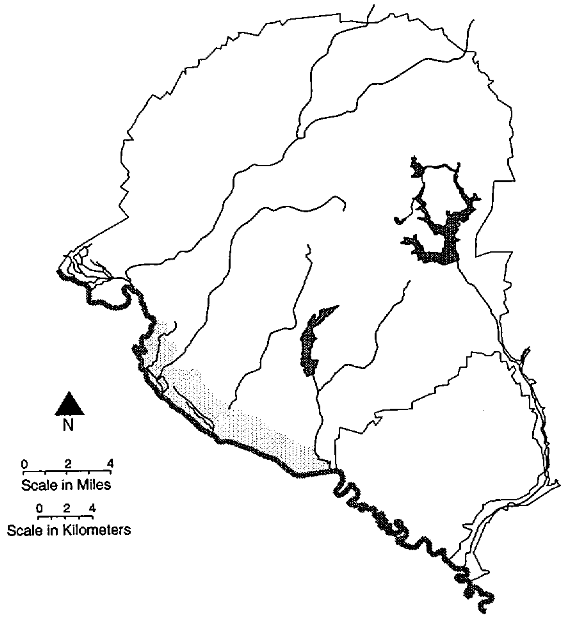
Figure 6-6. Monthly Probabilities of the Savannah River Flooding

hauled logging chains or "snakes" into the woods. These were attached to logs, hauled back by the "snaker," and loaded onto railroad cars. Dikes were built at breaks in the levee along the Savannah River to lower the water level in the swamp, and roads were constructed along and outward from the railroad. Staging areas were established at points along the railroad to which the logs were snaked. Railroad, staging areas, and haul lines allowed greater access to the bottomland hardwoods and created distinctive patterns in the swamp that are distinguishable on the historical aerial photography.

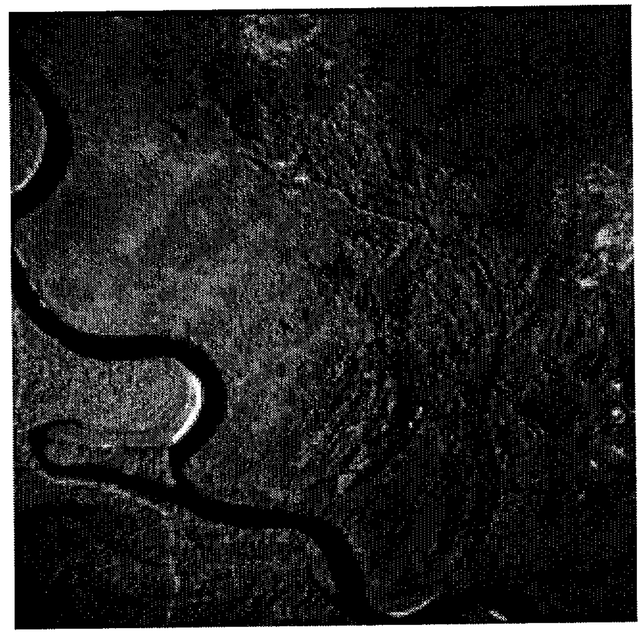
Logging operations started in earnest in the upper SRS Savannah River swamp after the turn of the century. Standard 1:20,000 scale, black-and-white, vertical aerial photography of the SRS swamp in 1938 shows extensive lumbering. The extent of later logging was evident in aerial photography from 1943 and 1951. With the purchase of SRS in 1951 by DOE's predecessor, the Atomic Energy Commission, lumbering operations ceased. Logging did take place in the swamp between Beaver Dam Creek and the Savannah River in the early 1970s (Figure 6-7), but its related data are not included in this report.

The timbering features in the swamp in 1938, 1943, and 1951 were classified as railroad, logging roads, drag points (the staging areas to which logs were hauled), haul lines, and an areal boundary of harvested land (Figure 6-8 through Figure 6-10). Buffers were generated around the roads, drag points, and haul lines to approximate the area of disturbance for each year (Figure 6-11 through Figure 6-13). Estimates of land disturbed by lumbering in the swamp were calculated for each year to provide an estimate of lumbering impact prior to SRS. These totals are presented in Table 6-2.

The data derived from the aerial photography indicate that the 3800-ha (9400-acre) SRS Savannah River swamp had been disturbed by lumbering activities prior to the government



Approximate Area of Coverage



Beaver Dam Creek Area

Figure 6-7. Timber Harvest in the Savannah River Swamp West of Beaver Dam Creek

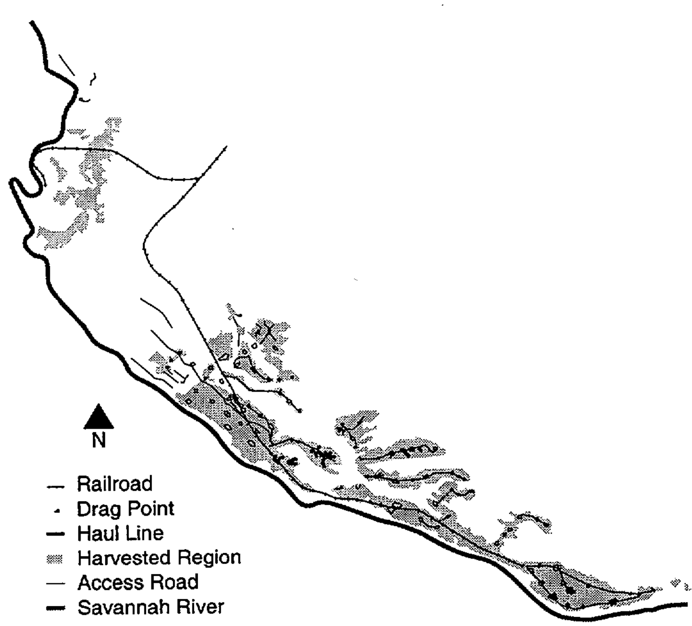


Figure 6-8. Timber Harvesting Activities in the SRS Savannah River Swamp (from 1938 Aerial Photography)

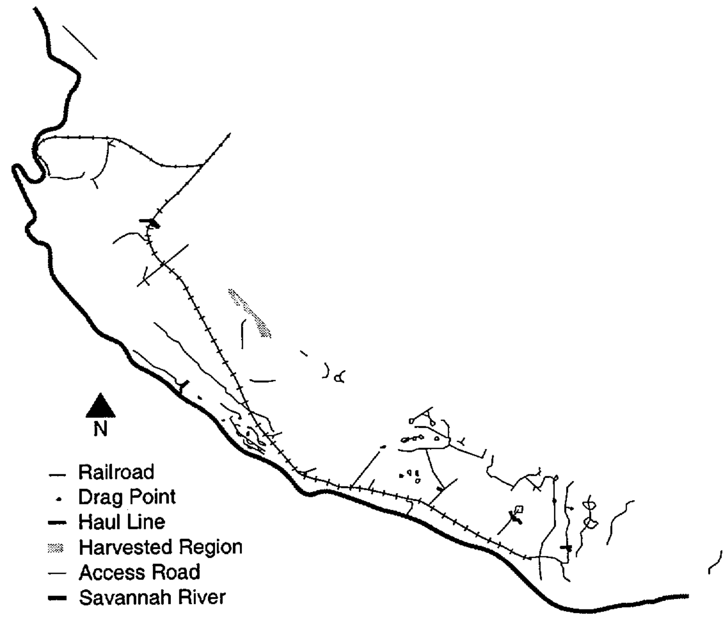


Figure 6-9. Timber Harvesting Activities in the SRS Savannah River Swamp (from 1943 Aerial Photography)

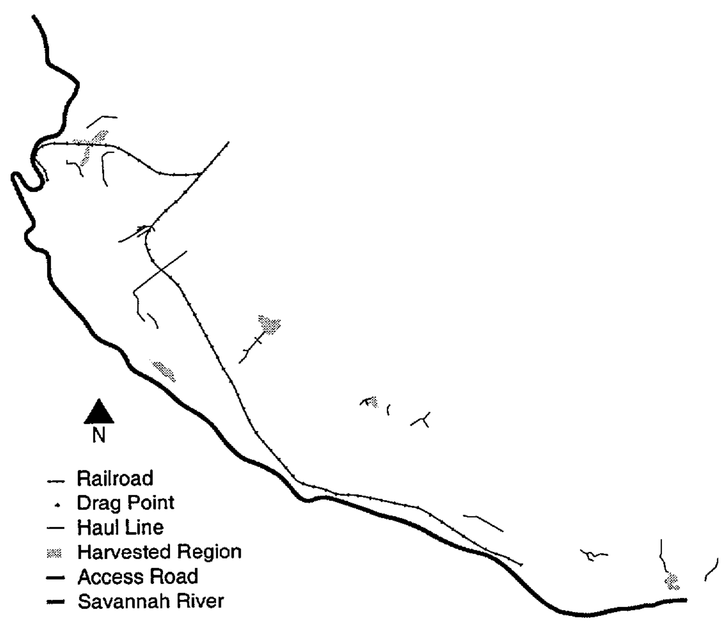


Figure 6-10. Timber Harvesting Activities in the SRS Savannah River Swamp (from 1951 Aerial Photography)

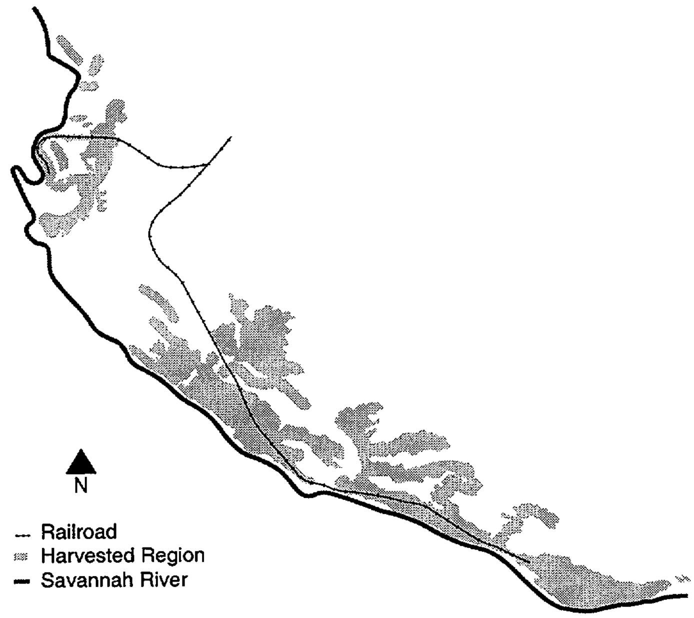


Figure 6-11. Estimate of Lumbered Areas within the SRS Savannah River Swamp (from 1938 Aerial Photography)

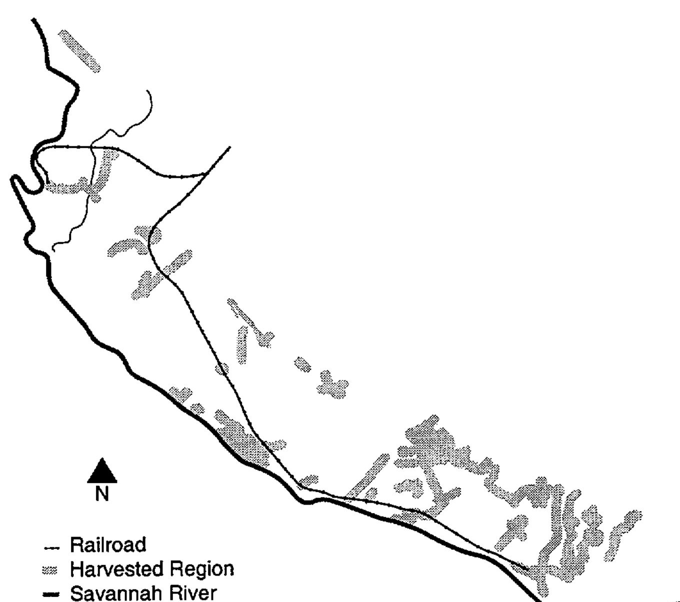


Figure 6-12. Estimate of Lumbered Areas within the SRS Savannah River Swamp (from 1943 Aerial Photography)

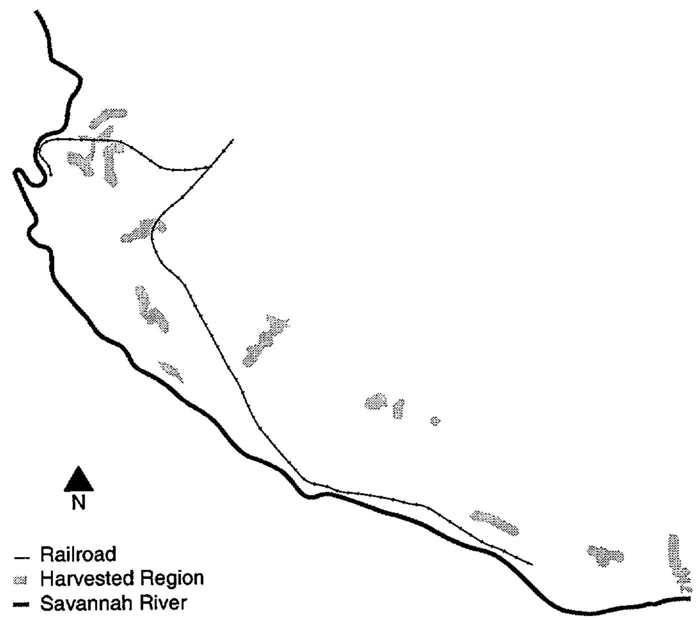


Figure 6-13. Estimate of Lumbered Areas within the SRS Savannah River Swamp (from 1951 Aerial Photography)

Table 6-2. Areal Estimates of Pre-SRS Lumbering in the SRS Savannah River Swamp

Year	Buffered Lumbered Zones (Hectares)[a]	Harvested Areas (Hectares)[a]	Total (Hectares)[a]
1938	1,100	1,116	1,488
1943	856	17	871
1951	229	32	241
Total			2,600

[a]To convert to acres, multiply by 2.471.

purchase. The 1973 aerial photography shows that additional areas were lumbered after SRS was established. In total, approximately 2296 ha (5670 acres) was directly or indirectly impacted by lumbering operations (Burkhalter 1994). This lumbering information can be combined with photographic and image-change detection data, delta sedimentation data, and data on effects of previous thermal effluents to provide a more complete picture of the current SRS swamp environment.

Wetland Communities of the SRS Savannah River Swamp

The composition of the SRS Savannah River swamp forest has been examined extensively. Repaske (1981), Whipple et al. (1981), and Smith et al. (1981, 1982) have provided summaries of the wetland community structure of the swamp. Gladden et al. (1985) also studied the swamp in 1983 and 1984. These data provided information on density, size class (relative basal area), and importance values of woody species distributed throughout disturbed and relatively undisturbed portions of the SRS Savannah River swamp (Table 6-3). In addition, since 1981, numerous remote sensing surveys have been conducted of the swamp, which provide evaluations of changes in specific areas of the swamp largely influenced by cooling water effluents from SRS operations (Brewster and Tinney 1984; Christensen et al. 1986, 1988; Ezra et al. 1986; Jensen et al. 1983, 1984, 1986a and b, 1987; Tinney et al. 1986; Mackey 1990, 1993; Blohm 1993).

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

Each site was assigned a relative value of 1 to 3 based on a hydrologic scale (1 = deeply and continuously flooded, 2 = shallowly and continuously flooded, 3 = occasionally flooded) and on a perturbation scale (1 = tree mortality characteristic of natural swamp, 2 = low perturbation with slight tree mortality, 3 = high perturbation and high tree mortality). Based on these scalars, the swamp forest communities are distributed along two major environmental axes: a water depth or hydrologic gradient and a disturbance gradient. Thus, in Figure 6-14, quadrats symbolized by squares or triangles show no or low levels of disturbance. Quadrats symbolized by circles are highly disturbed and contain no or almost no species representative of the original swamp forest. Open symbols represent sites occurring in areas of only occasional flooding. Partially darkened or completely darkened symbols represent quadrats at shallow or deeply flooded sites (Gladden et al. 1985).

The two-way indicator species analysis (Hill 1979b) separated the swamp forest into major wetlands community types (Figure 6-15). Deciduous bottomland hardwood forests occur in areas that are slightly elevated and better drained and that are flooded only occasionally during the year. These communities are dominated by a mixture of oak species (*Quercus nigra,*

Table 6-3. Importance Values[a] of Dominant Woody Species in the SRS Savannah River Swamp[b]

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

Source: Gladden et al. 1985.

[a] Importance value (Curtis and McIntosh 1950) = relative density + relative dominance (as percentage).
[b] All values are prior to reactor shutdowns beginning in 1985.
[c] N = number of plots sampled.

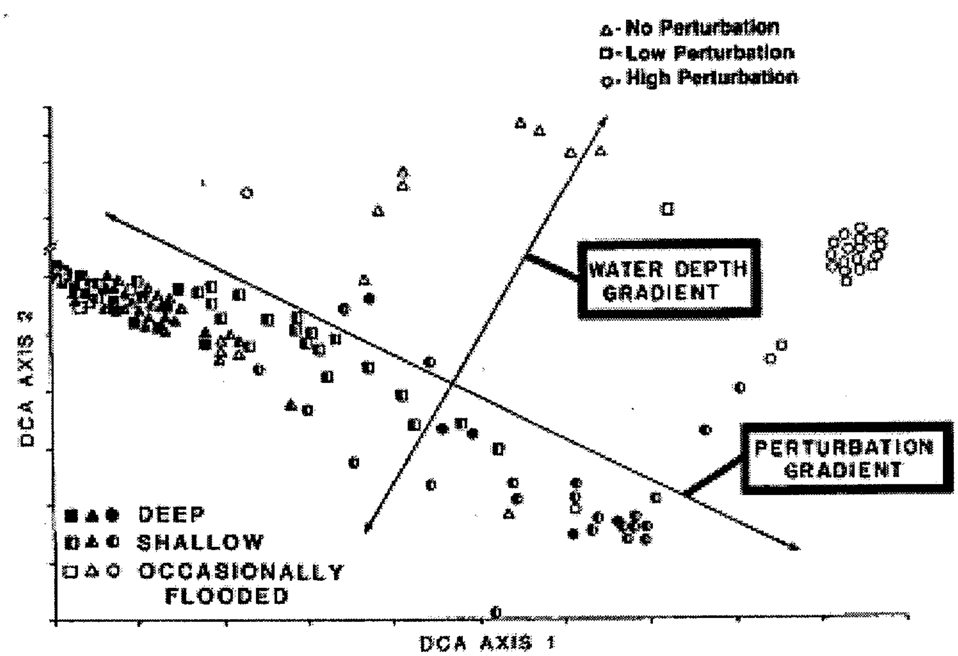


Figure 6-14. Detrended Correspondence Analysis Ordination of Forested and Shrub-Dominated Sites in the SRS Savannah River Swamp (Source: Gladden et al. 1985)

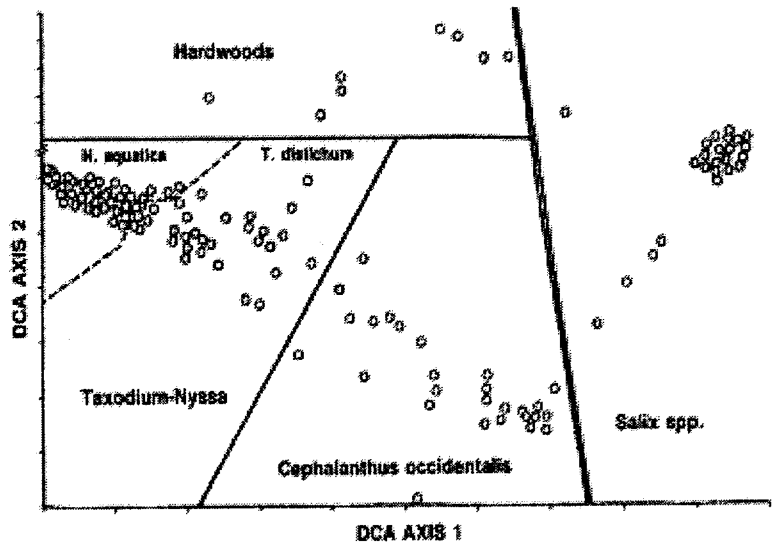


Figure 6-15. Two-Way Indicator Species Analysis of the SRS Savannah River Swamp Forest Data Indicated on Detrended Correspondence Analysis Ordination (Source: Gladden et al. 1985)

Q. laurifolia, Q. michauxii, Q. lyrata), as well as red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), ash (*Fraxinus caroliniana and F. americana*), and other hardwood species. The wetness of the substrate appears to control the species composition of the understory. Sweet bay (*Magnolia virginiana*), tulip poplar (*Liriodendron tulipifera*), and hollies (*Ilex* spp.) are found in drier localities, while red bay (*Persea borbonia*) and ironwood (*Carpinus caroliniana*) occur in stands with longer periods of soil saturation. Greenbrier (*Smilax* spp.) and woody vines are common (Gladden et al. 1985).

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

Woody plant community types occurring in the most highly disturbed areas are dominated by successional scrub-shrub species, such as willow (*Salix* spp.) and buttonbush (*Cephalanthus occidentalis*). These scrub-shrub communities occur where the original swamp forest has been eliminated, but where water temperatures are not too high to preclude the growth of woody species. Willow-dominated scrub-shrub communities tend to occur on sand bars or on occasionally flooded sites; buttonbush-dominated scrub-shrub communities occur on sites with deeper water and represent the early successional invasion of deeper

water sites (Gladden et al. 1985). The understory of the buttonbush community contains nonpersistent emergent wetland species such as hydrolea (*Hydrolea quadrivalvis*), aneilema (*Aneilema keisak*), waterpepper (*Polygonum hydropiperoides*), water purslane (*Ludwigia palustris*), and wapato (*Sagittaria latifolia*). Climbing hemp (*Mikania scandens*) and pepper-vine also occur (Gladden et al. 1985). Herbaceous vegetation in the willow community is often sparse due to the dense canopy. Small patches of herbs include redtop panicgrass (*Panicum agrostoides*), waterpepper, false nettle, St. John's wort, sensitive fern (*Onoclea sensibilis*), climbing hemp, and pepper-vine (Gladden et al. 1985).

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

Wetlands Classification Scheme

The Savannah River swamp contains areas of diverse cover types, such as woody vegetation, mud flats, and open water. A classification scheme comparable with ground survey data collected from the swamp was developed for use with the remotely sensed data. The classification scheme selected was adopted with minor modifications from the wetlands classification system developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) and used for the National Wetland Maps (Stewart et al. 1980). Nine of the wetland classes commonly identified in the SRS Savannah River swamp are (Jensen et al. 1984; Christensen 1987; Sharitz et al. 1990; Burkhalter 1994):

- Water (W) appears as open water in the photographs.
- Mudflat (MF) appear as bare, unvegetated mudflats.
- Persistent emergent (PE) wetland dominated chiefly by perennial herbaceous species, including cattail (*Typha latifolia*), bulrush (*Scirpus cyperinus*), cutgrass (*Leersia* spp.) and false nettle (*Boehmeria cylindrica*). *Aneilema keisak*, an annual, also is abundant locally.
- Nonpersistent emergent (NPE) wetland contains several species of knotweed (*Polygonum* spp.), and hydrolea in the deeper water areas. The NPE vegetation type is characterized by water primrose (*Ludwigia* spp.) on shallow sandbars and mud flats.
- Scrub-shrub (SS) wetland dominated by willow (*Salix nigra* and *S. caroliniana*) on the sandbars, and buttonbush in deeper water. Typically, SS represents a transition from emergent marsh to swamp forest.
- Deciduous swamp forest (DSF) dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*).
- Deciduous bottomland forest (DBF) characterized by oaks, red maple, sweetgum, and hickory (*Carya* spp.). DBF vegetation is less water-tolerant than DSF vegetation.
- Pine characterized by loblolly pine (*Pinus taeda*).

Estimates of the wetland vegetation areas for the Steel Creek, Pen Branch, and Fourmile Branch deltas in 1981 and 1992 are listed in Table 6-4 through Table 6-6. Discussions of classification methods, accuracy assessment, and phenology problems are presented in Jensen et al. (1984, 1986a), Christensen et al. (1986) and Burkhalter (1994).

Table 6-4. Wetland Classification of the Steel Creek Delta based on 1981 and 1992 MSS Data

	1981		1992		
Wetland Cover Class	**Ha[a]**	**Percent of Delta Area**	**Ha[a]**	**Percent of Delta Area**	**Difference**
Water (W)	4.0	3	9.3	6	+3
Mudflat (MF)	0.0	0	0.0	0	-
Nonpersistent emergent (NPE)	36.9	25	2.6	2	-23
Persistent emergent (PE)	36.3	25	14.6	10	-15
Scrub-shrub (SS)	19.6	13	62.3	43	+30
Pine	0.0	0	0.0	0	-
Decidious bottomland forest (DBF)	10.0	7	13.7	9	+2
Deciduous swamp forest (DSF)	39.5	27	43.9	30	+3
Total Area	146.4	100	146.4	100	

Source: Burkhalter 1994.
[a]To convert to acres, multiply by 2.471.

Table 6-5. Wetland Classification of the Pen Branch Delta based on 1981 and 1992 MSS Data

	1981		1992		
Wetland Cover Class	**Ha**	**Percent of Delta Area**	**Ha**	**Percent of Delta Area**	**Differences**
Water (W)	36.5	18	18.5	9	-9
Mudflat (MF)	9.4	5	0.0	0	-5
Nonpersistent emergent (NPE)	32.2	16	24.8	12	-4
Persistent emergent (PE)	0	0	67.9	34	+34
Scrub-shrub (SS)	0	0	25.1	12	+12
Pine	2.5	1	0.0	0	-1
Decidious bottomland forest (DBF)	52.6	17	29.2	15	-11
Deciduous swamp forest (DSF)	68.7	34	36.4	18	-16
Total Area	201.9	100	201.9		

Source: Burkhalter 1994.
[a]To convert to acres, multiply by 2.471.

Table 6-6. Wetland Classification of the Fourmile Branch Delta based on 1981 and 1992 MSS Data

	1981		1992		
Wetland Cover Class	**Ha**	**Percent of Delta Area**	**Ha**	**Percent of Delta Area**	**Difference**
Water (W)	44.7	11	19.0	5	-6
Mudflat (MF)	32.3	8	4.9	1	-7
Nonpersistent emergent (NPE)	14.2	4	6.5	2	-2
Persistent emergent (PE)	0.0	0	17.0	4	+4
Scrub-shrub (SS)	42.4	11	51.7	13	+2
Pine	14.3	4	25.3	6	+2
Decidious bottomland forest (DBF)	104.1	26	177.7	45	+19
Deciduous swamp forest (DSF)	144.1	36	94.1	24	-12
Total Area	396.2	100	396.2	100	

Source: Burkhalter 1994.
[a]To convert to acres, multiply by 2.471

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

Introduction

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

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

Multispectral remote sensing data from 1981 to 1993 are also available for the SRS swamp areas. These multispectral scanner (MSS) data allow estimation of changes by wetland community types for the delta areas for given time periods. For example, Christensen et al. (1986) evaluated changes in the swamp delta areas for 1981-1985 with MSS data and updated the Steel Creek delta through 1987, and Blohm (1993) conducted a detailed evaluation of the Pen Branch delta for 1987-1991. Burkhalter (1994) compared historic photos with 1992 MSS data.

The wetlands changes in Steel Creek are particularly interesting. Both L and P Reactors discharged effluents into the stream from 1954 to 1963. L Reactor continued to discharge

thermal effluent to Steel Creek from 1963 to 1968. When P Reactor stopped releasing thermal effluents to Steel Creek in 1963, the upper Steel Creek corridor began to revegetate. In 1968, thermal discharges into Steel Creek ceased and the lower Steel Creek floodplain and delta region began undergoing post-thermal succession or revegetation (Smith et al. 1981, 1982; Christensen et al. 1986). In 1985, L Lake was built on the midreach of Steel Creek. It received thermal output from the reactivated L Reactor intermittently until 1988. Flow and temperature increased downstream of the L-Lake dam when the reactor discharged.

Pen Branch and Fourmile Branch began receiving reactor effluents in 1954 and 1955, respectively. In contrast to Steel Creek, neither stream received effluents from more than one reactor. Additionally, both reactors operated with only minor changes in operating conditions after the initial startup. C Reactor was shut down in late June 1985, and the Fourmile Branch corridor and delta began undergoing successional revegetation. K Reactor was shut down in the spring of 1988, and Pen Branch delta began undergoing successional revegetation (Mackey 1990, 1993; Blohm 1993). Neither creek has received thermal discharge since the reactors were shutdown; however, Pen Branch received elevated flows during testing of the K-Reactor cooling tower.

A fourth source of thermal effluent to the SRS Savannah River swamp is from D Area, which contained a heavy water production facility (placed on standby in 1982 and since dismantled) and a coal-fired power plant (currently operating). Effluents from D Area were consistently lower in both volume and temperature than effluents from the reactor areas.

Multispectral Scanner Surveys of the SRS Swamp Delta Areas

One of the most powerful uses of digital remote sensing data is to evaluate land-use and land-cover changes through time. Remote sensing change detection combines multiple-date data and image analyses to identify temporal and spatial changes. Multispectral scanner (MSS) data analysis can quantitatively discriminate among a variety of vegetation types (Jensen 1986). Baseline vegetation maps of the Savannah River swamp and the four delta swamp areas (Beaver Dam Creek, Fourmile Branch, Pen Branch, and Steel Creek) were prepared using aircraft MSS data (Jensen et al. 1984; Gladden et al. 1985) (Figure 6-16). Satellite MSS data (Landsat, Thematic Mapper, and SPOT) are commonly used to detect and monitor change. For the most part, satellite data are useful for large-scale change detection because the ground resolution currently available with Thematic Mapper is 30 x 30 m (98 x 98 ft) with SPOT HRV is 20 x 20m (66 x 66 ft), and with SPOT panchromatic is 10 x 10 m (33 x 33 ft). Aircraft-based sensors fly lower and have ground resolutions of a few meters. At this scale, much more detailed discrimination of vegetation types and area estimates can be made. However, change detection using high-resolution, aircraft MSS data seldom is conducted. Classification consistency and registration difficulties are probably the two major reasons that aircraft MSS data are used infrequently for change detection studies. Research on the Savannah River swamp deltas addressed both of these considerations (Christensen et al. 1986; Jensen et al. 1987; Blohm 1993).

Portions of the Pen Branch, Fourmile Branch, Steel Creek, and Beaver Dam Creek deltas in the Savannah River swamp were evaluated for wetlands vegetation change using aircraft MSS data acquired at 1220 m (4003 ft) and 2440 m (8006 ft) altitude from 1981 to 1985. The MSS data for each delta were registered and classified, and wetlands vegetation change detection categories were determined (Christensen et al. 1986; Jensen et al. 1983, 1984, 1986a and b, 1987).

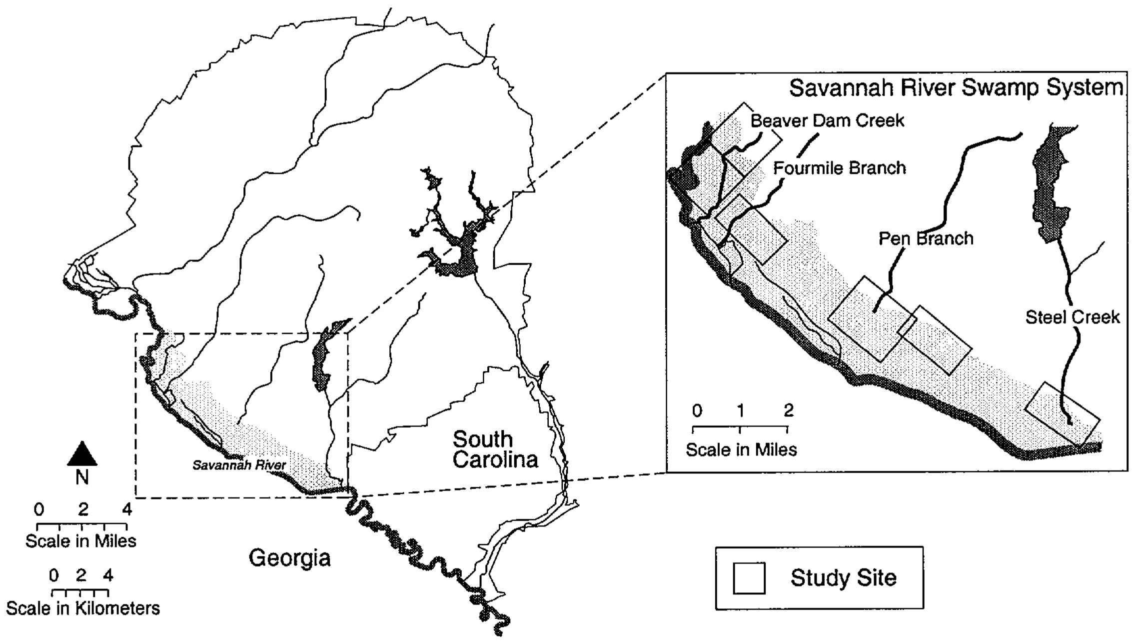


Figure 6-16. Areas of the SRS Savannah River Swamp Analyzed Using MSS Data, 1981-1985

Comparison of the Photographic and MSS Surveys, 1981-1992

In general, even though the data were analyzed with different approaches and criteria for wetland change detection, the wetland community trends in the delta areas of the SRS Savannah River swamp observed with the MSS surveys from 1981 to 1985 agreed with the changes in the photographic surveys. For example, in the thermally influenced deltas of Fourmile Branch (until 1985) and Pen Branch, expansion of these deltas into the deciduous swamp forest (DSF) was still occurring. Using photographic techniques, about 30 ha (74 acres) of cypress-tupelo forest were estimated to have been converted to open water marsh or scrub-shrub wetlands in the Fourmile Branch delta area from 1981 to 1984. Using MSS data to analyze about one-half of the same Fourmile Branch delta area, approximately 14 ha (35 acres) of swamp forest were estimated to have been converted to either marsh or scrub-shrub wetland communities. When evaluated with photographic methods, the thermally influenced Pen Branch delta showed a decline in cypress-tupelo forest of about 37 ha (91 acres) from 1981 to 1985 with most of the decline occurring in the Pen Branch "tail" area. MSS data analyses of the tail region showed a decline of swamp forest of 28.7 ha (71 acres) from 1981 to 1985.

Burkhalter (1994) continued monitoring changes in the swamp by comparing 1992 MSS data with the 1981 surveys. The remainder of this chapter describes the changes to the swamp due first to sediments deposition and increased water temperature and more recently to reduced flows and ambient water temperatures.

Beaver Dam Creek

Beaver Dam Creek Watershed Characteristics

Beaver Dam Creek is a small stream that carries thermal effluents from the D-Area coal-fired power plant. Until 1982, it also carried effluent from the heavy water production facility. Prior to SRS operations, Beaver Dam Creek was probably an intermittent stream. The creek is 1-3 km (0.6-1.8 mi) west of Fourmile Branch (Figure 6-17). A narrow band of bottomland hardwoods and scrub-shrub forest borders the stream from the D-Area process-water outfall to the river swamp. Beaver Dam Creek received from 2.1 to 3.5 m^3/sec (74 to 123.5 ft^3/sec) of heated process water discharges from the heavy water production plant and the steam plant when both were operating. As heavy water operations were reduced, discharges decreased.

Beaver Dam Creek Delta Characteristics

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

Of the four deltas, the most change from 1991 to 1995 was on the Beaver Dam Creek delta, even though the change period had been the shortest. Almost the entire upper portion of the delta experienced extensive revegetation. At the present due to a reduction in discharges, the upper delta remains dry most of the year (except during flooding of the Savannah River). As a result, less water-tolerant scrub-shrub (willow and buttonbush) and deciduous bottomland forest species (sycamore [*Platanus occidentalis*], ash, tulip poplar, and oak) have colonized the former marsh (persistent emergent and nonpersistent emergent).

Beaver Dam Creek Delta Trends

In 1952, D Area began discharging heated effluents through a canal to Beaver Dam Creek (Figure 6-17). Both the D-Area heavy water facility and the coal-fired powerhouse used Savannah River water for cooling. Additionally, river water was pumped for the extraction of heavy water (Gladden et al. 1985). Table 6-7 and Figure 6-18 summarize the history of discharges to and changes in the Beaver Dam Creek delta. Canopy decline was observed in 1956 aerial photography. The affected area totaled 19 ha (47 acres) and received an average flow of about 120 cfs (33 cm^3/sec). During the next 11 years, the Beaver Dam Creek delta expanded at a variable rate with a maximum rate of about 10 ha (25 acres)/yr between 1961 and 1966. Effluent temperatures began to decrease in 1973 and continued to decline until 1978; a concurrent net decline of delta expansion occurred. By 1985, a total of about 14 ha (34 acres) had revegetated in the Beaver Dam Creek area. The annual average effluent temperature declined from 38°C (100° F) to 27-28°C (81-82° F). The affected Savannah River swamp area associated with Beaver Dam Creek in 1985 totaled about 160 ha (395 acres) and was revegetating at a rate of about 4.2 ha (10.3 acres)/yr. Relatively little change has been noted in the Beaver Dam Creek delta from 1986-1992 (Figure 6-19). In addition to thermal discharges, the Beaver Dam Creek delta area also received coal fly ash basin efflu-

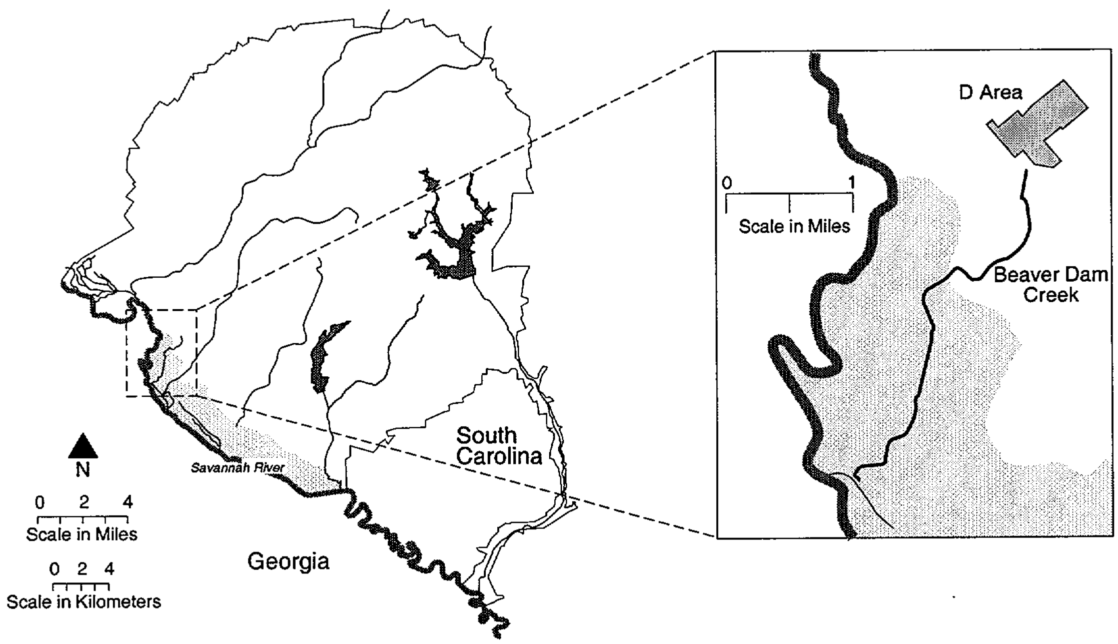


Figure 6-17. Location of Beaver Dam Creek on SRS

Table 6-7. Discharge Conditions and Estimated Impacts to Beaver Dam Creek from D-Area Discharges, 1952-1995

Year	Total Impacted Area (ha)[a]	Average Expansion Rate (ha/yr)	Average Annual Discharge (cfs) or Flow at USGS Station[b]	Average Annual Temperature (°C)[c]
1952	-	-	-	-
1953	-	-	-	-
1954	-	-	-	-
1955	-	-	-	
1956	19.0	-	121	-
1957	-	-	123	-
1958	-	-	108	-
1959	-	-	104	-
1960	-	-	91	-
1961	54.0	7.0	88	-
1962	-	-	89	-
1963	-	-	-	-
1964	-	-	88	-
1965	-	-	-	-
1966	103.7	9.9	-	-
1967	-	-	-	-
1968	-	-	-	-
1969	-	-	-	-
1970	-	-	-	-
1971	-	-	-	-
1972	-	-	-	38
1973	-	-	-	38
1974	167.0	7.9	-	36
1975	-	-	92	34
1976	-	-	78	32
1977	-	-	78	28
1978	164.8	0.6[d]	74	27
1979	-	-	79	28
1980		-	82	27
1981	-	-	113	27
1982	157.0	2.0[d]	90	27
1983	-	-	89	27
1984	164.1	3.6[d]	84	-
1985	159.9	4.2[d]	89	-
1986	-	-	89	-
1987	-	-	88	-
1988	-	-	71	-
1989	-	-	67	-
1990	-	-	73	-
1991	-	-	95	-
1992	-	-	70	-
1993	-	-	78	-
1994	-	-	71	-
1995	-	-	71	-

[a]To convert to acres, multiply by 2.471.

[b]For the years 1956-1964, the data are for the 681-5G pumphouse, which supplies river water to D Area. For the years 1975-1982, the data are flow measurements at the Health Protection Monitoring Station on Beaver Dam Creek before the flow discharges into the Savannah River swamp on SRS. For the year 1983-1991, the data are from the USGS recording station (35.32 cfs =1 m^3/sec).

[c]For the years 1972-1983, the temperature data are annual average data at the Health Protection Monitoring Station on Beaver Dam Creek before the flow enters the Savannah River swamp on SRS. To convert to °F, multiply by 9/5 and add 32.

[d]Revegetation rate.

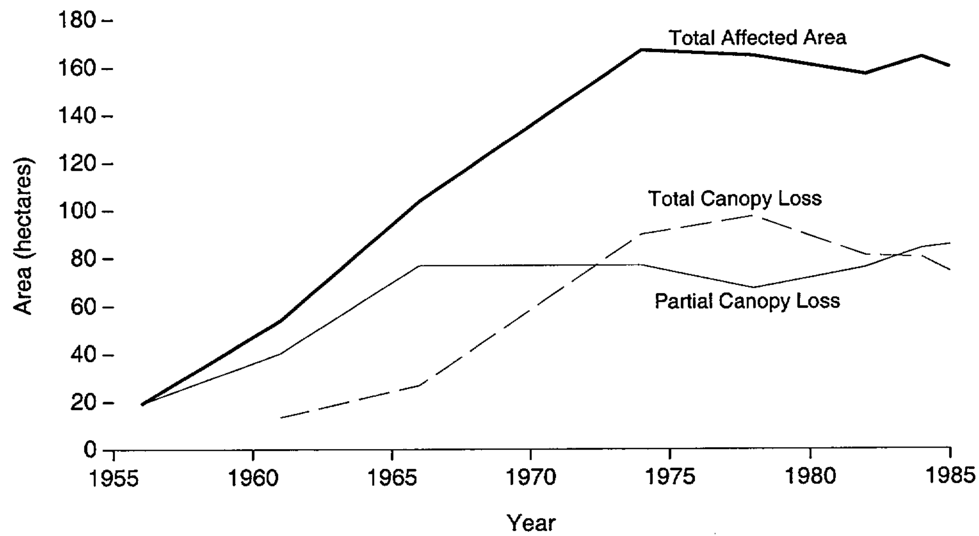


Figure 6-18. Canopy Change in Beaver Dam Creek Delta (Source: Tinney et al. 1986)

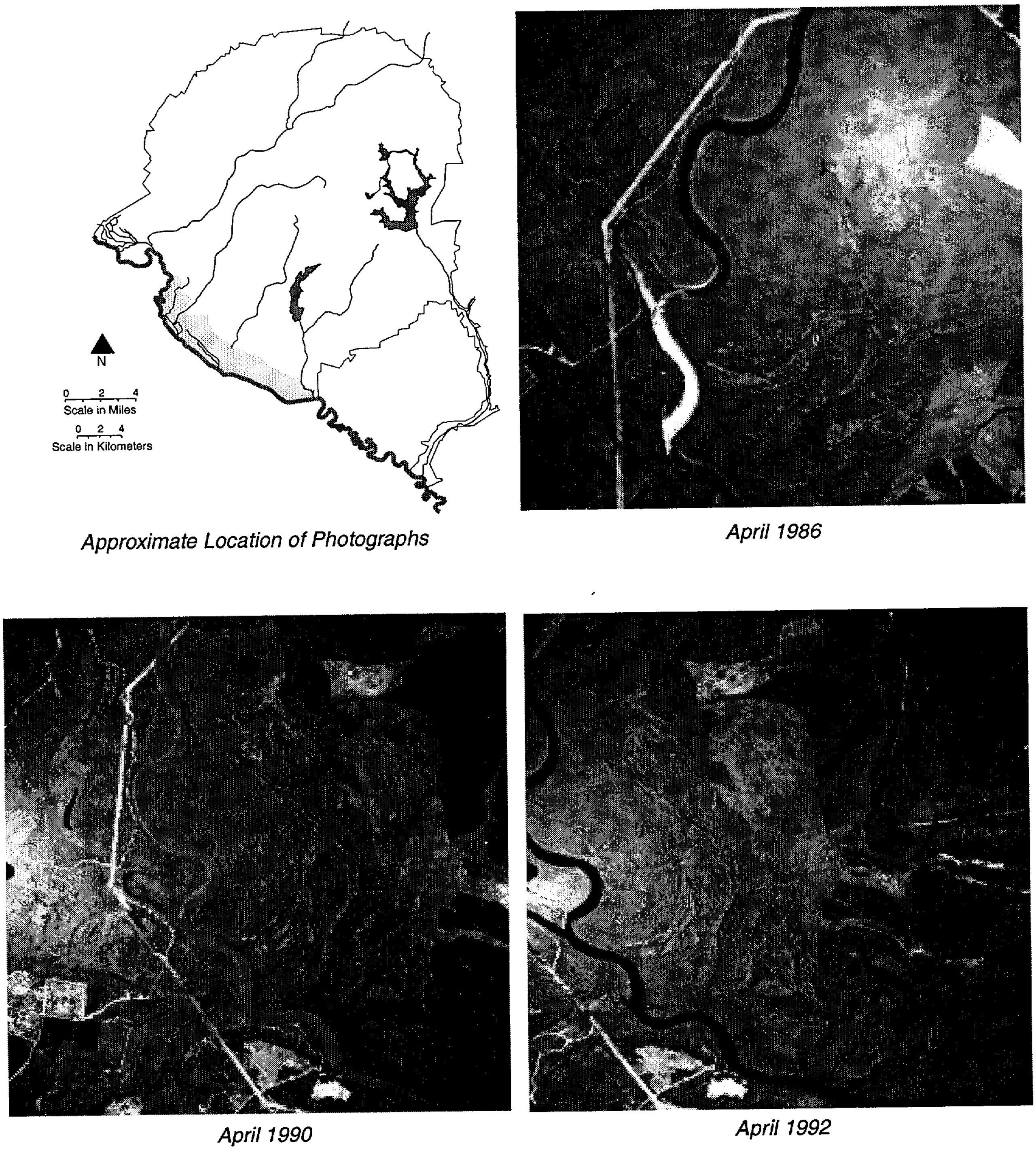


Figure 6-19. Vertical Aerial Photography of the Beaver Dam Creek Delta Area, Spring 1986, 1990, and 1992

(Evans and Giesy 1978). Coal fly ash deposition affected at least 8-10 ha (20- 25 acres) of swamp (Gladden et al. 1985).

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

Multispectral scanner (MSS) data of the Beaver Dam Creek delta were acquired at 2440 m (8006 ft) above ground level (AGL) on March 31, 1981, and at 1220 m (4003 ft) on April 26, 1985. Table 6-8 and Table 6-9 list the changes in landcover from March 31, 1981, to April 26, 1985. For the upper Beaver Dam Creek delta, the most noticeable decreases in landcover type were of nonpersistent emergent marsh (60.0%), persistent emergent marsh (52.2%), and deciduous swamp forest (12.6%). Conversely, the area experienced increases in deciduous bottomland forest (35.7%), scrub-shrub (10.0%), and water (13.5%). The upper Beaver Dam Creek area returned to a more wooded condition.

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

Fourmile Branch

Fourmile Branch Watershed Characteristics

Fourmile Branch flows southwest for 24 km (15 mi) before emptying into the Savannah River, and together with Beaver Dam Creek drains more than 59 km^2 (23 mi^2). In the swamp, part of the flow from Fourmile Branch combines with Beaver Dam Creek. Most of the Fourmile Branch flow discharges into the Savannah River through an opening in the levee between the swamp and river, while another portion of the flow moves downstream through the swamp and joins water from Steel Creek and Pen Branch, which leaves the swamp by Steel Creek. During river flooding the flow from Fourmile Branch travels through the swamp beyond Steel Creek and enters the river near or downstream from Steel Creek. Fourmile Branch receives effluents from F and H Areas. Until 1985, it received thermal discharges from C Reactor (about 11.3 m^3/sec [399 ft^3/sec]).

Fourmile Branch Corridor and Delta

Photographic data of the Fourmile Branch corridor and delta were evaluated (Table 6-9, Figure 6-20, and Figure 6-21). As of 1985, 450.3 ha (1000 acres) of Fourmile Branch had been affected (Table 6-10). The impacted area of the Savannah River swamp canopy totaled 357.3 ha (883 acres) and the area in the Fourmile Branch corridor totaled 93 ha (230 acres). Figure 6-22 shows the typical flow through the Fourmile Branch delta during periods of C-Reactor operation. Since late June 1985, C Reactor has been shutdown and natural successional revegetation is occurring in the corridor and delta. Flows to Fourmile Branch have remained low since June 1985 (Table 6-9). Figure 6-23 shows the progression of revegetation in the Fourmile Branch delta area from 1986-1992 with invasion of a scrub-shrub community into the lower corridor and the delta sediment fan.

Table 6-8. Wetlands Change in the Upper Beaver Dam Creek Area from 1981-1985 Based on Aircraft MSS Data

	Number of Hectares[a]			
Wetlands Type	**1981**	**1985**	**Difference**	**Percentage Change**
water	14.8	16.8	+2.0	+13.5
nonpersistent emergent marsh	8.5	3.4	-5.1	-60.0
persistent emergent marsh	32.9	15.7	-17.2	-52.2
scrub-shrub	35.7	39.3	+3.6	+10.0
deciduous swamp forest	65.8	57.5	-8.3	-12.6
deciduous bottomland forest	70.3	95.4	+25.1	+35.7

[a] To convert to acres, multiply by 2.471.

Table 6-9. Wetlands Change in the Lower Beaver Dam Creek Area from 1981-1985 Based on Aircraft MSS Data

	Number of Hectares[a]			
Wetlands Type	**1981**	**1985**	**Difference**	**Percentage Change**
water	35.2	34.8	-0.4	-1.1
nonpersistent emergent marsh	7.1	0.0	-7.1	-99.9
persistent emergent marsh	9.4	11.7	+2.3	+24.4
scrub-shrub	8.5	8.8	-0.3	-3.5
deciduous swamp forest	76.0	70.4	-5.6	-7.4
deciduous bottomland forest	194.2	204.8	+10.6	+5.5

[a] To convert to acres, multiply by 2.471.

Table 6-10. Discharge Conditions and Estimated Impacts to Fourmile Branch from Reactor Discharges, 1955-1995

	Fourmile Branch Savannah River Swamp		Fourmile Branch Corridor		Annual Average Reactor Discharge or Fourmile Branch Flows	
Year	**Total Affected Area (ha)[a]**	**Expansion Rate (ha/yr)**	**Total Affected Area[a] (ha)**	**Expansion Rate of Forest Canopy Mortality (ha/yr)**	**Flow (cfs)[b]**	**Temperature (°C)[c]**
1955	-	-	-	-	100[d]	47
1956	0.0	-	-	-	156	60
1957	0.0	-	-	-	220	66
1958	-	-	-	-	200	71
1959	-	-	-	-	273	71
1960	-	-	-	-	327	71
1961	15.8	-	105.8	17.5	389	66
1962	-	-	-	-	389	67
1963	-	-	-	-	385	68
1964	-	-	-	-	390	66
1965	-	-	-	-	385	30
1966	97.9	16.4	106.7	0.2	390	67
1967	-	-	-	-	391	71
1968	-	-	-	-	395	71
1969	-	-	-	-	390	70
1970	-	-	-	-	387	64
1971	-	-	-	-	388	65
1972	-	-	-	-	387	67
1973	-	-	-	-	387	58
1974	246.8	18.6	-	-	316	62
1975	-	-	-	-	352	59
1976	-	-	-	-	376	62
1977	-	-	-	-	376	62
1978	-	-	-	-	376	62
1979	-	-	-	-	376	61
1980	-	-	-	-	377	63
1981	-	-	-	-	376	63
1982	-	-	-	-	376	64
1983	-	-	-	-	375	68
1984	350.8	10.4	-	-	375	-
1985	357.3	6.5	93.0	0.7[e]	220	-
1986	-	-	-	-	47	-
1987	-	-	-	-	32	-
1988	-	-	-	-	20	-
1989	-	-	-	-	24	-
1990	-	-	-	-	33	-
1991	-	-	-	-	64	-
1992	-	-	-	-	44	-
1993	-	-	-	-	54	-
1994	-	-	-	-	30	-
1995	-	-	-	-	35	-

[a]
[b]Greater than 5% canopy loss; to convert to acres, multiply by 2.471.
[c]35.32 cfs = 1 m^3/sec. For years 1955-1984, the data are from Tinney et al. 1986. For years 1985-1991, the data are from the USGS.
To convert to F, multiply by 9/5 and add 32.
[d]Approximate.
[e]Revegetation rate.

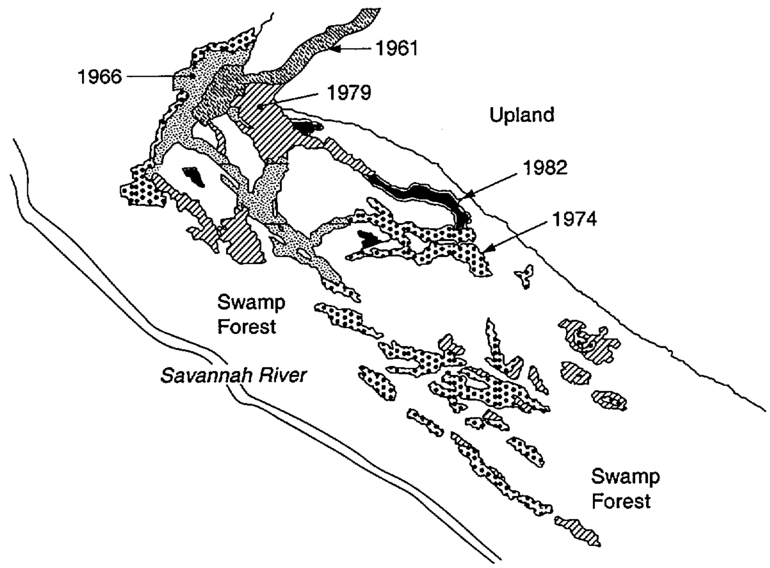


Figure 6-20. Fourmile Branch Delta Expansion Composite Image, 1961-1982 (Source: Gladden et al. 1985)

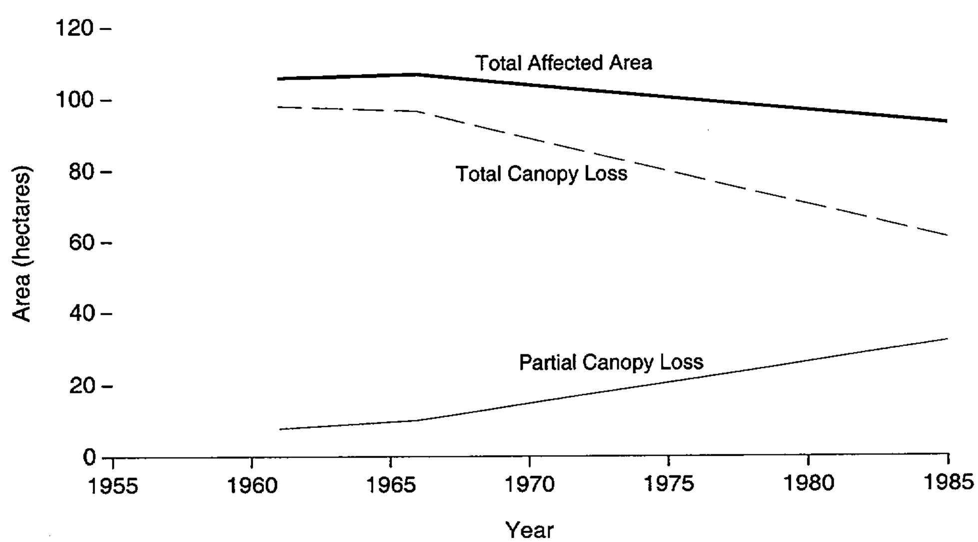


Figure 6-21. Canopy Changes in Fourmile Branch Corridor (Source: Tinney et al. 1986)

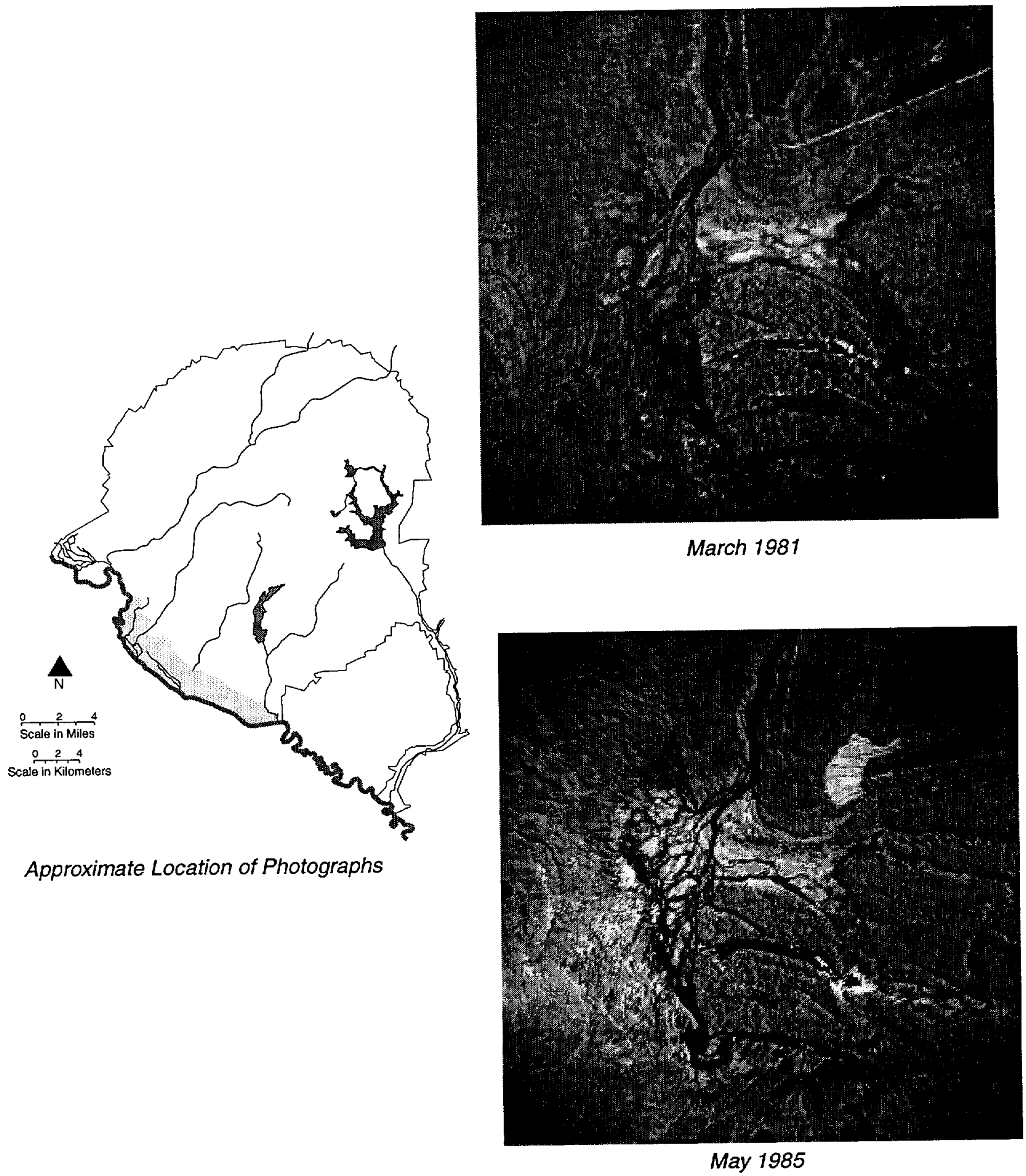
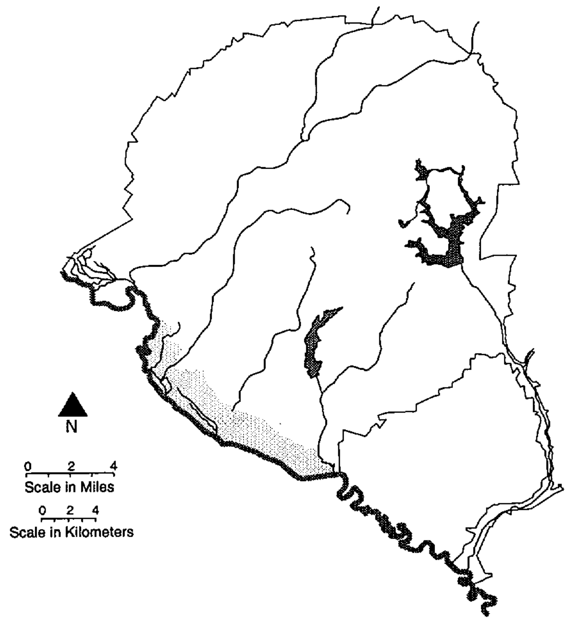
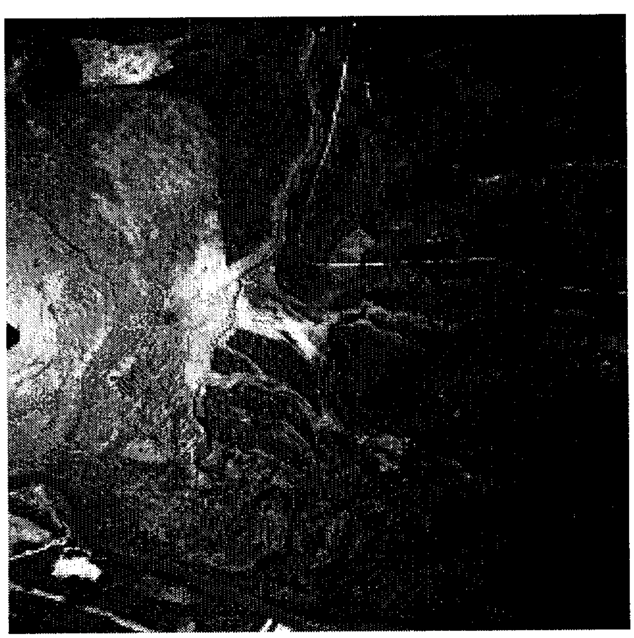


Figure 6-22. Vertical Aerial Photography of the Fourmile Branch Delta Area During Thermal Operations of C Reactor



Approximate Location of Photographs

April 1986



April 1990

May 1992

Figure 6-23. Vertical Aerial Photography of the Fourmile Branch Delta Area After C-Reactor Shutdown

The shape and expansion history of the Fourmile Branch impact delta are different from other areas of the swamp receiving reactor effluents. Even though Fourmile Branch had a flow and temperature history similar to that of Pen Branch, the Fourmile Branch impact area (357 ha [883 acres]) is more than twice as large as the Pen Branch delta impact area (152 ha [375 acres]).

One explanation for the size difference is that the geomorphology of the swamp at the mouth of Fourmile Branch is not like that at the other two deltas (Stevenson 1982). Hardwood islands and former river channels are common in the region of the Savannah River swamp contiguous to the Fourmile Branch. In contrast, Steel Creek and Pen Branch drain into an area of the swamp with fewer hardwood islands and former river channels in the immediate vicinity. As a result of the local geomorphology, Fourmile Branch discharges to the swamp spread not only in the traditional deltaic form (similar to Pen Branch and Steel Creek deltas), but also between elevated hardwood ridges in the Savannah River swamp (Figure 6-20).

Fourmile Branch Delta – MSS Surveys 1981-1992

A 190-ha (469-acre) area of the Fourmile Branch delta was evaluated for wetlands changes using 1981 and 1984 airborne MSS data, (Figure 6-16). The April 1984 image was registered to the March 1981 image. The major change was a loss of swamp forest (cypress-tupelo) to nonpersistent emergent (NPE) wetland (9.3 ha [23 acres]). Most of the change occurred along the northern and western delta fringes, where a thinned cypress community had existed in 1981. Two areas of persistent emergent (PE) wetland (1.6 ha [4 acres]) replaced swamp forest near the southern edge of the delta. Swamp forest loss totals were similar to those in the Pen Branch delta, and loss rates from 1981 to 1984 were similar to previous rates determined from aerial photographic techniques (Gladden et al. 1985; Tinney et al. 1986).

Since the cessation of effluent in 1985, the amount of water flowing across the delta decreased significantly. A few distinct channels remain; the rest of the delta is being revegetated by scrub-shrub species. A pine stand is developing along the northern border of the delta. Table 6-11 shows degradation in vegetation communities and Table 6-12 shows revegetation in the Savannah River swamp deltas between 1981 and 1992 (Burkhalter 1994).

Fourmile Branch Ground Surveys 1982, 1987, 1989, 1990

Fourmile Branch received cooling water discharge from C Reactor between 1955 when the reactor began operation, and June 1985, when the reactor was shut down (Table 6-9). The delta was criss-crossed by numerous small channels interspersed with islands (Figure 6-22). With the shutdown of C Reactor in 1985, all but two of the main channels disappeared and the delta became much drier (Figure 6-23). In mid-August 1987, a fire caused by lightning burned a large portion of the delta. Another lightning fire started on the delta in June 1988.

Field surveys in 1982 and photography and MSS analyses of 1981 data identified six communities that seemed to be defined by water temperature and depth of deposited sediments. These were (1) thermal delta; (2) post-thermal delta; (3) scrub-shrub wetland; (4) reduced-canopy cypress-tupelo forest; (5) bottomland hardwood ridges; and (6) closed-canopy cypress-tupelo forest. Communities 1-4 are in decreasing order of disturbance, and 5 and 6 are undisturbed communities.

Table 6-11. Degradation of Savannah River Swamp Vegetation Communities in the Vicinity of the Deltas Formed by Formerly Thermal Creeks[a]

	Delta Area = Hectares[c]		
Vegetation Change Class[b]	**Fourmile Branch**	**Pen Branch**	**Steel Creek**
DSF to SS	1.76	8.9	6.27
DSF to PE	3.91	17.34	0.15
DSF to NPE	2.64	6.25	0.05
DSF to MF	0.22	-	-
DBF to SS	2.68	3.94	0.54
DBF to PE	1.09	4.04	-
DBF to NPE	0.42	3.08	-
DBF to MF	0.13	-	-
PINE to SS	0.62	0.22	-
PINE to PE	0.2	0.26	-
PINE to NPE	0.14	0.18	-
PINE to MF	0.02	-	-
SSF to SS	-	2.04	-
SSF to PE	-	10.04	-
SSF to NPE	-	2.8	-
SS to PE	1.24	-	1.9
SS to NPE	0.21	-	0.33
SS to MF	0.33	-	-
PE to NPE	-	-	1.74
PE to MF	-	-	-
NPE to MF	0.58	-	-
Total Degradation	16.19	59.09	10.98

Source: Burkhalter 1994.

[a] Calculation of vegetation change based on analysis of Daedalus MSS data obtained on March 31, 1981 and April 23, 1992 using the change matrix (degradation).

[b] DSF = deciduous swamp forest.
SS = scrub-shrub.
PE = persistent emergent.
NPE = nonpersistent emergent.
SSF = stressed swamp forest; defined as swamp forest with a notably thinned canopy.
DBF = deciduous bottomland forest.
MF = mud flat.

[c] To convert to acres, multiply by 2.471.

Table 6-12. Revegetation of the Savannah River Swamp in the Vicinity of the Deltas Formed by Formerly Thermal Creeks[a]

	Delta Area = Hectares[c]		
Vegetation Change Class	**Fourmile Branch**	**Pen Branch**	**Steel Creek**
SSF to DSF	-	1.71	-
SSF to DBF	-	1.17	-
SSF to PINE	-	-	-
SS to DSF	10.27	-	3.33
SS to DBF	23.66	-	1.8
SS to PINE	2.7	-	-
PE to DSF	-	-	2.31
PE to DBF	-	-	1.04
PE to PINE	-	-	-
PE to SS	-	-	21.15
NPE to DSF	2.53	0.88	5.25
NPE to DBF	2.61	0.51	1.22
NPE to PINE	0.85	-	-
NPE to SS	5.32	3.49	19.96
NPE to PE	1.44	18.7	4.02
MF to DSF	4.62	0.18	-
MF to DBF	3.87	0.12	-
MF to PINE	3.46	-	-
MF to SS	11.21	1.05	-
MF to PE	4.55	5.69	-
MF to NPE	0.42	2.06	-
Total Revegetation	77.51	35.56	60.08

Source: Burkhalter 1994.
[a]Calculation of vegetation change based on analysis of Daedalus MSS data obtained on March 31, 1981 and April 23, 1992 using the change matrix (Revegetation).
[b]DSF = deciduous swamp forest.
SS = scrub-shrub.
PE = persistent emergent.
NPE = non-persistent emergent.
SSF = stressed swamp forest; defined as swamp forest with a notably thinned canopy.
DBF = deciduous bottomland forest.
MF = mud flat.
[c]To convert to acres, multiply by 2.471.

The Fourmile Branch delta vegetation was resampled during the summers of 1987 and 1989 by the Savannah River Ecology Laboratory (SREL) (Wike et al. 1994). Sampling was conducted in the mid and lower corridors, the delta, and in nearby cypress-tupelo and hardwood island stands. Community analyses were grouped to correspond to the six communities identified in the 1982 surveys. An additional category, the dry delta, was added. The closed-canopy cypress-tupelo swamp was not sampled. The reduced canopy cypress-tupelo community remained largely unchanged with false nettle still a dominant herb. Marsh St. Johns wort (*Hypericum walteri*) replaced bugleweed (*Lycopus* spp.) as another dominant. Pepper-vine, buttonbush, and Virginia willow were common shrubs in this community.

The bottomland hardwood island showed little change in woody flora between 1982, 1987, and 1989 with a continued high diversity of trees. Due to C-Reactor shutdown, the island no longer received woody detritus from the disturbed delta and the ground layer shifted from greenbrier, poison ivy, and grape (*Vitis rotundifolia*) to two grasses (*Panicum* spp. and *Arundinaria gigantea*) and palmetto (*Sabal minor*).

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

As would be expected in an early successional stage, the most dominant species were herbaceous. Fireweed and false nettle were found in more than 50% of the plots surveyed in 1987. Species having a mean cover greater than 25% included fireweed, bulrush, *Sacciolepsis striata,* and plume grass (*Erianthus giganteus*). Shrubs were less frequent, with young willows, the most abundant, occurring in 20.7% of the plots. Trees were even less abundant (approximately 1900/ha), especially those greater than 10 cm diameter-breast height (dbh) (approximately 300/ha). Willows and ash (*Fraxinus* spp.) had the greatest densities (more than 500/ha) but were primarily less than 10 cm dbh.

In 1989, the two species most frequently found in 1987 were joined by three additional species (knotweed [*Polygonum hydropiperoides*], bulrush, and grass [*Paspalum urvillei*]) with combined frequencies greater than 50%. No species had a mean percent cover greater than 25%. Seventeen herbaceous species were found in 1989, in contrast to the 12 found in 1987. New species included broom sedge (*Andropogon virginicus*), poison ivy, and briars (*Rubus* spp.) Rush (*Juncus effusus*) doubled its frequency from 1987 to 1989, while *Carex alata* was absent by 1989. The most frequently occurring shrub in 1989 was briar, which replaced the young willow found in 1987. The abundance of trees did not change greatly between 1987 and 1989. Willow density declined by a third, while ash density increased slightly. Two additional species, sweetgum and southern red oak *(Quercus falcata*), were found. Sweetgum is an aggressive species, capable of dominating sites. Southern red oak is more characteristic of a mixed-species bottomland forest.

In the summer of 1990, an additional survey was conducted of the lower corridor and upper delta area of Fourmile Branch (Wike et al. 1994); 68 species were found within the sampling area. Summaries of the major strata are in the following subsections.

Overstory Stratum

No overstory vegetation was found in the area of braided stream in the Fourmile Branch floodplain. Overstory vegetation was killed by the thermal effluent and sedimentation from C Reactor operations. Snags, mainly bald cypress, remained standing in the delta region of Fourmile Branch.

Understory Stratum

The understory stratum had a total of seven species. Tag alder and black willow were the dominant species. Both tag alder and black willow had a relative frequency of 23.08%. Tag alder had the greatest relative dominance (41.14%) and the greatest relative density (45.3%).

Shrub Stratum

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

Ground Cover Stratum

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

Pen Branch

Pen Branch Watershed Characteristics

Until Pen Branch enters the Savannah River swamp, it follows a path parallel to Steel Creek and Fourmile Branch. Pen Branch enters the swamp and flows southeast toward the Steel Creek delta 5 km (3 mi) before it enters the river. The only significant tributary is Indian Grave Branch, which flows into Pen Branch about 8 km (5 mi) upstream from the Savannah River swamp. Pen Branch and Indian Grave Branch drain about 55 km^2 (21 mi^2) of SRS. Indian Grave Branch received effluent cooling water from K Reactor. Above the K-Area discharge, Indian Grave Branch flow averages about 0.03 m^3/sec. Above the confluence of Indian Grave Branch, Pen Branch is also a small stream, with a flow averaging 0.14 to 0.28 m^3/sec (Newman et al. 1986).

The headwaters of Pen Branch consist of a largely unperturbed blackwater stream. Downstream from K Area, thermal effluent from K Reactor entered Pen Branch via Indian Grave Branch. When K Reactor operated, cooling water from K Area accounted for more than 98% of the stream volume. Where Pen Branch discharges into the swamp, it formed a delta. The flow from Pen Branch usually spread over the delta and continued through the

swamp as shallow sheet flow until it entered the lower reaches of Steel Creek and discharged into the Savannah River. However, when the Savannah River inundated the floodplain swamp, the flow from Pen Branch was forced against the northern upland edge of the swamp, across the Steel Creek delta, to discharge into the Savannah River downstream from the mouth of Steel Creek (Shines and Tinney 1983).

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

Pen Branch Corridor and Delta Trends

In 1951, the Savannah River swamp and Pen Branch corridor had a closed canopy forest. In 1954, K Reactor began discharging thermal effluent to Pen Branch. The discharge volume (approximately 2.8 m^3/sec [100 cfs]) and temperature were low (Table 6-13). However, canopy change in the corridor was visible in the aerial photographs taken as early as 1955 and 1956 (Figure 6-24). About 11 ha (27 acres) of bottomland hardwood forest along the corridor were partially defoliated by May 1955. Because discharge temperatures were relatively low, flooding from reactor effluents was probably the major cause of damage.

Reactor discharge temperatures began to rise steadily during 1955 and 1956, and by the end of March 1956, 54 ha (133 acres) along the corridor had been affected. By 1961, canopy defoliation was apparent throughout the corridor (113 ha [279 acres]) and had reached the Savannah River swamp (4.5 ha [11 acres]) (Table 6-13, Figure 6-24 and Figure 6-25). Most of the trees were affected, probably due to the increasing temperatures ($\bar{x}$ = 65°C [149°F]) and flows ($\bar{x}$ = 10 m^3/sec [338 cfs]). During the next five years, the Pen Branch corridor impact area stabilized (at 116 ha [287 acres]), and a delta formed in the swamp at a rate of 9 ha (22 acres)/yr, reaching 51 ha (126 acres) by 1966 (Table 6-13 and Figure 6-25). Average flow (11 m^3/sec [395 cfs]) and temperature (64°C [147°F]) remained relatively high (Tinney et al. 1986).

With lower K-Reactor power levels, discharge temperatures were reduced to 53°C (127°F) by 1966 (Table 6-13). The delta expansion rate decreased to 1.6 ha (4 acres)/yr. Reduced power operations and discharge temperatures continued through 1974 when SRS began an energy conservation program in all reactor areas. Because less cooling water was used, K-Reactor discharges dropped an average of 0.56 m^3/sec (20 cfs) (Table 6-13). However, delta growth accelerated to 6.6 ha (16 acres)/yr after 1973 despite the reduced flows and temperatures. After 1979, reactor power levels began to return to higher levels. Effluent temperatures increased ($\bar{x}$ = 65°C [149°F]) and the Pen Branch growth continued to expand. In 1985, the impact zone was about 152 ha (375 acres) and was expanding at a rate of about 4 ha (10 acres)/yr (Table 6-13) (Tinney et al. 1986).

As of 1985, approximately 245 ha (605 acres) of forested wetlands had been affected by thermal discharges from K Reactor. Defoliated canopy was visible in both the stream floodplain (93 ha [230 acres]) and SRS swamp (152 ha [375 acres]). Although the Pen Branch delta was expanding at a rate of 4-5 ha (10-12 acres)/yr in 1985, no additional wetlands changes were expected in the stream corridor (Tinney et al. 1986).

Much of the swamp canopy loss in the early to mid-1980s near Pen Branch delta occurred southeast of the main Pen Branch delta, adjacent to the upland terrace along the Savannah River swamp (Figure 6-26) (Sharitz et al. 1986; Christensen et al. 1986; Jensen et al. 1987).

Table 6-13. Discharge Conditions and Estimated Impacts to Pen Branch from Reactor Discharges, 1954-1995

	Pen Branch Savannah River Swamp		**Pen Branch Corridor**		**Annual Average Reactor Discharge or Pen Branch Flows**	
Year	**Total Affected Area[a] (ha)**	**Expansion and Revegetation Rate (ha/yr)**	**Total Affected Area[a] (ha)**	**Expansion Rate of Forest Canopy Mortality (ha/yr)**	**Flow (cfs)[b]**	**Temperature (°C)**
1954	-	-	-	-	100[d]	26
1955	0	-	11.0	-	100[d]	42
1956	0	-	53.8	42.8	131	63
1957	-	-	-	-	183	64
1958	-	-	-	-	214	66
1959	-	-	-	-	277	70
1960	-	-	-	-	334	66
1961	4.5	9.4	112.9	11.8	398	63
1962	-	-	-	-	399	63
1963	-	-	-	-	394	66
1964	-	-	-	-	394	67
1965	-	-	-	-	392	62
1966	51.4	-	115.7	0.6	389	53
1967	-	-	-	-	389	58
1968	-	-	-	-	389	63
1969	-	-	-	-	389	57
1970	-	-	-	-	386	46
1971	-	-	-	-	388	57
1972	-	-	-	-	390	55
1973	63.1	1.7	-	-	388	59
1974	-	-	-	-	324	61
1975	-	-	-	-	373	58
1976	-	-	-	-	376	57
1977	-	-	-	-	375	57
1978	-	-	-	-	378	57
1979	102.4	6.6	-	-	379	61
1980	-	-	-	-	380	64
1981	-	-	-	-	380	64
1982	121.0	6.2	-	-	381	67
1983	-	-	-	-	380	-
1984	147.4	13.2	-	-	370	59
1985	151.8	4.4	92.6	-1.2	367	-
1986	-	-	-	-	270	-
1987	-	-	-	-	329	-
1988	-	-	-	-	140	-
1989	-	-	-	-	78	-
1990	-	-	-	-	57	-
1991	-	-	-	-	200	-
1992	-	-	-	-	160	-
1993	-	-	-	-	54	-
1994	-	-	-	-	56	-
1995	-	-	-	-	49	-

[a]Includes greater than 5% canopy loss; to convert to acres, multiply by 2.471.

[b]35.82 cfs = 1 m^3/sec. For years 1954-1984, the data are from Tinney et al. 1986. For years 1985-1991, the data are from the USGS recording station as SRS Road A_6-13.2. For 1992 the data are from Mackey 1993.

[c]To convert to 60 F, multiply by 9/5 and add 32.

[d]Approximate.

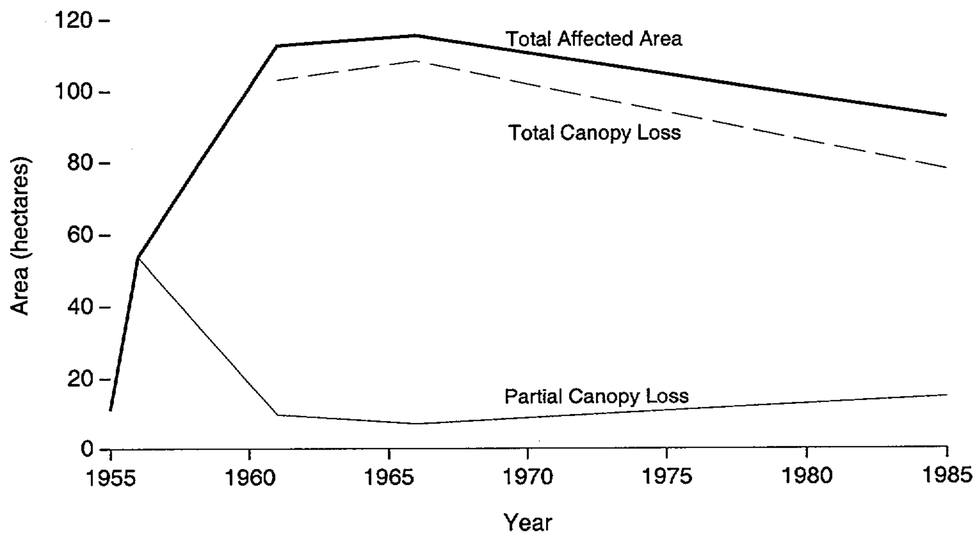


Figure 6-24. Wetland Changes in the Pen Branch Corridor, 1955-1985 (Source: Tinney et al. 1986)

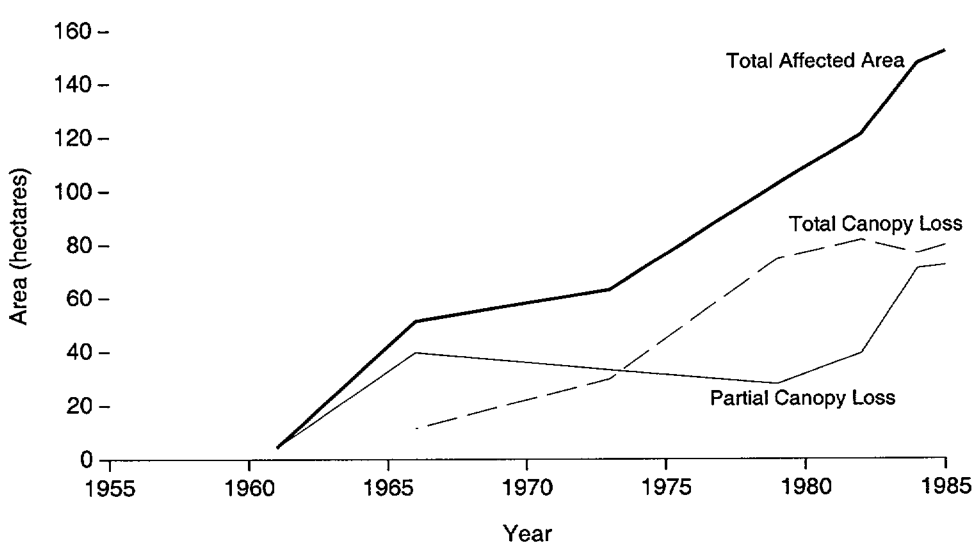


Figure 6-25. Pen Branch Delta Expansion, 1955-1985 (Source: Tinney et al. 1986)

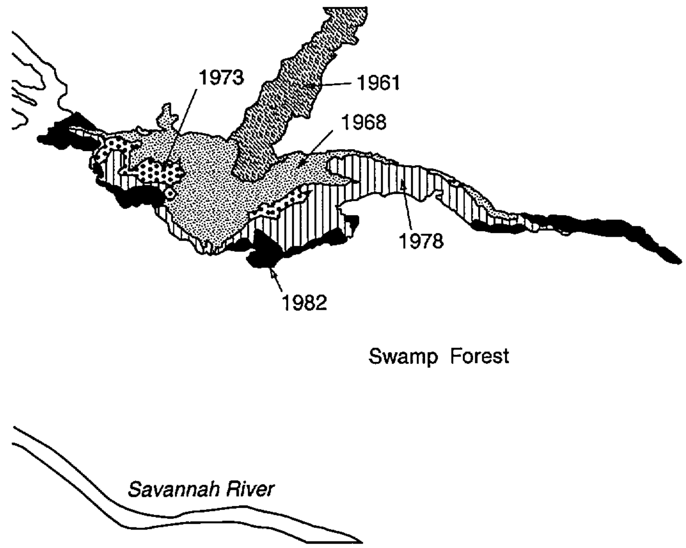


Figure 6-26. Pen Branch Delta Expansion Composite Image, 1961-1982 (Source: Wike et al. 1994)

Thermal infrared surveys showed that during river flooding, thermal effluents from both Fourmile Branch and Pen Branch were channeled along the northeast bank of the swamp away from the river (Figure 6-27) (Shines and Tinney 1983). Times of river flooding seemed to correlate with the southeastern progression of the Pen Branch delta. From 1966 to March 1973, the southeastern tail changed little (Figure 6-26). Spring flooding frequency and duration were low during this period. After 1973, there was an increase in springtime flooding frequency and the tail began to increase in size. The channeling of thermal effluents during the spring and summer growing season, when the cypress-tupelo forest is most sensitive, may have increased mortality (Sharitz et al. 1986). The post-1973 increase in river flooding intensity may have caused the increase in the delta expansion rate from 1.7 to 6.6 ha (4 to 16 acres)/yr, when reactor discharge temperatures and flows remained relatively constant (Wike et al. 1994).

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

Pen Branch received thermal effluent from K Reactor. Temperatures of the reactor effluents at the point of release into Pen Branch commonly exceeded 65°C (149°F). Water temperatures throughout the length of the then-thermal portion of Pen Branch typically exceeded 40°C (104°F) in the summer. The original flora of the stream and associated floodplains were destroyed and the area underwent successional revegetation. Sharitz et al. (1974a) found only 34 species of vascular plants in the Pen Branch corridor at a site immediately above the delta where the stream enters the Savannah River swamp. All of the plants were growing above the water on sandbars or small islands formed by fallen logs and tree stumps. Only 56% of the floodplain area sampled supported vascular plant life. The Pen Branch floodplain flora was characterized by herbaceous plants. The dominant species was water primrose (*Ludwigia leptocarpa*), which was shown to have a relatively high tolerance to the elevated thermal conditions of the SRS swamp (Christy and Sharitz 1980). The other species were mostly perennial herbaceous plants characteristic

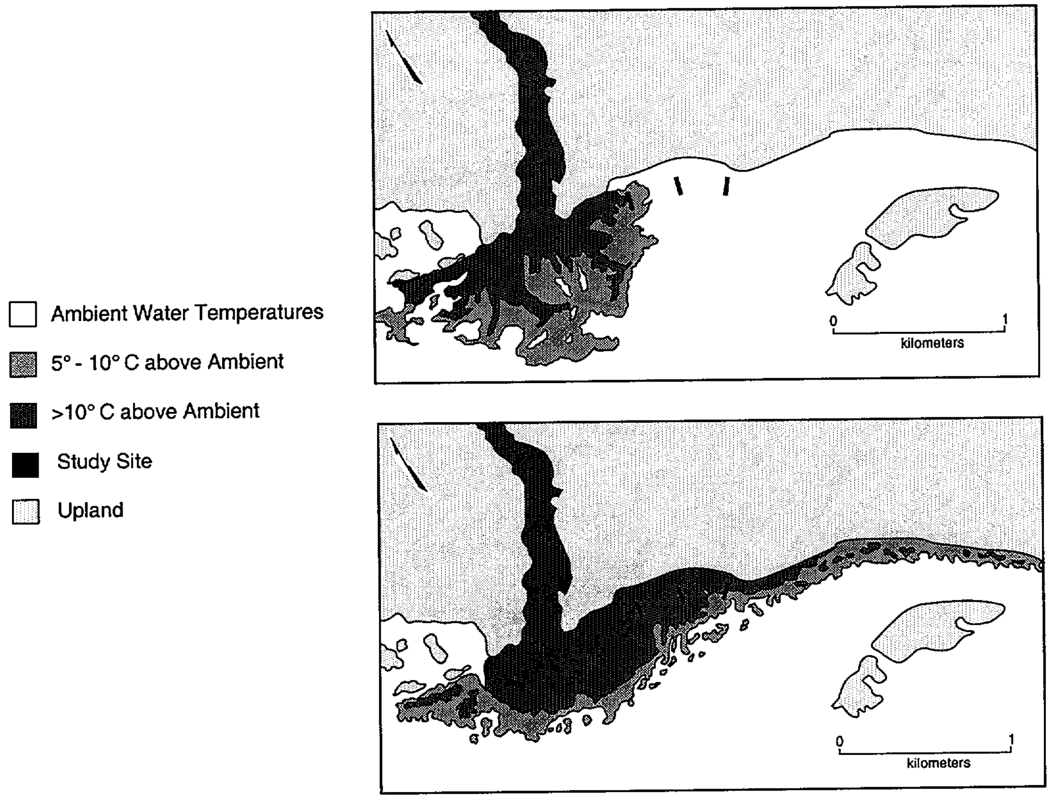


Figure 6-27. Thermal Patterns in the Pen Branch Delta Under Nonflood (Top) and Flood (Bottom) Conditions of the Savannah River (Source: Scott et al. 1986)

of disturbed areas. Perennial herbs constituted 60% of the Pen Branch flora and annual herbs another 20%. In another early survey, Irwin (1975) sampled the vegetation of stump communities at three sites in the thermal portion of Pen Branch. Fifteen stumps were evaluated from each of three areas corresponding to mean annual water temperatures of approximately 50℃, 45℃, and 40℃ (122℉, 113℉, and 104℉). The vegetation of the stump communities in Pen Branch included old-field species, roadside weeds, and aquatic herbs. Twenty-six of the species were herbaceous, and of the nine woody species, three were tree seedlings. There was no clearly distinguishable relationship between stream water temperature and stump community composition, although the upstream sites (water temperature approximately 50℃ [122℉]) were dominated by several old-field species, including dogfennel (Eupatorium spp.) and broom sedge. Downstream sites (water temperatures approximately 40-45℃ [104-113℉]) had a greater dominance of aquatic species, such as water primrose and swamp loosestrife. Woody plants were relatively intolerant of the elevated temperatures and substrate conditions. The Comprehensive Cooling Water Study and other studies at SRS from 1983 to 1985 (Firth et al. 1986) summarize additional information on the in-stream habitat formers of the thermal and nonthermal SRS streams.

MSS Surveys—Pen Branch Delta

Central Portion MSS Surveys, 1981–1994

The April 1984 MSS data were registered to March 1981 data for a 190-ha (469 acre) area centered on the Pen Branch delta (Figure 6-16). The most obvious difference between 1981 and 1984 was the expansion of the emergent marsh into thinned cypress-tupelo areas. Nonpersistent emergent and persistent emergent wetlands replaced about 12 ha (30 acres) of cypress-tupelo. The majority of the cypress-tupelo area lost was adjacent to the existing thermal delta or to the southeast, along the Savannah River swamp terrace edge.

Burkhalter (1994) compared 1992 MSS data with 1981 data and determined that deciduous swamp forest beyond the delta in 1981 had been degraded to persistent emergent and scrub-shrub wetlands by 1992. The most striking feature was the tremendous invasion of the persistent emergent marsh (mostly cattails, particularly in the tail region). The delta had been exposed mudflat or vegetated with nonpersistent emergent vegetation in 1981. By 1992, much of the delta supported persisted emergent and scrub-shrub species, an indication that the delta was undergoing succession.

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

In mid-April 1988, K Reactor shut down. Flows in Pen Branch decreased from levels near $11 m^3/sec$ (400 cfs) to 1.4-1.7 m^3/sec (50-60 cfs) in 1989 and 1990. This decrease in flow was reflected in a decline in the deep- and open-water areas as evaluated with the SPOT HRV data (Table 6-14). As the Pen Branch delta became drier in 1988 through 1990, it also became more difficult to distinguish areas of *Ludwigia* dominance from areas dominated by cattail beds. Part of this difficulty is the result of large beds of dead, brown biomass from the *Ludwigia* areas and cattail beds still present in the spring from growth during the previous summer. Furthermore, some areas in the lower Pen Branch stream corridor north of the upper delta began to resemble old-field sites. Similar invasion of old-field species has been observed in the drier portions of the Fourmile Branch corridor and delta since C-Reactor shutdown. Since 1990, the main portion of the Pen Branch delta has become increasingly dominated by persistent cattails beds and by invading scrub-shrub species, primarily willow and buttonbush (Table 6-14). The overall shift from wetland communities dominated by more thermally and flood tolerant herbaceous species to wetland communities dominated by persistent and scrub-shrub species is likely to continue without disturbance.

Summary of Changes

Table 6-15 and Table 6-16 summarize trends in wetlands for the Pen Branch corridor and delta. After the reduction in K-Reactor operations in 1987, the shift was from nonpersis-

Table 6-14. Major Wetland Cover Types Based on Classification of SPOT HRV Data for the Pen Branch Delta, Spring 1987-1992

	Year and Date of SPOT HRV Data					
Wetland Cover Type	**1987 Apr 24**	**1988 May 02**	**1989 May 17**	**1990 May 11**	**1991 May 02**	**1992 May 5**
Deep/open water	13.1[a]	4.0	0.0	1.1	23.2[b]	26.2[b]
Non-Persistent emergent marsh						
Shallow water/mud flats	65.5	29.0	0.4	11.4	-	-
Ludwigia spp.	34.0	56.8	97.4[c]	92.2	66.2[b]	31.8[b]
Duckweed	3.2	10.1	3.6	0.1	0.3	-
Persistent emergent marsh, primarily cattails (*Typha* spp.)	31.2	38.5	c	6.0	44.8	55.5
Scrub-shrub	-	-	-	11.7	3.4	23.6
Total	147.0	138.4	101.4	122.5	137.9	137.1

Source: Mackey 1993.
[a] Hectares; to convert to acres, multiply by 2.471.
[b] In May 1991 and 1992, the Pen Branch delta was wetter from spring Savannah River flooding and moderate flows to Pen Branch, thus it was difficult to sort between shallow-water/mudflats and *Ludwigia* beds. This difficulty probably accounts for an apparent increase in deep water areas.
[c] In May 1989, it was not possible to distinguish between the nonpersistent beds of *Ludwigia* and stands of cattails in the SPOT HRV data.

Table 6-15. Wetland Classification Scheme for the Pen Branch Tail Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data

	Representative Species	
Wetlands Class	**Common Name**	**Scientific Name**
Open water		
Emergent marsh	Bulrush	*Scirpus cyperinus*
	Cutgrass	*Leersia* spp.
	False Nettle	*Boehmeria cylindrica*
	Water Primrose	*Ludwigia* spp.
	Hydrolea	*Hydrolea quadrivalvis*
Deciduous swamp forest	Cypress	*Taxodium distichum*
	Tupelo	*Nyssa aquatica*
Deciduous bottomland forest	Oak	*Quercus* spp.
	Sweetgum	*Liquidambar styraciflua*
	Red Maple	*Acer rubrum*
	Hickory	*Carya* spp.

Table 6-16. Pen Branch Tail Wetlands Change Detection Based on March 31, 1981, and April 29, 1985, Aircraft MSS Data

From	To	Hectares
Deciduous swamp forest (DSF)	Emergent marsh	3.64
DSF	Transition-DSF	12.14
DSF	Open water	9.30
Transition-DSF	Emergent marsh	2.42
Transition-DSF	Open water	1.21
Transition-DSF No Change		5.66

tent vegetation and water to more persistent vegetation and drier conditions. The area of willows and hardwoods increased tremendously, as the willows and scrub-shrub expanded down the corridor into the delta, gradually being replaced by other hardwoods or becoming large enough to be classified as hardwoods. The area of deep water was large in the early years, but decreased substantially in 1990-1992, reflecting the drying of the corridor and delta. As the delta dried, water primrose declined markedly from 1990 to 1991. This allowed other vegetation, such as cattails, to increase dramatically by 1991 (Mackey 1993; Blohm 1993).

MSS data were used to assess the continuing successional changes in the Pen Branch corridor and delta in 1993 and 1994. Cypress acreage was increasing. The hardwood and scrub-shrub classes were gaining acreage until the area was treated by herbicides in the winter of 1993 in preparation for selective planting. Some of the hardwood class were actually willow that were mislabeled in the earlier assessment. Old-field acreage in the corridor has increased, due to site preparation prior to seedling planting. In general, the nonpersistent vegetation that maintained dominance under conditions of thermal discharges and fluctuating water levels (such as *Ludwigia* spp.) is being replaced by more persistent species (such as cattails). Drier conditions in the delta support increased acreages of the most tolerant hardwoods, scrub-shrub, and willow stands, cypress, and persistent wetlands vegetation (Christel 1996). Hardwoods expanded down the corridor, and cattails expanded over the delta (Blohm 1993).

Tail MSS Surveys, 1981-1994

Expansion of the Pen Branch delta occurred southeast of the main portion of the delta along the SRS Savannah River swamp terrace edge. The Pen Branch tail extended southeast for approximately 3 km (2 mi) along an upland terrace adjacent to the Savannah River swamp. This area was influenced by thermal effluents, especially during flood events (Figure 6-27). A separate evaluation of this area was conducted using aircraft MSS data from March 31, 1981, and April 29, 1985. Two 375-ha (927-acre) subsets from the 1981 and 1985 MSS data were evaluated (Figure 6-16).

The MSS data were classified into the following wetland vegetation classes once the 1981 and 1985 imagery were registered to one another:

- Open water
- Emergent marsh (persistent and nonpersistent)
- Deciduous swamp forest
- Deciduous bottomland forest

One additional class of deciduous swamp forest, referred to as a transition deciduous swamp forest, was found in both the 1981 and 1985 imagery. A transition deciduous swamp forest consists of cypress-tupelo swamp forest with a sparse, stressed canopy, which allows radiant flux from the emergent marsh below to be integrated within a typical pixel. The stressed cypress-tupelo community was documented *in situ* in the Pen Branch tail by Scott et al. (1986) and radiometrically by Jensen et al. (1986b). Table 6-16 summarizes the statistics associated with the changes in the Pen Branch delta from 1981 to 1985. Table 6-10 and Table 6-12 show changes between 1981 and 1992. Since 1992, there has been some return of young cypress to the tail area (Christel 1996). Section 6.7 of this chapter discusses the reforestation project in the Pen Branch corridor and delta.

Pen Branch Ground Surveys, 1990

In the summer of 1990, a series of vegetation surveys was conducted along the Pen Branch drainage from the K-Reactor discharge canal to the Pen Branch tail area (Wike et al. 1994). These surveys are summarized in the following paragraphs by survey area along the creek and for each vegetation stratum.

Indian Grave Branch Section

Introduction - Indian Grave Branch, a 4-km (2.5-mi)-long tributary to Pen Branch, has steep, incised banks with a flow approximately 4.5-6 m (15-20 ft) wide. Sampling plots were established along Indian Grave Branch beginning approximately 300 m (1000 ft) north of Road B and extending south to the confluence of Pen Branch. Ninety-nine species were found.

Overstory Stratum - Thirteen species were found in the overstory. The average height of the overstory canopy was 19 m (62 ft). The most dominant species occurring within the sample plots were yellow poplar and black gum. Red maple had the highest density within the sampling plots. Following red maple in relative density were black gum, yellow poplar, sweet gum, and sycamore.

Understory Stratum - Fourteen species were found in the understory. American holly (Ilex *opaca*) had the highest importance value. Following American holly were sweet gum, red-bay, and tag alder. American holly also had the greatest relative density.

Shrub Stratum - Twenty-seven species were found in the shrub stratum. American holly had the greatest relative dominance, followed by tag alder. Red bay had the greatest relative density, followed by American holly and sweet bay.

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

Mid-Corridor Section

Introduction - This section began approximately 60 m (100 ft) north of South Carolina Highway 125 and extended south for approximately 5 km (3 mi). For approximately 0.6 km (1 mi), the sampling area has steep banks leading down to the floodplain of the creek. Downstream of this point, the topography around Pen Branch flattens. Due to the flat terrain, the surface runoff contributing to Pen Branch flows as wide sheets of water rather than being confined to small intermittent tributaries. Eighty-eight plant species were found along this section of Pen Branch.

Overstory Stratum - The average canopy height of the overstory vegetation was 21 m (70 ft). Red maple, black gum, yellow poplar, and ash were the most common species in this stratum.

Understory Stratum - Fifteen species were recorded within the understory of this section. Wax myrtle (*Myrica cerifera*) was the dominant species. Wax myrtle had the highest importance value for the area, followed by black willow, tag alder, and sweet gum.

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

Ground Cover Stratum - One hundred one species were recorded from the ground cover. False nettle had the highest importance value, followed by woolgrass (*Scirpus cylindrica*), jewel weed (*Impatiens capensis*), climbing hemp, and marsh dewflower (Murdannia keisak), all with about equal importance values.

Lower Pen Branch Corridor

Introduction - The lower Pen Branch corridor begins south of Road A-13.2 (Risher Pond Road) and extends south for approximately 0.2 km (0.75 mi). This stretch of Pen Branch drops only 3 m (10 ft) in elevation. This area had a series of parallel braided streams and was dominated by scrub-shrub growth. Within the braided streams were many islands on which thick masses of persistent emergent ground cover were thriving. Nonpersistent emergent vegetation also was well represented. Seventy-six species were found.

Overstory Stratum - The overstory vegetation in this area was represented by seven species. The average canopy height was 19.5 m (64 ft). Sweetgum and black gum were the dominant species, followed by red maple.

Understory Stratum - Nine species were found in the understory. The dominant species was black willow. Following black willow were black gum, tag alder, buttonbush, and American holly.

Shrub Stratum - Thirteen species of shrubs were recorded. Black willow had the highest importance value. Black willow was the most common, followed by tag alder, buttonbush, and sweet bay.

Ground Cover Stratum - Seventy-eight species were found in the ground cover. False nettle was the dominant species, followed by fireweed and woolgrass.

Upper Delta Area

Introduction - The upper delta (Figure 6-28) was similar to the lower corridor in that it had braided streams and islands within the broad, flat floodplain. Elevation ranged from 29.5 m (97 ft) above msl to 24 m (80 ft) above msl. Standing dead trees were common, and woody debris was scattered throughout. The lack of an overstory resulted in thick scrub-shrub and persistent emergent vegetation. Sixty-one species were found in the upper delta.

Overstory Stratum - No overstory vegetation was recorded. All sampling plots were located in the wide floodplain of the lower section of Pen Branch. The area once was well forested; however, in 1990 it contained only many snags of black gum and bald cypress.

Understory Stratum - Only five species were found in the understory stratum. Black willow was the dominant species, followed by buttonbush.

Shrub Stratum - The shrub stratum had 12 species. Black willow dominated followed by buttonbush.

Ground Cover Stratum - The ground cover was dominated by false nettle, followed by fireweed and dogfennel. The presence of dogfennel, an upland species, demonstrates the drier nature of the Pen Branch delta sediments since K-Reactor shutdown in 1988 (Mackey 1993).

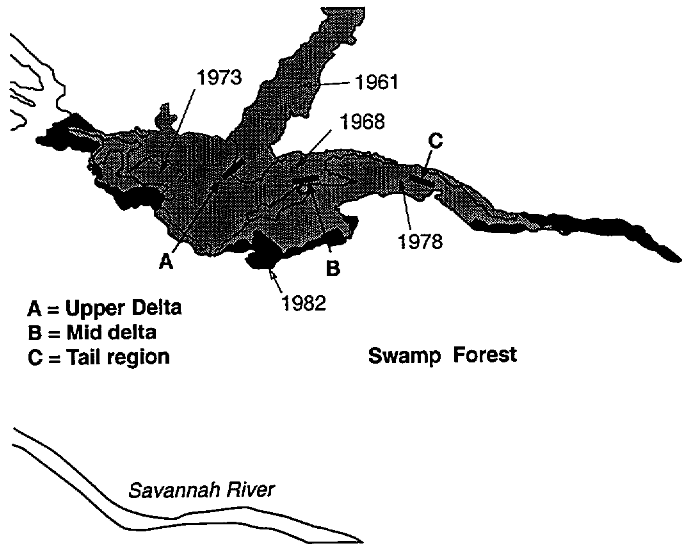


Figure 6-28. Locations of Upper Delta, Mid-Delta, and Tail Region of Pen Branch Delta

Mid-Delta Area

Introduction - The mid-delta area (Figure 6-28) is within the confluence of Pen Branch and the Savannah River floodplain swamp. The area has a soft substrate that is inundated with water. It was dominated by persistent and nonpersistent vegetation. The elevation of the sampling area is approximately 24 m (80 feet) above msl. This area is west of the Pen Branch boardwalk. Little shrub and understory vegetation was observed, and no overstory stratum was sampled. Thirty-one plant species were found within the mid-delta region.

Overstory Stratum - There was no overstory vegetation.

Understory Stratum - Only one wax myrtle met the criterion for understory vegetation.

Shrub Stratum - The shrub layer contained three species: black willow, buttonbush, and wax myrtle.

Ground Cover Stratum - Thirty-four species were measured in the ground cover stratum. Broad-leaf arrowhead (*Sagittaria latifolia*) had the greatest importance value, followed by water primrose (*Ludwigia leptocarpa*), cattail (*Typha latifolia*), and beggar tick (*Bidens frondosa*).

Pen Branch Tail Area

Introduction - The Pen Branch tail area begins east of the Pen Branch boardwalk and extends east for approximately 2 km (1.25 mi). Persistent and nonpersistent emergent vegetation dominated the area. Eastward, there was an increase in mature bald cypress, and the density of seedlings and saplings greatly increased. Seventy-seven species were found in the area.

Overstory Stratum - The overstory consisted of bald cypress, water tupelo, and black gum. The average height of the sparse canopy was 24 m (78 ft). The overstory vegetation became progressively more dense as distance from the mouth of Pen Branch increased.

Understory Stratum - Four species were measured in the understory stratum; wax myrtle was the most common, followed by black willow.

Shrub Stratum - The shrub stratum, like the overstory and understory strata, was represented by only a few species, in this case five. Wax myrtle was the dominant species, followed by buttonbush.

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

Ground Cover Stratum - Sixty-eight species were found in the ground cover stratum of the Pen Branch tail. Marsh dewflower, a highly successful introduced plant, was the most common. Broad-leaf arrowhead, cattail, and false nettle were also common.

Summary of 1990 Pen Branch Ground Survey

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

Steel Creek

Steel Creek Watershed Characteristics

Steel Creek is near the eastern boundary of SRS. Steel Creek and its major tributary, Meyers Branch, drain approximately 91 km^2 (35 mi^2) of upland before entering the swamp and flowing to the Savannah River. The drainage basin for Meyers Branch constitutes more than half of the watershed (50.85 km^2 [20 mi^2]). The stream slope changes from 4.6 m/km (25 ft/mi) at the head to 0.8 m/km(5 ft/mi) as it enters the Savannah River (Newman et al. 1986).

Steel Creek Corridor and Delta Through 1982

In 1951, a closed canopy forest extended throughout much of the Savannah River swamp and Steel Creek corridor. Although portions of the forest had been previously logged (Jensen et al. 1993), a second-growth forest of bald cypress, water tupelo, and bottomland hardwoods was present. In 1954, both L and P Reactors began releasing thermal effluents to Steel Creek. The discharge volume (approximately 5.6 m^3/sec [200 cfs] total) and temperature (30-48°C [86-104°F]) were relatively low (Table 6-17). Approximately one year after startup, 48 ha (119 acres) of bottomland forest were partially defoliated in the Steel

Creek corridor below both L and P Reactors (Table 6-17 and Figure 6-29). Canopy loss continued into 1956 with 132 ha (326 acres) of corridor floodplain forest damaged (Table 6-17 and Figure 6-29). At the same time, the first signs of canopy loss also appeared in the swamp (Figure 6-30). In one year, 73 ha (180 acres) of cypress-tupelo canopy were partially defoliated in the swamp. Canopy loss in the swamp continued at an overall rate of 10 ha (24 acres)/yr while in the Steel Creek floodplain defoliation slowed to 2.2 ha (5.4 acres)/yr from 1956 to 1961 (Table 6-17). During this period, reactor discharge temperatures averaged approximately 70°C (158°F) (Table 6-17).

Maximum flow in Steel Creek occurred between 1960 and 1963 (Table 6-17). However, from 1961 to 1966, the floodplain and the swamp impact zones grew at a rate of about 0.5 ha (1 acre)/yr (Figure 6-29 and Figure 6-30). The slower growth rate probably occurred because P-Reactor thermal effluents were diverted to Par Pond in 1963. From 1961 to early 1963, reactor discharges to Steel Creek averaged 21 m^3/sec (760 cfs), but dropped to about 10 m^3/sec (370 cfs) from 1963 to 1968 (Table 6-17). Water temperatures remained relatively constant. In 1966, the total impact area was near its maximum size at 124 ha (306 acres) in the swamp and 146 ha (360 acres) in the Steel Creek corridor (Table 6-17).

In 1963, P-Reactor thermal effluents were diverted to Par Pond, allowing the natural successional revegetation of bottomland forest to begin in the upper portion of the Steel Creek corridor. When L Reactor discontinued operations in 1968, the swamp and remainder of the corridor floodplain forest also began to revegetate. Between 1968 and 1982, new forest canopy cover established in the swamp at a rate of less than 1 ha (2.5 acres)/yr (Figure 6-30). After 1982, the canopy recovery rate accelerated to about 8 ha (20 acres)/yr as young hardwoods matured. However, most new regrowth of woody species was of willow (*Salix* spp.) and not the original cypress-tupelo swamp forest (Repaske 1981; Smith et al. 1981). Some cypress-tupelo regeneration occurred in fringe areas of the swamp impact zone where thermal exposure had been less extreme (Tinney et al. 1986).

Some cypress-tupelo regeneration occurred offsite in the Creek Plantation swamp (southeast of SRS). Thermal effluent from Steel Creek entered the area beginning in 1956, particularly when the swamp was flooded in late winter and early spring. By 1961, about 5 ha (12 acres) of offsite swamp canopy had been altered. After 1963, the canopy began to recover. By 1966, the impact area visible on aerial photographs had been reduced to 4 ha (10 acres). Currently, a closed canopy exists in the previously impacted offsite area (Tinney et al. 1986).

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

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

With long-term reactor shutdown, plant succession on the Steel Creek delta proceeded rapidly. The initial flora of the emergent sandbars was dominated by fimbristylis (*Fimbristylis autumnalis*), water primrose (*Ludwigia leptocarpa* and *L. decurrens*), sedges (*Cyperus* spp.), and echinochloa (*Echinochloa walteri*) (McCaffrey 1982). Knotweed, broad leaved

Table 6-17. Discharge Conditions and Estimated Impacts to Steel Creek from Reactor Discharges, 1954-1995

	Steel Creek Delta Savannah River Swamp		Steel Creek Corridor		Annual Average Reactor Discharge or Creek Flow	
Year	Total Affected Area[a] (ha)	Expansion and Revegetation Rate (ha/yr)	Total Affected Area[a] (ha)	Expansion Rate of Forest Canopy Mortality (ha/yr)	Flow (cfs)[b]	Temperature (°C)[c]
1954	0	-	-	-	200	32
1955	0	-	48.1	48.1	200	44
1956	72.8	72.8	132.2	84.1	257	64
1957	-	-	-	-	270	71
1958	-	-	-	-	386	69
1959	-	-	-	-	557	72
1960	-	-	-	-	649	72
1961	122.6	10.1	143.4	2.2	758	67
1962	-	-	-	-	763	68
1963	-	-	-	-	372	66
1964	-	-	-	-	376	67
1965	-	-	-	-	371	69
1966	124.2	0.4	146.0	0.5	370	70
1967[d]	-	-	-	-	368	69
1968	-	-	-	-	370	67
1974	120.6	0.4	147.0	0.1	-	-
1981	-	-	-	-	32	-
1982	113.3	0.9[d]	-	-	56	-
1983	-	-	-	-	72	-
1984	90.1	7.8[d]	-	-	79	-
1985	81.9	8.1[d]	76.1	5.9[e]	83	-
1986	-	-	-	-	249	-
1987	-	-	-	-	260	-
1988	-	-	-	-	242	-
1989	-	-	-	-	127	-
1990	-	-	-	-	128	-
1991	-	-	-	-	160	-
1992	-	-	-	-	112	-
1993	-	-	-	-	116	-
1994	-	-	-	-	87	-
1995	-	-	-	-	78	-

[a] ~~Greater than 5% can~~opy loss; to convert to acres, multiply by 2.471.
[b] 35.31 cfs = 1 m^3/sec. For years 1954-1968, the data are from Tinney et al. 1986. For years 1981-1991, the data are from the USGS recording station.
[c] To convert to °F, multiply by 9/5 and add 32.
[d] L Reactor discharged for two months before shutdown.
[e] Revegetation rate.

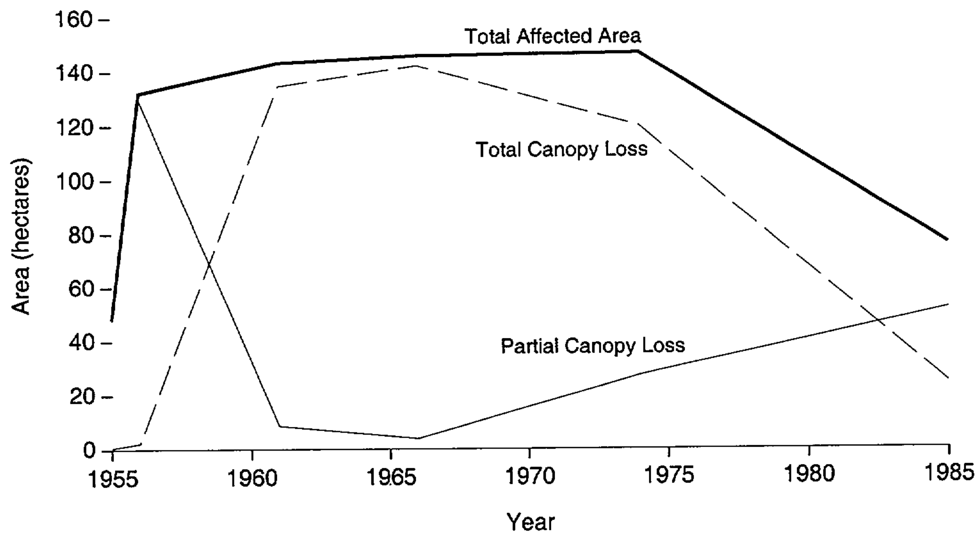


Figure 6-29. Steel Creek Wetlands Changes, 1955-1985 (Source: Tinney et al. 1986)

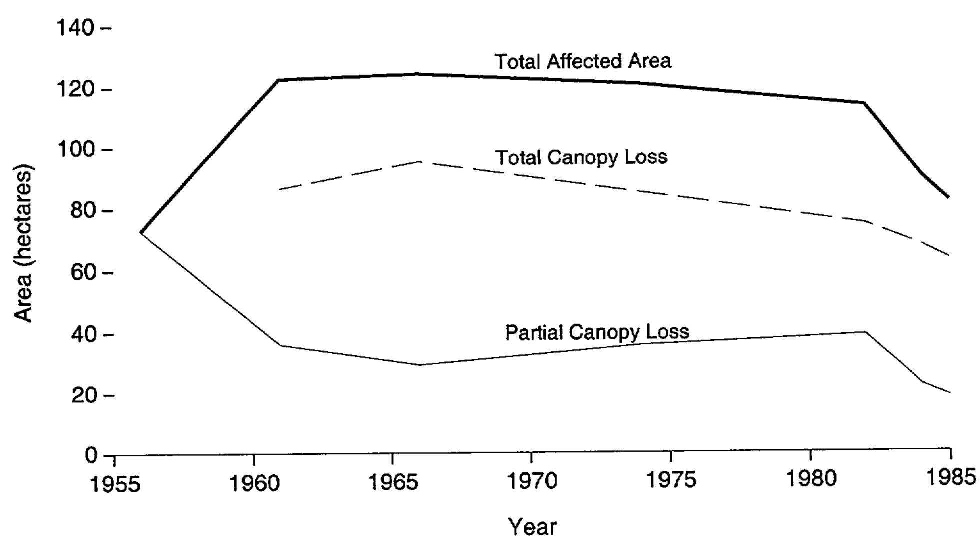


Figure 6-30. Steel Creek Growth and Revegetation Trends, 1951-1985 (Source: Tinney et al. 1986)

arrowhead, and cut grass became dominant species four to eight years after reactor shutdown. Seven years after shutdown *Aneilema keisak* became an additional dominant; cut grass increased and smartweed decreased in dominance.

Begger ticks, marsh St. John's-wort, false nettle, and bulrush had an intermediate ranking in importance four to eight years after reactor shutdown. Redtop panicgrass also had an intermediate ranking at the later date. Buttonbush and willow appeared during this time; while seedlings of other woody species were ephemeral. According to Martin et al. (1977), the Steel Creek delta was covered with water and resembled a freshwater marsh in 1975. The vegetation was characterized by a low, dense herbaceous cover with numerous clumps of large graminoids and widely spaced shrubs. In 1981, there were three major stages of succession in the persistent emergent wetland: areas of abundant knotgrass that generally fit the description by Martin et al. (1977), areas in which numerous small buttonbush and willow plants were nearly as tall as the knotgrass (approximately 1.5 m [5 ft]), and other areas dominated by a mixture of willow and buttonbush taller than the knot grass.

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

After 15 years of successional revegetation, the dominant species was willow. Seedlings of bald cypress, water ash, water elm, and red maple also occurred, especially toward the delta periphery. The survival and growth of these plants are largely dependent upon the duration and timing of flooding (Broadfoot and Williston 1973; Whitlow and Harris 1979; Sharitz et al. 1986; McLeod et al. 1986; Scott et al. 1985).

Because of a raised substrate on which hardwood species can become established, it is likely that the deltaic fan eventually will become more like deciduous bottomland hardwood forest (overcup oak— water hickory [*Carya aquatica*] — water tupelo) than the original deciduous swamp forest.

Succession in areas of deeper water is dependent upon water depth and flow. Here, submerged aquatic plants (coontail and *Myriophyllum brasiliense* [parrot feather]) colonized submerged logs. These species are joined by numerous emergent aquatic species, including knotweed and aneilema in deeper water with low flow. Hydrolea dominated the periphery of the deltaic fan and occurred over a wide range of water depths, along with parrot-feather and *Ludwigia* spp. The shallower areas had broad-leaved arrowhead abundant rhynchospora (*Rhynchospora corniculata*). Waterpepper occurs in similar habitats. Both wapato and waterpepper are transitional species occurring in both nonpersistent emergent wetlands and in persistent emergent wetlands.

Steel Creek Corridor and Delta, 1985-1992

The L-Lake/Steel Creek Biological Monitoring Program (1985-1992) monitored the effects of the restart of L Reactor on the riparian wetland habitat of Steel Creek from L Lake dam to the Savannah River. During 1986 through 1989, quarterly surveys were conducted at 12 stations on Steel Creek and 1 station on Meyers Branch (Peter and Westbury 1990). In 1990-1992, the program was reduced to four stations sampled semiannually when L Reactor was shutdown (Westbury 1993). At each station, two parallel belt transects were established perpendicular to the main channel and bisecting instream habitat mapping reaches.

These belt transects extended to the upland boundary of the floodplain or for a total length of no more than 150 m (522 ft). Variables reported in these data include the frequency, width and cross-sectional area of all channels; percent inundation; the density of logs, knees, and stumps; the density, diameter, basal area, and importance values of trees; shrub density; canopy cover; taxa richness; growth form analysis; and herbaceous cover (Table 6-18 through Table 6-24). Taxonomic identification and analysis were largely at the species level, with annual taxa lists exceeding 200 species in 1989 (Table 6-25 and Table 6-26) (Peter and Westbury 1990).

The Steel Creek corridor station (290) was chosen to represent the upper portion of the study area. The floodplain was relatively narrow, and the influence of L-Lake discharge rates was the greatest. The decrease in percent inundation between 1988 and 1989 (Table 6-20) is a result of L Reactor shutdown. The reduction in canopy cover observed during the same time (Table 6-21) was due to wind damage from several violent storms. Mean stand basal area was not affected because no trees in the belt transects were thrown. The decrease in canopy cover due to the storm damage increased herbaceous cover (Table 6-24).

Station 330 represented the open-canopy marsh habitat of the Steel Creek delta, which had the lowest canopy cover, shrub density, and tree basal area. L-Lake discharge and water levels in the Savannah River influenced inundation at this station. High river water levels were responsible for the increase in inundation observed in 1990. Herbaceous cover was high at this station, but generally decreased in response to fluctuating water levels during the period of L-Reactor operation. A drop in herbaceous cover in 1991 was attributed to an infestation of smut fungus on the fruit of the dominant plant, *Polygomun densiflorum*.

Station 350 characterized the semipermanently flooded, closed-canopy Savannah River swamp system. Inundation at this station was influenced by flow rates from Steel Creek, Pen Branch, and by water levels in the Savannah River. Despite the high inundation, canopy cover at this station was reduced during 1988-1989, apparently due to the small leaf size in response to low rainfall. Trees at station 350 were water tupelo; shrubs were confined to stumps and logs. The most common herbaceous plants at this station were duckweed and waterweed.

The Steel Creek channel station (370) was in a mature mixed deciduous forest. A wide, deep channel contained the flow from the delta and upstream Savannah River swamp. Water levels in the Savannah River influenced this station. High release volumes from Lake

Table 6-18. Steel Creek Delta Wetland Areas Based on Aircraft MSS Data, March 31, 1981, and April 26, 1985

	March 31, 1981		**April 26, 1985**	
Wetland Classes	**Hectares[a]**	**Percentage**	**Hectares**	**Percentage**
Water	0.00	0.00	4.26	1.79
Non-persistent emergent	29.75	12.53	16.33	6.84
Persistent emergent	27.07	11.40	11.32	4.74
Scrub-shrub	28.17	11.87	56.82	23.81
Deciduous swamp forest	82.04	34.56	80.57	33.75
Deciduous bottomland hardwood	14.40	6.07	13.47	5.64

[a] To convert to acres, multiply by 2.471.

Table 6-19. Steel Creek Delta Wetland Areas Based on Aircraft MSS Data with Improved Discrimination of Scrub-Shrub and Deciduous Swamp Forest, April 26, 1985

Wetland Classes	Hectares[a]	Percentage
Water	4.26	1.79
Nonpersistent emergent marsh	16.33	6.84
Persistent emergent marsh	11.32	4.74
Scrub-shrub (buttonbush)	38.63	16.18
Scrub-shrub (willow)	18.20	7.62
Deciduous swamp forest (tupelo)	36.26	15.19
Deciduous swamp forest (cypress)	44.31	18.56
Deciduous bottomland hardwood	13.47	1.79

[a]To convert to acres, multiply by 2.471.

Table 6-20. Annual Mean Percent Floodplain Inundation

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	71.3	60.4	65.0	54.2	49.7	58.4	44.4
Marsh	330	100	100	55.4	55.4	81.6	76.6	58
Swamp	350	100	99.5	87.8	96.8	86.7	87.1	93.4
Channel	370	17.1	27.1	16.1	20.7	31.8	26.6	35.7

[a]See Section 5.5 for location of Steel Creek sampling stations.

Table 6-21. Mean Percent Summer Canopy Cover

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	89.0	92.8	80.7	62.4	61.1	58.3	66.9
Marsh	330	33.1	26.8	21.9	17.9	20.0	20.2	21.2
Swamp	350	88.8	78.8	67.1	61.6	78.2	71.2	73.1
Channel	370	90.6	83.1	63.6	67.8	84.1	85.1	81.0

[a]See Section 5.5 for Steel Creek sampling stations.

Table 6-22. Mean Stand Tree Basal Area (m^2/ha)

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	10.6	11.8	12.8	13.3	13.8	13.6	12.7
Marsh	330	5.9	6.9	6.8	6.6	6.5.	7.0	7.9
Swamp	350	59.1	59.2	57.5	58.3	58.5	59.8	60.5
Channel	370	28.6	31.1	31.8	31.9	31.7	31.7	32.2

[a]See Section 5.5 for Steel Creek sampling stations.

Table 6-23. Mean Shrub Density (no./m^2)

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	0.95	1.37	1.04	1.18	0.65	1.30	1.30
Marsh	330	0.06	0.07	0.02	0.05	0.04	0.05	0.04
Swamp	350	0.13	0.21	0.07	0.14	0.14	0.09	0.09
Channel	370	0.13	0.29	0.49	0.55	0.32	0.19	0.28

[a]See Section 5.5 for Steel Creek sampling stations.

Table 6-24. Mean Percent Herbaceous Plant Cover

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	9.3	15.8	10.1	17.6	54.3	38.1	51.0
Marsh	330	104.7	76.1	50.5	46.2	95.7	73.6	110.9
Swamp	350	86.2	92.9	51.2	32.8	67.9	42.9	68.3
Channel	370	7.9	6.4	10.3	7.5	7.1	2.4	1.4

[a]See Section 5.5 for Steel Creek sampling stations.

Table 6-25. Total Number of Plant Taxa Identified

Location	Station[a]	1986	1987	1988	1989	1990	1991	1992
Corridor	290	91	86	89	91	100	111	105
Marsh	330	49	44	51	66	47	38	50
Swamp	350	47	47	58	66	65	58	52
Channel	370	91	100	121	117	99	72	65

[a]See Section 5.5 for Steel Creek sampling stations.

Table 6-26. Aquatic, Semiaquatic and Riparian Taxa Identified at Select Steel Creek Sampling Stations, January-December 1992

Family	Taxon	290	330	350	370
Acanthaceae	*Justicia ovata*				X
Aceraceae	*Acer rubrum*	X			X
Alismataceae	*Echinodorus cordifolius*		X		
Alismataceae	*Sagittaria latifolia*	X	X		
Alismataceae	*Sagittaria subulata*			X	
Amaranthaceae	*Alternanthera philoxeroides*	X	X	X	
Anacardiaceae	*Toxicodendron radicans*	X		X	X
Apocynaceae	*Trachelospermum difforme*				X
Aquifoliaceae	*Ilex decidua*				X
Aquifoliaceae	*Ilex opaca*	X			
Araceae	*Peltandra virginica*	X			
Asclepiadaceae	*Asclepias perennis*				X
Aspidiaceae	*Onoclea sensibilis*	X	X		X
Azollaceae	*Azolla caroliniana*		X	X	
Balsaminaceae	*Impatiens capensis*	X	X	X	
Betulaceae	*Alnus serrulata*	X			
Betulaceae	*Carpinus caroliniana*				X
Betulaceae	*Ostrya virginiana*				X
Bignoniaceae	*Bignonia capreolata*	X			X
Bignoniaceae	*Campsis radicans*	X			X
Blechnaceae	*Woodwardia areolata*	X			X
Blechnaceae	*Woodwardia virginica*	X			
Bromeliaceae	*Tillandsia usneoides*	X	X	X	X
Bryophyta	*Riccia* sp.		X	X	
Callitrichaceae	*Callitriche heterophylla*	X	X	X	
Campanulaceae	*Lobelia cardinalis*	X			
Caprifoliaceae	*Lonicera japonica*	X			
Cariophyllaceae	*Styrax americana*	X		X	X
Ceratophyllaceae	*Ceratophyllum demersum*	X	X	X	
Charophyta	*Nitella* sp.		X		
Chlorophytae	Unidentified macro algae		X		
Commelinaceae	*Commelina virginica*	X			X
Commelinaceae	*Murdannia keisak*	X	X	X	
Compositae	*Aster pilosus*				X
Compositae	*Aster* sp.	X			
Compositae	*Bidens tripartita*	X	X	X	
Compositae	*Compositae* sp.				X
Compositae	*Erechtites hieracifolia*	X			X
Compositae	*Eupatorium compositifolium*	X			
Compositae	*Gnaphalium purpureum*	X			
Compositae	*Krigia virginica*	X			
Compositae	*Mikania scandens*	X		X	
Compositae	*Senecio vulgaris*	X			
Compositae	*Solidago* sp.	X	X		
Compositae	*Spirodela polyrhiza*	X		X	
Convolvulaceae	*Cuscuta* sp.	X			
Cornaceae	*Cornus foemina*	X			
Cucurbitaceae	*Melothria pendula*				X

Table 6-26. (cont)

Family	Taxon	290	330	350	370
Cyperaceae	*Carex comosa*				X
Cyperaceae	*Carex glaucescens*				X
Cyperaceae	*Carex lurida*	X			
Cyperaceae	*Carex* sp.	X			
Cyperaceae	*Cyperaceae*	X	X		X
Cyperaceae	*Cyperus haspan*	X			
Cyperaceae	*Cyperus* sp.	X		X	X
Cyperaceae	*Cyperus virens*			X	
Cyperaceae	*Rhynchospora caduca*	X			
Cyperaceae	*Rhynchospora corniculata*		X		
Cyperaceae	*Scirpus cyperinus*	X	X		
Ebenaceae	*Diospyros virginiana*	X			
Euphorbiaceae	*Acalypha gracilens*				X
Fagaceae	*Quercus laurifolia*	X	X		X
Fagaceae	*Quercus lyrata*				X
Fagaceae	*Quercus nigra*				X
Fagaceae	*Quercus* sp.	X			
Gramineae	*Andropogon virginicus*	X			
Gramineae	*Arundinaria gigantea*	X			X
Gramineae	*Chasmanthium latifolium*				X
Gramineae	*Erianthus giganteus*	X			
Gramineae	*Leersia lenticularis*		X		X
Gramineae	*Leersia oryzoides*	X	X	X	
Gramineae	*Leersia virginica*				X
Gramineae	*Panicum dichotomum*				X
Gramineae	*Panicum gymnocarpon*	X	X	X	
Gramineae	*Panicum rigidulum*	X	X		
Gramineae	*Panicum scoparium*	X			
Gramineae	*Panicum* sp.	X	X	X	
Gramineae	*Paspalum distichum*				X
Gramineae	*Paspalum notatum*	X			
Gramineae	*Paspalum repens*	X	X		
Gramineae	*Sacciolepis striata*	X	X		
Guttiferae	*Hypericum hypericoides*	X			
Guttiferae	*Hypericum mutilum*	X			
Guttiferae	*Triadenum walteri*	X		X	
Haloragaceae	*Myriophyllum aquaticum*	X	X	X	
Hamamelidaceae	*Liquidambar styraciflua*	X			X
Hydrocharitaceae	*Egeria densa*	X	X	X	
Juncaceae	*Juncus effusus*	X			
Juncaceae	*Juncus* sp.	X			
Juncaceae	*Juncus validus*	X			
Labiatae	*Lycopus rubellus*	X		X	
Labiatae	*Lycopus virginicus*	X		X	
Labiatae	*Scutellaria lateriflora*	X			
Leguminosae	*Apios americana*	X			
Leguminosae	*Gleditsia aquatica*			X	X
Leguminosae	*Wisteria frutescens*	X		X	
Lemnaceae	*Lemna* spp.	X	X	X	

Table 6-26. (cont)

Family	Taxon	290	330	350	370
Liliaceae	*Smilax bona-nox*				X
Liliaceae	*Smilax rotundifolia*	X		X	X
Liliaceae	*Smilax sp.*				X
Liliaceae	*Smilax walteri*			X	
Malvaceae	*Hibiscus militaris*		X		X
Malvaceae	*Hibiscus moscheutos*	X			
Moraceae	*Morus rubra*				X
Myricaceae	*Myrica cerifera*	X			
Nymphaceae	*Nuphar luteum*			X	
Nyssaceae	*Nyssa aquatica*		X	X	X
Oleaceae	*Forestiera acuminata*		X		
Oleaceae	*Fraxinus caroliniana*	X	X	X	X
Onagraceae	*Ludwigia alternifolia*	X			
Onagraceae	*Ludwigia glandulosa*	X			
Onagraceae	*Ludwigia leptocarpa*	X		X	
Onagraceae	*Ludwigia palustris*	X		X	X
Ophioglossaceae	*Botrychium biternatum*				X
Osmundaceae	*Osmunda regalis*			X	
Palmae	*Sabal minor*			X	
Passifloraceae	*Passiflora lutea*				X
Pinaceae	*Pinus sp.*	X			
Platanaceae	*Platanus occidentalis*				X
Polygonaceae	*Polygonum cespitosum*			X	
Polygonaceae	*Polygonum densiflorum*	X	X	X	
Polygonaceae	*Polygonum hydropiperoides*	X			
Polygonaceae	*Polygonum punctatum*	X	X	X	X
Polygonaceae	*Polygonum sagittatum*	X			
Polygonaceae	*Polygonum setaceum*			X	
Polypodiaceae	*Polypodium polypodioides*				X
Potamogetonaceae	*Potamogeton diversifolius*		X		
Rhamnaceae	*Berchemia scandens*			X	X
Rosaceae	*Crataegus viridis*				X
Rosaceae	*Rubus betulifolius*	X			X
Rubiaceae	*Cephalanthus occidentalis*	X	X		
Rubiaceae	*Galium obtusum*	X			
Rubiaceae	*Galium sp.*	X	X	X	
Rubiaceae	*Galium tinctorium*	X	X	X	
Salicaceae	*Populus deltoides*				X
Salicaceae	*Salix nigra*	X	X		
Saururaceae	*Saururus cernuus*	X	X	X	X
Saxifragaceae	*Itea virginica*	X	X	X	X
Scrophulariaceae	*Bacopa caroliniana*	X			
Scrophulariaceae	*Micranthemum umbrosum*	X		X	
Scrophulariaceae	*Mimulus ringens*	X			
Sparganiaceae	*Sparganium americanum*	X	X	X	
Taxodiaceae	*Taxodium distichum*	X	X	X	X
Ulmaceae	*Celtis laevigata*			X	
Ulmaceae	*Celtis occidentalis*	X			
Ulmaceae	*Planera aquatica*		X		X

Table 6-26. (cont)

Family	Taxon	290	330	350	370
Ulmaceae	*Ulmus americana*		X		X
Umbelliferae	*Cicuta maculata*	X			
Umbelliferae	*Hydrocotyle ranunculoides*		X	X	
Umbelliferae	*Hydrocotyle verticillata*	X		X	
Urticaceae	*Boehmeria cylindrica*	X	X	X	X
Urticaceae	*Pilea pumila*	X			
Violaceae	*Viola papilionacea*				X
Violaceae	*Viola rafinesquii*	X			
Vitaceae	*Ampelopsis arborea*	X	X		X
Vitaceae	*Parthenocissus quinquefolia*				X
Vitaceae	*Vitis aestivalis*				X
Vitaceae	*Vitis cineria*	X			X
Vitaceae	*Vitis rotundifolia*	X			X

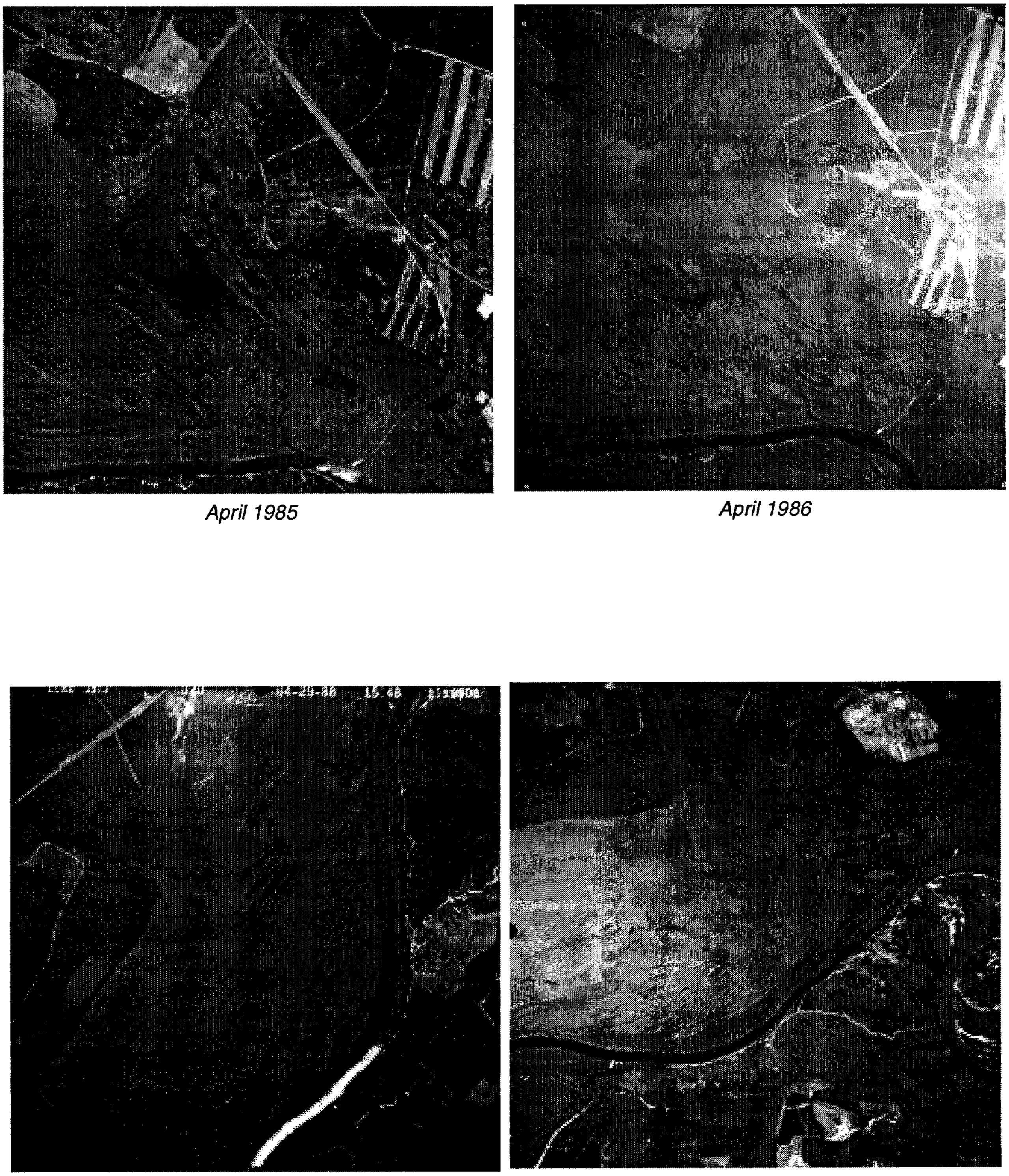
Strom Thurmond in 1990 greatly reduced the shrub density and herbaceous cover. Although the mean basal area at station 370 was lower than at station 350 due to the wider spacing of the trees, canopy cover was greater due to the larger crowns and greater diversity of species.

During 1986-1992, few changes were observed that could be directly attributed to L-Reactor operations (Figure 6-31). L-Lake discharge was the dominant hydrologic influence only at the corridor station. The greatest changes in the riparian wetlands of Steel Creek during this period were caused by the wind storm in the corridor, the smut fungus infection of *Polygonum densiflorum* in the marsh in 1991, and flooding of the Savannah River in 1990.

Steel Creek Delta MSS Surveys, 1981-1992

The Steel Creek delta was formed between 1954 and 1968 by cooling water discharges from L and P Reactors. The visibly impacted zone covered about 140 ha (346 acres) and was shaped in the traditional deltaic form, with an extended tail stretching parallel to the adjacent upland terrace and Savannah River (Tinney et al. 1986). Steel Creek delta revegetation has been well documented (Sharitz et al. 1974b; Smith et al. 1981; Mackey 1982; Jensen et al. 1984; Christensen et al. 1986; Gladden et al. 1985; Mackey et al. 1985). Early Steel Creek delta wetland maps based on ground surveys and vertical aerial photographic interpretation showed fairly distinct communities, distributed according to sedimentation patterns and water levels (Smith et al. 1981). After 1981, successional vegetation changes continued on the Steel Creek delta. The most obvious change observed with the MSS data was the extensive replacement of persistent emergent communities with scrub-shrub communities in the center portion of the delta. Sediment accumulations from past reactor discharges raised this part of the delta, keeping water depths lower and favoring scrub-shrub invasion and establishment. Scrub-shrub vegetation has expanded in the marsh, replacing nonpersistent emergent vegetation; persistent emergent vegetation has colonized areas that formerly had nonpersistent emergent vegetation. Most of the thinned cypress-tupelo canopy was consolidated along the margins of the Steel Creek delta area (Christensen et al. 1986).

Multispectral Scanner data for Steel Creek delta were collected on April 26, 1985, and compared to the March 31, 1981, data. Multispectral Scanner data for 1981 and 1985 for an area



April 1985

April 1986

April 1990

May 1992

Figure 6-31. Vertical Aerial Photography of the Steel Creek Delta Area Before (1985), During (1986), and After (1990, 1992) L-Reactor Shutdown

of 240 ha (590 acres) centered on the Steel Creek delta was registered (Figure 6-16). The 1981 and 1985 data were classified into the following wetland vegetation classes:

- Water
- Emergent marsh (persistent and nonpersistent)
- Deciduous swamp forest
- Deciduous bottomland forest

Christensen et al. (1986) describes wetlands classification techniques used with these data. The wetland acreage statistics for the 1981 and 1985 classification maps are shown in Table 6-27 and Table 6-28, respectively.

The classification maps were compared to document the change from 1981 to 1985. Table 6-27 summarizes the results. With the restart of L Reactor, additional water was in Steel Creek delta in 1985. The delta wetlands vegetation changed rapidly from 1981 to 1985. Approximately 1.9 ha (4.7 acres) of persistent emergent marsh changed to nonpersistent emergent marsh. About 14 ha (35 acres) of persistent emergent marsh changed to scrub-shrub. Approximately 1.1 ha (2.7 acres) of nonpersistent emergent marsh changed to persistent emergent marsh. Also, 8.6 ha (21 acres) of non-persistent emergent marsh changed to scrub-shrub. Some nonpersistent emergent marsh was replaced by water (3.3 ha [8 acres]). Some scrub-shrub (3.3 ha [8 acres]) changed to persistent emergent marsh, and some (1.4 ha [3.5 acres]) changed to nonpersistent emergent marsh in certain regions of the delta.

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

Bottomland hardwood and scrub-shrub vegetation dominated the Steel Creek corridor area between L-Lake Dam and the Savannah River swamp (Table 6-28). The only trend evident across the three years was a shift from bottomland hardwood to emergent wetland vegetation types. Portions of the hardwood forest canopy along the Steel Creek corridor became more open, and herbaceous vegetation invaded areas where light penetrated the canopy. Although changes in coverage occurred in both the scrub-shrub and open-water classes, consistent trends did not appear during the survey years.

Vegetation cover changes in the delta were small after the restart of L Reactor in 1985 (Table 6-29). Neither deciduous bottomland forest nor deciduous swamp forest vegetation classes exhibited changes that indicated substantial community alteration from 1985 to 1987. Scrub-shrub, nonpersistent emergent marsh, persistent emergent marsh, submerged, and open-water cover classes appeared to have undergone changes related to increased flooding from L-Reactor operations. Specifically, cover of scrub-shrub and persistent emergent marsh vegetation appeared to decline while nonpersistent emergent marsh, submerged, and open-water cover classes increased in aerial extent from 1985 to 1987. Between 1987 and 1993, flows to Steel Creek remained low to moderate (Table 6-17) and little change was noted in the vegetation patterns of Steel Creek delta.

Burkhalter (1994) noted that while the process of revegetation was interrupted from 1985-1987 with L-Reactor restart, imagery from 1992 indicated continued revegetation. In 1992, much of the thermally altered areas were revegetated with scrub-shrub vegetation, and deciduous swamp forest was returning around the periphery of the affected area.

Table 6-27. Steel Creek Delta Wetlands Changes Based on Aircraft MSS Data, March 1981 and April 1985

From	To	Hectares[a]
Nonpersistent emergent marsh	Water	1.10
Nonpersistent emergent marsh	Persistent emergent marsh	3.26
Nonpersistent emergent marsh	Scrub-shrub	8.62
Persistent emergent marsh	Nonpersistent emergent marsh	1.87
Persistent emergent marsh	Scrub-shrub	13.79
Scrub-shrub	Persistent emergent marsh	3.26
Scrub-shrub	Nonpersistent emergent marsh	1.40

[a] To convert to acres, multiply by 2.471.

Table 6-28. Changes in Area of Wetland Vegetation Classes in Steel Creek Corridor from L-Lake Dam to Steel Creek Delta. Estimates of Areas Covered (in hectares) by Wetland Vegetation Types in Steel Creek Corridor in 1985, 1986, and 1987

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

[a] To convert to acres, multiply by 2.471.

Table 6-29. Changes in Area of Wetland Vegetation Classes in Steel Creek Delta, 1985, 1986, and 1987

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

[a] To convert to acres, multiply by 2.471.

6.3 Wetlands of L Lake

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Wetlands of L Lake

L Lake is a 400-ha (1000 acre), once-through cooling reservoir constructed on SRS in 1985 to receive thermal effluent from L Reactor (Figure 6-32). (The water quality, limnology, and biology of L Lake are described in Chapter 5—Streams, Reservoirs, and the Savannah River.) Aquatic macrophytes began natural invasion of the L Lake shoreline upon completion of the lake's filling (Firth and Irwin 1987; Firth 1988; Westbury 1989, 1990, 1991, 1992). Additionally, extensive and reasonably successful macrophyte planting was done along the L-Lake shoreline (Wein and McCort 1988; Kroeger 1990; Wein et al. 1987). Survival and growth of the natural and introduced macrophytes along the L-Lake shoreline continued following the L-Reactor shutdown in 1988 and the cessation of thermal discharges to the lake (Jensen et al. 1992).

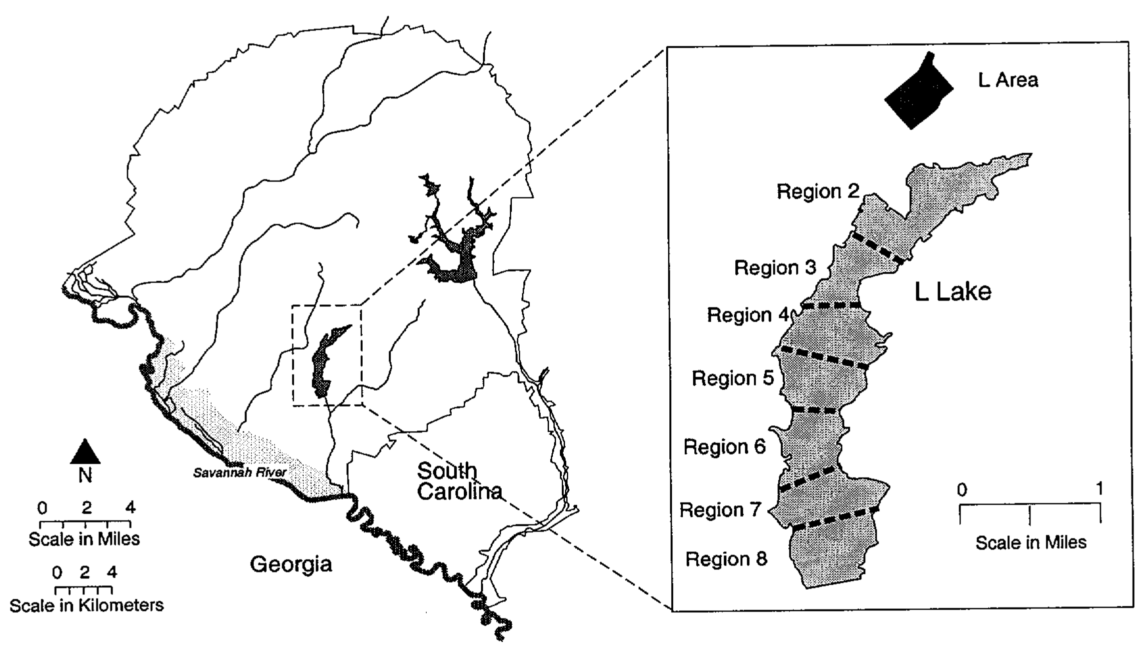

Figure 6-32. Location of L Lake on SRS

Habitat Formers

Introduction

During construction of L Lake, most of the upland vegetation in the lake bed was removed or burned onsite. The shoreline was cleared to 1-1.5 meters (3-5 ft) above maximum pool elevation and seeded to control erosion. The shoreline vegetation above the cleared area was primarily planted pine.

The L-Lake habitat formers (macrophytes) portion of the L-Lake and Steel Creek biological monitoring program addressed the development and composition of the shoreline and littoral-zone plant communities (Westbury 1992). Monitoring was conducted at four study plots in L-Lake Regions 5 and 7, and on 100-m (328-ft) transects in Regions 4 through 8 of the lake (Figure 6-32). A variety of plants, some of which have been reported from thermal areas of SRS (Irwin 1975; Sharitz et al. 1974a and b), were in L Lake in 1987. Because the littoral community in L Lake was in an early successional stage, its diversity was low in 1987 compared with Par Pond and other older lakes of similar morphometry and environmental characteristics in the southeast (Grace 1985a and b; Dames and Moore 1984; Barry 1980).

Plant Community Composition

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

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

Between 1986 and 1988, plant taxa identified at each station increased every year (Table 6-30). In 1989, taxa decreased at Region 5 East but increased at all other stations. In 1991, taxa decreased at all stations except Region 7 East (Westbury 1992).

In 1990, the number of hebaceous species at each station was lower than it had been in 1989. In 1991, the number of herbaceous taxa at each station continued to decrease except at Station 7 East. Changes in numbers of herbaceous species accounted for most of the year-to-year changes in number of taxa (Westbury 1992).

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

Table 6-30. Total Number of Plant Taxa Identified on the Shoreline of the Two Regions, January 1986-December 1991

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

Source: Westbury 1992.

Between 1986 and 1988 the number of plant taxa identified at each station increased every year (Table 6-30). In 1989 the number of taxa decreased at Region 5 East but increased at all other stations. In 1991 taxa numbers decreased at all stations except Region 7 East (Westbury 1992).

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

Areal Cover and Expansion

Between 1986 and 1990, the areal cover of aquatic macrophytes in the littoral zone of the survey plots of L Lake was low. The annual mean areal cover increased markedly, from 527.51 m^2/ha in 1990 to 1359.9 m^2/ha in 1991. Water celery *(Vallisneria americana)*, water lotus *(Nelumbo lutea)*, and pondweed (*Potamogeton diversifolius*) accounted for most of the increase in cover in the study plots. The mean extent of vegetation into the lake as measured along 100-line transects also increased from 13.59 m (44.58 ft) in 1990 to 21.15 m (69.38 ft) in 1991. The mean percent cover of the first 24 m (79 ft) increased from 28.39% in 1990 to 49.40% in 1991 (Westbury 1989, 1990, 1991, 1992).

Line Transects vs. Plots

Aquatic macrophyte coverage measured along the first 24 m (79 ft) of the 100-line transects was higher than the coverage within the monitoring program study plots, none of which occurred in planted areas. The line transects included areas planted by the University of Georgia's Savannah River Ecology Laboratory (SREL) and covered more of the shoreline than did the plots. The transects were sampled in the summer, near the time of maximum plant cover. When only summer data were considered for the study plots, the increase in percent cover from 1990 to 1991 was similar for both line transects and study plots. The summer-only percent cover of the study plots in 1991 was similar to the percent cover of the line transects in 1990 (Westbury 1992).

Littoral-Zone Change

In the six years that the littoral vegetation was monitored after the creation of L Lake, plant cover in littoral-zone communities increased. Taxa present in the plots changed from terrestrial species that are common invaders of disturbed sites to the more aquatic species likely in littoral habitats. While percent cover in areas that were planted was greater than the percent cover in study plots (which were not planted), the plant cover in the study plots increased markedly in 1991 (Westbury 1992).

Macrophyte Planting Program

Introduction

The SREL in 1987 conducted a wetlands planting program in L Lake. Plant material, either transplanted from Par Pond or obtained from commercial nurseries, was planted between January and August, 1987. Approximately 100,000 plants of more than 40 species were planted along more than 4000 m (13,123 ft) of the southern shoreline of L Lake (Table 6-31). A submersed/floating-leaved zone, an emergent zone, and an upper emergent/shrub zone were created. During the summers of 1987, 1988, and 1989, SREL sampled the vegetation in plots along permanent transects established in planted and unplanted areas. Details on species planted, source of plant material, and planting density are in Wein et al. (1987) and Kroeger (1990).

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

Nine plant species were transplanted into the submersed and floating-leaved zone. Water lotus, a floating-leaved species, and water celery, a submersed plant, were the only species that survived through 1989. Wave action and low initial planting density apparently made establishment difficult or impossible for some species (Kroeger 1990).

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

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

Emergent Zone (Waterline to 30-cm Water Depth)

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

Within the planted areas, changes in emergent species from 1987 to 1989 were a slight increase in relative frequency of spikerush and cattails, a large increase in relative frequency of water pennywort and water celery, a slight increase in relative frequency and

Table 6-31. Species Planted at L Lake between January and August 1987

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

Source: Kroeger 1990.

relative cover of the *Panicum/Sacciolepis* group of grasses, and a large decrease in both relative frequency and cover of the shoreline grasses. Water lotus and water celery, which grew into the emergent zone from the submersed and floating-leaved zone, had become important components of the emergent zone by 1989 (Kroeger 1990).

In contrast to that in planted areas, emergent vegetation in unplanted shoreline areas established slowly. The annual frequency of empty plots remained approximately 85% from 1987 to 1989. Those plots containing vegetation had low species diversity. Alligator weed (*Alternanthera philoxeroides*), water pennywort, and cattails were the only emergent species in unplanted areas with absolute frequencies greater than 5% in 1989 (Kroeger 1990).

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

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

Changes from 1987 to 1989 included major growth of black willow (*Salix nigra*) shoots; a striking decrease in relative frequency and cover of shoreline grasses; a gradual increase in frequency and cover of *Panicum/Sacciolepis*; and a decrease in frequency and cover of cattails. Black willow and the *Panicum/Sacciolepsis* grasses were the most important species in this vegetation zone. The emergents, soft rush (*Juncus effusus*), knotweed, arrowhead (*Sagittaria latifolia*), and cattails, were also important species in this zone (Kroeger 1990).

In unplanted areas, facultative emergent and terrestrial species were the most important components. No soft rush, smartweed, or *Panicum/Sacciolepis* was found. Black willow had a higher frequency in the unplanted areas than in the planted areas (Kroeger 1990).

Seed Bank Enhancement

Five years after the macrophtye plantings, the seed bank of L-Lake did not reflect planted and unplanted regions, indicating that planting wetland vegetation in a created reservoir does not enhance seed bank development or create a seed bank that differs from natural revegetation. In addition, shoreline convolutions, which might be constructed, apparently have little influence on the number of seeds, although species accumulated in coves. This would suggest that the inclusion of variable shoreline in created wetlands design would not enhance the development of the seed bank in systems with a stable water level. In contrast, the common management practice of a periodic drawdown may enhance seed bank and vegetation development in a reservoir such as L Lake by redistributing seeds with the waterline and by allowing input of seeds of facultative wetland species. (Collins and Wein 1995).

6.4 Wetlands of the Par Pond System

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Wetlands of the Par Pond System

Par Pond, a 1012-ha (2,500-acre) reactor cooling-water reservoir, was created in 1958 by constructing an earthen dam (Cold Dam) on Lower Three Runs. Par Pond formed along the course of Poplar Branch, Joyce Branch, and the upper reach of the Lower Three Runs drainage system (Wilde and Tilly 1985).

Par Pond served as a recirculating cooling-water reservoir for R Reactor until 1963 and for P Reactor from 1961 until 1988. P Reactor operated approximately 70% of the time prior to 1988. During the summer, the temperatures near the bubble-up in Par Pond (Figure 6-33) ranged from 22 to 42°C (72 to 108°F) (Jones et al. 1979). Maximum shoreline water temperatures in the vicinity of the bubble-up ranged from 32 to 35°C (90 to 95°F) (Liu et al. 1978). The thermal effluent cooled rapidly as it dispersed, primarily through the southern half of the reservoir (Ezra and Tinney 1985). The north and south arms of Par Pond had temperatures at or only slightly above typical for the region (Liu et al. 1978). Since 1988, Par Pond has received no thermal effluents.

The water level of Par Pond remained relatively stable, fluctuating typically less than 0.15 m (0.5 ft) in most years. Natural invasion of macrophytes occurred over the 33-year history of the lake prior to mid-1991, when Par Pond was lowered from 61 m (200-ft) above mean sea level (msl) to 55 m (181 ft) above msl. Prior to lowering in 1991, extensive beds of persistent and nonpersistent aquatic macrophytes bordered Par Pond. These beds often exceeded 20-40 m (65-130 ft) in width and in several areas exceeded 100 m (328 ft).

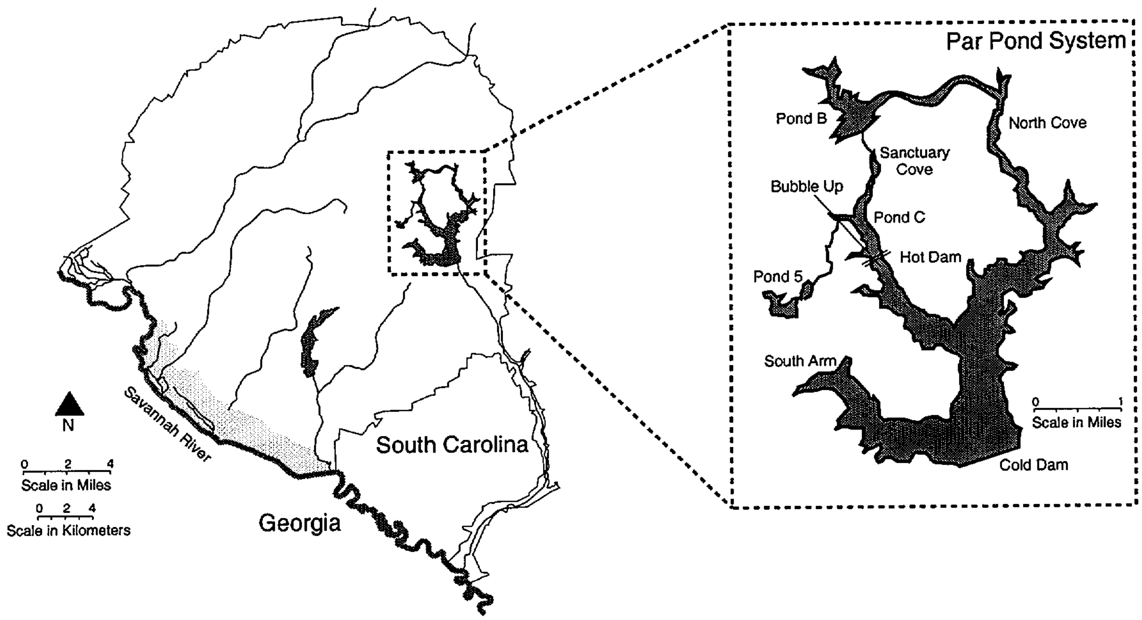


Figure 6-33. Map of the Par Pond System

Macrophyte Distributions

Introduction

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

- A well-developed macrophyte community occurs in Par Pond.
- Relatively stable water levels enhance macrophyte development.
- The dominant macrophyte species in Par Pond are typical of this geographical region.

Grace (1985a) provided a series of maps on wetland vegetation observed in July 1984 at several sites throughout the reservoir (Table 6-32 and Figure 6-34). Most of the species had been reported in earlier studies (Wilde and Tilly 1985). Grace (1985a) concluded that Par Pond wetlands are principally middle-to-late successional and relatively homogeneous.

Scrub-Shrub Communities

The shoreline scrub-shrub communities along the lake include willow, buttonbush, red maple, and alder.

Cattails

Cattail (*Typha* spp.) beds exist year-round in Par Pond. Their phenological cycle is illustrated in Figure 6-35. They begin to sprout in early to mid-April and often form a full, green canopy by late May. Cattails begin to senesce in late September or early October, remaining brown throughout the winter. A similar pattern of cattail development has been documented in the Pen Branch delta (Mackey 1990, 1993). Cattails generally occupy the shallow water (1 m [3 ft] in depth or less) adjacent to the lake shoreline. Cattail beds were considerably reduced during the drawdown (1991-1994) and had not recovered by the 1997 growing season.

Nonpersistent Macrophytes

Water lilies, lotus, and several other species along the Par Pond shoreline do not persist through the winter. They generally begin to appear at the water edge of the cattail beds by late April or early May and reach full growth 6-8 weeks later. The water lily beds generally continue to expand into the open-water areas of the lake through September and typically extend to depths of 2-5 m (6-15 ft) (Figure 6-35 and Figure 6-36). The beds persist until about mid-October to mid-November (Figure 6-35) with lotus beds senescing before the water lily beds. The best time of year to estimate the areal extent of these beds is from June until mid-October. These phenological or seasonal patterns are important when interpreting historical aerial photography or satellite remote sensing data of Par Pond (Jensen et al. 1991, 1993). After refill in 1995 and through the 1997 growing season, water lilies and lotus occupies much of the area occupied by cattails prior to the drawdown.

Comparison of Par Pond Macrophyte Communities to Regional Reservoirs

Relatively little data are available to compare macrophyte communities in Par Pond to other Coastal Plain reservoirs. It appears, however, that the floating-leaved macrophyte communities of Par Pond are similar to those in other large Coastal Plain ponds and reservoirs with

Table 6-32. Plant Species Observed in Par Pond Wetlands, July 1984

Species	Common Name
Acer rubrum	red maple
Alnus serrulata	tag alder
Alternanthera philoxeroides	alligator-weed
Bacopa caroliniana	blue hyssop
Betula nigra	river birch
Boehmeria cylindrica	false-nettle
Brasenia schreberi	water shield
Cephalanthus occidentalis	buttonbush
Echinodorus cordifolius	creeping water plantain
Eleocharis quadrangulata	square-stem spike-rush
Erianthus giganteus	giant plume grass
Hydrocotyle sp.	pennywort
Juncus effusus	rush
Myrica gale	sweet gale
Nelumbo lutea	water lotus
Nymphaea odorata	water lily
Panicum hemitomon	maidencane
Peltandra virginica	arrow-arum
Polygonum sp.	knotweed
Pontederia cordata	pickerelweed
Salix nigra	black willow
Scirpus americanus	three-angled bulrush
Scirpus cyperinus	bulrush
Sphagnum sp.	sphagnum moss
Typha domingensis	southern cattail
Typha latifolia	common cattail
Woodwardia virginica	Virginia chain-fern

Source: Grace 1985a.

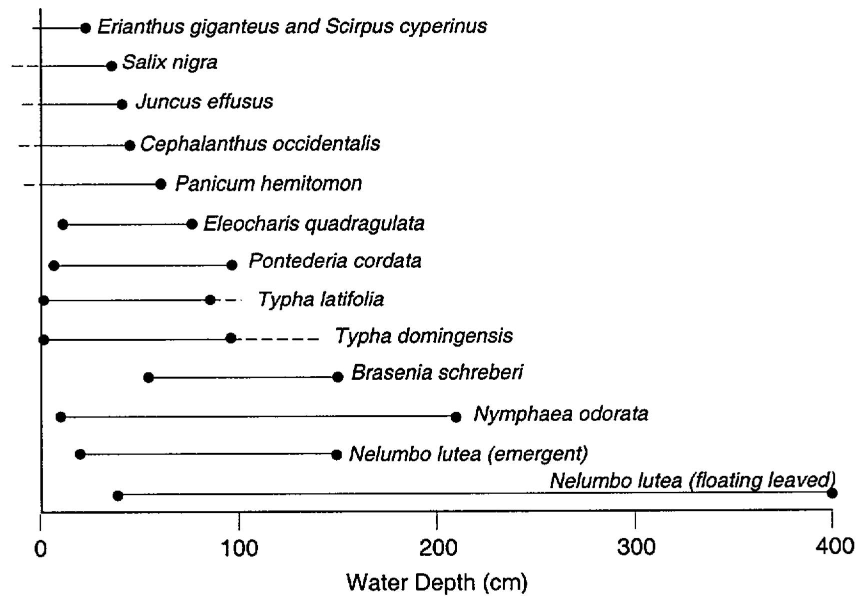


Figure 6-34. General Distribution, by Depth, of Macrophytes along the Par Pond Shoreline (Source: Grace 1985a).

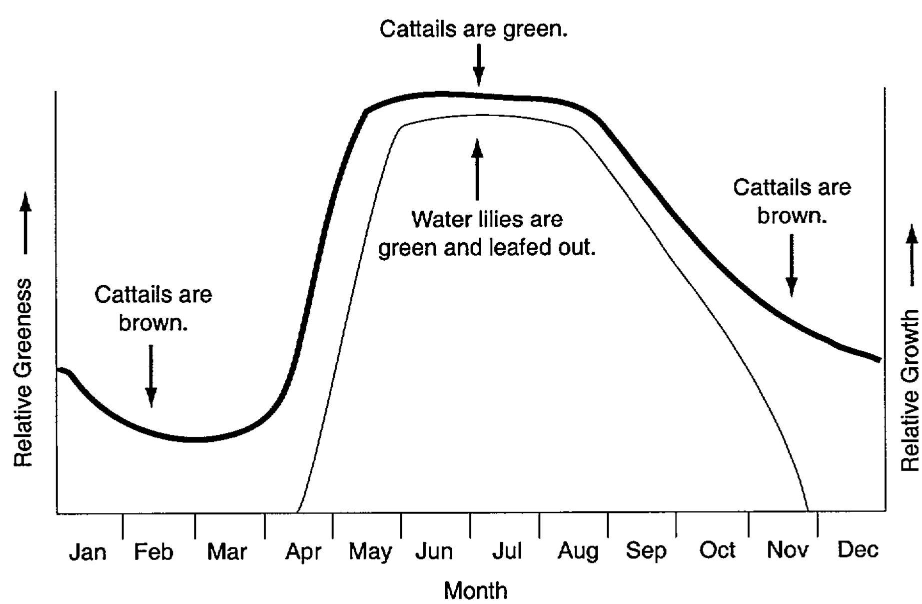


Figure 6-35. Phenological Cycle of Cattails and Water Lilies in Par Pond (Source: Jensen et al. 1993)

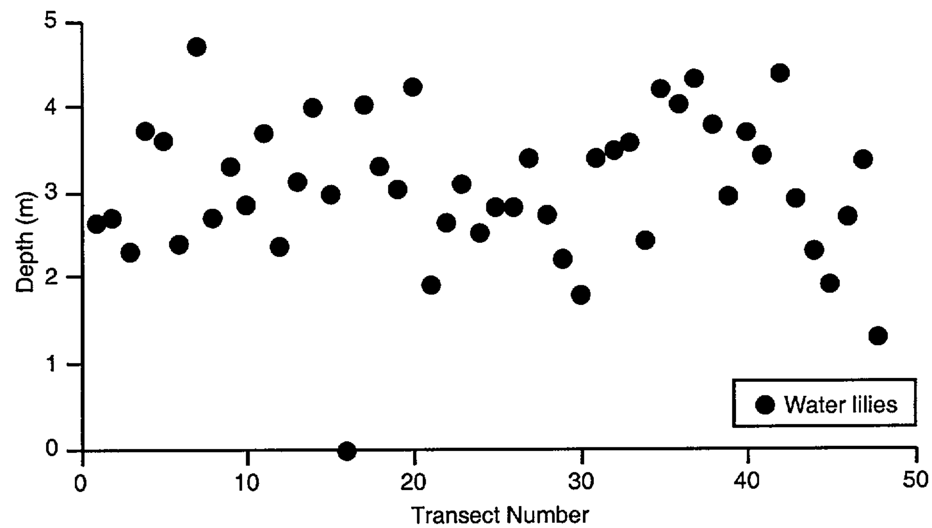


Figure 6-36. Depth at Outer Edge of Water Lily Beds in Par Pond, 1988

moderate or low turbidity (Wilde and Tilly 1985). Emergent macrophyte communities are generally similar except stands of cattails and bulrush may be better developed in Par Pond.

Thermal Effects on Par Pond Vegetation

Changes in Phenological Cycle

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

Floating-Leaved and Emergent Macrophytes

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

Plants Tolerant of Thermal Conditions

Studies from Par Pond also have indicated that some plants are more tolerant than others of exposure to thermal effluents. These more tolerant species may become abundant when temperatures are too high for the less tolerant species (Gibbons and Sharitz 1974). The nature of these tolerance mechanisms has been examined for cattails in Par Pond. For example, Liu et al. (1978) examined the thermal sensitivities of two species of cattail (*T. latifolia* and *T. domingensis*) that occur along the Par Pond shoreline. Their study concluded that *T. latifolia* was more thermally tolerant than *T. domingensis*, and they presented a possible biochemical explanation for the differences in thermal tolerance. Both species had six major malate dehydrogenase (MDH) isozymes. Three of the isozymes in *T. latifolia* were stable at 50°C (122°F); whereas, all six of the isozymes in *T. domingensis* were denatured at this temperature. It was hypothesized that the apparent increased temperature tolerance of *T. latifolia* is related to the thermal stability of the MDH isozymes (Jones et al. 1979).

Changes in Par Pond Macrophyte Growth

Introduction

Surface macrophyte maps of Par Pond have been prepared on occasion using *in situ* measurements, aerial photography, multispectral scanner data, and SPOT satellite data (Ezra and Tinney 1985; Jensen et al. 1991, 1993). Field studies examined the distribution and abundance of submerged macrophytes in Par Pond (Grace and Tilly 1976). More recent mapping of surface macrophytes was accomplished using photographic interpretation and satellite analysis techniques, and represents conditions in Par Pond from 1988 to mid-1991 (Jensen et al. 1993). Recent surveys examined only the surface extent of aquatic macrophytes. No attempt was made to evaluate species composition, diversity, or total biomass. Additionally, examination of photographs from 1958 to 1990 allowed for an estimation of developmental and growth trends for these communities over the 33-year history of Par Pond, prior to the recent 6-m (19-ft) lowering of Par Pond. The size and type of macrophyte bed are dependent on depth, slope, soil type, and exposure to wave and wind action (Jensen et al. 1993).

Photographic Studies, 1958-1990

Introduction

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

Phenology data indicate that for many of the macrophyte species found in Par Pond, the later stages of the growing season prior to leaf-drop and dormancy is September to October. During this period, the macrophytes are at or near their maximum areal coverage or extent (Figure 6-35). Cowardin and Myers (1974) also found that spring and fall photography proved most useful in identifying wetland species.

Macrophyte Classification

Introduction

A detailed species inventory of Par Pond aquatic macrophytes was beyond the scope of the historical photographic survey. Thus, the classification scheme used for the macrophyte mapping included only two general life-form categories: floating-leaved and emergent macrophytes. Table 6-33 names the principal species in each of the two categories mapped for Par Pond.

Floating-Leaved Macrophytes

The floating-leaved macrophyte category consists of plants that grow primarily on the water surface for most of the growing season. This category corresponds with the rooted-vascular and floating-vascular subclasses of the aquatic bed class established in the U.S. Fish and Wildlife Service Wetlands and Deepwater Habitats classification scheme (Cowardin et al. 1979). These macrophytes are attached either to the substrate or float freely on the water surface. Water lotus and water lily, which are both in the rooted-vascular subclass primarily dominated the floating-leaved macrophytes.

Emergent Macrophytes

Emergent macrophyte species generally occurred between the upland scrub-shrub/tree boundary and the floating-leaved zone. The emergent macrophyte category consists of erect, rooted, herbaceous plants that are present for most of the growing season. Emergent macrophytes, which are included in the emergent wetland class described by Cowardin et al. (1979), are generally species that are considered either persistent emergent or nonpersistent emergent. Persistent emergent wetlands are dominated by species that normally remain standing at least until the beginning of the next growing season. Nonpersistent emergent wetlands are dominated by plants that fall to the surface of the substrate or below the surface of the water at the end of the growing season so that, in certain seasons of the year, there is no obvious sign of emergent vegetation. The emergent macrophytes in Par Pond consisted of persistent emergent beds of primarily cattails, spikerush (*Eleocharis quadrangulata*), and, to a lesser extent, maidencane (*Panicum hemitomon*), pickerel weed (*Pontederia cordata*) and bulrush (*Scirpus americanus*). Figure 6-34 and Figure 6-36 show the general distribution by depth of typical emergent and floating-leaved macrophytes around the shoreline of Par Pond. Cattails extend to an average depth of slightly more than 1 m (3 ft) and floating-leaved macrophytes to a depth of slightly more than 4 m (13 ft) at their outer margins.

In Situ Data and Aerial Photographic Comparison for Par Pond

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

Table 6-33. Par Pond Macrophyte Species

Class	Species	Common Name
Floating-leaved macrophytes		
	Brasenia schreberi	water shield
	Nelumbo lutea	water lotus
	Nymphaea odorata	water lily
Emergent macrophytes	*Alternanthera philoxeroides*	alligator-weed
	Bacopa caroliniana	blue hyssop
	Boehmeria cylindrica	false-nettle
	Echinodorus cordifolius	creeping water plantain
	Eleocharis quadrangulata	square-stem spike-rush
	Erianthus giganteus	giant plume grass
	Hydrocotyle spp.	pennywort
	Juncus effusus	rush
	Panicum hemitomon	maidencane
	Peltandra virginica	arum
	Polygonum spp.	smartweed
	Pontederia cordata	pickerelweed
	Scirpus americanus	three-angled bulrush
	Typha domingensis	southern cattail
	Typha latifolia	common cattail

Macrophyte Succession and Stabilization

Rapid growth of the persistent beds of macrophytes along the Par Pond shoreline apparently did not begin until the early to mid-1970s and essentially stabilized by the early 1980s (Figure 6-37). Extensive growth of the nonpersistent macrophytes began a few years after the persistent beds and stabilized by the early to mid-1980s. These results are valuable because they provide an estimate of how long succession takes to establish aquatic macrophytes and reach equilibrium in a relatively stable reservoir such as Par Pond.

Changes in Par Pond Wetland Macrophytes, 1975–1983

Grace (1985b) examined aerial photographs from 1975, 1980, and 1983 to evaluate changes to the wetland vegetation of Par Pond. He also compared the aerial photographs with ground-level vegetation maps developed from field surveys conducted during July 1984 (Grace 1985a). A comparison of photographs from August and December 1983 evaluated seasonal changes; the main seasonal change in the coverage of wetland vegetation was the wintertime loss of nonpersistent species such as lotus and water lily. Comparisons between September 1980 and August 1983 showed that the lakeward extent of nonpersistent macrophytes increased by an average of 8.2 m (27 feet), although not all sites changed equally. Grace (1985b) also found that for persistent macrophytes (principally cattails), the average increase in lakeward extent between December 1975 and August 1983 was 3.5 m (11 ft). Most of the cattail beds appear to have been well established by the mid-to-late 1970s with little expansion after the early 1980s (Jensen et al. 1993). This represents a 20% increase in width in three years. The extensive development

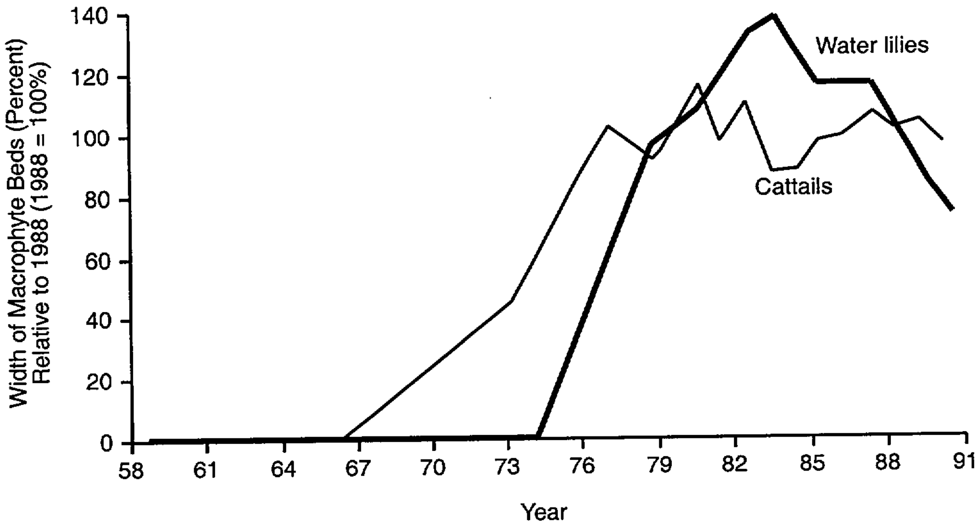


Figure 6-37. History of Par Pond Macrophyte Growth

of water lily beds in Par Pond and the substantial spread of vegetation between 1975 and 1983 indicated the high suitability of the habitat in Par Pond for the growth of these aquatic plants (Grace 1985b).

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

Seasonal Changes

The phenological cycle of cattails and water lilies provides a means to measure the areal extent of these two macrophyte communities in Par Pond. Cattail beds persist year-round in Par Pond and generally are found in shallow water (<1 m [3 ft] deep) adjacent to the shore. Figure 6-35 illustrates the phenological cycle of cattails. They begin growing in early April and often have a full, green canopy by late May (Workman and McLeod 1990). Cattails senesce in late September to early October, yet they persist through the winter (Mackey 1990; Gao and Coleman 1990). Conversely, water lilies and other nonpersistent species do not live through the winter. They appear at the outermost edge of the cattails in May and reach full emergence 6-8 weeks later. The waterlily beds sometimes persist above water into early November (Figure 6-35) but eventually disappear. Figure 6-38 shows an example of the 1988 distribution.

The Multiple Year Changes in Aquatic Macrophyte Distribution

Because the 1988, 1989, and 1990 SPOT data were registered to a common map projection, it was possible to perform multiyear aquatic macrophyte change detection. Analysis using image differencing revealed that there were 192 ha (475 acres) of cattails during the 1988 growing season, 179 ha (442 acres) in 1989, and 175 ha (432 acres) in 1990. There were 150 ha (370 acres) of water lilies in 1988, 126 ha (310 acres) in 1989, and 149 ha (368 acres) in 1990.

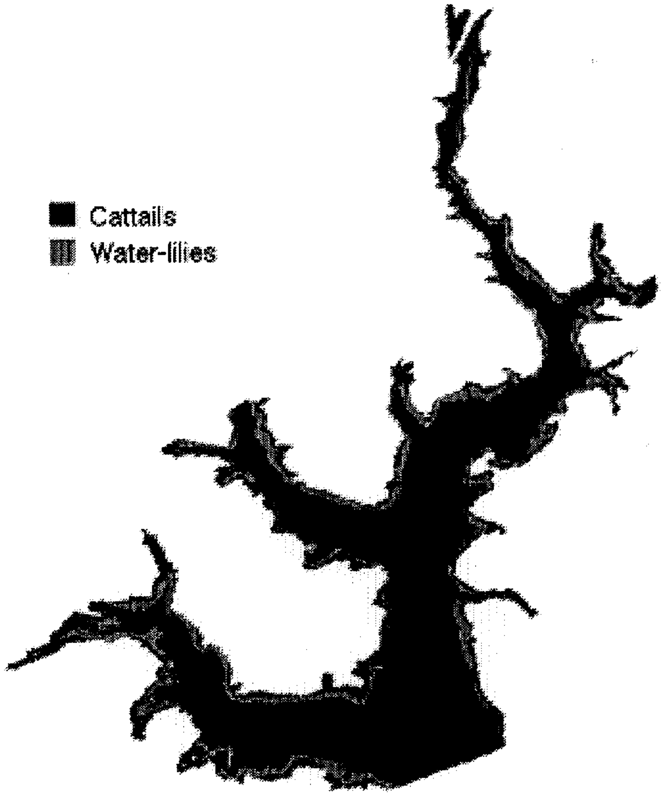


Figure 6-38. Water Lily and Cattail Distribution in Par Pond as Detected by SPOT Panchromatic Analysis, April 17, 1988, and October 25, 1988 (Source: Jensen et al. 1993).

Effects of Reduction in Cooling-Water Discharges

In situ and aerial photography data from Par Pond since early 1988 indicate that aquatic vegetation, especially floating-leaved macrophytes, was less abundant (as measured by bedwidth) following the cessation of cooling water-discharged to Par Pond (Figure 6-37). Spring-time emergence appears to be delayed approximately one month, from early to mid-April to mid- to late May, as measured by both percentage of cover and width of the macrophyte beds (Jensen et al. 1991, 1993).

Par Pond Drawdown

Beginning in June 1991, Par Pond was lowered from 61 m (200 ft) above msl to 55 m (181 ft) above msl (Figure 6-39 and Figure 6-40). Water was siphoned to Lower Three Runs and pumped to Steel Creek, Pen Branch, and Fourmile Branch during this drawdown. This lowering was sufficient to expose both the emergent and nonemergent macrophyte beds of the Par Pond shoreline to drying conditions. Therefore, extensive macrophyte losses occurred. Initial surveys in August 1992 by SREL indicated some reinvasion on the newly exposed shoreline. Plant succession was occurring on about 65% of the exposed lake bed with approximately 35% still barren. Grasses, sedges, and rushes were the dominant forms but were mixed with old-field species including dog-fennel and daisy fleabane (*Erigeron* spp.). Table 6-34 summarizes the August 1992 survey data.

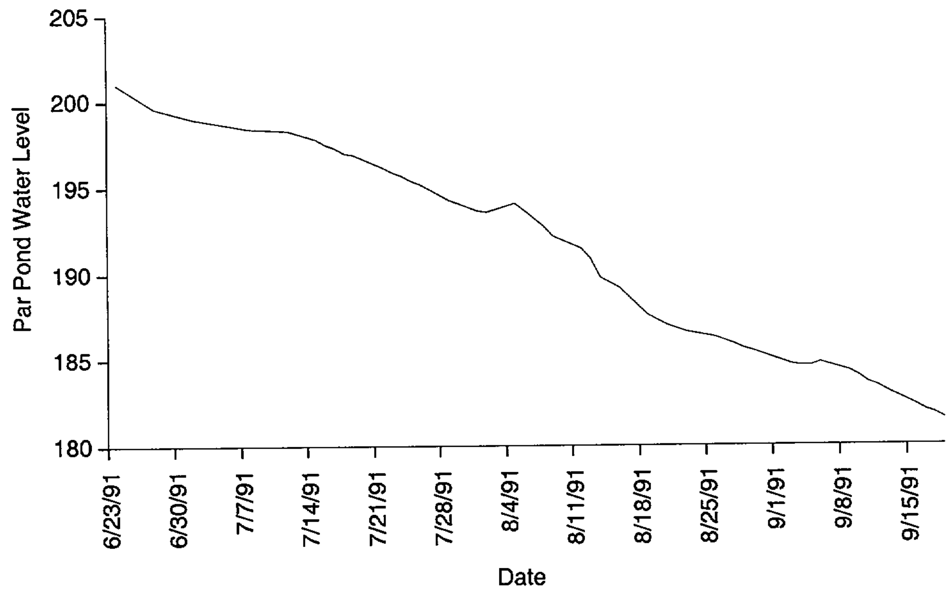
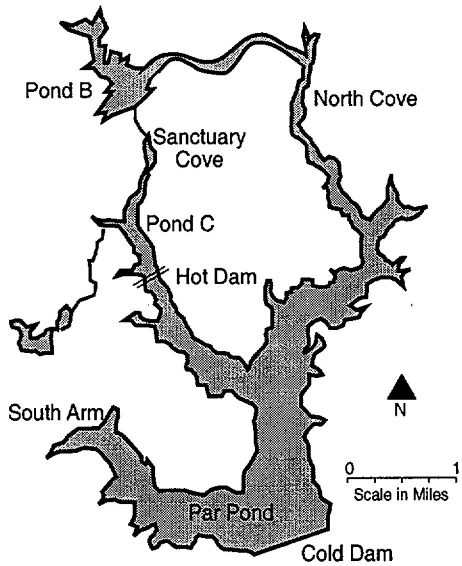
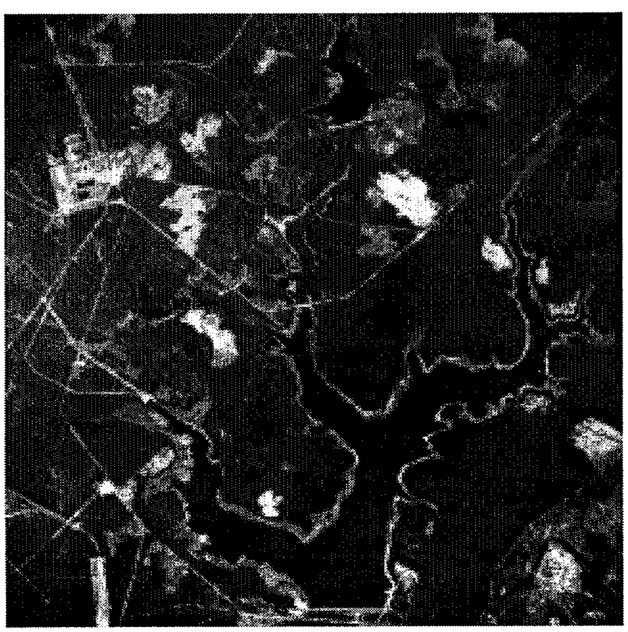


Figure 6-39. Par Pond Water-Level Change during Drawdown



Location Map of Par Pond

Spring 1989



August 1991

October 1991

Figure 6-40. Vertical Aerial Photography Showing the Results of the Par Pond Drawdown

Table 6-34. Par Pond Lake Bed Vegetation Cover, August 1992[a]

Vegetation type	Cover (%) Mean	Cover (%) ± Std Error	Frequency, % of transects
Bare ground	35	4	95
Juncus spp. (rushes)	15	2	86
Panicum hemitomon (maidencane)	13	2	95
Scirpus cyperinus (bulrush)	7.6	1.9	62
Eupatorium/Erigeron (dog-fennel/daisy-fleabane)	7.2	1.4	76
Cyperus erythrorhizos (sedge)	6.8	1.5	81
Typha (dead cattail beds)	5.3	2.1	29
Eleocharis acicularis (spike-rush)	2.0	0.9	24
Pinus spp. - (seedling pine)	1.5	0.8	19
Phytolacca americana (pokeweed)	1.3	0.6	24
Polygonum spp. (smart weed)	1.2	0.5	24
Unidentified grasses	1.2	0.5	24
Bacopa caroliniana (blue hyssop)	1.2	0.7	19
Unidentified forbs	0.8	0.4	19
Typha spp. (cattail)	0.5	0.3	10
Ludwigia spp.	0.4	0.2	14
Unidentified shrubs	0.4	0.4	5
Pontederia cordata (pickerelweed)	0.2	0.2	5
Hydrocotyle umbellata (pennywort)	0.2	0.2	5
Eleocharis equisetoides (spike-rush)	0.2	0.2	5

Source: data provided by the Savannah River Ecology Laboratory.

[a]All areas represented except South Arm. Based on 21 point-intercept transects, 501 total points, running perpendicular to shoreline and from new to previous shoreline. Mean transect length = 99 m (324 feet). Total length, all transects = 2.8 km (1.29 mi).

Several studies documented changes in the wetland and aquatic macrophyte communities that occurred from the four-year drawdown. Between June and September of 1991, the water level in Par Pond was lowered from 61 m (200 ft) above mean sea level to 55 m (181 ft) above mean sea level, exposing littoral zone sediments. It remained at that level until the spring of 1995. The vast majority of emergent and floating-leaved vegetation did not survive the drawdown (Narumalani et al. 1997). During that time, early successional plant species invaded the exposed shoreline.

In spring 1992, dead vegetation occupied approximately 35% of the exposed sediments, 7% was bare soil, and 9% had been invaded by spikerush (*Eleocharis* sp.). By May 1992, spikerush occupied 20% of the area. This species colonized the low-lying areas and coves where groundwater seeps or stream inflow maintained high soil moisture. As the soils dried over the extended drawdown, spikerush coverage declined. By the fall of 1994, it covered only 11% of the area (Jensen et al. 1997).

Old field species (dogfennel, broom sedge, poke berry [*Phytolacca americana*], briars, and others) quickly succeeded spikerush and bare soil. Between May and October 1993, old field land cover increased to 26%. Pine (lobolly) and hardwood (willow and red maple) seedling coverage also increased from little cover in 1992 to 10% by the fall of 1994 (Jensen et al. 1997).

Three months after Par Pond was refilled in March 1995, the shoreline aquatic plant communities were surveyed to document their reestablishment. Surveys were repeated at intervals throughout the summers of 1995 and 1996. A series of transects was resurveyed around Par Pond, based on transects that had been established in 1988. Two zones were established at each transect: an inner zone, from the original 1988 persistent and nonpersistent bed boundary shoreward, and an outer zone from the original 1988 persistent and nonpersistent boundary outward to deeper water.

In the first summer after refill, the shoreline vegetation rapidly reestablished. From June until the fall, maidencane was the most common emergent macrophyte. Other dominant species included lotus, water lily, watershield (*Brasenia schreberi*), and spike rush (Figure 6-41 through Figure 6-46). The increased occurrence of these species of macrophytes may represent widespread seed dispersion and availability from previous years. Cattails, which were common prior to drawdown, were present during the summer of 1995 in small, widely scattered beds. Water level fluctuated about 0.2 m (0.6 ft) the first summer following refill, allowing a small band of primrose to develop along the exposed shoreline (Mackey and Riley 1996).

The percent cover of the transects' outer zones in 1989 and 1991 was between 65 and 70%. In late 1995, the average cover for the outer zones of the same transects was approximately 45%. SPOT data from April 1995 estimated 994 ha (2455 acres) of open water in Par Pond, and data from October 1995 estimated 120 ha (297 acres) of emergent macrophytes at the end of the growing season (Mackey and Riley 1996).

Studies by Ezra and Tinney (1985) of airborne mutispectral scanner data estimated that there were approximately 266 ha (657 acres) of emergency macrophytes along the Par Pond shoreline in the fall of 1985. Estimates of cattails or persistent emergent macrophytes along the shoreline of Par Pond using SPOT satellite data, were 192 ha (474 acres) during the 1988 growing season, 179 ha (442 acres) during the 1989 growing season, and 175 ha (432

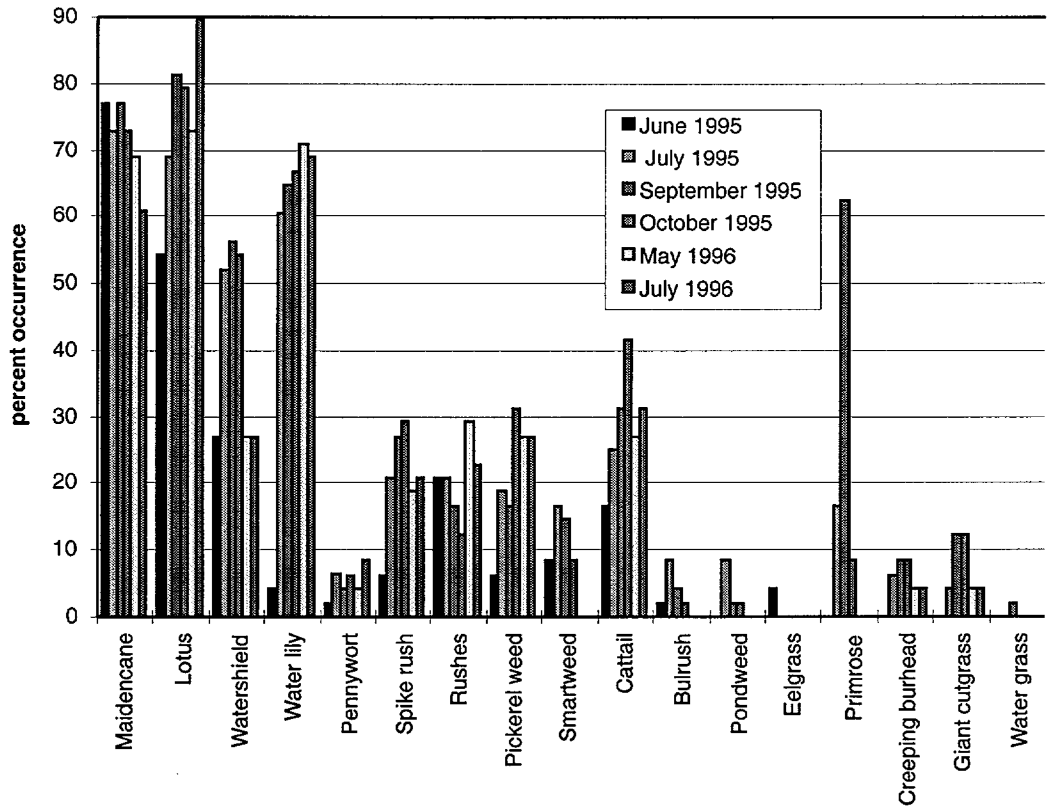


Figure 6-41. Herbaceous species percent occurrence at the inner zones of Par Pond transects, June 1995-July 1996

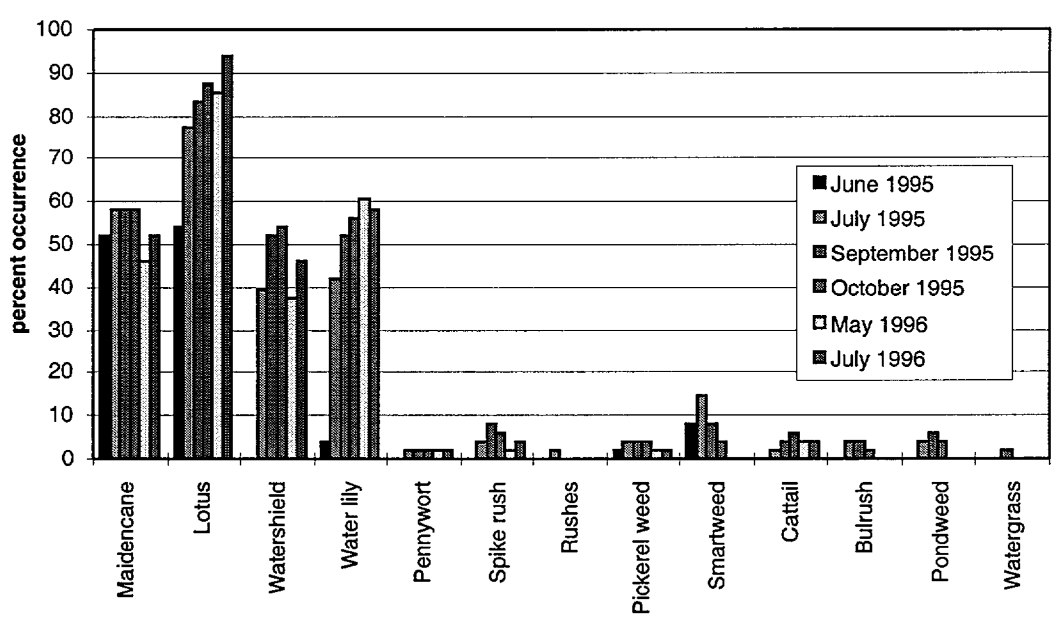


Figure 6-42. Herbaceous species percent occurrence at the outer zones of Par Pond transects, June 1995-July 1996

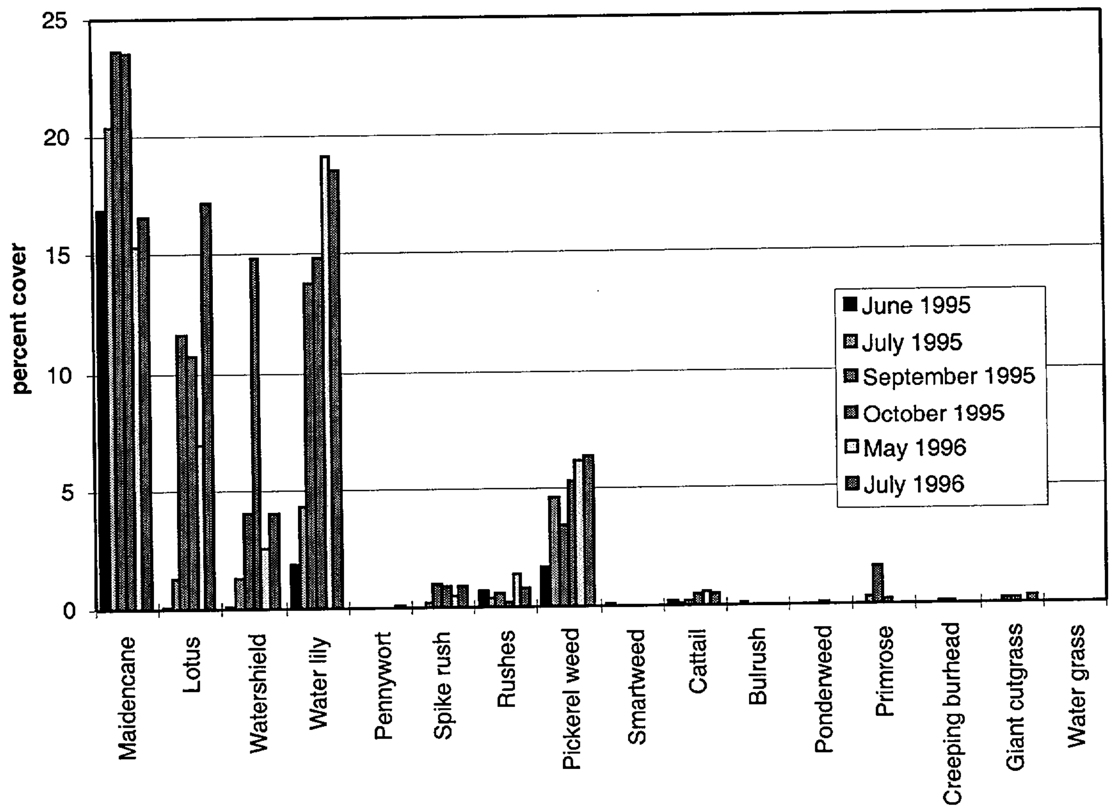


Figure 6-43. Herbaceous species percent cover at the inner zones of Par Pond transects, July 1995-July 1996

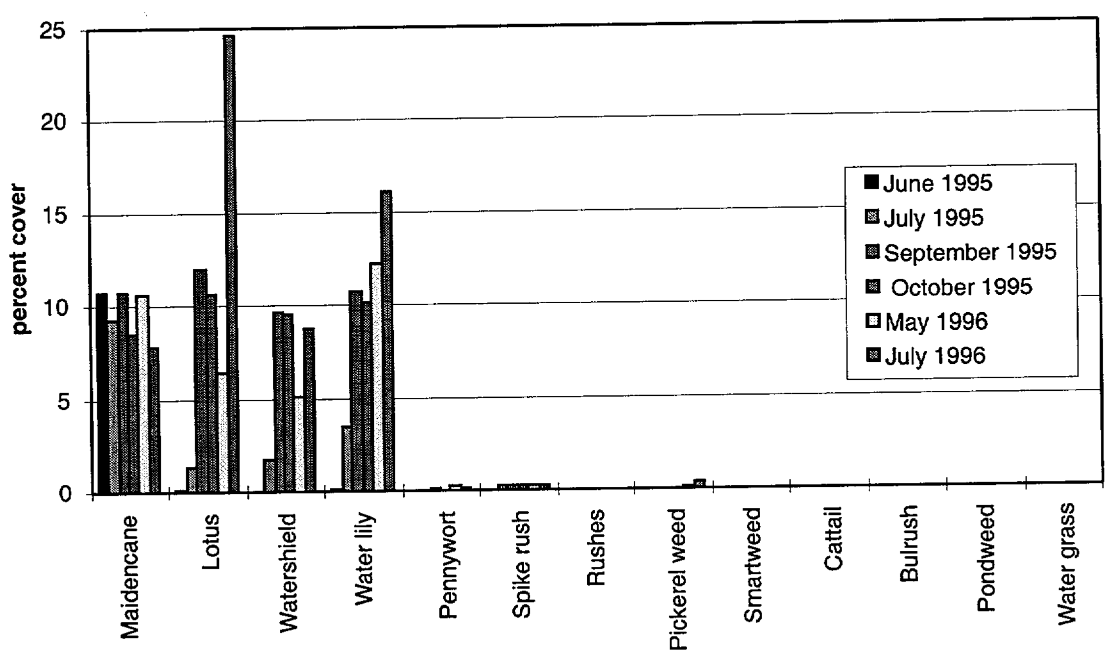


Figure 6-44. Herbaceous species percent cover at the outer zones of Par Pond transects, June 1995-July 1996

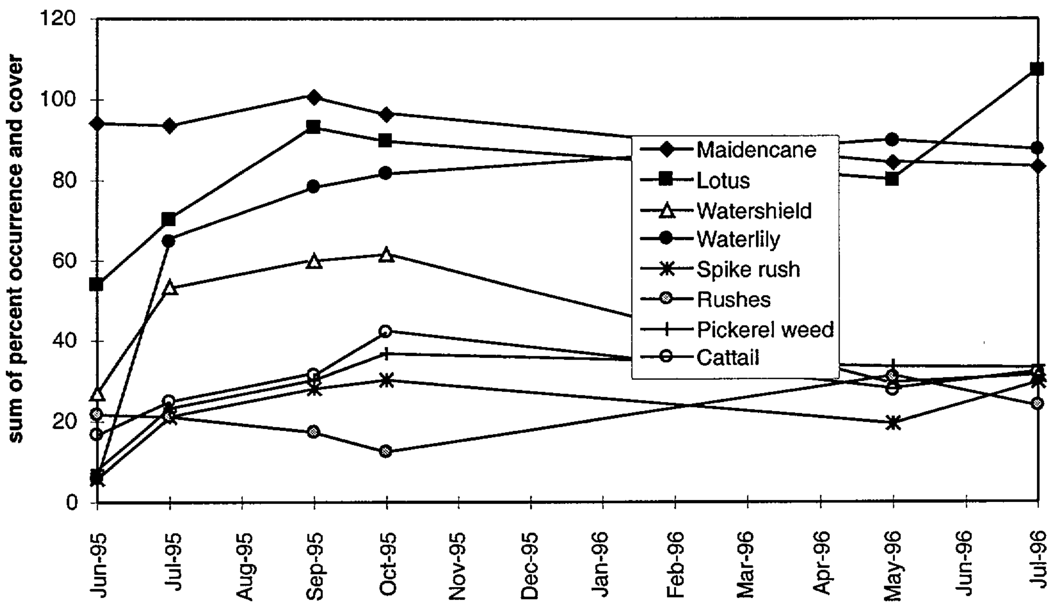


Figure 6-45. Trends in macrophyte growth at the inner zones of Par Pond transects, June 1995-July 1996

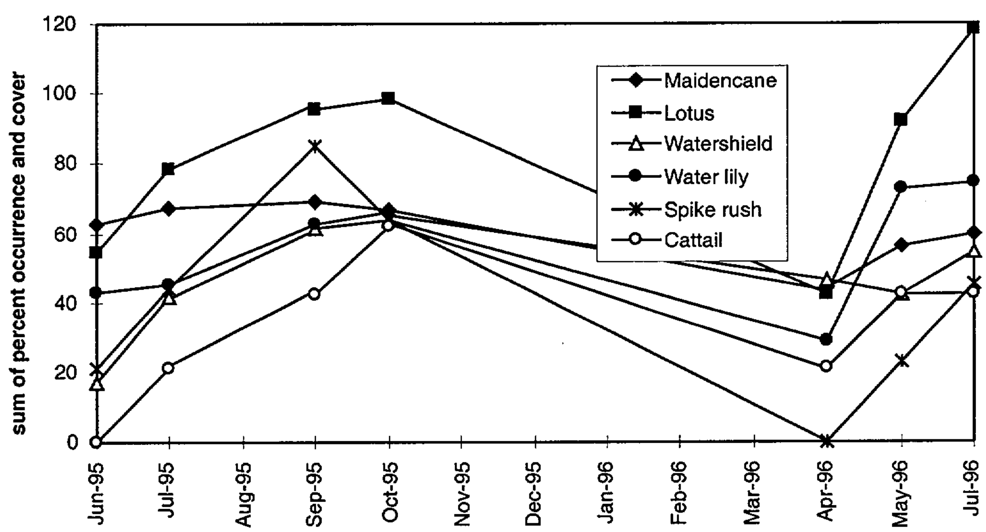


Figure 6-46. Trends in macrophyte growth at the outer zones of Par Pond transects, June 1995-July 1996

acres) during 1990. Estimates of water lilies or other nonpersistent macrophytes were 150 ha (371 acres) in 1988, 126 ha (311 acres) in 1989, and 149 ha (368 acres) in 1990 (Jensen et al. 1993; Narumalani 1993).

Surveys begun in 1995 continued in 1996. Maidencane remained the dominant species, although it declined from its 1995 peak in abundance in the outer zones. Other species that were dominant prior to the drawdown continued to increase in importance from 1995 to 1996, particularly lotus, water lily, and watershield in the outer zones and lotus and spikerush in the inner zones (Figure 6-41 through Figure 6-46). A new dominant in the inner zones, beginning in October 1995, is pickerel weed (*Pontederia cordata*). Cattails are throughout much of the lake, but no major beds developed in the first two summers after drawdown. Most shallow areas occupied by cattails prior to the drawdown now support maidencane, pickerel weed, and lotus as the dominant species. The occurrence of lotus increased in 1996 in many of the deeper areas formerly dominated by cattails (Mackey and Riley, 1996).

Pond B

Site Description

Pond B, an 87-ha (215-acre) impoundment (Figure 6-47) constructed in 1960 as part of the Par Pond cooling reservoir system, received cooling-water discharge until 1964. Since then, Pond B has equilibrated to a water chemistry determined by precipitation-dominated hydrologic inputs and has developed extensive stands of aquatic macrophytes (Kelly 1989). Kelly (1989) and Whicker et al. (1990) provide a brief limnological description of Pond B and references to more detailed studies.

Macrophytes

Introduction

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

Macrophyte Distribution and Standing Crop

Introduction

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

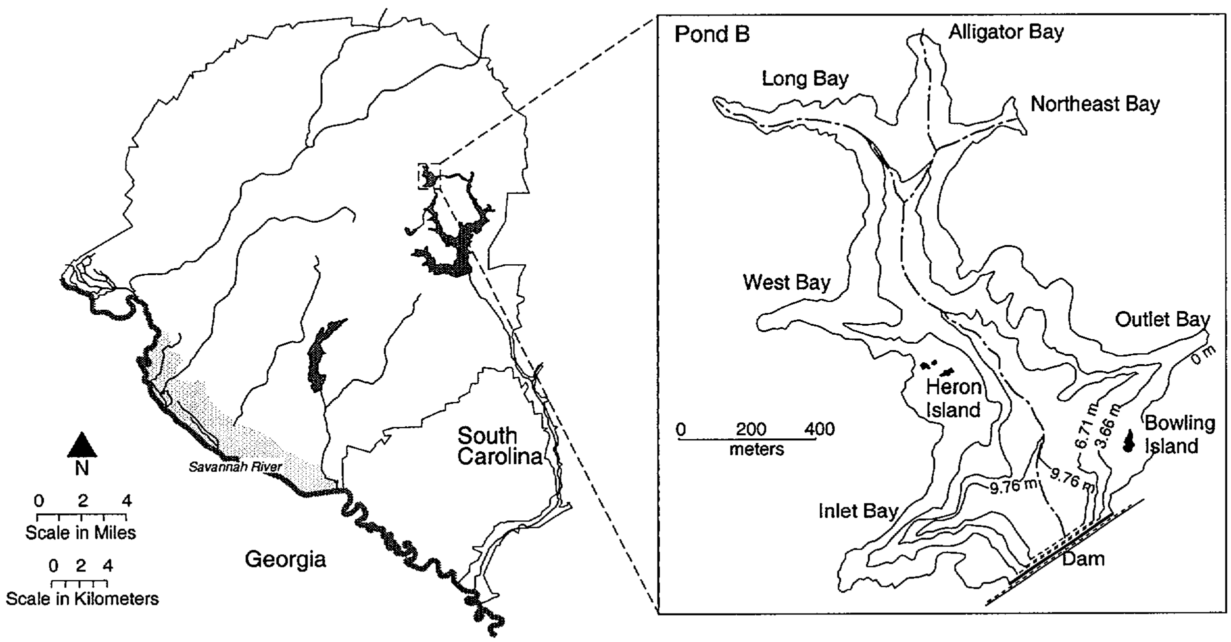


Figure 6-47. Map of Pond B

Species composition and structure

Fourteen species of vascular plants, in four growth forms, occurred in quadrats sampled in 1986. No ferns, macroalgae, or mosses were found. Three floating-leaved species, water lily, water shield, and *Nymphoides cordata*, which occurred primarily in the two shallowest sampling depths, made up more than half (51.8%) of the total standing crop harvested. Two species of bladderworts, *(Utricularia floridana* and *Utricularia inflata)*, both free-floating, nonrooted submerged forms, made up 32.0% of the total standing crop. The free-floating growth form (as *U. floridana)* was important at all sampling depths and was most abundant at depths from 2.5 to 3.0 m (8 to 10 ft). Rooted submerged species, principally fanwort *(Cabomba caroliniana*), and blue hyssop (*Bacopa caroliniana*) accounted for 15.4% of the total standing crop. Other rooted submerged species included spike rush, bushy pondweed (*Najas guadalupensis*), bag moss (*Mayaca aubleti*), and parrot feather. Two emergent species, pennywort and arrowhead (*Sagitaria isoetiformis)*, were infrequently encountered only at the 0.5-m (1.5-ft.) sampling depth, and together made up less than 1% of the standing crop (Kelly 1989).

Floating-Leaved Macrophytes

Water lily (Nymphaea odorata) - In 1986, water lilies formed dense, monospecific stands in shallow areas of the narrow bays at the north end of Pond B. They also occurred in disjunct, variably sized patches along all shorelines. Water lily rhizome apices tended to be fairly widely separated (on the order of 1 m [3 ft]) so that rosettes of leaves usually did not overlap. Because of their patchy distribution and clumped growth form, water lilies had a relatively low frequency (35%) within the 0.5- and 1.5-m (1.5- and 5-ft) sampling depths (Figure 6-48), but had large standing crops (up to 294 grams dry mass [gdm]/m2, average of 130 gdm/m^2] in quadrats where it occurred (Kelly 1989).

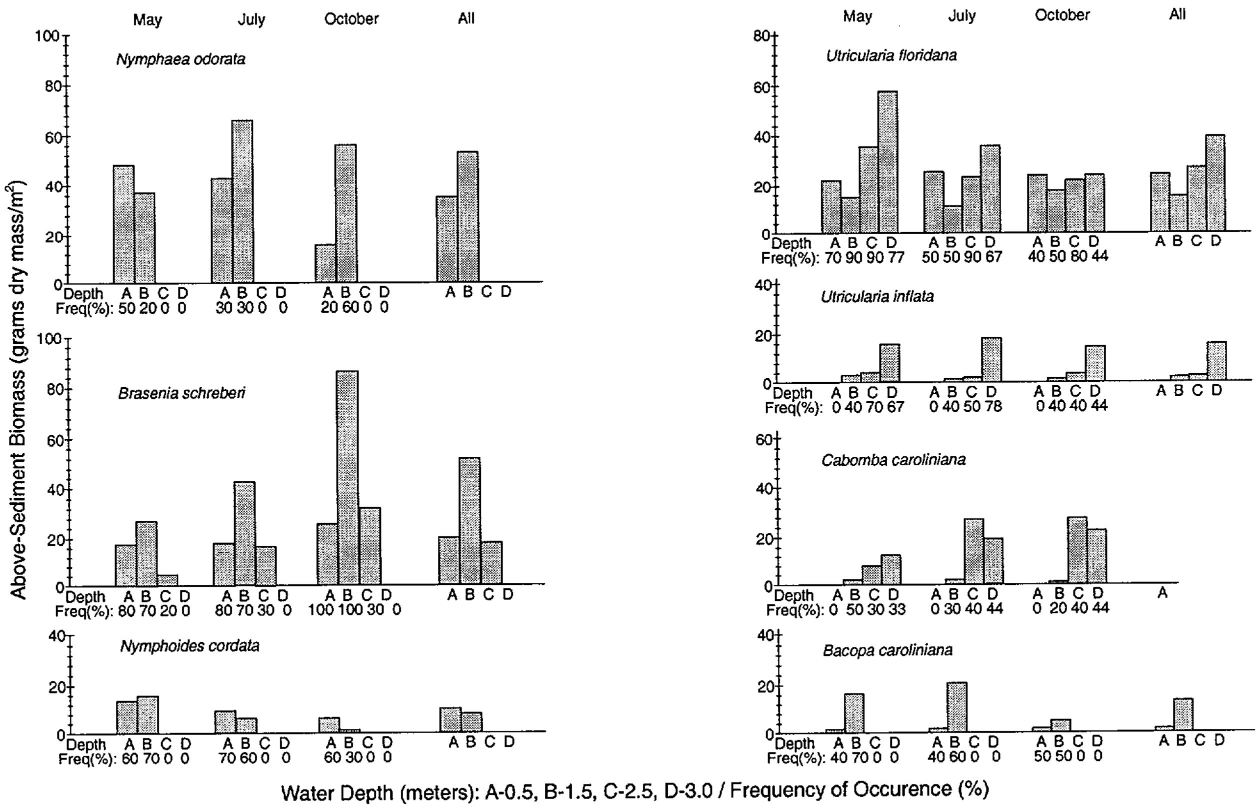


Figure 6-48. Standing Crop of Dominant Macrophyte Species at Four Samplings Depth and Three Sampling Periods During 1986 in Pond B

Water lily mean standing crops for the combined 0.5- and 1.5-m (1.5- and 5-ft) depths were 42 ± 84 gdm/m^2 in May, 56 ± 97 gdm/m^2 in July, and 36 ± 55 gdm/m^2 in October 1986. The clumped distribution and resulting variation in biomass among plots made assessing seasonal changes in standing crop difficult with the sampling regime used (Kelly 1989). A related study (Kelly 1988) indicated that maximum standing crop of water lily leaves occurred in late August.

The range of values for water lily standing crop at the 0.5- and 1.5-m (1.5- and 5-ft) depths in Pond B (Figure 6-48) is comparable to those reported for nymphaeids from other sites including the Okefenokee Swamp, the Chowan River in North Carolina, and the Ogeechee River in Georgia. Those values are higher than annual standing crop values reported for water lilies in an herbaceous Carolina bay (Kelly 1989).

Water shield (*Brasenia schreberi*) - Water shield, in a 1986 survey of Pond B, had a frequency of 83.3% at the 0.5- and 1.5-m (1.5- and 5-ft) depths and a mean standing crop of 36 gdm/m^2 (Figure 6-48) (Kelly 1989). It had a frequency of 26.6% at a depth of 2.5 m (8 ft) and was the only floating-leaved species encountered at that depth. The standing crop of water shield increased in the 0.5- to 2.5-m (1.5- to 8-ft) sampling depths from May to October. It was the only species for which average standing crop was significantly different by month. Mean standing crop for water shield across the 0.5- to 2.5-m (1.5- to 8-ft) depths was 16 ± 27 gdm/m^2 in May, 25 ± 37 gdm/m^2 in July, and 49 ± 61 gdm/m^2 in October. Mean standing crop of water shield for the 1.5-m (5-ft) depth was significantly different

from the means of the 0.5-m (1.5-ft) depth and 2.5-m (8-ft) depth. Frequency of water shield in 0.5- to 2.5-m (1.5- to 8-ft) sampling depths increased from 60% in May to 75% in October; and in October, water shield was encountered with 100% frequency at the 0.5- and 1.5-m (1.5- and 5-ft) depths (Figure 6-48) (Kelly 1989).

Field observations during the 1986 growing season indicated that water shield spread into progressively deeper zones so that by fall, there was a marked increase both in the amount of water surface covered by water shield leaves and in the extent of the floating-leaved zone at most shoreline locations (Kelly 1989). The stoloniferous growth habit of water shield is considered typical of pioneer nymphaeid species that are capable of rapid colonization of large areas (Brock et al. 1983). The spread and increasing standing crop observed for water shield during 1986 may represent a typical annual cycle of establishment and spread from overwintering turions. According to Kelly (1989) it is more likely that 1986 was a favorable year for water shield and its establishment over large areas of the littoral zone of Pond B resulted, in part, from its response to a 0.15-m (0.5-ft) drop in lake levels over the summer. Schalles (1979) observed a similar rapid colonization (within a single growing season) by water shield of large, previously open areas in Thunder Bay, an herbaceous Carolina bay on SRS.

<u>Nymphoides cordata</u> - The third floating-leaved species, *Nymphoides cordata,* occurred only at 0.5- and 1.5-m (1.5- and 5-ft) sampling depths, with an overall frequency of 62% at these depths (Figure 6-48). Mean standing crop values for the 0.5- and 1.5-m (1.5- and 5-ft) depths were not significantly different by month or depth, although standing crop decreased from May through October. The pattern of decreasing standing crop for *Nymphoides* during the 1986 growing season also was observed in a related Pond B study (Kelly 1988). Some of the larger standing crop of *Nymphoides* sampled in May possibly represented newly sprouted young plants, which may not have established or persisted (Kelly 1989).

According to Kelly (1989) *Nymphoides cordata* may be undergoing a general decline in Pond B or becoming surpassed in importance by other species. In 1984, *Nymphoides* made up 51% of the system-wide standing crop of floating-leaved species; whereas, in May 1986, at its greatest abundance, *Nymphoides* made up only 30% of the total floating-leaved biomass. By October 1986, it made up less than 7%. In 1986, *Nymphoides* occurred interspersed with other species along all shorelines of Pond B, but was observed to be most abundant on broad, shallow (1- to 1.5-m [3- to 5-ft] deep) shelves extending into the main body of the lake, where it existed as nearly monospecific stands of large, perennated individuals (Kelly 1989).

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

<u>*Water lotus (Nelumbo lutea) and Pondweed (Potamogeton sp.)*</u> - Two other floating-leaved plants, water lotus and pond weed, which in 1986 were observed growing as isolated individuals in one or two locations in Pond B, were not encountered during sampling (Kelly 1989).

Nonrooted Submerged Macrophytes

Bladderwort (*Utricularia floridana*) - *Utricularia floridana,* listed as a state threatened species by South Carolina, was the most common species of *Utricularia* found in 1986 and occurred at all four sampling depths with an overall frequency of 66% (Figure 6-48) (Kelly 1989). Mean standing crop across all depths was 31 ± 44 gdm/m^2 in May, 23 ± 37 gdm/m^2 in July, and 21 ± 36 gdm/m^2 in October, with no significant differences between means for months or depths. *U. floridana* typically formed a loose mat along the bottom, occurring in shallow locations beneath the canopy of floating-leaved species, and at deeper locations, where it was the only species present, forming mats of variable height. The consistently lower biomass for *U. floridana* at the 1.5-m (5-ft) depth (Figure 6-48) may be related to shading by or competition with the floating-leaved species, which had maximum biomass at this depth (Kelly 1989).

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

Bladderwort (*Utricularia inflata*) - According to Kelly (1989), *Utricularia inflata* was primarily a deep-water species in Pond B (Figure 6-48). It was not encountered at the 0.5-m (1.5-ft) depth. It had the most biomass at 3.0 m (10 ft). Its average standing crop was significantly different by depth. Mean standing crop at 1.5- and 3.0-m (5- and 10-ft) depths was similar for the three sampling periods: 6 ± 11 gdm/m^2 in May, 8 ± 16 gdm/m^2 in July, and 7 ± 20 gdm/m^2 in October. Like *U. floridana, U. inflata* most often occurred in mats along the bottom. At deeper locations, *U. floridana* and *U. inflata* often were found growing intertwined in the same mat (Kelly 1989).

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

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

Rooted Submerged Macrophytes

Fanwort (*Cabomba caroliniana*) - Kelly (1989) reported the mean standing crop of fanwort to be greatest at 2.5 and 3.0 m (8 and 10 ft) (Figure 6-48). Fanwort was not encountered in the shallowest quadrats. At the 1.5- and 3.0-m (5- and 10-ft) depth, mean standing crop for fanwort increased over the three sampling periods (7 ± 19 gdm/m^2 in May, 16 ± 45 gdm/m^2 in July, and 18 ± 44 gdm/m^2 in October), but did not differ significantly by month (Kelly 1989). These numbers are similar to mean above-sediment biomass of 19.6 gdm/m^2 reported for fanwort in a permanently flooded site in the Okefenokee Swamp. In Pond B, fanwort grew in dense, nearly monospecific stands in deep water within the channels of the

narrow bays at the north end of the pond. In 1984, fanwort occurred in deeper water than any other species in Pond B; its maximum standing crop occurring between 3 and 4 m (10 and 13 ft). It occurred as deep as 6 m (20 ft), the depth of the mid-summer thermocline and the maximum depth of epilimnetic sediments (Kelly 1989). Intact stems and leaves of fanwort were visible 1 to 2 m (3 to 6 feet) below the surface in water more than 3 m (10 ft) deep as late as February. Like bladderwort, fanwort may maintain significant amounts of biomass in winter in Pond B (Kelly 1989).

Blue hyssop (*Bacopa caroliniana*) - Blue hyssop was encountered at only the 0.5- and 1.5-m (1.5- and 5-ft) depths (Figure 6-48) and had significantly greater average standing crop at the 1.5-m (5-ft) depth (Kelly 1989). Mean standing crops for hyssop were 9 ± 16 gdm/m^2 in May, 10 ± 30 gdm/m^2 in July, and 3 ± 5 gdm/m^2 in October. This species tended to occur as large, mounded, many-stemmed individuals scattered among other species.

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

Emergent Macrophytes

The two emergent species, pennywort and arrowhead, which occurred infrequently in samples collected at the 0.5-m depth (1.5-ft), were fairly common along all shorelines of Pond B at depths shallower than those sampled (Kelly 1989). While a diversity of emergent species occurred at depths of less than 0.5 m (1.5 ft), most emergents occurred in low densities in a narrow band along the shoreline. In 1986, a well-developed emergent zone was generally lacking in Pond B, except at the heads of bays and along shallow bars adjoining several small islands (Kelly 1989).

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

Comparison With Other Aquatic Systems

The macrophyte vegetation in shallow areas (<2.5 m [8 ft] deep) of Pond B was dominated in 1986 by an association of floating-leaved species and bladderwort (Kelly 1989). Bladderwort and fanwort dominated macrophyte vegetation in deeper areas. Similar associations of floating-leaved species and bladderwort have been described from numerous other permanently flooded freshwater habitats on the southeastern coastal plain, all of which have been described as having dilute water chemistry from precipitation-dominated hydrologic inputs. These habitats include freshwater ponds and lagoons in southeastern Louisiana, the Okefenokee Swamp, and permanently or semipermanently flooded herbaceous Carolina bays (Kelly 1989).

Comparison with Par Pond

Historically, the macrophyte vegetation of Pond B was similar to that in Par Pond, with cattails the dominant offshore macrophyte (Kelly 1989). In a 1971 survey, Parker et al. (1973) listed 19 vascular plant species. Cattails *(Typha latifolia)* occurred in large stands and were widely distributed over 39% of the shoreline. Low numbers of water lilies occurred in two

of the north coves. Pondweed, hornwort (*Ceratophyllum* sp.), and parrot weed were listed as present. However, macrophyte vegetation of Pond B as described by Kelly (1989) differed in several respects from that described for Par Pond by Grace (1985a), Wilde and Tilley (1985), and Liu et al. (1978).

6.5 Pen Branch Restoration

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Pen Branch Restoration

Introduction

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

Wetland patterns of the Pen Branch corridor and delta area were evaluated using aerial photographic surveys (Sharitz et al. 1974b; Repaske 1981; Tinney et al. 1986), MSS aircraft surveys (Christensen 1987; Christensen et al. 1986, 1988; Jensen et al. 1986a, 1987), and ground-based surveys (Dunn and Scott 1987; Huenneke and Sharitz 1986; Scott et al. 1985, 1986; Sharitz and Lee 1985; Gladden et al. 1985; Christy and Sharitz 1980). These surveys generally indicated that the Pen Branch delta continued, at least through 1985, to expand at a rate of about 5-10 ha (12-25 acres) per year (Tinney et al. 1986), primarily along a terrace bordering the northern edge of the SRS Savannah River swamp (Jensen et al. 1987; Scott et al. 1986). Expansion into this Pen Branch delta "tail" area may have been related primarily to thermal effluent from Pen Branch being directed southeasterly along the terrace edge by flood waters during late spring and summer months (Scott et al. 1985, 1986; Jensen et al. 1987; Tinney et al 1986).

The Record of Decision for the Final Environmental Impact Statement, Continued Operation of K, L, and P Reactors, Savannah River Site, Aiken, S.C. (DOE 1991) required degraded Pen Branch wetlands to be restored to functional forested wetlands to the extent possible. In the years since 1991, pumping was reduced, allowing the natural succession of mostly herbs, grasses, and shrubs. Areas with sufficient natural vegetation of desired species will be allowed to continue natural revegetation. Areas that are not naturally reforesting have been planted with seedling of desired species.

A mitigation action plan (MAP) was formulated to guide the restoration. The Environmental Analysis Section (EAS) of the Savannah River Technology Center is overseeing and coordinating a multidisciplinary and multi-organizational approach to restore the Pen Branch wetland forest. Many organizations are implementing the MAP, including the U.S. Army Corps of Engineers, the U.S. Forest Service, the Center for Forested Wetlands

Research, the Savannah River Ecology Laboratory, Clemson University, the University of South Carolina, the University of South Carolina-Aiken, and the University of Georgia. The U.S. Forest Service Savannah River Forest Station had been coordinating seedling plantings in sections of the corridor. EAS has coordinated and developed remote sensing and monitoring methods to follow the progress of the mitigation. Through these cooperative efforts, a better understanding of the forested wetland ecosystem will emerge and provide a basis for making decisions on the mitigation of similarly impacted areas.

The successful completion of the MAP will require three approaches. The first and second are occurring simultaneously: (1) the rehabilitation of the Pen Branch corridor and delta by natural succession and (2) the reforestation of the corridor and delta by planting. The third approach will be the compensatory mitigation of other impacted areas on the SRS and will be initiated following evaluation of the success of the first two approaches. The process is expected to take a decade. Success criteria for evaluating the establishment and functionality of the forested wetlands will be established based on the monitoring of the project. Presentation to the regulatory agencies is expected to occur in 2000 (Nelson 1996).

History of Thermal Discharge

Pen Branch is a third order stream whose watershed lies entirely within the SRS. Pen Branch flows into the Savannah River swamp, a mosaic of bottomland hardwood and cypress-tupelo (*Taxodium distichum-Nyssa aquatica*) forests. Between 1950 and 1954, the Atomic Energy Commission constructed K Reactor adjacent to Indian Grave Branch, a first-order tributary of Pen Branch. Heat was dissipated from the reactor's closed-loop cooling system by pumping water from the Savannah River across a heat exchanger and discharging the heated water into Indian Grave Branch.

K Reactor began discharging thermal effluent into Indian Grave in 1954. The reactor's contribution to streamflow varied temporally, but was consistently 1 to 2 orders of magnitude greater than the stream's base flow. The average annual temperature of the effluent was as high as 70°C (158°F). Thermal discharges ended in 1989.

Environmental Impacts

Deforestation

In 1951, the Savannah River swamp and Pen Branch corridor had closed-canopy forests (Wike et al. 1994). During the early years of reactor operation, as discharge rates and temperatures increased, flooding and elevated temperatures progressively killed the vegetation in the stream corridor. By 1961, canopy defoliation was apparent through 113 ha (279 acres) of the corridor and 4.5 ha (11 acres) of the delta (Wike et al. 1994). From 1961 to 1989, the thermal effluent gradually denuded a fan-shaped delta in the Savannah River swamp forest and a narrow tail to the southeast toward Steel Creek, near the swamp's upland boundary. The area of severe canopy loss in the delta reached a maximum of about 152 has (275.5 acres) in the mid 1980s (Wike et al. 1994).

Colonization by Pioneer Species

Early successional plants recolonized the corridor and delta since the cessation of reactor operations. In the corridor, these consisted of willow (*Salix* spp.), alder (*Alnus* spp.), wax

myrtle (*Myrica cerifera*), buttonbush (*Cephalanthus occidentalis*), and sumac (*Rhus* spp.), with a few red maple (*Acer* rubrum). Almost no species were typical of the canopy of a mature bottomland hardwood forest. The prolonged thermal discharges had eliminated seed sources and living root stocks from the floodplain. Most of the delta remained flooded, even after reactor operations stopped. The delta was colonized by cattails (*Typha* spp.) and bulrush (*Scirpus* spp.).

Reforestation

The primary mitigation objective is to establish a bottomland hardwood ecosystem on 69 ha (170 acres) in the Pen Branch corridor and a cypress-tupelo system on 202 ha (500 acres) in the delta. The corridor includes a stream reach 2.5 km (1.5 mi) long with a floodplain from 100 to 300 m (328 to 1000 ft) wide immediately upstream of the delta. About 53 ha (130 acres) around the edge of the delta are naturally revegetating with cypress and tupelo.

Twenty-five percent of the total artificial regeneration area was reserved for nontreated, nonplanted control strips (Figure 6-49). The sites were prepared for planting beginning in 1992. The lower corridor was planted in February and March 1993, the upper corridor in January 1994, and the delta in January and February 1995. Also in 1995, the upper and lower corridor was interplanted to compensate for mortality (Dulohery et al. 1995).

Approximately 8700 seedlings were planted (747 trees/ha [303/acre]) in the lower corridor (15 ha [37 acres]) without site preparation, which was deemed unnecessary. Species composition of the seedlings was cherrybark oak (*Quercus pagodaefolia*; 7%), swamp chestnut oak (*Q. michauxii*; 30%), green ash (*Fraxinus pennsylvanica*; 33%), water tupelo (11%), and bald cypress (19%) (Dulohery et al. 1995).

The upper corridor (24 ha [59 acres]) was planted in the winter of 1994, after the application of a wetland-approved herbicide to control the willow population and a prescribed burn to clear brush and vines. Target planting density was 747 trees/ha (303/acre) with a mix of swamp chestnut oak (17%), cherrybark oak (16%), water oak (*Q. nigra*; 20%), water hickory (*Carya aquatica*; 18%), green ash (14%), persimmon (*Diospyros virginiana*; 7%), swamp tupelo (*N. sylvatica*, var. *biflora*; 2%), and bald cypress (4%).

Clearing and burning the understory appeared to induce severe herbivory by feral hogs such that two-thirds of the planted seedlings, including nearly all of the oaks and hickories, were lost to the hogs before the beginning of the first growing season. The hog herbivory occurred only in the burned areas. Recovery of the herbaceous understory during the second growing season provided sufficient cover for the seedlings to protect them from the hogs.

The delta was planted (and portions of the corridor replanted) in 1995 after the application of only herbicide on about 12 ha (30 acres) to eliminate dense willow thickets. The target density was 1078 trees/ha (436/acre). Estimated percentages of the planted species were 60% water tupelo, 30% bald cypress, and 10% green ash.

The upper corridor was replanted with 1078 trees/ha (436/acre), composing cherrybark oak (26%), water oak (17%), green ash (5%), sycamore (*Platanus occidentalis*; 9%), pignut hickory (*C. glabra*; 2%), shumard oak (*Q. shumardii*; 13%), water hickory (11%), and

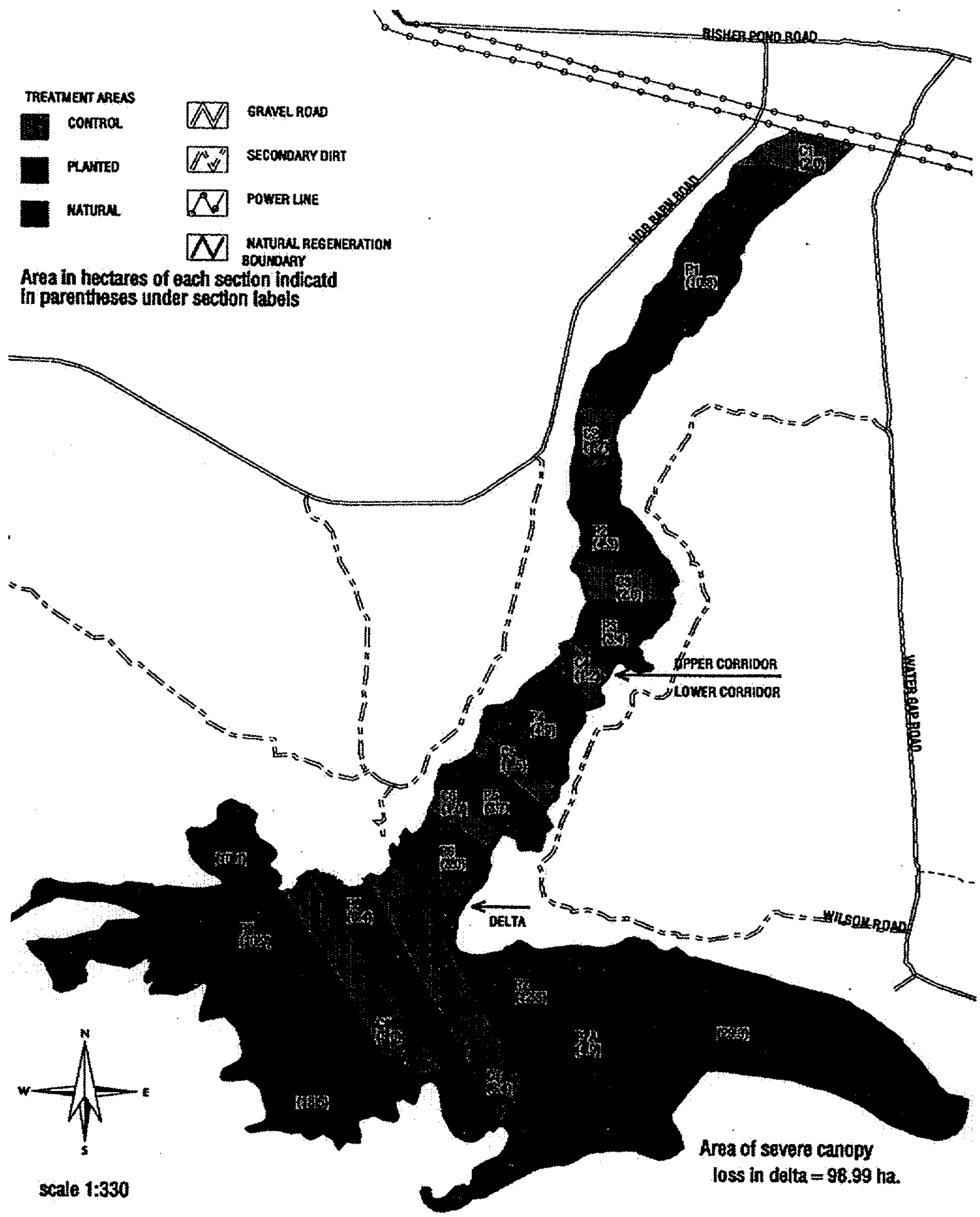

Figure 6-49. Pen Branch Treatment Areas (Source: Dulohery et al. 1995)

swamp tupelo (17%). The lower corridor was replanted with 549 additional trees/ha (222/acre): bald cypress (7%), green ash (13%), cherrybark oak (6%), water tupelo (13%), and swamp tupelo (61%) (Dulohery et al. 1995). Table 6-35 describes the planting process for each section of the stream.

Recovery of the Wetland Ecosystem

The remainder of this section describes various studies of the reforestation as of 1997.

The Pen Branch reforestation offers many opportunities to study the dynamics of a wetland ecosystem and apply what is learned to future wetland restoration projects. This chapter describes on-going research. At the time of the revision of this document, many of the studies had not been completed. Results will be presented here if available. Annual progress is documented in annual reports prepared by the U.S. Forest Service, and future revisions of this document will include the results of these studies. Many of the studies will be published in technical journals as well.

Hydrology

Intensive monitoring between 1991 and 1995 characterized the hydrology of Pen Branch, Fourmile Branch, and Steel Creek (Dulohery et al. 1995). The objective was to determine the influence of pumping less Savannah River water through the system on the hydrology of SRS streams and swamp, and to determine suitable tree species and management practices based on the expected hydrology. Results indicate that:

- Water pumped from K Reactor flooded the Pen Branch corridor and saturated the soils as late as the summer of 1992. Pumping at that level limits the tree species that could establish themselves in the corridor.
- A few continuous recording water-level monitors are adequate to maintain long-term monitoring of the hydrology. There is a strong correlation among water table depths in the monitoring wells and surface water levels.

Soils

Three studies are examining different aspects of the wetland soils: one is looking at the development of the soil organic matter, one at the distribution and function of the organic matter pools among different successional stages, and one at the comparison of carbon and nutrient fluxes among different successional stages.

Soil organic matter (SOM) is critical for the exchange of nutrients between vegetation and soil and is directly linked to forest productivity. Research has been conducted on SOM in upland soils, but not on the formation of SOM in wetland systems. This research studies forest floor development and SOM formation in four seral stages of floodplain forest to determine the rate of conversion of litter to SOM, the importance of the labile fraction, and the amount of forest floor mass and carbon and the carbon:nitrogen ratios in the different stages.

Forest floor mass increased rapidly during early succession, reaching a maximum in early mid-succession, then declined in late succession forests. Differences in the composition of the forest floor fraction between the various stages were noted: the herbaceous fraction declined through succession (from 74% in the earliest stages to <1% in the latest stages)

Table 6-35. Description of Primary Treatment Zones, Site Preparation Techniques and Planting Scheme

Zone	Area (ha)	Description	Site Preparation	Planting
Upper Corridor	24	Mesic bottomland. Water table typically at 30 to 80 cm depth during the growing season. One or two well-defined stream channels. Initially covered by dense unbroken willow thickets.	Aerial herbicide application to control willows in September 1993. Burned to improve access for planting crews in November 1994	Planted 747 trees/ha in December 1993 and January 1994. Planted an additional 1078 trees/ha in January 1995 to compensate for loss.
Lower Corridor	16	Poorly drained bottomland. Water table within 20 or 30 cm of the soil surface during the growing season. Braided stream with up to four or five water courses. Initially covered by willow thickets and grassy openings.	None	Planted 747 trees/ha in February and March 1993. Planted an additional 549 trees/ha in January and February 1995.
Delta	46	Swamp. Continuously flooded, except on sandy ridges near the mouth of streams, where water table remains within 20 cm of the soil surface. Initial cover was about two-thirds cattail and one-third scattered willow ridges.	Herbicide application to control willow on levees and alluvial deposits (12 ha) in September 1994.	Planted 1078 trees/ha with 4.9 ha planted at about 500 trees/ha due to deep muck and standing water in January and February 1995.

and woody foliage increased from 6.7% in the earliest stages to >70% in late succession. Carbon and nitrogen concentrations increase during early succession and reach equilibrium during late succession. Carbon:nitrogen ratios were relatively stable throughout all stages of succession, with ratios ranging from 41 to 48. The rates of transformation of litter to SOM as measured by the lignocellulose index were not significantly different between stages of succession; however, the hydrologic dynamics of floodplains and the warm climate of the southeastern U.S. may render this method invalid in floodplain forests (Lockaby and Wiggonton 1997).

Carbon and nitrogen pools and fluxes are being studied in Pen Branch, Fourmile Branch, and Meyers Branch forests to understand the dynamic processes that affect carbon and nitrogen allocation and transport in bottomland hardwood wetlands at various successional stages. The goals of the studies are to characterize the mass balance for organic carbon and nutrient pools, assess the influence of organic carbon on the transport of forest nutrients, and establish indicator relationships among and within wetland forests (Kolka and Trettin 1997; Aust and Giese 1997). These studies were just beginning at the time of this document's revision; therefore, no results were available.

Vegetation

Following planting, vegetation surveys were conducted to monitor survival and growth (Dulohery et al. 1995). In 1996, a systematic survey was conducted of seedling establishment (Table 6-36). Results indicated good survival of planted seedlings with means in corridor planted areas of 666 trees/ha (270 trees/acre) and in delta areas of 1360 trees/ha (550 trees/acre). Approximately 12% of the seedlings were volunteers from species that had not been planted (Kolka and Trettin 1997).

A long-term study is assessing the physiological and morphological responses of four species – bald cypress, water tupelo, swamp tupelo, and green ash – to flooding. These species were chosen because of their high flood tolerance and similarity to species in the original forest. The soil in the delta was saturated for most of the two-year study. Seedlings were planted in four different microhabitats: one, in the forb layer, was cleared with lawn maintenance equipment. In a second, the grass remained. A third was dominated by willows, and the fourth was mucky and wetter than the other sites. Periodically over two years, seedlings were collected and measured; the viability of their root tips determined; the activity of the enzyme alcohol dehydrogenase (ADH) was measured; and their leaf area and the fresh and dry weights of leaves, stems, and roots were determined (Hook and Rozelle 1997).

The level of ADH activity and root viability quantify a seedling's capacity for anaerobic metabolism. The capacity for anaerobic metabolism has some bearing on a seedling's survival in flooded wetlands. A computer model is expected to be developed to show the relative responses of the various species over time. Early results indicate that green ash seedlings are stressed in all four habitat types, but that the other three species are not (Hook and Rozelle 1997).

The effect of root pruning and tree shelters on seedling growth and survival also is being studied in areas that are continually saturated. Differences between root-pruned and non-root-pruned seedlings were variable, depending on the species, but moderate root pruning was not detrimental to seedling survival. Tree shelters increased seedling height and survival. The amount of herbaceous vegetation around the seedling affected the quantity of light a seedling received. Because root-pruned seedlings are easier to plant in the swamp,

Table 6-36. Results of 1996 Seedling Establishment Survey

	Mean ± SE (trees/acre[a])	N
Upper Corridor, planted	290.2 ± 6.2	51
Upper Corridor, control	211.5 ± 51.6	13
Lower Corridor, planted	225.0 ± 44.0	24
Lower Corridor, control	63.3 ± 21.5	15
Upper Delta, planted	550.0 ± 80.0	48

Source: Kolka and Trettin 1997.
[a]To convert to trees/ha, divide by 0.4047.

this information will be useful in future wetland restorations. The impacts of root pruning on long-term growth and survival require further study (Conner 1997).

A study determined the effects of overstory removal on the environmental factors influencing the growth and survival of seedlings (McKevlin and Dulohery 1997). Specific objectives were to determine the optimum overstory condition for planted seedlings, based on seedling growth and survival; the effect of overstory on microhabitat factors such as light intensity, soil temperature, depth to the water table, and herbaceous competition; and the influence of these environmental characteristics on seedling survival, growth and biomass allocations. Four species – bald cypress, water tupelo, swamp chestnut oak, and green ash – planted in a variety of flood and shade conditions were treated to one of four overstory conditions. These included no competition control, partial removal of overstory with the stems left in place, complete removal of the overstory with the stems left in place, and clearcut.

There are significant differences among treatments in the diurnal fluctuations of the depth to the water table, the quantity and quality of light available to seedlings and biomass of herbaceous competition. The large diurnal fluctuations in the depth of the water table occurred in the treatments where the willow canopy was undisturbed. Greater light transmittance in the clearcut plots resulted in greater herbaceous competition. Initial results suggest that there are both height growth and survivorship differences among species and among treatments. Sparse to moderate willow canopy can ameliorate the stresses of growth-limiting hydrology and herbaceous competition and be beneficial to the establishment, growth, and survival of bottomland hardwood species (McKevlin and Dulohery 1997).

Fish

Studies of differences in stream morphology and fish community characteristics among Pen Branch, Meyers Branch, Fourmile Branch, and Upper Three Runs will allow scientists to determine how the morphology of a stream influences its fish community. As of this writing, the morphology and fish community data had been collected and were being analyzed (Reichert and Dean 1997). A technical report is expected to be published in 1997.

Scientists are examining the effects of past effluent releases on the physiology and behavior of individual fish, the demography and habitat segregation of populations, and the structure

and function of the entire community. Results from Fourmile Branch and Pen Branch studies indicate that streams formerly impacted by reactor operations have two to five times the densities and at least as many species as streams that did not experience similar perturbations. Although species richness is similar, evenness differs greatly. A few fish taxa (suckers [Catastomidae], mosquitofish [*Gambusia* spp.], minnows, and sunfishes [*Lepomis* spp.]) dominate the impacted streams. The unimpacted streams have a more even distribution of numbers among species. The community composition differs among the streams, suggesting a change in the functional organization of the fish communities (Fletcher et al. 1997).

The preliminary results of one study indicate that dusky shiners (*Notropis cummingsae*) spawn on the nests of redbreast sunfish (*L. auritus*). Spawning on redbreast nests is probably obligatory for the shiners, which feed on sunfish larvae and embryos, selectively eating the offspring of their host. The research is expanding to study nesting microhabitats and the selection by the fish of their location in the streams (Fletcher et al. 1997).

Invertebrates

A study will examine the recovery of the aquatic invertebrates in Pen Branch by investigating the invertebrate community and stream characteristics that may influence insect distribution and abundance. The effect of the reforestation efforts on the invertebrate community, the periphyton, and the macrophytes will be evaluated. The study will evaluate the importance of factors such as woody debris, litterfall, macrophytes, river form, and riparian zones on the development of an invertebrate community. Results of this study will be used to assess the long-term implications of reforestation on the eventual invertebrate community. This information also will be applied to reforestation projects in other Coastal Plain streams (McArthur and Lakly 1997).

Birds

Populations of Neotropical migrants have declined over the last decades due to reductions in the breeding and overwintering habitats. Many Neotropical migrants breed in southeastern late successional bottomland hardwood forests. Although efforts are being made to restore bottomland forests, no attempt has been made to determine if the restored forests serve the same function for birds as natural forests. By studying the birds in the different successional stages of the Pen Branch forest, scientists may determine if the community in a restored forest is similar to that in a natural forest, and if so, how long it takes for the bird community to develop. Miller and Chapman (1997) examined the differences between communities in early, mid, and late successional forests. The study sites were an early successional forest at Pen Branch, a mid-successional forest at Steel Creek, and a late successional forest at Tinker Creek.

Results are that although there are few differences in the avian community composition in the different forest restoration treatments, those plots that were herbicided, burned and planted tended to have greater species richness in 1994 and greater abundance in 1995 ($P<0.05$) than the control plots. Steel Creek bottomland forests had fewer individuals than Pen Branch, but there was no difference between Pen Branch and Tinker Creek. Species diversity was greater at Tinker Creek than at Pen Branch. Short-distance migrants and species associated with forest edge/scrub habitats were more common in the early successional bottomland of Pen Branch than at the other sites (Table 6-37). Neotropical migrants were more common in the mature forest associated with Tinker Creek (Miller and Chapman 1997).

Table 6-37. Birds that were Detected at Pen Branch, 1994-1995

Common Name	Scientific Name
Green Heron	*Butorides striatus*
Wood Duck	*Aix sponsa*
American Woodcock	*Scolopax minor*
Mourning Dove	*Zenaida macroura*
Yellow-billed Cuckoo	*Coccyzus americanus*
Ruby-throated Hummingbird	*Archilochus colubris*
Downy Woodpecker	*Picoides pubescens*
Acadian Flycatcher	*Empidonax virescens*
Great-crested Flycatcher	*Myiarchus crinitus*
Fish Crow	*Corvus ossifragus*
Carolina Chickadee	*Parus carolinensis*
Tufted Titmouse	*Parus bicolor*
Carolina Wren	*Thryothorus ludovicianus*
Blue-gray Gnatcatcher	*Polioptila caerulea*
White-eyed Vireo	*Vireo griseus*
Red-eyed Vireo	*Vireo olivaceous*
Northern Parula	*Parula americana*
Black-and-white Warbler	*Mniotilta varia*
Common Yellowthroat	*Geothlypis trichas*
Hooded Warbler	*Wilsonia citrina*
Yellow-breasted Chat	*Icteria virens*
Summer Tanager	*Piranga rubra*
Northern Cardinal	*Cardinalis cardinalis*
Blue Grosbeak	*Guiraca caerulea*
Indigo Bunting	*Passerina cyanea*
Painted Bunting	*Passerina ciris*
Rufous-sided Towhee	*Pipilo erythrophthalmus*
Red-winged Blackbird	*Agelaius phoeniceus*
Brown-headed Cowbird	*Molothrus ater*
Orchard Oriole	*Icterus spurius*

Source: Buffington 1996.

The foraging behavior of hooded warblers (*Wilsonia citrina*), white-eyed vireos (*Vireo griscus*), and parula warblers (*Paula americana*) were examined. Each species appears to occupy a slightly different foraging niche differentiated by foraging maneuver and the position of the bird relative to the trunk and the top of the tree (Miller and Chapman 1997).

Mammals

During the summer of 1996, the small mammal population in the Pen Branch corridor was monitored (Wike 1997). Three habitats – wooded upland, streambank, and islands (often no more than sand bars) – were sampled. Preliminary results suggest that there are substantial populations of rice rats (Oryzomus palustris), cotton rats (Sigmodon hispidus), and cotton mice (Peromyscus gossypinus) at Pen Branch. The Lincoln-Peterson method for estimating populations estimated the populations of each species in the 40 ha (100 acre) study area (Table 6-38).

Table 6-38. Small Mammal Population Estimates at Pen Branch, Summer 1996

Species	Number of Individual Trapped	Estimated Population Size	Females[a]	Males[a]
P. gossypinus	44	161	13	25
O. palustris	47	186	19	25
S. hispidus	66	224	12	43

Source: Wike 1997.
[a]Some animals could not be sexed.

Several other species were trapped, but in smaller numbers: Southern short-tailed shrew (*Blarina carolinensis*), star-nosed mole (*Condylura cristata*), wood rat (*Neotoma floridana*), and golden mouse (*Ochrotomys nuttalli*). Virginia opossums (*Didelphis virginiana*) and a racoon (*Procyon lotor*) were trapped in rabbit boxes and several swamp rabbits (*Sylvilagus aquaticus*) were seen (Wike 1997).

Reptiles and Amphibians

The reptile and amphibian populations in the Pen Branch corridor were monitored from January 1, 1995, to September 30, 1996, with drift fences and pitfall traps, coverboards, aquatic turtle traps, and modified minnow traps (Hanlin and Guynn 1997). All animals were identified, sexed if possible, marked, and released at their point of capture. The animals were collected in eleven of the planting strips, with the traps lines divided between the planted zones and the control zones. A total of 11,802 individuals representing 70 species were captured in 13,834 captures over 221,126 trap nights (12% were recaptures and 3% escaped before being marked). The most frequently captured species was the narrow-mouthed toad (*Gastrophryne carolinensis*; 30.5% of captures) followed by southern toad (*Bufo terrestris*; 19.1%), southern leopard frog (*Rana utricularia*; 16.7%), marbled salamander (*Ambystoma opacum*; 6.7%), and slimy salamander (*Plethodon glutinosus*; 6.0%). These five species represented approximately 79% of the total captures.

Twenty-four species of snakes (524 animals), 16 species of anurans (8281 animals), 13 species of salamanders (1818 animals), 9 species of turtles (459 animals), 8 species of lizards (718 animals), and 2 alligators were collected (Table 6-39) (Hanlin and Guynn 1997).

Evaluation

Finally, a technique for evaluating the success of the Pen Branch restoration was developed using appropriate parts of existing wetland assessment methodologies. In addition to developing an assessment system uniquely suited to the condition of the Pen Branch wetland, researchers compiled an extensive annotated bibliography of all information relevant to the restoration. The bibliography identified data gaps and in the future should provide scientists with information to prevent the collection of redundant data sets.

Restored sites must be compared to healthy and functional reference ecosystems to determine the success of rehabilitation. For restoration to be considered a success, wetland function needs to be restored or the community must be developing in the direction of the restoration of function. Easily measured indicators should be developed and interactions

Table 6-39. Reptile and Amphibian Species Captured in Pen Branch Corridor, 1995-1996

Common Name	Scientific Name
Salamanders	
spotted salamander	*Ambystoma maculatum*
marbled salamander	*A. opacum*
mole salamander	*A. talpoideum*
two-toed amphiuma	*Amphiuma means*
southern dusky salamander	*Desmognathus auriculatus*
southern two-lined salamander	*Eurycea cirrigera*
three-lined salamander	*E. longicauda guttolineata*
dwarf salamander	*E. quadridigitata*
eastern red-spotted newt	*Notophthalmus viridescens*
slimy salamander	*Plethodon glutinosus*
mud salamander	*Pseudotriton montanus*
lesser siren	*Siren intermedia*
greater siren	*S. lacertina*
Frogs and Toads	
southern cricket frog	*Acris gryllus*
southern toad	*Bufo terrestris*
eastern narrowmouth toad	*Gastrophryne carolinensis*
bird-voiced treefrog	*Hyla avivoca*
Cope's gray treefrog	*H. chrysoscelis*
green treefrog	*H. cinerea*
pine woods treefrog	*H. femoralis*
squirrel treefrog	*H. squirella*
spring peeper	*Pseudacris crucifer*
southern chorus frog	*P. nigrita*
little grass frog	*P. ocularis*
ornate chorus frog	*P. ornata*
bullfrog	*Rana catesbeiana*
bronze frog	*R. clamitans*
southern leopard frog	*R. utricularia*
eastern spadefoot toad	*Scaphiopus holbrookii*
Turtles	
common snapping turtle	*Chelydra sepentina*
spotted turtle	*Clemmys guttata*
striped mud turtle	*Kinosternon baurii*
eastern mud turtle	*K. subrubrum*
eastern river cooter	*Pseudemys concinna*
Florida cooter	*P. floridana*
common musk turtle	*Sternotherus odoratus*
eastern box turtle	*Terrapene carolina*
yellowbelly slider	*Trachemys scripta*
Crocodilians	
American alligator	*Alligator mississippiensis*

Table 6-39. (cont)

Common Name	Scientific Name
Lizards	
green anole	*Anolis carolinensis*
six-lined racerunner	*Cnemidophorus sexlineatus*
five-linked skink	*Eumeces fasciatus*
southeastern five-lined skink	*E. inexpectatus*
broad-headed skink	*E. laticeps*
slender glass lizard	*Ophisaurus attenuatus*
eastern glass lizard	*O. ventralis*
ground skink	*Scincella lateralis*
eastern fence lizard	*Sceloporus undulatus*
Snakes	
eastern cottonmouth	*Agkistrodon piscivorus*
eastern worm snake	*Carphophis amoenus*
scarlet snake	*Cemophora coccinea*
black racer	*Coluber constrictor*
timber rattlesnake	*Crotalus horridus*
southern ringneck snake	*Diadophis punctatus*
corn snake	*Elaphe guttata*
rat snake	*E. obsoleta*
mud snake	*Farancia abacura*
rainbow snake	*F. erytrogramma*
eastern hognose snake	*Heterodon platirhinos*
southern hognose snake	*H. simus*
eastern kingsnake	*Lampropeltis getula*
scarlet kingsnake	*L. triangulum elapsoides*
redbelly water snake	*Nerodia erythrogaster*
banded water snake	*N. fasciata*
brown water snake	*N. taxispilota*
rough green snake	*Opheodrys asetivus*
brown snake	*Storeria dekayi*
redbelly snake	*S. occipitomaculata*
southeastern crowned snake	*Tantilla coronata*
eastern ribbon snake	*Thamnophis sauritus*
eastern garter snake	*T. sirralis*
rough earth snake	*Virginia striatula*

Source: Hanlin and Guynn 1997.

between biotic and abiotic factors need to be understood. To date, the information collected from Pen Branch indicates the following (Trettin et al. 1997):

- The four parameters measured in the aquatic macroinvertebrate community (mean number of taxa per sampler, mean density, mean biomass, and total taxa collected) are higher in the reforested wetland than in the reference community. Moving from the era of thermal impacts to postreforestation, all four indicator parameters have increased in value.
- Fish communities in the reforested wetland are more diverse, with higher densities and more sensitive species than the undisturbed reference site. There appears to be a higher level of biotic integrity and freedom from ecosystem disturbance in the reforested site compared to the pristine site.
- Water quality monitoring at Pen Branch indicates decreases in water temperature and velocity, and increases in conductivity. The pH, dissolved oxygen, and hardness at Pen Branch and the control site are comparable and unchanged.
- Bird and reptile and amphibian communities resemble those of early successional systems.
- Vegetation communities are the most distinctly different between the two sites. The diversity and net primary production are greater at the restored site, but the desirable species have not yet established themselves as the dominant vegetation.

It appears that Pen Branch is functioning as a viable wetland. For some faunal communities, it may provide greater opportunities for establishment and survival than later successional forests.

Based on the research as of the date of the revision of the document, several valuable conclusions regarding vegetation restoration are already evident. Seedling establishment appears to be hampered in open conditions because of herbaceous competition and herbivory. The best chance for seedling survival is when a shrub cover or nursery crop is present. Shading slows seedling growth somewhat; however, the effects are offset by the protection from herbaceous competition and herbivory the larger plants afford the seedlings. Future restoration plans should consider minimal site preparation. Tree tubes and tree shelters ensure greater survival, although they would be cost-prohibitive for large scale restorations. Root pruning makes planting in muck easier and does not appear to have a detrimental effect on seedling survival of the species planted in Pen Branch. Green ash is more susceptible to prolonged flooding than the other experimental species.

6.6 Carolina Bays of SRS

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Carolina Bays of SRS

General Characteristics of Carolina Bays

Carolina bays are shallow, poorly drained, oval, or elliptical depressions found throughout the southeastern Coastal Plain. Bennett and Nelson (1991) described their abundance and distribution in South Carolina, excluding SRS. Much of this chapter was taken from the National Environmental Research Park (NERP) report of the Carolina bays of SRS (Schalles et al. 1989). Carolina bays are a common feature of the SRS landscape (Figure 6-50). The 194 bays Shields et al. (1982) identified support a variety of aquatic and wetland communities. Most of the bays have limited development of organic or peat substrates, and the soils are typically sandy clay loam underlain by a clay hardpan. Many were ditched and drained for agricultural use prior to the acquisition of the land for the SRS (Christel-Rose 1993). Few have been disturbed since the early 1950s; therefore, most of the altered bays have undergone successional revegetation (Schalles et al. 1989). In recent years, SRS has begun a program to restore some bays to their former hydrology.

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

Carolina bays occur throughout the upper Coastal Plain of Georgia and the Carolinas. Their origin is unknown, but because they are seasonally inundated and isolated wetlands, they provide valuable habitat. Carolina bays on SRS have remained largely undisturbed since the advent of SRS in the early 1950s and are valuable examples of these ecosystems.

Previous Research on SRS Carolina Bays

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

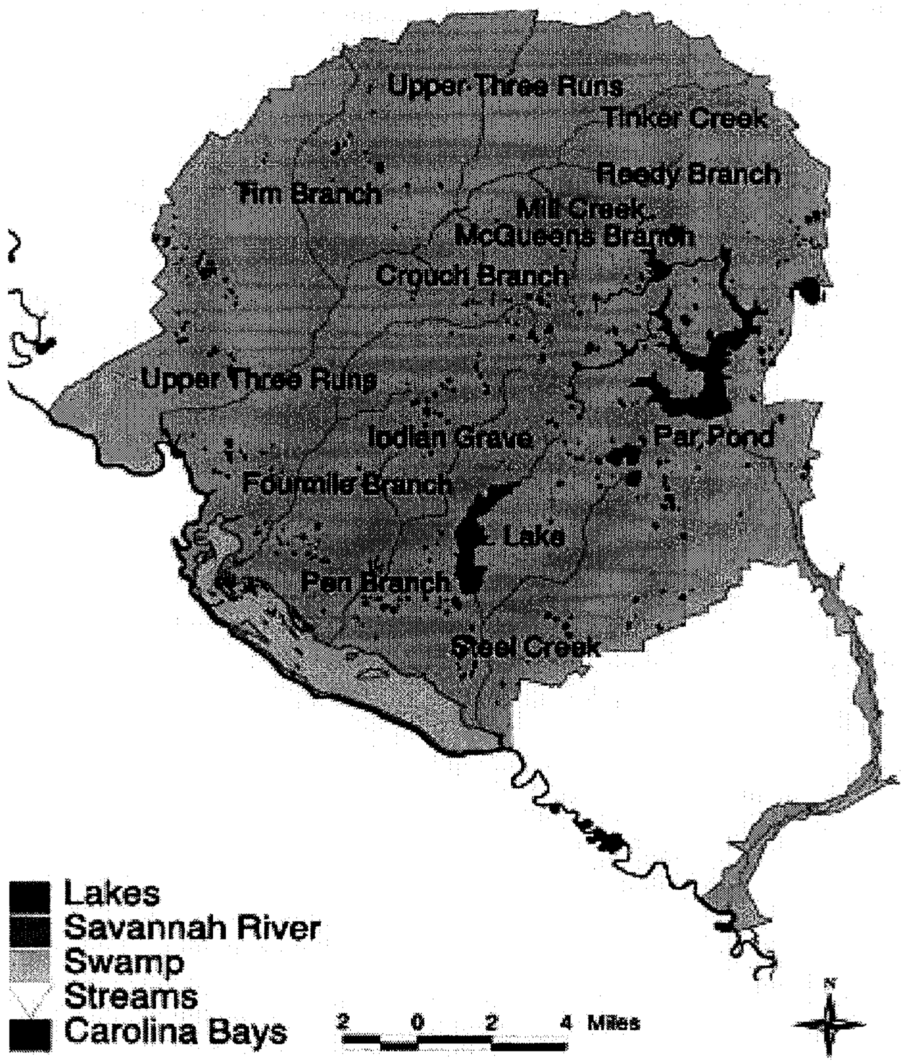


Figure 6-50. Location of Carolina Bays on SRS (Kirkman et al. 1996)

Size and Distribution of Carolina Bays on SRS

An inventory of the Carolina bays on SRS was made by examining false-color infrared photography (scale 1:15,840) (Shields et al. 1982). This inventory identified 194 confirmed or suspected bays; each bay was assigned a number, and its position was located on a topographic map of SRS (USGS 1:48,000). The identification number, name, location, wetland surface area, and habitat type of each bay are presented in *Locations and Areas of Ponds and Carolina bays at the Savannah River Plant* (Shields et al. 1982). A more recent survey by Kirkman et al. (1996) identified 299 Carolina bays and bay-like wetlands on SRS (Figure 6-50).

Carolina bays are distributed in clusters and broad bands across SRS (Figure 6-50). The bays occur at elevations ranging from 36 to 104 m (118 to 341 ft) above mean sea level. The surface areas of bays on SRS range from less than 0.1 ha (0.2 acres) to about 50 ha (125 acres). Aerial photography from the 1940s reveals that three large bays southwest of Par

Pond, at the headwaters of Meyers Branch, may be remnants of a large bay covering about 220 ha (545 acres). The median size of SRS bays is about 0.8 ha (2 acres); only 15 sites exceed 4 ha (10 acres) (Shields et al. 1982; Schalles et al. 1989).

Hydrology

Water chemistry of undisturbed Carolina bays on SRS is typical of precipitation-dominated systems (Schalles et al. 1989). Surface inflow channels generally are absent. Drainage channels are common and many are man-made. Today, none of these channels is maintained; most are partially filled with sediments and discharge only during periods of high water.

Figure 6-51 compares water levels in three extensively studied bays on SRS. Although the water levels of these bays generally were related to the amount of precipitation, the amplitude and timing of changes differed. For example, Ellenton Bay and Thunder Bay have similar overall patterns; whereas, Rainbow Bay has greater water-level fluctuation. Schalles (1979) found that maximum water-level fluctuation over an annual cycle in 1974-1975 was between 35 and 83 cm (14 and 33 in.) in six local bays. Water level changes in excess of 50 cm (20 in.) from the summer of 1990 through the summer of 1992 were common at Lost Lake (Figure 6-52). Continuous or temporary connection to near-surface groundwater is probably a common feature of Carolina bays (Lide 1991). Comparisons of surface-water levels to the piezometric levels in four adjacent monitoring wells (Schalles et al. 1989) revealed conditions favorable to almost continuous subsurface seepage loss and periodic groundwater recharge at Thunder Bay. Later work with a series of 34 shallow piezometers in Thunder Bay monitored the hydrology for 5 years (Lide et al. 1995). This work indicates that Thunder Bay is not a perched system, but a surface expression of the water table. Schalles (1979) proposed that most groundwater surface-water interactions occur laterally,

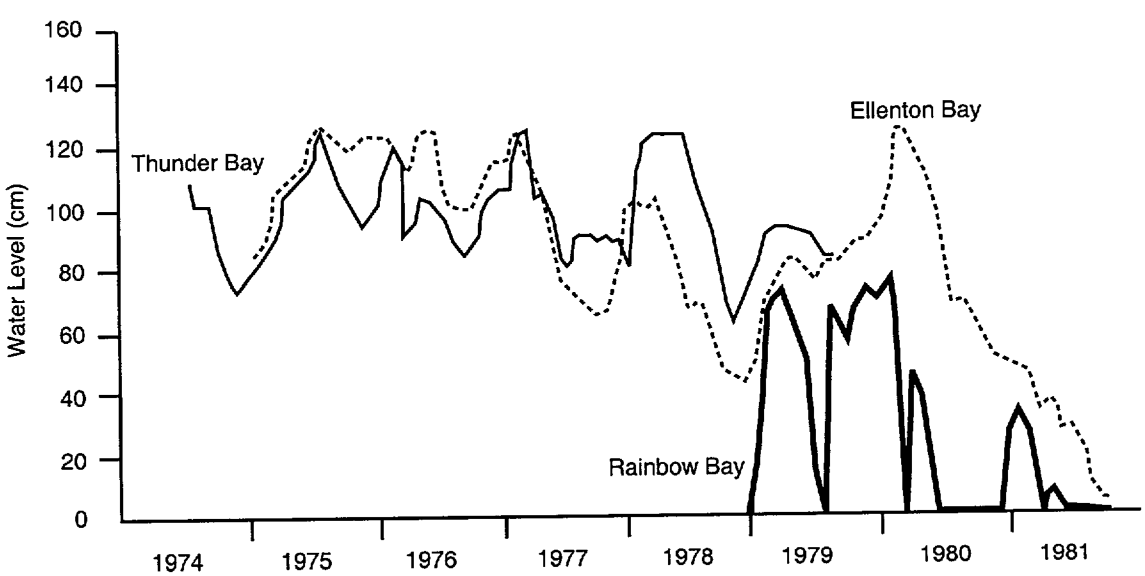


Figure 6-51. Surface Water Levels of Three Carolina Bays on SRS: Thunder Bay, Ellenton Bay, and Rainbow Bay (Source: Shalles et al. 1989)

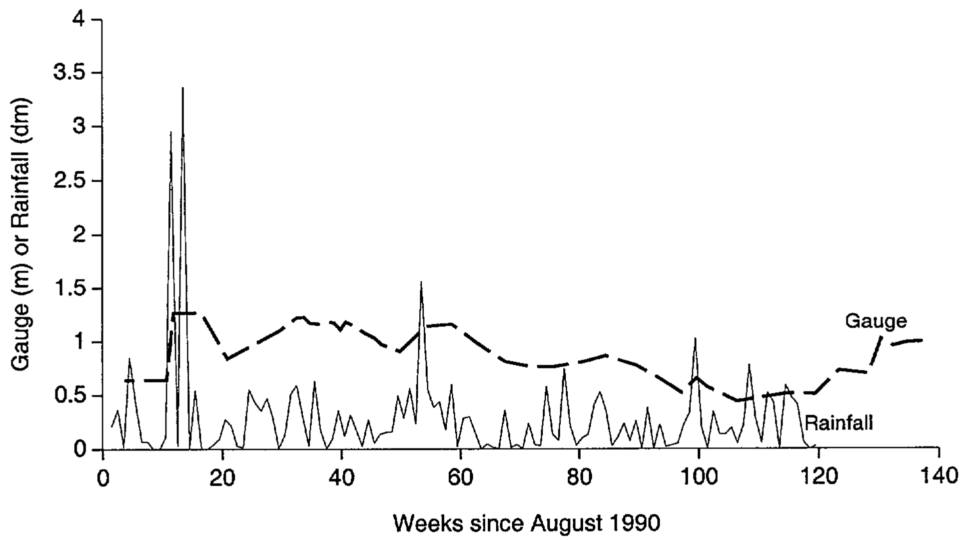


Figure 6-52. Water Level and Rainfall Data for Lost Lake, August 1990-August 1992

around the margins of the depressions, and that these connections are often lost during periods of low water levels.

An impervious clay lens appears to underlie many of the SRS Carolina bays. Soils in the center of the bays contain higher percentages of clays and silts than those closer to the rims. Consequently, soils in the center are less permeable and more poorly drained. Many Carolina bays on SRS dry periodically. Many of the smaller bays contain surface water only during wet seasons; whereas some of the larger depressions dry only during prolonged drought (e.g., Craigs Pond and Ellenton Bay). Ellenton Bay experienced severe drying with only a few deep holes holding water during droughts in 1968, 1981, 1987, and 1988 (Sharitz and Gibbons 1982; Schalles et al. 1989). Craigs Pond was dry to at least 20 cm (7.8 in.) below the soil surface in 1988 (Schalles et al. 1989).

Water Chemistry

General Chemical Characteristics

Newman and Schalles (1990) made several surveys of surface water chemistry in Carolina bays of SRS. The surface waters of the surveyed bays were acidic (pH 3.8-5.5) with low levels of calcium and total inorganic solutes (conductivities of 20-40 μS/cm). Bay waters had low to moderate color and dissolved organic carbon (mean = 22 mg/l). The moderate levels of color and dissolved organic carbon (DOC) in the bays can be attributed to the low calcium levels, abundance of living and decaying plant materials, and the shallow depths of the ponds. No single element dominates cations in the bay waters. In 1980, calcium was the most abundant cation (25% of total meq/l). However, sodium, magnesium, and hydrogen ions were also significant (Table 6-40). The relatively high monovalent/divalent cation ratios, low total inorganic solutes, and occurrence of moderate acidity and dissolved organic carbon in the bays are probably the result of sea salt contributions to atmospheric chemistry in the region; restricted watersheds with sandy, leached soils; periodic exchanges with low solute-strength shallow groundwater, and high nutrient retention by vegetation (Schalles et

Table 6-40. Cation Proportions for Various Southeastern Coastal Plain Surface Waters (Softwater, Lentic Systems)

Cation (% meq/l)[a]	SRS Carolina Bay[1]	SRS Farm Ponds[2]	North Carolina Pocosins[3]	Georgia Okefenokee Swamp[4]	Florida Cypress Dome[5]	Virginia-Lake Drummond, Dismal Swamp[6]
Ca^{++}	24.4	18.6	34.9	7.6	25.4	38.2
Mg^{++}	17.4	21.0	16.6	9.4	20.1	16.9
Na^{+}	23.7	51.6	36.6	45.9	38.3	31.3
K^{+}	5.6	7.4	2.6	2.0	1.6	9.4
H^{+}	18.2		9.2	32.3	5.7	1.8
Fe^{++}	5.9			2.6	3.4	2.4
Mn^{++}	4.9		< 0.1	1.4	1.4	
Σ(meq/l)	0.261		0.573	0.392	0.561	0.875

Sources: [1]Schalles et al. 1989; [2]Tilly 1973; [3]Daniel 1981; [4]Abule 1984; [5]Dierberg and Brezonik 1984; [6]Lichtler and Walker 1979.
[a]Iron and manganese probably were present as colloids and thus do not contribute to total cation charge.

al. 1989). Overall, the SRS bays had lower total cation levels than other Coastal Plain wetlands (Table 6-40). Manganese concentrations in the bays on SRS were about one order of magnitude greater than the freshwater global average (0.0013 meq/l) reported by Livingston (1963). A possible source of the manganese is conifer litter (Wetzel 1983) from marginal pine forests; thus manganese concentrations in the bays may attest to the importance of exchange pathways between these bays and adjacent terrestrial habitats (Schalles et al. 1989).

Detailed Chemical Analyses of Bays of SRS

Detailed chemical analyses of bays on or in the vicinity of SRS were made as part of a 1988 regional survey of 53 sites (Table 6-41). Overall, solute levels were higher than levels seen in previous surveys of bays on SRS. Potassium levels were notably higher and hydrogen-ion levels lower. A dry period during the early and mid-1980s and corresponding ecosystem responses may account for these differences. Chloride was the dominant inorganic anion, with sulfate second in abundance (Table 6-41). Dissolved organic carbon averaged 14.1 mg/l and accounted for 39% of the total anionic charge. Dissolved silica values were moderate, but quite variable. The dilute acidic chemistry is a probable indicator of moderate to severe nutrient limitations in the bays. The acidic nature of the surface waters suggests a dystrophic condition. The acidity seems largely related to biological phenomena and low regional alkalinities. Interestingly, sphagnum moss, often implicated in bog acidity (Clymo 1964), is uncommon or absent from bay communities on SRS (Schalles et al. 1989).

Variation in Oxygen and Temperature

Spatial and temporal variability in oxygen and temperature were found in the bays. Strong oxygen and temperature stratification often existed when emergent or floating-leaf vegetation was present, even in shallow waters (Figure 6-53). Bottom strata exhibited low oxygen

Table 6-41. Detailed Chemical Analysis, Including Anion/Cation Charge Balance, for Surface Waters in Six Carolina Bays Sampled as Part of a Regional Survey in January 1988[a]

Variable	$\bar{x}$	range (mg/l)	$\bar{x}$ (meq/l)	$\bar{x}$ (% meq)
DOC[b]	14.09	(8.08-21.71)	0.155	39.0
Cl^-	4.94	(3.44-7.99)	0.139	35.0
SO_4--	3.32	(0.50-10.34)	0.069	17.4
HCO_3	2.07	(0.13-6.89)	0.034	8.6
Anions(Σ)	--		0.397	100.0
Na^+	3.08	(0.82-6.64)	0.134	32.8
Ca^{++}	2.12	(0.72-4.53)	0.106	26.0
K^+	3.83	(1.09-14.5)	0.098	24.0
Mg^{++}	0.78	(0.49-1.25)	0.064	15.7
H^+	0.006	(0.001-0.013)	0.006	1.5
Cations (Σ)	--		0.408	100.0
Sp. Conductance[c]	47.4	(28.6-98.2)		
pH	5.2	(4.9-6.1)		
SiO_2	2.82	(0.10-9.24)		
Fe (reactive)[d]	0.35	(0.28-0.63)		
Mn (reactive)[d]	0.18	(0.09-0.32)		

Source: Schalles et al. 1989.

[a]The sites were Flamingo Bay, Enchantment Bay, Thunder Bay, Mathis Lake in Aiken County, and Sister Lake and an unnamed site near Williston in Barnwell County. Four replicates were collected per site. Anions were determined with ion chromatography, metals with atomic absorption spectrophotometry, and silica with molybdenum blue method.

[b]Dissolved organic carbon, charge estimated from the analysis of Perdue et al. (1984).

[c]µS/cm.

[d]From acid-pretreated samples; may be largely colloidal; values were not used in the charge balance analysis.

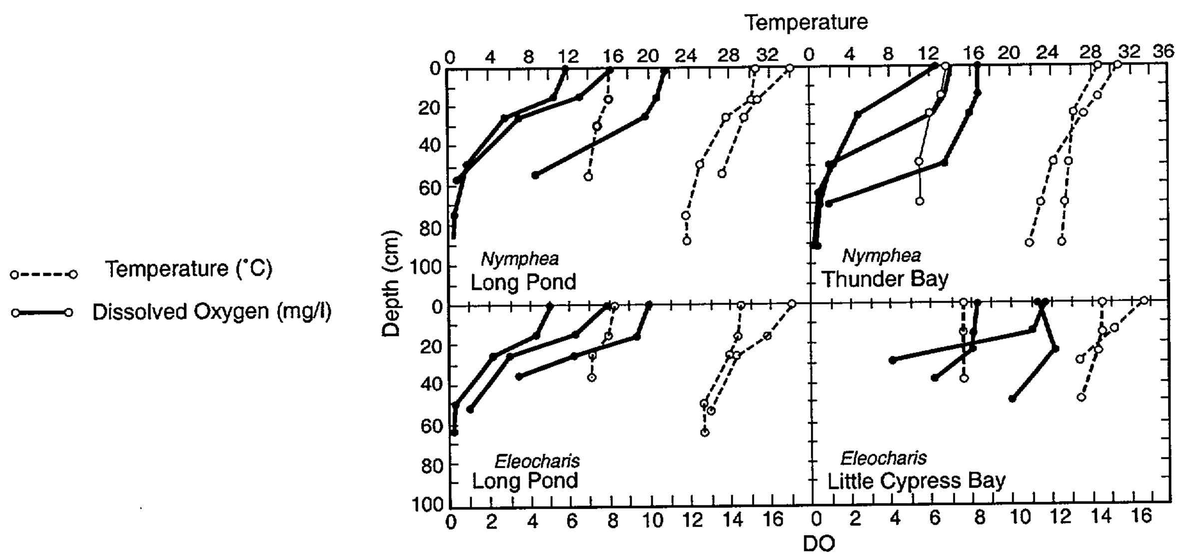


Figure 6-53. Vertical Profiles of Dissolved Oxygen and Temperature at Four Sampling Stations in Macrophyte Beds in Three Carolina Bays, 1974-75 (Source: Schalles 1979)

concentrations (less than 0.5 mg/l) during most of the year. Stratification and destratification can occur almost daily. Horizontal patterns were demonstrated with *in situ* measurements made in December 1979 in Dry Bay. The highest oxygen concentrations were found in shallow water with abundant filamentous algae, while the lowest concentration was found in a macrophyte-shaded area with abundant detritus. In general, bay margins had the greatest overall physical-chemical variability. Thunder Bay displayed marked seasonal patterns (Schalles et al. 1989). Average water-column oxygen concentrations ranged from about 7 to 8 mg/l in mid-winter to about 1.5 to 2 mg/l in late summer. Average water column temperatures varied from approximately 7°C (44.6°F) in mid-winter to 27°C (80.6°F) in mid-summer.

Soils

Bay soils generally grade from well-drained sands on the xeric rims to consolidated sandy loams in the wetland centers. Unpublished research by Hodge (unpublished, cited in Schalles et al. 1989) documented two conditions in sandy surface soils of the bay rims and adjacent interbay areas on or near SRS. In one condition, the surface sand was 75-150 cm (29.5-59 in.) thick and was underlain by a sandy clay loam (Blanton series). In the second condition, the surface layer was excessively drained sand with depths exceeding 2 m (6 ft) (Lakeland series). Interior to the bay rims, Hodge (unpublished, cited in Schalles et al. 1989) found a narrow zone with loamy surface sands 15-35 cm (6-14 in.) thick overlying a sandy clay loam horizon about 45 cm (18 in.) thick and a third horizon of about 75 cm (29.5 in.) composed of sandy loams or loamy sands. The central floors of most bays on or near SRS have shallow, consolidated loamy soils that vary from 15-75 cm (6-29.5 in.) in thickness. A consolidated, gray clay hardpan is consistently found below the loamy stratum. Hodge (unpublished, cited in Schalles et al. 1989) determined that these hardpans averaged about 70 cm (27.5 in.) thick and that soils immediately below the hardpans were sandy clay loams. Organic horizons are generally thin, but often thicken with increasing water depths and hydroperiods. The surface mineral soils of the bay interiors are typically dark and contain numerous fine charcoal fragments indicating earlier fires (Schalles 1979). Most soils occurring in the interiors of bays on SRS and vicinity fit an Ochraquult classification. Ochraquult soils have thin, dark peptones, thin to moderately thick argillic horizons, and base saturations of less than 50%. Such soils are inundated for at least three months of the year and have poor drainage. Soils of the SRS bays are largely Rembert and Ogeechee series loams, but also include Williman and Lumbee loamy sands. Duplin, Plummer, Faceville, Orangeburg, and Johnston soil series are found less frequently inside the sandy bay rims.

Many bays of SRS have surface organic layers of less than 15 cm (6 in.). However, the maximum thickness of peat in Peat Bay exceeds 1 m (3 ft). The occurrence of significant peat in Peat Bay could reflect a more stable hydrology with almost continual groundwater recharge that reduces exposure to the atmosphere and enhances peat development. This bay is between 42.7-45.9 m (140-150.5 ft) above mean sea level and is relatively close to Steel Creek and the Savannah River floodplain. However, other SRS bays with similar locations near streams or the floodplain lack significant peat buildup. Hodge (unpublished, cited in Schalles et al. 1989) found several Carolina bays on SRS and in adjacent Barnwell and Aiken Counties with peat layers of 50-100 cm (20-39 in.).

Vegetation

Introduction

Several wetland community types typical of undrained coastal plain sites are found in SRS. Topographical relief and hydrology are the principal determinants of vegetation composition in the bays. The duration and magnitude of inundation creates a range of conditions favoring different vegetation associations. Many Carolina bays are dominated by grasses and sedges that generally occur in monospecific stands. These stands change in area and in community dominance as water conditions change (Kirkman 1992; Schalles et al. 1989; Kirkman and Sharitz 1994; Kirkman et al. 1996).

Vegetation Pattern Control

The hydrologic regime of Carolina bays is one of the most important factors controlling patterns of vegetation in the bay. Kirkman (1992) concluded that it was during extremes of the hydrologic regime (i.e., very wet or very dry conditions) that recruitment from the seed bank becomes a more significant factor influencing vegetation change. Species diversity and density of seed banks of Carolina bays are among the highest reported for wetlands; however, these seed banks do not necessarily reflect standing vegetation (Kirkman 1992; Schalles et al. 1989; Kirkman and Sharitz 1994).

Vegetation Zones

A xeric to hydric gradient occurs from the peripheral sand rim to the center of the bays. Kelley and Batson (1955) described several concentric vegetational zones in Craigs Pond. The outermost zone lies along the sandy rim of the bay and is dominated by trees such as loblolly (*Pinus taeda*) and longleaf pines (*P. palustris*), black gum (*Nyssa sylvatica*), blackjack oak (*Quercus marilandica*), turkey oak (*Q. laevis*), and sweetgum (*Liquidambar styraciflua*). Several shrubs, such as sumac (*Rhus copallina*), gallberry (*Ilex glabra* and *I. coriacea*), and red bay (*Persea borbonia*) also occur here. Inside this zone of woody species are several bands of herbaceous vegetation, each of which is dominated by grass species. The driest zone is characterized by broomsedge (*Andropogon virginicus*) but also contains numerous herbs including pitcher plants (*Sarracenia* spp.). Inside this zone, closer to the bay's center, is a band of vegetation dominated by threeawn grass (*Aristida affinis*), and in deeper water areas, surrounding the central pool of water, species of maidencane (*Panicum* spp.) are abundant. The pond in the middle of the bay contains typical floating-leaved aquatic plants such as the water lilies (*Nymphaea odorata* and *Nymphoides aquaticum*). In a subsequent floristic study of Craigs Pond, Hodge (unpublished, cited in Schalles et al. 1989) found similar patterns.

Community Types

Seventeen herbaceous community types were found in the eight Carolina bays studied by Hodge (unpublished, cited in Schalles et al. 1989). As many as six types were found in one bay (Craigs Pond). Figure 6-54 and Figure 6-55 illustrate the composition and distribution of herbaceous species in community types along the hydrologic gradient from the rim to the hydric center at Craigs Pond and Ellenton Bay (Schalles et al. 1989).

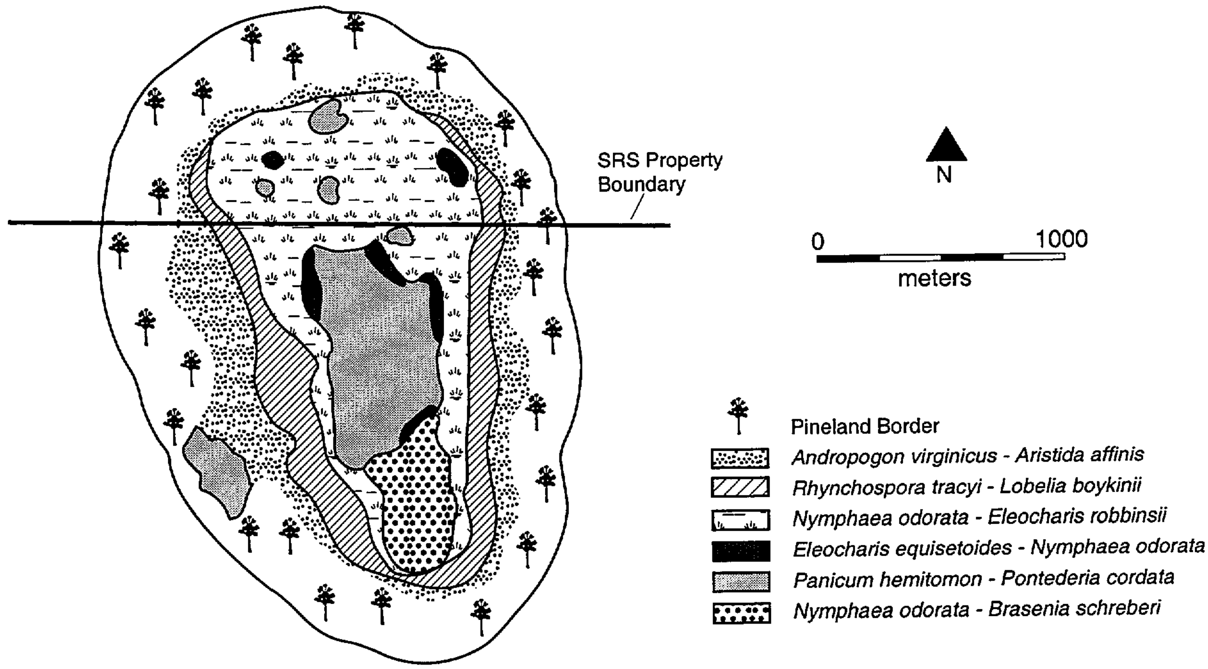


Figure 6-54. Wetland Vegetation Community Types at Craigs Pond (Site 77) (Source: Schalles et al. 1989)

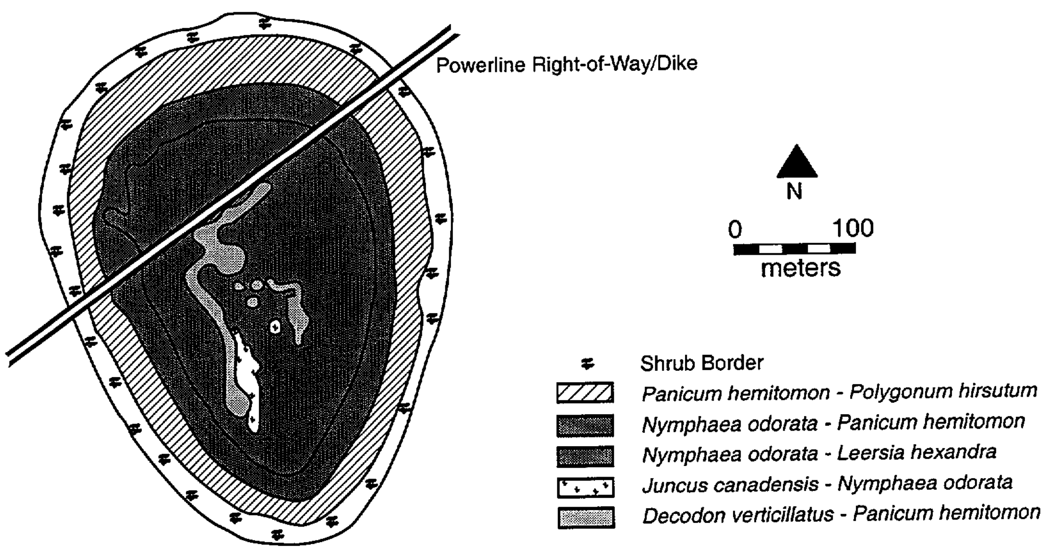


Figure 6-55. Wetlands Vegetation Community Types at Ellenton Bay (Site 176) (Source: Schalles et al. 1989)

Short-Term Succession

Field observations and the results of the study by Hodge (unpublished, cited in Schalles et al. 1989) suggest that short-term succession of herbaceous to woody-dominated communities in bays of the upper Coastal Plain occurs when water levels are low. After a bay has been ditched and drained buttonbush (*Cephalanthus occidentalis*), persimmon (*Diospyros virginiana*), or sweetgum commonly germinate on the exposed soil. A woody-dominated community soon becomes established. In undisturbed bays, organic material accumulates faster in the semipermanently to permanently inundated areas where conditions are at or approaching anoxia throughout the year. In these deeper areas of the bays, peat may accumulate until it is exposed during periods of low water levels. During these periods, seeds of woody species may become established and initiate the development of a woody-dominated community (Schalles et al. 1989).

Effect of Previous Land Use on Bay Recovery

About 25% of the 299 bays or bay-like depressions on SRS were either pasture or cultivated in 1951. By 1992, most had reverted to mixed hardwood and pine or had been converted to pine plantations. No distinctively different patterns in vegetative recovery could be associated with cultivation versus pasture.

Many of the depression wetlands at SRS once were disturbed by agricultural practices or ditched prior to 1951, implying considerable resilience in the recovery to a functioning wetland if hydrologic regimes are restored. Although the longevity of seeds is unknown, the presence of persistent soil seed banks (including rare species) in depression wetlands (Kirkman and Sharitz 1994) may greatly contribute to the restoration potential of the vegetation.

Herb-dominated wetlands are relatively stable. Based on the results of Kirkman et al. (1996), an herbaceous bay may not necessarily be a successional stage toward an eventual hardwood forest, but a climax wetland. After 1951, upland uses adjacent to depression wetlands undoubtedly influenced recovery processes following disturbances. A better understanding of the role of adjacent land uses on wetland vegetative recovery dynamics is clearly needed, particularly in regard to seed and nutrient inputs, implications for fire corridors, and potential hydrologic modifications (Kirkman et al. 1996).

Invertebrate Fauna

Introduction

The invertebrate fauna from only a few Carolina bays on SRS has been described. Cross (1955) surveyed Odonata distributions in Carolina bays and other aquatic habitats of SRS. Invertebrates were intensively surveyed in 1979 at Rainbow Bay and Sun Bay (no longer in existence), with detailed listings of taxa and their relative abundances (SREL 1980). Intensive work at Sun Bay disclosed a diverse insect assemblage with 119 families from 14 orders identified. Dipterans were the most abundant taxa at both Sun Bay and Rainbow Bay. Oligochaetes and isopods were relatively common in Rainbow Bay, but were not collected in Sun Bay (Table 6-42) (Schalles et al. 1989).

Table 6-42. Density of Certain Insect Orders, Oligochaetes, and Isopods (Number of Individuals/m^2) Determined by Artificial Substrate Sampling at Rainbow Bay and Sun Bay

	Taxa						
Microhabitat	**Ephemeroptera**	**Coleoptera**	**Diptera**	**Hemiptera**	**Odonata**	**Oligochaeta**	**Isopoda**
Rainbow Bay							
deep open water	6.25	0	111.25	1.25	7.5	41.25	26.25
shallow water in buttonbush	11.25	3.25	2.4	8.25	4	12.5	38.25
Sun Bay							
open disturbed pond	0	3.75	76.25	2.5	0	0	0
open weed-filled pond	0	5	147.5	2.5	1.25	0	0
pond in buttonbush	0	16.5	102.5	0	0	0	0
drainage ditch	7.5	2.5	96.25	1.25	1.25	0	
drainage ditch flowing	0	12.5	252.5	0	0	0	0

Source: SREL 1980.

Macroinvertebrates

Macroinvertebrates were quantified from 1975-1977 at Thunder Bay (Schalles and Shure 1989). Four insect orders dominated the invertebrates: odonates, dipterans, hemipterans, and coleopterans. Macroinvertebrates in Thunder Bay were taxonomically similar to the macroinvertebrates of an abandoned SRS farm pond studied by Benke (1976), but had only about 20% of the benthic biomass of the farm pond. The dystrophic bog chemistry and periodic drying apparently prevent or severely restrict the occurrence of several freshwater invertebrate groups in the Thunder Bay wetland community. Ephemeropterans, megalopterans, and trichopterans were infrequent, and plecopterans, amphipods, isopods, decapod crustaceans, gastropods (except the limpet *Ferrisia*), bivalves, and oligochaetes were absent during that study. The low calcium levels in undisturbed, upper coastal plain bays may be the primary limiting factor for molluscs, decapods and other malacrustaceans, and, perhaps, annelids. Snails frequently were observed in two nearby Carolina bays at the Barnwell County Industrial Park. The bays had received runoff and sediments from a construction area and had higher calcium levels (averages of 9.5 and 14 mg/l for the two sites) (Schalles et al. 1989).

Zooplankton

The zooplankton of Carolina bays on SRS are diverse, abundant, and at least moderately productive (Taylor et al. 1989). Calanoid and cyclopoid copepods, cladocerans, and rotifers are ubiquitous. Anostracans and conchostracans are sporadically distributed, but may be abundant where they occur. The Rainbow Bay community showed marked changes in species composition during the wet season (Figure 6-56). In such bays, which function as temporary ponds, all of the zooplankton have resting stages and lie dormant in the sediments during the dry season. Varied times of emergence from these resting stages contribute to the succession of species in Rainbow Bay. Zooplankton are an important part of the diets of larval salamanders (Taylor et al. 1988). Insect larvae may also prey heavily on the zooplankton (Schalles et al. 1989).

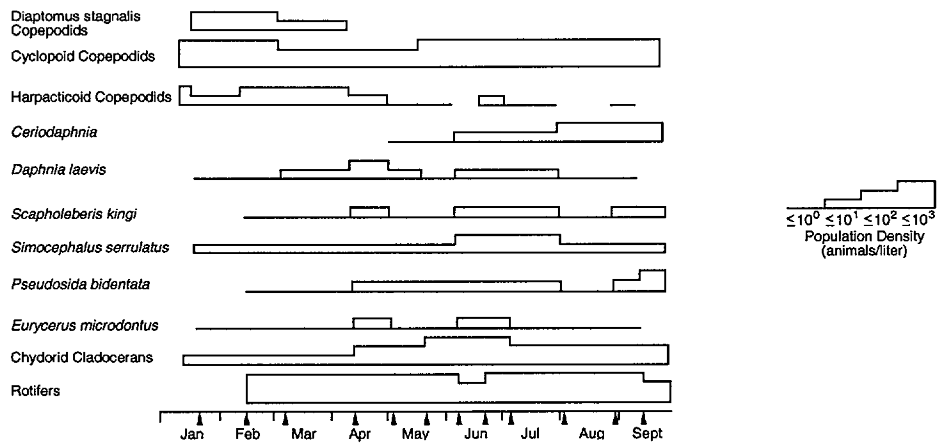


Figure 6-56. Changes in Zooplankton Species Composition at Rainbow Bay, January to September 1989 (Source: Shalles et al. 1989)

Vertebrate Fauna

Introduction

Vertebrates are conspicuous and relatively abundant members of the fauna of Carolina bays. Perhaps because of the water-level oscillations and dry periods, no vertebrates found in SRS bays are considered strictly endemic to these habitats. All aquatic and semiaquatic vertebrates, except fish, apparently use migration or aestivation strategies during dry periods. For example, sirens (*Siren intermedia* and *Siren lacertina*) form cocoons and aestivate during dry-outs (Conant and Collins 1991). The mole salamander (*Ambystoma talpoideum*) is commonly terrestrial as an adult, but is paedogenic in situations where water is usually permanent. It may have evolved this pattern of metamorphosis in response to unpredictable water levels that may result in potentially ephemeral aquatic habitats becoming permanent ponds with no fish predators (Patterson 1978; Semlitsch 1985; Schalles et al. 1989).

Fishes

Fishes have been observed in several Carolina bays on SRS (Bennett and McFarlane 1983). The following fish were observed in four Carolina bays on SRS during 1978-1983: redfin pickerel (*Esox americanus*), mud sunfish (*Acantharchus pomotis*), sunfish (*Lepomis* spp.), lake chubsucker (*Erimyzon sucetta*), and mosquitofish (*Gambusia affinis*). Fewer than 10% of the Carolina bays on SRS are known to have permanent fish populations, although overwash from neighboring swamps or streams may reestablish the ichthyofauna of formerly dry basins (Schalles et al. 1989).

Amphibians in Carolina Bays

Although fishes are not a dominant feature in most bays, other vertebrates are diverse. Many species of reptiles and amphibians are associated with Carolina bays on SRS (Gibbons and Patterson 1978; Gibbons and Semlitsch 1990). Gibbons (1970) observed more than 30 species of amphibians and reptiles in and around Ellenton Bay. The use of bays by vertebrates is sometimes astonishing, as revealed by the high number of semiaquatic animals migrating to and from the water. Rainbow Bay, which has an aquatic perimeter of less than 450 m (1476 ft), had approximately 10,000 individuals of the southern leopard frog (*Rana utricularia*) migrating to or from this bay in one year (Schalles et al. 1989). This is an average of

one frog for every 2 cm of pond margin. A similar calculation for Ellenton Bay, which is larger, indicates that one adult mole salamander (*Ambystoma talpoideum*) enters to breed each winter per 20 cm (7.8 in.) of perimeter (Patterson 1978) and as many as 11,000 metamorphosed individuals may exit during one week. Schalles and Shure (1989) obtained *in situ* estimates of salamander density and biomass in the aquatic area of Thunder Bay. Over an annual cycle in a 1-ha (2.5-acre) sampling grid, *Siren intermedia, Notophthalmus viridescens,* and *Ambystoma talpoideum* populations averaged 0.15, 1.18, and 1.46 individuals/m^2 and 8.03, 3.12, and 1.23 kg dry wt/ha, respectively. During the same period, anuran larvae (primarily Ranidae) averaged 1.03 kg dry wt/ha. (Schalles et al. 1989).

Abundance in Altered Bays

The abundance of amphibians in Carolina bays altered by agricultural, forest management, or construction activities (e.g., Sun Bay, Lost Lake), may be higher than expected (Bennett et al. 1979). In 1979, more than 500 ornate chorus frogs (*Pseudacris ornata*), 5000 southern leopard frogs, and 500 mole salamanders entered or left Sun Bay, a bay of less than 1 ha (2.5 acres) which had been drained by construction activity in the previous year. Similarly, Lost Lake on SRS had been altered by agricultural practices prior to the 1950s and later by the release of industrial by-products into the lake (Bennett et al. 1979). Extrapolation of captures by intermittent fencing and pitfall traps to the shoreline length bordered by a pine forest around the bay yielded estimates of 5000 southern toads (*Bufo terrestris*), 2000 mole salamanders, and 1000 spadefoot toads (*Scaphiopus holbrooki*) entering or leaving Lost Lake in one summer (Bennett et al. 1979).

Amphibian Community Dynamics in a Carolina Bay

The amphibian community of Rainbow Bay, a Carolina bay with a widely variable hydroperiod and a surface area of 1 ha (2.5 acres), was studies for 16 years. Results of the study are that the hydroperiod is the primary determinant of amphibian community reproduction. Competition and predation also have an influence, but theirs is mediated by pond hydroperiod. However, the effects were difficult to separate. All 13 amphibian species studied experienced episodic reproduction, with most of the larvae produced in only a few (1-7) of the 16 years. Not all species reproduced in all years. Temporal variation in hydroperiod may favor the reproductive success of different species in different years. Juvenile recruitment was limited for all species by a short hydroperiod during the driest years. In years with longer hydroperiods, competition influenced the density of metamorphosing juveniles. Apparently community structure of a temporary pond is regulated by an interaction of rainfall, timing of the hydroperiod, competition and predation (Semlitsch et al. 1995).

Other Vertebrate Species that use Carolina Bays

Although amphibians are the prevalent terrestrial vertebrates using Carolina bays (Patterson 1978; Bennett et al. 1979; Semlitsch 1981) and a major contributor to secondary productivity, other vertebrates may be important in these communities. The American alligator (*Alligator mississippiensis*), six species of turtles, and several species of snakes are reptiles common to bays (Table 6-43; Gibbons 1970; Gibbons et al. 1977; Gibbons and Patterson 1978; Gibbons and Semlitsch 1990). Though quantitative data are unavailable, mammals such as deer, raccoons, skunks, and opossums may use bays for water or feeding sites. Beaver (*Castor canadensis*) have been found in Thunder Bay and several other sites and could be an important agent in hardwood species composition and abundance. In the sandhills regions of the Carolinas, many bird species including hawks, egrets, and migratory water-

Table 6-43. Use of Carolina Bay Habitats by Small Vertebrates[a]

	Rainbow Bay				Sun Bay			
	Entering		Exiting		Entering		Exiting	
Species	**Adult**	**Juvenile**	**Adult**	**Juvenile**	**Adult**	**Juvenile**	**Adult**	**Juvenile**
Class Amphibia								
Order Caudata								
Ambystoma talpoideum	1,750	154	499	3,856	6,028	0	938	0
A. tigrinum	129	46	42	992	57	1	4	1
Notophthalmus viridescens	1,625	968	609	15,013	3,452	5	2,100	23
total of all salamanders	3,953	1,201	1,212	19,874	9,595	6	3,087	24
Order Anura								
Scaphiopus holbrooki	69	33	39	34	1,803	134	483	58
Bufo terrestris	424	644	79	689	580	375	98	622
Hyla crucifer	346	212	205	1,329	594	12	239	50
Pseudacris ornata	235	28	89	1,158	392	9	79	18
Gastrophryne carolinensis	1,122	18	418	15	887	1	420	0
Rana clamitans	27	30	19	1,136	27	35	1	7
R. utricularia	699	2,024	610	52,287	154	29	24	7
total of all frogs	3,197	3,053	1,569	57,106	4,486	680	1,355	767
Class Reptilia								
Order Chelonia								
Kinosternon subrubrum	29	6	25	6	49	59	14	11
Deirochelys reticularia	8	9	10	2	14	14	4	1
total of all turtles	43	16	39	9	70	74	19	14
Order Squamata								
Suborder Sauria								
Anolis carolinensis	26	2	19	2	5	0	12	0
Sceloporus undulatus	18	1	8	3	9	3	5	6
Cnemidophorus sexlineatus	2	2	1	0	19	7	19	2
total of all lizards	53	7	43	5	36	11	40	9
Suborder Ophidia								
Storeria occipitomaculata	26	1	37	0	4	0	2	0
Diadophis punctatus	7	2	10	0	7	1	15	3
Tantilla coronata	17	0	11	0	42	0	46	0
total of all snakes	92	7	88	2	68	5	85	5
Class Mammalia								
Blarina brevicauda	68	1	40	0	26	0	20	0
Reithrodontomys humulis	16	0	146	8	1	0	0	0
Sigmodon hispidus	7	0	14	0	5	0	18	0
total of all mammals	168	3	251	9	76	1	63	1
total of all species	7,506	4,287	3,202	77,005	14,331	777	4,649	820

Source: Gibbons and Semlitsch 1982.

[a]Numbers indicate selected vertebrate species captured (original and recaptured) in drift fences with pitfall at Rainbow Bay and Sun Bay, for one year, March 1979-March 1980.

fowl use the bays at least part of the year. Wood storks, an endangered bird species, have been observed foraging in Ellenton Bay. In bays with standing water and mature trees with cavities for nesting sites, wood ducks (*Aix sponsa*) may also be found (Mayer et al. 1986). The use of wood duck boxes as nesting sites in Carolina bays is common in some years (Schalles et al. 1989).

Quantitative data are available for many small mammals using the periphery of Carolina bays (Table 6-43). Though shrews (*Blarina brevicauda* and *Sorex longirostris*) and small rodents (*Sigmodon hispidus*, *Peromyscus gossypinus*, and *Microtus pinetorum*) may be abundant, only certain species, e.g., the rice rat (*Oryzomys palustris*), actually inhabit the marshy areas. Many small mammals captured by drift fences and pitfall traps around Carolina bays are equally abundant in strictly terrestrial habitats in the region (Briese and Smith 1974; Brown 1980; Gibbons and Semlitsch 1982; Schalles et al. 1989).

Lost Lake Restoration

Introduction

Before 1943 and until the early 1950s, a ditch to the south drained the Carolina bay known as Lost Lake for agriculture use. After the land was removed from farming in the early 1950s, the watershed above the lake was planted in loblolly pine (*Pinus taeda*) for erosion control. Without ditch maintenance, Lost Lake began to refill and function as a wetland. Impacts to the watershed occurred as the nearby M-Area industrial facility was constructed with associated roads, drainage ditches, railroads, and soil-fill areas. In addition, Lost Lake received overflow from the M-Area seepage basin until 1984 (Figure 6-57), contaminating it over the years with heavy metals, solvents, and cleaning fluids (Figure 6-57 and Figure 6-58). Restoration of the 10-ha (25-acre) bay to a "natural wetland system" was required as

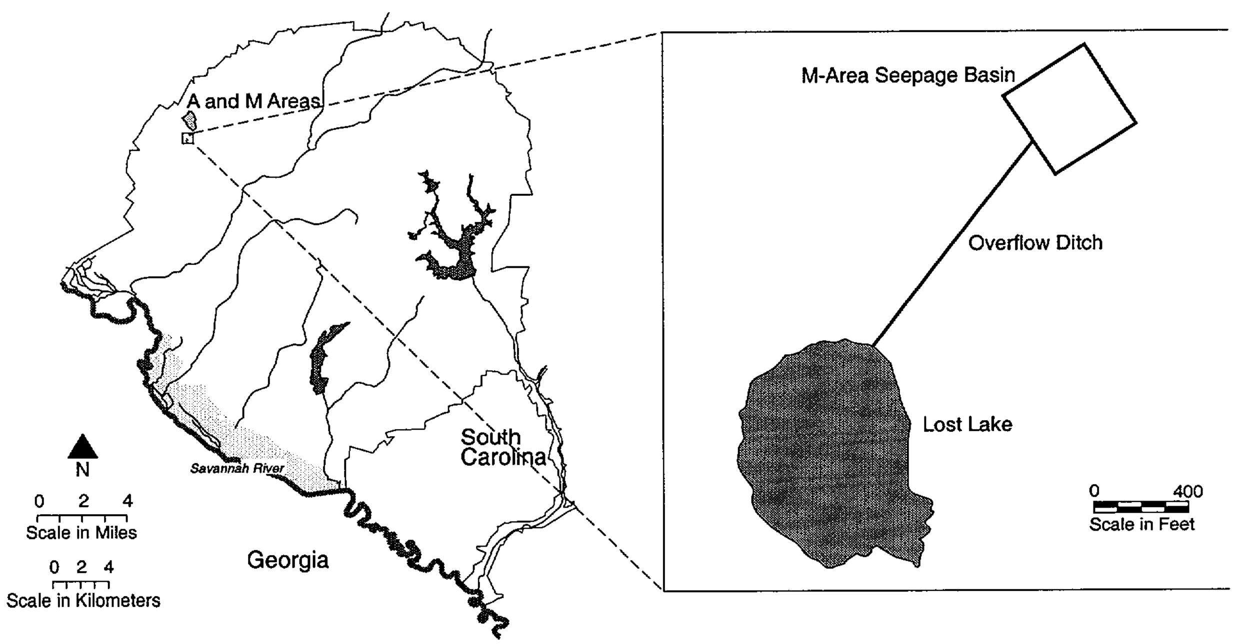
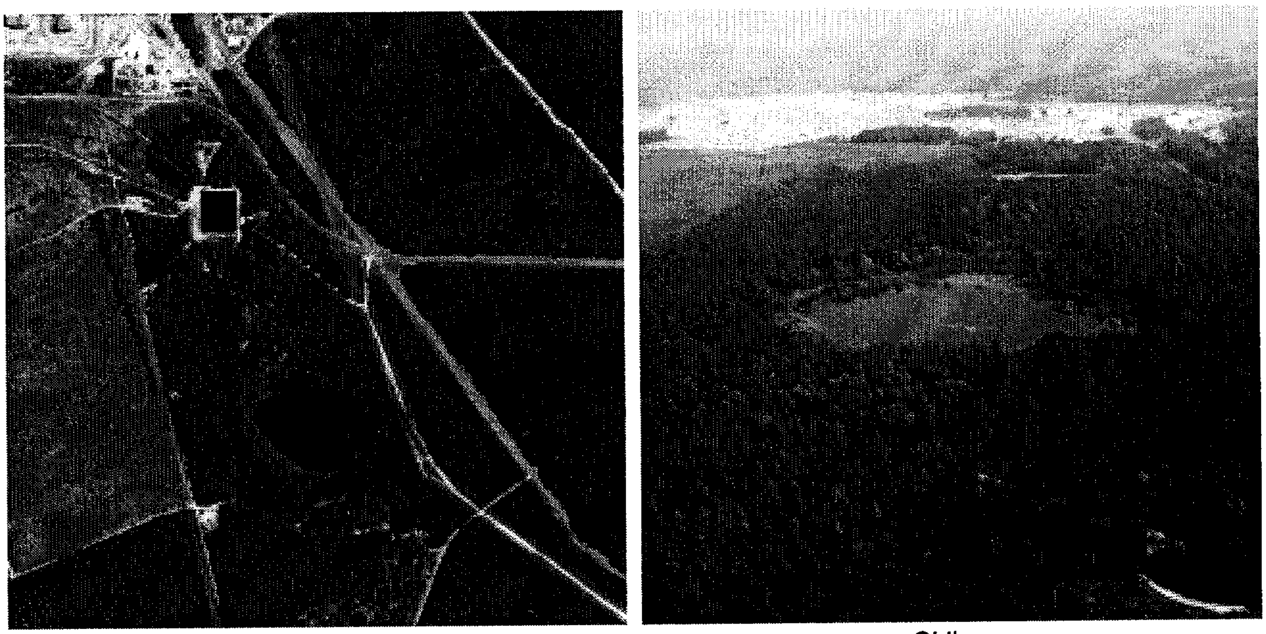


Figure 6-57. Location of Lost Lake and the M-Area Seepage Basin on SRS



Vertical *Oblique*

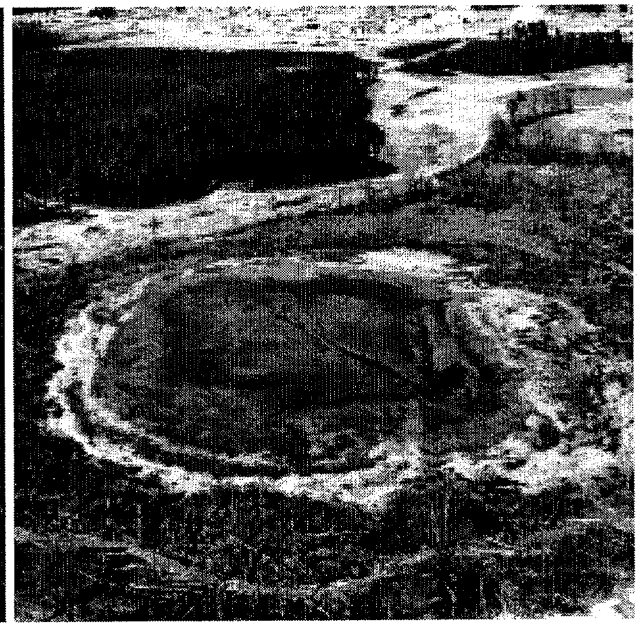
Figure 6-58. Lost Lake and the M-Area Seepage Basin Prior to Cleanup (Vertical and Oblique Photography)

part of the Resource Conservation and Recovery Act (RCRA) closure plan for the M-Area seepage basin. The closure plan was approved in July 1987 (DOE 1992).

Restoration Plan

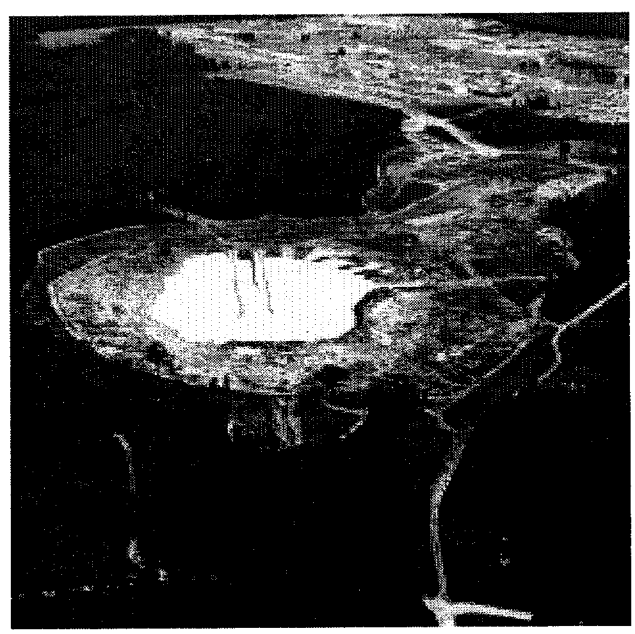
The reclamation of Lost Lake was an opportunity to restore a degraded natural area to a functional wetland; however, the closure plan did not include a specific plan for the restoration. The restoration was to be coordinated with the Natural Resources Conservation Service and the U.S. Forest Service and was to produce low maintenance, self-sustaining natural vegetation. Despite the removal of up to 30 cm (12 in) of soil, a sufficient clay layer remained to retain water (Figure 6-59); therefore, reclamation as a wetland was considered feasible (DOE 1992). The project strategy was to stabilize surrounding areas, use only native plant species, and fill an old drainage ditch at the south end of the bay to restore hydrology, thus creating Carolina bay like-conditions. The restoration was divided into two parts: upland planting and wetland restoration. An extremely wet fall in 1990 delayed soil preparation and partially refilled the basin. The water level was lowered in December 1990 to facilitate soil treatment in January 1991. Trees were planted in the upland areas during the winter of 1991. Macrophyte planting was staggered from early February through mid-April 1991. Erosion control was improved in the ditch leading from the M-Area Basin to Lost Lake in late April 1991 (DOE 1992).

1988-Vertical



1988-Oblique

1989-Vertical



1989-Oblique

Figure 6-59. Lost Lake and the M-Area Seepage Basin During Cleanup (Vertical and Oblique Photography)

Restoration Objectives

There were two major objectives in the reclamation plan for Lost Lake. First, and most important, was to restore the wetland ecosystem following hazardous waste cleanup. The second goal was to study and evaluate a restoration project. To this end, a research design was developed that would allow the evaluation of several wetland restoration levels-of-effort to determine minimum requirements to restore a disturbed Carolina bay. A third goal of the project was an opportunistic one. The scientific community is developing aerial imagery as a tool for evaluating changes to landscapes over time. This project also was used to study the success of using aerial imagery to monitor the re-establishment of the wetland community (Mackey 1993).

Strategy Considerations

Treatment Scheme

A four-treatment scheme was developed to determine how much manipulation was needed to successfully restore a functioning wetland. The bay was divided into eight treatment zones (Figure 6-60), with four treatments applied in duplicate. One of the treatments was no treatment. The initial treatment zones were rearranged when a sensitive plant species, little bur-head (*Echinodorus tenellus*), was found in significant numbers in one quadrant of the bay (Zone IIB, Figure 6-60). This plant does not grow well in fertile soils, so the area it occurred in received no treatment (DOE 1992).

The four treatments zones are shown in Figure 6-60 and outlined as follows:

- no treatment (IIA, IIB) (i.e., controls)
- addition of fertilizer, gypsum, and plantings (IVA, IVB)
- subsoiling, disking, fertilizer, gypsum, and plantings (IIIA, IIIB)
- subsoiling, disking, gypsum, topsoiling, fertilizer, and plantings (IA, IB)

The area of the lakebed classified as A zone had more extensive soil removal during remediation than the B zone area.

Gypsum (calcium sulfate dihydrate) was added to all the zones that received any treatment because the pH of the bay was approximately 6.0 and needed to be lowered slightly to mimic the acidic nature of natural bays in the region. There were two replicates of each treatment. Planting plots were sized and arranged within each treatment zone (Figure 6-61) to facilitate future monitoring and to test the aerial photography monitoring techniques.

Soil Conditions

In designing the restoration project, several factors had to be considered. Contaminated soils had been removed from the bay. The soil had been somewhat compacted from heavy equipment, and the lack of organic matter and the presence of debris in the subsoil caused concern. To improve soil conditions, topsoil was added to two of the treatment areas, and four of the treatment areas were disked. When spreading the topsoil, care was taken to minimize compaction from trucks and earth moving equipment (DOE 1992).

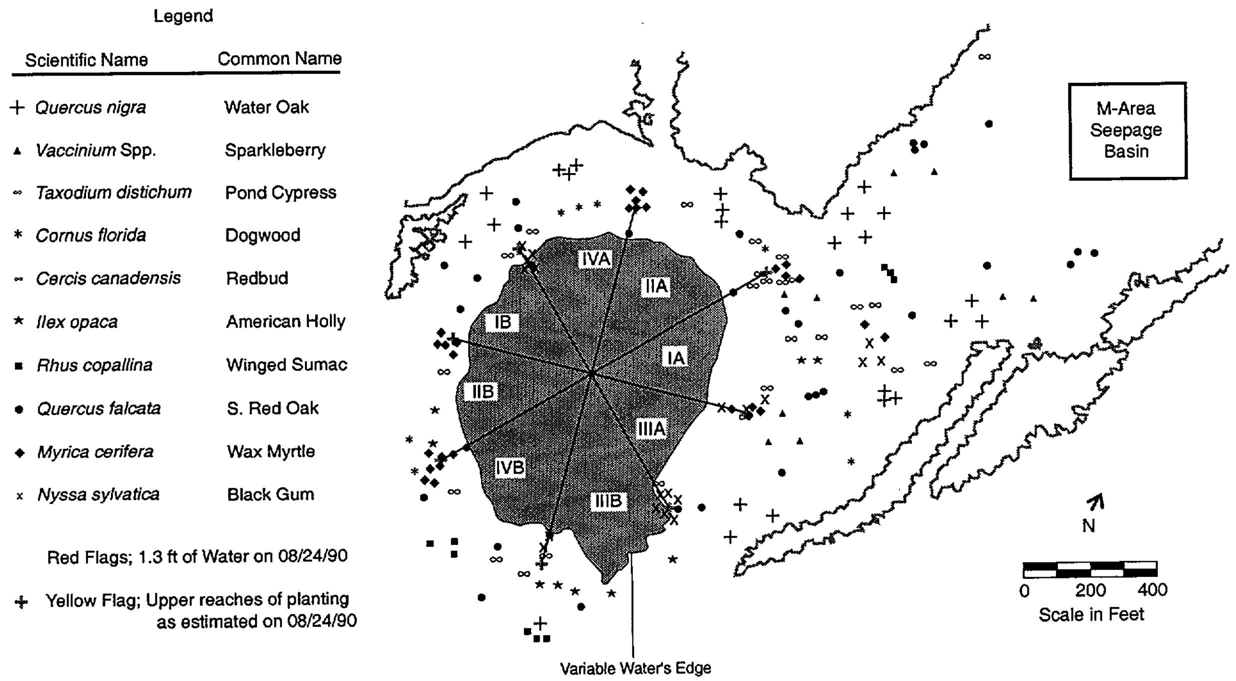


Figure 6-60. Planting Plan at the Lost Lake/M-Area Seepage Basin Restoration Site

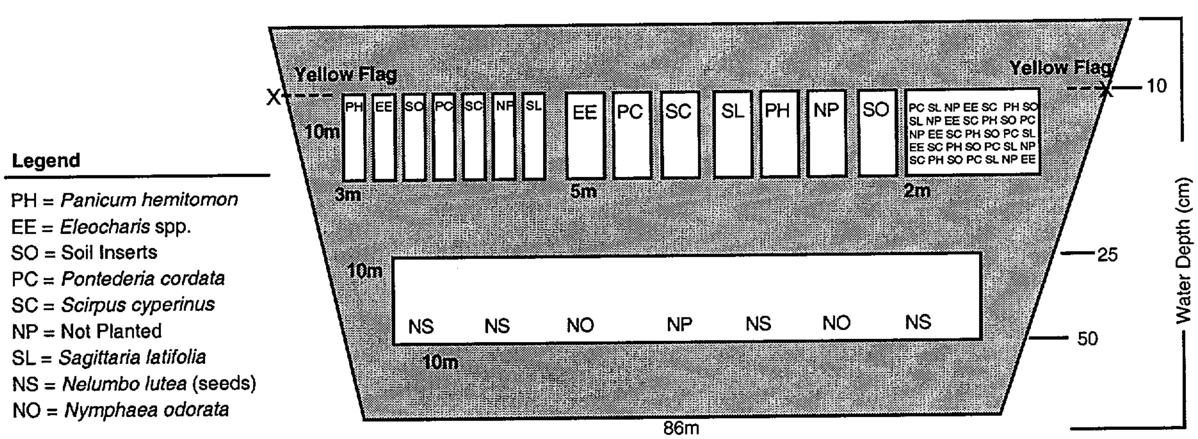


Figure 6-61. Planting Scheme for Zone IB at the Lost Lake/M-Area Seepage Basin Restoration Site (Zone IB is Representative of the Eight Treatment Zones)

Hydrology

A significant factor in the restoration of Lost Lake to a functional wetland was the decision not to control the hydrologic regime, but to let it fluctuate naturally after initial planting of the vegetation in early 1991 (DOE 1992).

Monitoring

A final consideration in the plan was the ability to monitor the program of the restoration and apply the information to future restorations. Low-altitude aerial photography, airborne multispectral scanner data, and, later, satellite imagery will be used to monitor the successful growth of the vegetation. The location and placement of plots (Figure 6-61) were designed to aid in the interpretation of future photographs (DOE 1992). In addition to remote sensing and vegetation monitoring, a cooperative program is in place with the University of South Carolina-Aiken to monitor and evaluate reptile and amphibian recolonization at Lost Lake.

Plantings

Ten tree and shrub species were planted on the upland areas. Regional nursery stock was used for these plantings. Five species of shallow water emergent herbaceous vegetation were planted. All the herbaceous plants were taken from aquatic habitats on SRS. Adequate numbers of all plants except duck potato (*Sagittaria latifolia*) were available at SRS to allow transplanting without depleting the donor stock. Lotus seeds (*Nelumbo lutea*) and water lily (*Nymphaea odorata*) were planted in the deeper plots. Because of the configuration of the treatment zones and the size of the bay, the planned plot sizes and arrangements had to be slightly modified.

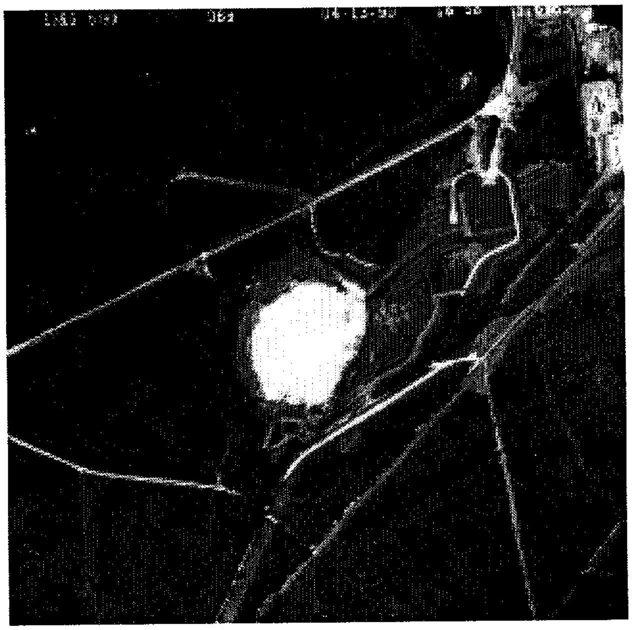
Initial Results

1991 Results

In 1991, it was too early to determine the success of the wetlands restoration. Despite the unanticipated problems and delays in implementation, Lost Lake was beginning to resemble a natural Carolina bay (Figure 6-62). Monitoring efforts started in the fall of 1991 and included measurements within each of the eight treatment zones of percent cover, density, and percent survival of wetland plants in the experimental plots. Preliminary results from the fall of 1991 showed an 80-90% survival rate of the deep water species and 20-30% for the emergent species. Cattails invaded heavily in the areas with soil amendments and fertilizer. Of the macrophyte species planted, three were the most successful (*Panicum hemitomon*, spike rush, and pickerelweed). Successful naturally invading species included spike rush, dogfennel, cattail, knotweed, *Panicum dichotomiflorum,* and foxtail grass (*Setaria* sp.). Woody species (e.g., buttonbush) also occurred in some areas.

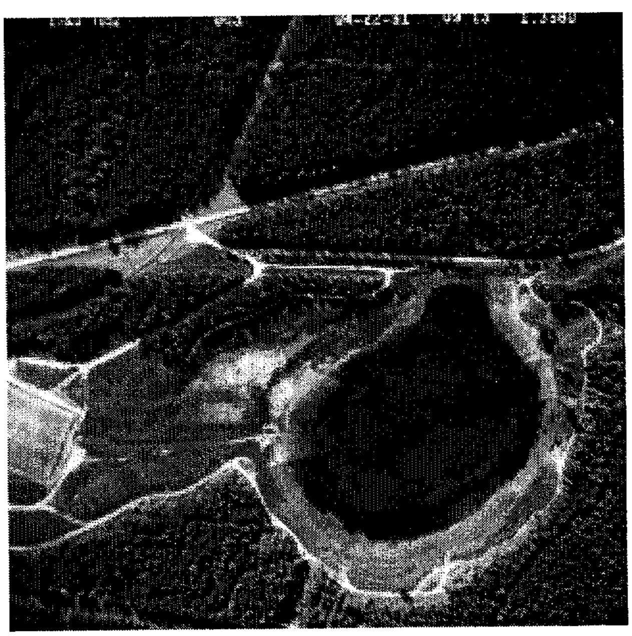
1992 Results

Subsequent monitoring in 1992 of percent cover, density, and percent survival indicate that *Panicum* continues to be the most successful of the introduced species, with a density increase of 3184% ±1598%. Other successful plants include spike rush and pickerelweed, with density increases of 1838% ± 435% and 1016% ± 412%, respectively (Youngblood et al. 1993a, b). Analysis of hydrology data show that several periods of low water probably



1990-Vertical

1990-Oblique



1991-Vertical

1991-Oblique

Figure 6-62. Lost Lake and the M-Area Seepage Basin During Early Restoration Activities (Vertical and Oblique Photography)

resulted in lotus not establishing from the germinated seeds and the continued low occurrence of water lilies.

1994 and 1995 Results

Panicium hemitomon continued to be the most successful planted species in 1994; however, its percent cover was much reduced (from a high of 57% in 1992 to a low of 0.4% in 1994 across all treatments). Percent cover ranged from 0.4% to 12% in 1994. Other successful planted species were rushes, *Scirpus* spp., and pickerelweed, although, again, densities were lower than in previous years. In 1994, *Typha* spp. averaged less than 1% cover. More common species in 1994 included dog fennel, *Erigeron* sp., briars, and *Digitaria* sp., all facultative or facultative upland plants.

The plant community at Lost Lake appears to be composed of more upland species. Water levels dropped from 1991 to 1992 to 1993 and 1994. In 1995, water level returned to 1991 levels, so the community composition could change.

Based on these results, revegetation strategies should be based on the potential for extreme hydrologic conditions and be a mix of species adapted to drought and wet conditions. Under natural conditions, many rare and aquatic plants persist in the seed bank. Since Lost Lake's topsoil was removed to a depth of 30 cm (12 in.), the Lost Lake seed bank was lost, which is evident by the species mix now seen at the bay (Ornes and Youngblood 1995).

Recolonization by Reptiles and Amphibians

The reptile and amphibian populations have been monitored around Lost Lake to study their recolonization of a restored wetland. Fifty species were observed or collected at the bay between May 1993 and December 1995 (Table 6-44). Missing from this list and perhaps significant, are the snakes most often associated with aquatic environments (e.g., most of the genus *Neurodia*, the mud snake [*Farancia abacura*] and the rainbow snake [*F. erytrogramma*] and aquatic salamander (e.g., the genus *Eurycea*) known to inhabit Carolina bays on the SRS (Hanlin et al. 1996).

Restoration of Other SRS Wetlands

The Savannah River Natural Resource Management and Research Institute and SREL developed a cooperative research program to evaluate the effects of restoring the hydrology of a degraded Carolina bay and the potential of other treatments that might be necessary to restore wetland function. Aerial photography from 1951 indicated that a 4-ha (10-acre) bay currently supporting a pine-sweetgum forest had supported an herbaceous wetland at one time. In November 1993, the ditch draining Carolina bay 93 was plugged, approximately 50% of the timber was removed, and portions of the timbered and untimbered sections were burned to remove litter. Water levels the first year after plugging the ditch were higher than in previous years, but lower than expected due to unseasonably dry conditions. Upland species dominated vegetation. During the second year, the bay had more water and the plant community was characterized by more wetland species. Preliminary results indicate that part of the wetland seed bank may have survived the drier hydrologic regime in existence since 1951. Increased light and soil disturbance created by the clearing and burning stimulated the germination of the seeds (Sharitz and Wein 1995).

Table 6-44. Amphibian and Reptile Species Collected or Observed at Lost Lake, May, 1993-December, 1995

Species	Number Collected
CLASS AMPHIBIA	
Order Caudata - Salamanders	
Ambystoma opacum (marbled salamander)	29
[1]*A. talpoideum* (mole salamander)	3,506
[1]*A. tigrinum* (tiger salamander)	417
[1]*Notophthalmus viridescens* (eastern newt)	3,183
[1]*Plethodon glutinosus* (slimy salamander)	50
Order Anura - Frogs and Toads	
[1]*Acris gryllus* (southern cricket frog)	763
Bufo quercicus (oak toad)	47
[1]*B. terrestris* (southern toad)	55,916
[1]*Gastrophryne carolinensis* (narrow-mouthed toad)	6,414
Hyla chrysoscelis (Cope's gray treefrog) (observed only)	0
[1]*H. cinerea* (green treefrog)	170
[1]*H. gratiosa* (barking treefrog)	1,910
[1]*H. squirella* (squirrel treefrog)	229
[1]*Pseudacris crucifer* (spring peeper)	30
P. nigrita (southern chorus frog)	4
[1]*P. ornata* (ornate chorus frog)	89
[1]*Rana catesbeiana* (bullfrog)	2,633
R. clamitans (green frog)	3
[1]*R. utricularia* (southern leopard frog)	939
Scaphiopus holbrooki (eastern spadefoot toad)	69
CLASS REPTILIA	
Order Crocodilia - Crocodilians	
Alligator mississippiensis (American alligator)	1
Order Chelonia - Turtles	
Chelydra serpentina (common snapping turtle)	1
Chrysemys picta (painted turtle)	1
[1]*Deirochelys reticularia* (chicken turtle)	29
Kinosternon subrubrum (eastern mud turtle)	7
Pseudemys floridana (Florida cooter)	1
[1]*Trachemys scripta* (slider turtle)	102
Order Squamata - Lizards and Snakes	
Suborder Lacertilia - Lizards	
Anolis carolinensis (green anole)	89
Cnemidophorus sexlineatus (six-lined racerunner)	4
[1]*Eumeces fasciatus* (five-lined skink)	2
[1]*E. inexpectatus* (southeastern five-lined skink)	2
[1]*E. laticeps* (broadhead skink)	28
[1]*Sceloporus undulatus* (eastern fence lizard)	6
[1]*Scincella lateralis* (ground skink)	52

Table 6-44. (cont)

Species	Number Collected
Suborder Serpentes - Snakes	
[2]*Cemophora coccinea* (scarlet snake)	5
[1,2]*Coluber constrictor* (racer/black racer)	44
[2]*Crotalus horridus* (canebrake rattlesnake)	4
[2]*Diadophis punctatus* (ringneck snake)	2
[2]*Elaphe guttata* (corn snake)	4

Source: Hanlin et al. 1996.
[1]Successful reproduction documented by presence of larvae, recent metamorphs, hatchlings, or newborns.
[2]Species is terrestrial and associated with the periphery of bays.

6.7 References

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