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UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

Establishment Report

prepared for

Savannah River Technology Center
Westinghouse Savannah River Co.

REFORESTATION OF THE PEN BRANCH CORRIDOR AND DELTA

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PREFACE

This report documents the role of the USDA Forest Service in the reforestation of the Pen Branch floodplain and delta. The report focuses upon the reforestation activities and monitoring to characterize the sites.

ACKNOWLEDGMENTS

John Blake of the Savannah River Forest Station (SRFS) has coordinated the planning, operations, and research by enlisting expertise from the SRFS and the Southern Research Station. Rick Davalos, also of the SRFS, has managed most operational aspects of the reforestation. There have been many other contributions by other employees of the SRFS and Region 8 of the Forest Service. Our efforts have been fully supported by the active involvement and leadership of Eric Nelson, Mike Paller, Winona Specht and other personnel of the Westinghouse Savannah River Technology Center. Our appreciation is also extended to Jan Gay and Ron Moseley, formerly of the Center for Forested Wetlands Research, for their critical roles in establishing the study site and building the preliminary data sets.

BACKGROUND

HISTORY OF THERMAL DISCHARGE

Pen Branch is a small, 3rd order stream whose watershed lies entirely within the boundaries of the Savannah River Site, a U.S. Department of Energy (DOE) nuclear materials facility (Figure 1). Pen Branch flows into the Savannah River swamp, a mosaic of bottomland-hardwood and cypress-tupelo forests. Between 1950 and 1954, the DOE constructed a nuclear reactor, K Reactor, adjacent to a first order tributary of Pen Branch, Indian Grave Creek. Heat was dissipated from the reactor's internal closed-loop cooling system by pumping water from the Savannah River across a heat exchanger, eventually discharging the heated water into Indian Grave Creek.

K Reactor began discharging thermal effluent into the Indian Grave / Pen Branch system 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 rate (Figure 2). The average annual temperature of the effluent varied up to 70°C. Thermal discharges ended in 1989. At present, non-heated water is being added at the rate of about 0.006 $m^3 s^{-1}$, or less than 5% of the estimated base flow rate.

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 temperatures and outflow rates increased, flooding and scalding progressively deforested the corridor. By 1961, canopy defoliation was apparent throughout 113 ha of the corridor and 4.5 ha 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" of concentrated flow to the southeast toward Steel Creek, near the swamp's upland boundary (Figure 3). The area of severe canopy loss in the delta reached its maximum extent of about 152 ha in the mid 1980's (Wike et al., 1994). Due to the inflow of water from Pen Branch, the delta area had been poorly drained even before 1951, supporting a cypress-tupelo swamp surrounded by more elevated mixed hardwood hammocks. Today, the delta is distinguished by scattered gray cypress snags up to 40 m tall. During storms and episodes of high wind, these snags have gradually fallen into the sediment forming a tangle of woody debris.

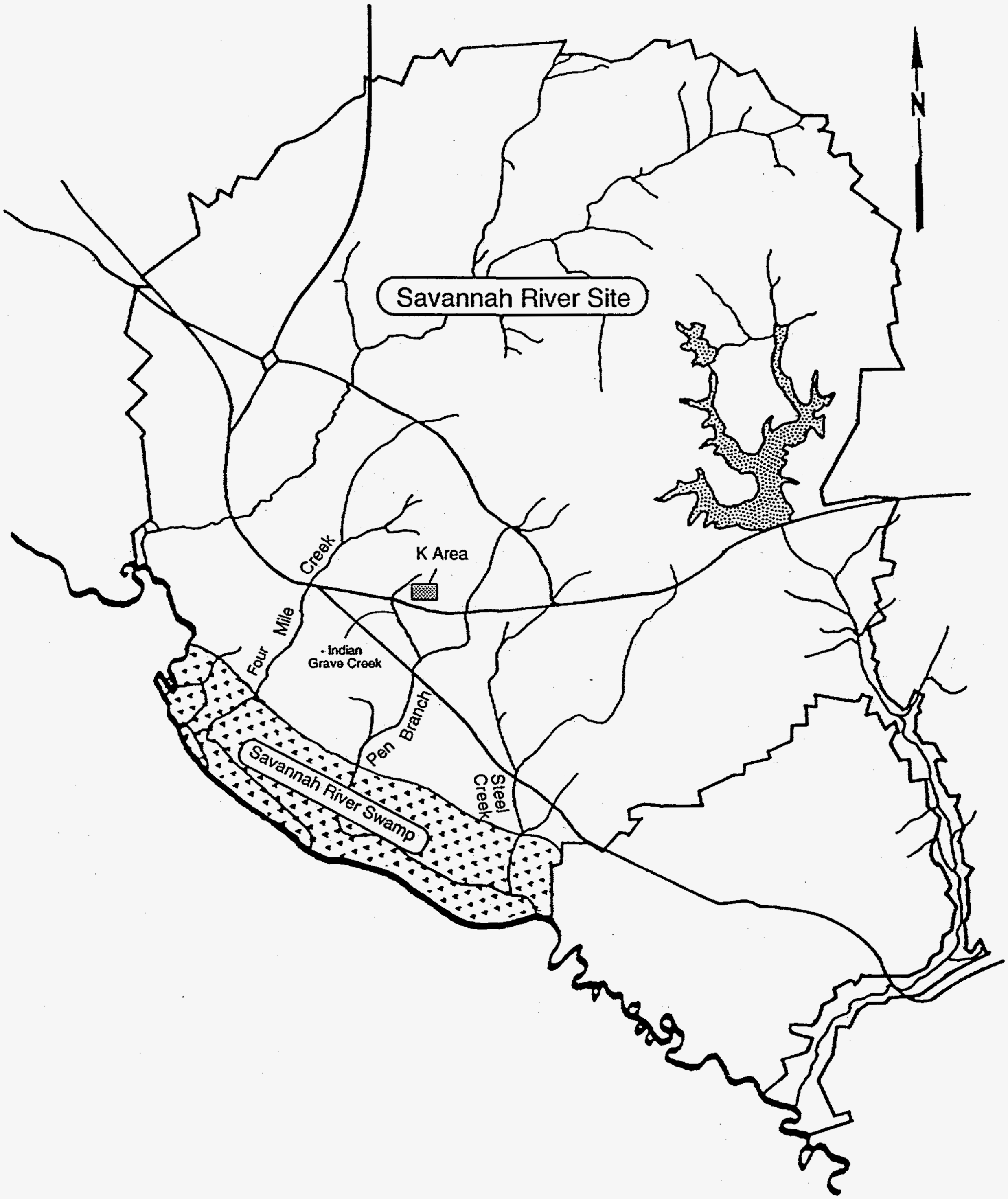

Figure 1. The Savannah River Site

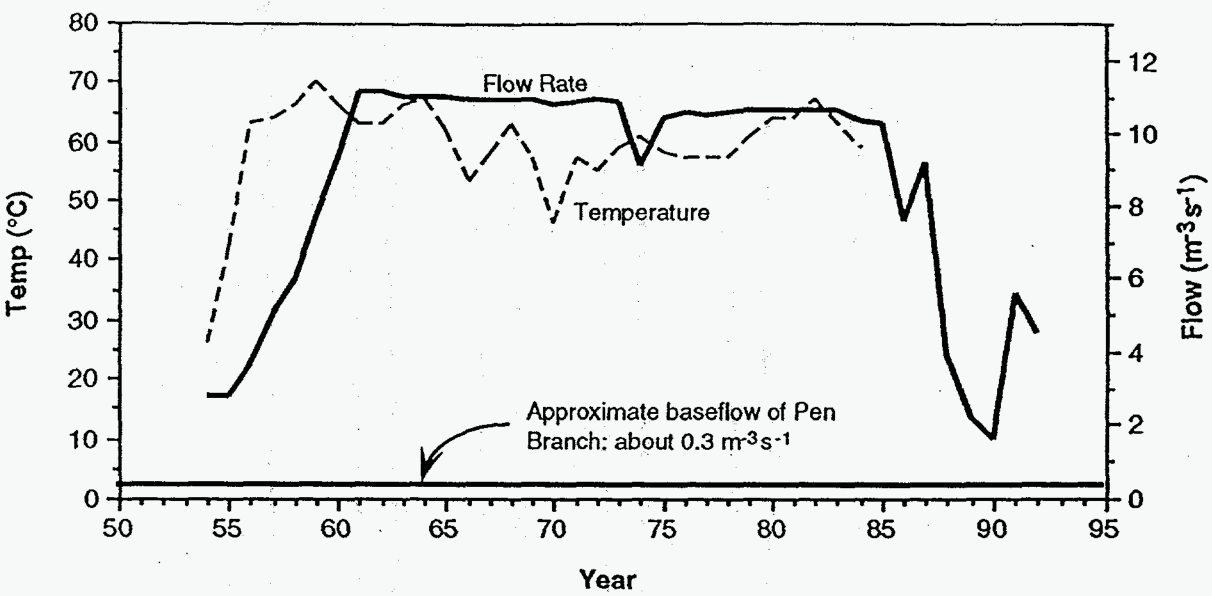

Figure 2. Average annual flow rate and temperature of K-Reactor effluent. Temperature data not available for 1985 to present. Adapted from Wike et al. (1994).

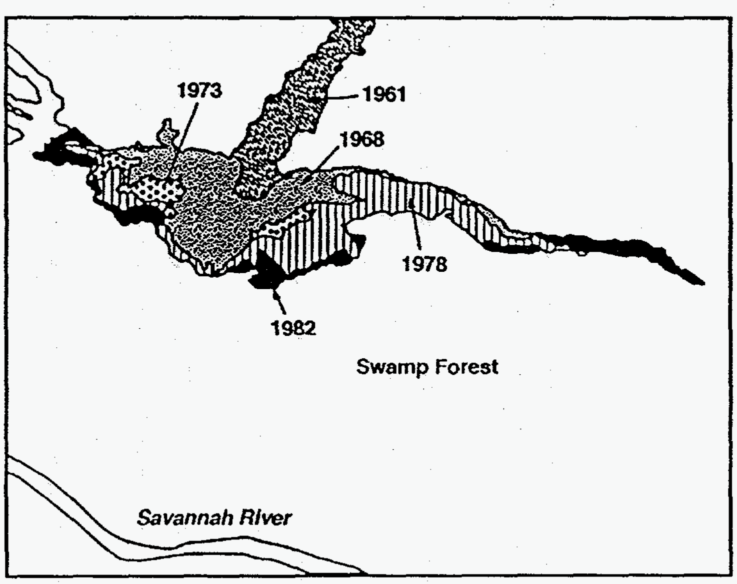

Figure 3. Pen Branch delta expansion composite image, 1961-1982 (from Christensen et al., 1984).

Colonization by Pioneer Species

As the thermal discharges and flooding declined, early-successional plants rapidly colonized the corridor and delta. By the early 1990's, dense thickets of black willow*, with minor elements of black alder, wax myrtle, button bush, and sumac occupied much of the corridor. A few red maple were present, but there was virtually no regeneration of other species typically present as large canopy trees in mature bottomland forests. These species failed to regenerate because the prolonged thermal discharges had eliminated seed sources and living root stocks from the floodplain—and there were few hydrophytic trees in the adjacent uplands.

Natural regeneration was also scant in the delta. Even after the thermal discharges had ceased, most of the delta remained continuously flooded and was colonized by a mixture of cattails and bulrush. Continuous flooding precluded germination of bald cypress and water-tupelo seeds, which may have disseminated into the area. Dry periods are required for widespread seed germination in cypress/tupelo swamps. Sharitz and Lee (1985) have attributed some forest regeneration failures in the Savannah River floodplain—where the Pen Branch Delta is located—to the absence of historically frequent dry periods after the installation of dams upstream on the Savannah River. Sediment deposition during reactor operations may also have altered the delta's hydrology.

REFORESTATION OBJECTIVES

As a result of an environmental impact statement concerning, in part, continued operation of K Reactor, the DOE (1991) decided to mitigate impacts both from potential thermal discharges before completion of a cooling tower and from continued discharges at ambient stream temperatures. In a record of decision published in the Federal Register, the DOE (1991) targeted 69 ha of land in the Indian Grave / Pen Branch Corridor and 202 ha in the Pen Branch delta for mitigation due to historical impacts. Westinghouse Savannah River Company subsequently developed a mitigation strategy (Nichols, 1992), which included recommendations by the USDA Forest Service concerning site evaluation, hardwood-regeneration research, and reforestation.

In developing specific mitigation objectives, 2 constraints were agreed upon among the parties involved:

1) Only those areas judged not to be revegetating satisfactorily would be replanted with indigenous bottomland tree species appropriate for the local soils and hydrology (Nichols, 1992).

* Common names are used throughout this report. Appendix B provides corresponding scientific and common names.

2) Some portions of the corridor and delta would remain in non-treated control strips to a) provide reference areas to judge the effectiveness of mitigation measures, b) enhance scientific interest in the project, and c) leave some habitat in an early successsional state for certain wildlife species.

Primary Mitigation Objective

The primary mitigation objective was to accelerate the establishment of a bottomland-hardwood ecosystem in the Pen Branch corridor and a cypress-tupelo ecosystem in the delta.

REFORESTATION

PHYSICAL LAYOUT

Project-Area Boundaries

The northern boundary of the artificial-regeneration zone is a powerline right-of-way crossing Pen Branch about 200 m south of Risher Pond Road. From this point northward to K Reactor, the floodplain is sufficiently well drained to permit regeneration of facultative wetland tree species present in the adjacent uplands. The area targeted for artificial regeneration includes a stream reach 2.5 km in length with a floodplain varying in width from 100 to 300 m, and a denuded delta region into which Pen Branch flows. About 53 ha along the fringes of this delta are regenerating naturally with bald cypress and water tupelo (Figure 4).

The boundary between the naturally-regenerating and more deficient areas of the delta was determined by ground reconnaissance and visual inspection. Aerial photographs were of little use in locating natural regeneration in this area due to a lack of distinctive patterns or shading, and the small size of the seedlings. A variety of regeneration was present in the fringe, including seedlings, saplings and recovering snags. Densities varied from in excess of 10,000 stems ha^{-1} in small pockets to a only few hundred ha^{-1} elsewhere. All regeneration in the fringe was judged to be sufficient for the development of a closed canopy forest. The natural regeneration boundary was usually distinct, with virtually no volunteer seedlings in the continuously flooded central delta. Stocking in the naturally regenerating fringe area will be surveyed in 1996.

Primary Treatment Zones

Within the artificial-regeneration area, 3 treatment zones were identified (Figure 4), based upon the differing species mixtures and silvicultural treatments required for the conditions of each zone (Table 1).

Control Strips

Twenty-five percent (21 ha) of the total artificial regeneration area (85 ha) was reserved in 8 non-treated, non-planted control strips (Figure 4). These were established several months before planting in each section by placing pin flags along the boundaries and clearing all vegetation in 5 m wide swaths across the corridor.

Three of the strips were placed to accommodate operational concerns, with the remainder located randomly. In the upper corridor, a control strip was located immediately below the powerline right-of-way, so that the helicopter used for the herbicide application could remain clear of the powerlines. The other 2 control strips in the upper corridor were selected randomly from an number of equidistant points along the length of this section. A control strip was also placed at the northern limit of the lower corridor, with the other 2 in this zone selected randomly, as in the upper corridor. In the delta, the control strips were placed along topographic gradients, incorporating similar ranges of variation. The eastern strip in the delta was placed, so as to prevent herbicide application to experimental plots located in this area. The second control strip in the delta was located about 125 m westward.

Boundary Monumentation

Control-strip boundaries. The boundaries were initially maintained by annual clearing and herbicide application. However, in 1995-96, the boundaries will be monumented with high-visibility markers and cleared only where necessary for access. At both ends of each control line (upland/floodplain boundary in the corridor), will be a 13 cm diameter white PVC pipe, 2 m in height. At the base of each pipe, will be a steel bar with at least 50 cm above ground for relocation in case of fire. The lines will be flagged with durable safety tape, 5 cm in width. End points of control lines in the delta will be marked with 13 cm diameter piping, 3 to 4 m in height. Adjacent to each pipe will be a grooved aluminum pipe, 1 to 2 m in height for relocation in case of fire. Lines will be flagged with durable safety tape.

Delta planting-area boundary. This line was marked with 5 cm wide durable yellow safety tape affixed to 4 m tall, light-weight aluminum poles in cattail marshes.

Natural-regeneration boundary in the delta. This line was initially marked with blue and white striped flagging tape, but will not be maintained or monumented.

SITE PREPARATION AND PLANTING

The site was prepared and planted from 1992 to 1995. The lower corridor was planted in February and March of 1993, the upper corridor in January of 1994, and the delta in January and February of 1995. Also in 1995, the upper and lower corridors were interplanted to compensate for mortality, which was revealed in the 1994 stocking survey (discussed later). For each area, site preparation and species mixtures were varied to suit local conditions. Each year's activities are described below.

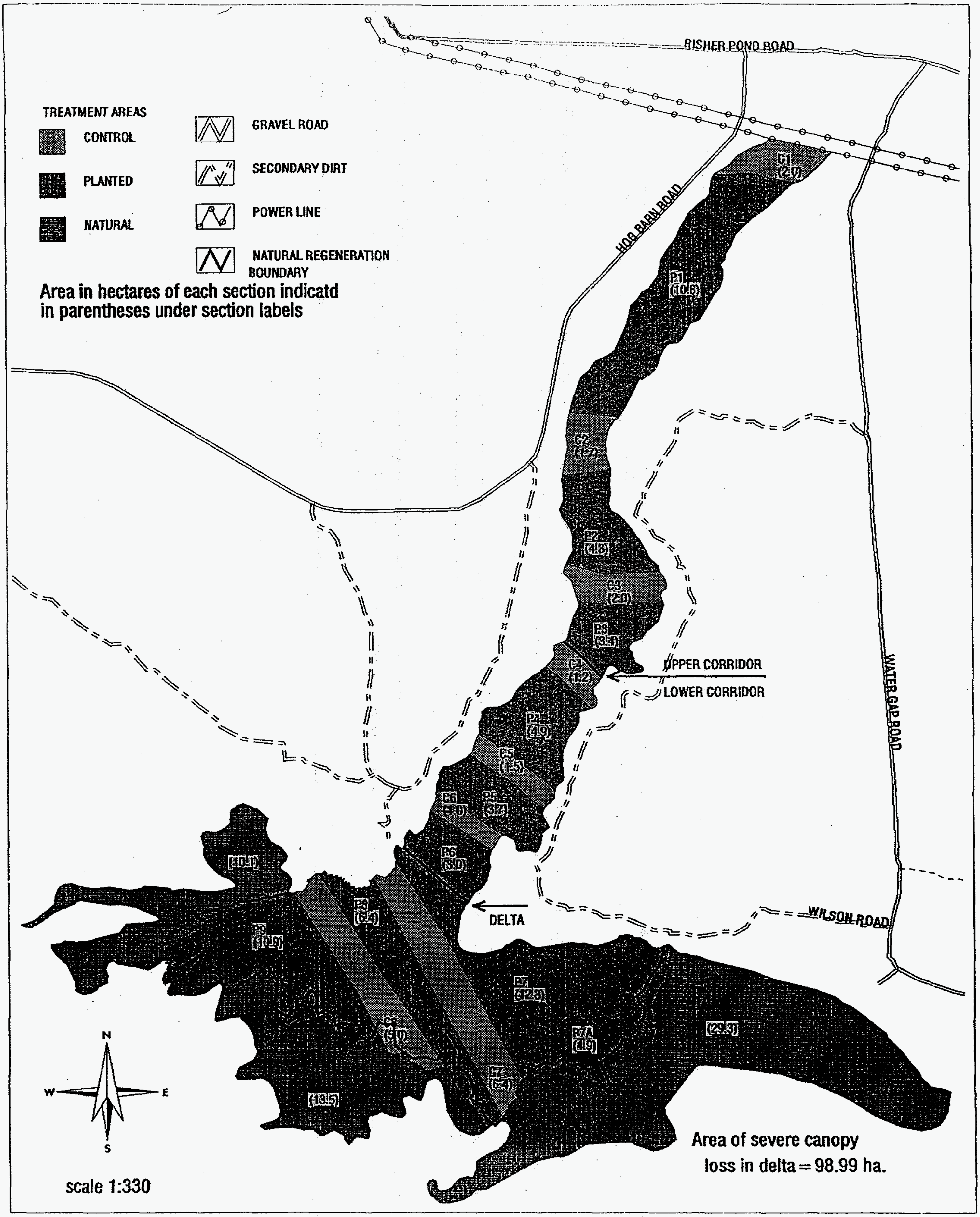

Figure 4. Pen Branch treatment areas

Table 1. Primary treatment zones.*

Zone	Area (ha)	Description
Upper Corridor	24.1	Mesic bottomland. Water table typically at a depth of 30 to 80 cm during the growing season. One or two well defined stream channels. To be planted with mixed bottomland hardwoods. Initially occupied by dense, virtually unbroken willow thickets.
Lower Corridor	15.3	Poorly drained bottomland. Water table within 20 or 30 cm of the soil surface during the growing season. Braided, unstable stream with up to 4 or 5 water courses. To be planted with mixed bottomland hardwoods, bald cypress, and water tupelo. Initially occupied by scattered willow thickets and frequent grassy openings where soils were too wet to support wood vegetation.
Delta	46.0	Swamp. Continuously flooded, except on sandy ridges near the mouth of Pen Branch, where water table remains within 20 cm of the soil surface. To be planted with bald cypress and water tupelo, with some green ash on better drained ridges. Initial cover: about 2/3 cattail or cattail-bulrush mixture, and about 1/3 scattered willow ridges.

* Boundaries shown in Figure 4.

Winter 1992-93

Only the lower corridor was planted in the winter of 1992-93. In this area, there were frequent grassy openings in the sparse willow cover, and intensive site preparation would have provided little benefit. Most of the species to be planted were at least moderately shade tolerant.

Lower-corridor planting. The target planting density was 747 trees ha^{-1} (303 ac^{-1}), on a square spacing of 3.66 m (12 x 12 ft). Three sections, totaling 11.6 ha, were planted in February and March of 1993. These were separated by control strips 60 m in width.

Approximately 8,700 trees were planted in this section. Estimated percentages of the 5 species used were cherrybark oak (7%), swamp chestnut oak (30%), green ash (33%), water tupelo (11%), and bald cypress (19%). These percentages were based upon the relative numbers of seedlings purchased, rather than counts at the time of planting, and should be considered coarse. Results of a seedling survey in the spring of 1994 suggested that these rankings were reasonable.

All seedlings were purchased from the Central Florida Lands and Timber Nursery, Mayo, FL. Seed sources were reportedly in southern Georgia. The seedlings were 1-0 bare root, averaging about 80 cm in height. They were transported from a refrigerated cooler at the forest station to the site in insulated fiberglass boxes. Roots were dipped with a water-retaining gel (Agrosoke™) in the field before planting. Seedlings were planted with an elongated trenching shovel, forming a slot as with a dibble.

The area was planted under contract by Dukes Grassing Company, New Ellenton, SC, with a crew of 4 to 6. Spacing was monitored continuously by 2 to 3 Forest Service inspectors and densities determined on 1/50th acre inspection plots at the rate of 1 to 2 per acre. Densities of 5% or more below the objective were corrected, but they were usually 5 to 15% over. No penalty was assessed to the contractor for over planting.

Winter 1993-94

Only the upper corridor was planted in 1994, after applying a wetland-approved herbicide to control dense willow competition and burning to clear brush and vines. Seedlings were produced from seeds collected under contract for the Forest Service from the South Carolina Coastal Plain.

Site preparation summary for the upper corridor. In the upper corridor, a virtually unbroken willow thicket intertwined with blackberry and other vines had developed by the early 1990's. Little light penetrated to the forest-floor, which appeared unsuitable for the growth of even shade-tolerant trees. In order to moderate competition and improve access for planting crews, sections of the upper corridor to be planted were prepared by aerial herbicide application and prescribed burning.

Herbicide application. The herbicide Rodeo™ (Monsanto Co., St. Louis, MO) was applied aerially on September 18, 1993, between 0930 and 1015. The contractor (Rutland Air, Ridge Spring, SC) used a helicopter equipped with a microfoil boom, which is designed to produce negligible drift, to apply the herbicide immediately above the canopy. Rodeo was applied at the rate of 5.8 $l\ ha^{-1}$ (5 pts ac^{-1}) or 3.8 $kg\ ha^{-1}$ of the active ingredient glyphosate (N-(phosphonomethyl) glycine). The herbicide was diluted in a mixture with water, the surfactant Ortho X-77 (0.28% by volume), and the dye Bullseye (0.44% by volume). The dilution was such that about 141 $l\ ha^{-1}$ (15 gal ac^{-1}) of the mixture were applied. Boundaries between control strips and planted areas were marked for easy visibility to the pilot with two-sided, tent-shaped fluorescent orange placards (50 x 80 cm), suspended at the top of bamboo poles 6 to 12 m in height.

Stream monitoring. The herbicide Rodeo is labeled for direct application to water bodies (Monsanto, 1990) and has a very low order of toxicity to terrestrial and aquatic fauna (USDA, 1989). However, because of the potential sensitivity of aquatic ecosystems, we provided an analysis of anticipated concentrations in stream water of the herbicide's active ingredient, glyphosate. This information was provided in our DOE site use application to permit the herbicide application (site use action no. 92-70-R). In this analysis, we assumed conservatively that stream flow would be the lowest 7-day average flow recorded without additions by SRS operations (minimal dilution) and that no herbicide would be intercepted by the overhanging canopy.

The expected peak glyphosate concentration was 0.5 mg l^{-1} (500 ppb), which was 2 to 3 orders of magnitude below published toxicity values for a variety of aquatic vertebrates and invertebrates, as summarized by the USDA, 1989. Most of these toxicity values were determined by several days of continuous exposure at much higher concentrations. We anticipated that exposure near the peak concentration would be less than 1 hour and that a negligible quantity of glyphosate would remain in the stream after 6 hydrologic turnovers—which would occur in about 8 hrs.

To document actual concentrations, we collected stream-water samples for analysis of glyphosate and a closely related degradation product, AMPA (Fierro, 1994). Samples were collected by submerging a 1 l plastic bottle in the center of the main stream channel to 1/2 of its depth (about 70 cm). Collection stations were where Risher Pond Road crosses Pen Branch (about 300 m upstream from the spray area) and at the lower boundary of the upper corridor. The samples were refrigerated within a few hours of collection, and transported to Charleston within a week, where they were frozen during storage. They were shipped frozen to the laboratory on March 9, 1994. Samples were collected 30 minutes to an hour before the operation began at 0930, then at about 1 hr intervals until 1800. Only a subset (as indicated in Figure 5) was analyzed, due to the high laboratory costs.

The results suggested that our analysis had placed reasonable bounds on expected stream concentrations. At the downstream station the observed peak concentration of glyphosate + AMPA was 0.24 mg l^{-1} (Figure 5), or about half that predicted. The peak occurred within 1 to 2 hrs of application, dissipating to an extremely low concentration within 3 hrs. The following morning, about 24 hrs after the application, no glyphosate was detected in the stream (0.0005 mg l^{-1} detection limit). AMPA was usually a negligible fraction of glyphosate, probably because there was little opportunity for decay in the brief interval between application and sampling.

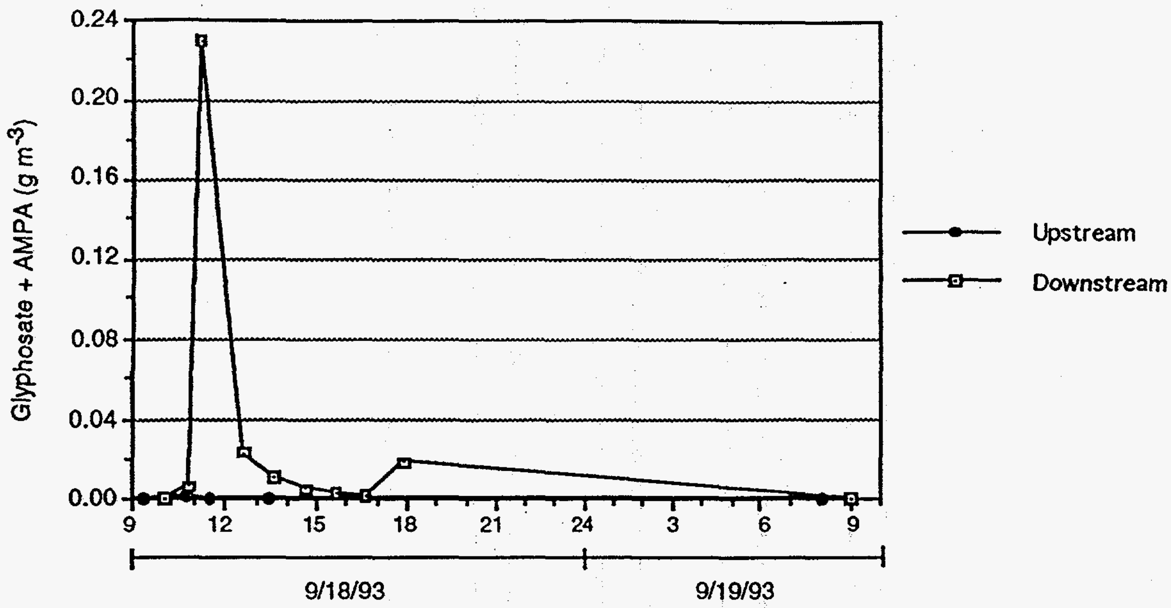

Figure 5. Stream glyphosate concentrations following aerial application of the herbicide, Rodeo.

Prescribed burning. In late November of 1993, the 3 sections of the upper corridor to be planted—where the herbicide had been previously applied—were burned. Fire was often stopped by streams, trails, and wet depressions, so personnel moved throughout the area igniting the understory with drip torches where needed. Using a bulldozer, fire lines were extended from the control strip boundaries to the roads paralleling Pen Branch to prevent fire spreading in the understory of adjacent hardwood stands.

Site preparation results. The herbicide application controlled 95 to 100% of the willows, with a few small isolated areas missed by the spraying. The herbicide was also highly effective against button bush and wax myrtle. Most red maples were resistant to the herbicide and survived. Burning cleared 70 to 80% of the understory, rendering the upper corridor easily accessible to planting crews. A blackened, ash forest floor resulted in most areas.

Unfortunately, clearing and burning the understory appeared to induce severe herbivory of the seedlings by feral hogs. In many areas, virtually all of the freshly burned ground was rooted. The feral hogs also browsed along the rows of seedlings, uprooting them, and biting off the tap roots. A survey conducted the following spring (presented later) would show that over 2/3 of the planted seedlings, and nearly all of the oaks, were lost before the beginning of the first growing season. Severe feral hog herbivory occurred exclusively in burned areas and has not been a significant problem elsewhere. Recovery of the herbaceous understory in the following growing season provided cover for seedlings and ameliorated herbivory. Feral hog activity has not been a significant problem since.

Site preparation radically altered the appearance of the upper corridor, producing a savanna-like condition with scattered surviving maples 5-10 m in height and a lush understory. Woody debris fell into backwater channels and sloughs. In the summers of 1994 and 1995, aquatic macrophyte densities appeared to increase dramatically in the upper corridor and downstream, perhaps in response to both greater light availability and nutrient fluxes from the cleared area.

Upper corridor planting. The target planting density in the upper corridor was 747 trees ha^{-1} (303 ac^{-1}), on a square spacing of 3.7 m (12 ft). Three sections, totaling 18.3 ha, were planted from Dec 27, 1993 to Jan 4, 1994. These sections were separated by control strips 90 to 120 m in width. A total of about 13,700 trees was planted.

Estimated percentages of the 9 species planted were swamp chestnut oak (17%), cherry bark oak (16%), water oak (20%), water hickory (18%), green ash (14%), persimmon (7%), swamp tupelo (2%), water tupelo (2%), and bald cypress (4%). These percentages were based upon bag counts and inventories in the refrigerated cooler. However, these estimates should be regarded as coarse—in part because the seedlings in the bags were not counted at the nursery, and the numbers per bag were approximate.

All seedlings were 1-0 bare root. They were stored at the Savannah River Forest Station in a refrigerated cooler and transported to the field on an open trailer covered with a tarp.

The planting was performed by Bill Kirby Reforestation (Kingstree, SC) with a crew of 15 to 20. Seedlings were planted with elongated trenching spades, forming a slot as with a dibble. Adequate spacing was assured through continuous inspection by Forest Service personnel, as in the previous year. Five to ten percent of the area was unplantable due to dense snags and *Rubus* thickets. Excluding unplantable areas, spacing below 95% of the target density was corrected, but values were generally 100 to 105% of the objective.

Seedlings. All seedlings planted in 1993-94 originated from seed collected on the South Carolina Coastal Plain. (The seed collection effort is described in the following section.) The majority were grown at the Georgia Forestry Commission's Flint River nursery. A small number (30% of the water hickory, 11% of the green ash, and 24% of the swamp chestnut oak) were grown by the International Forest Seed Company, Statesboro, Georgia, using the same seed source.

Winter 1994-95

The delta was planted in 1995, and both the upper and lower corridor were replanted to compensate for mortality. Site preparation was limited to applying herbicide in about 12 ha of the delta where there were dense willow thickets. The majority of seedlings again originated from seed collected under contract for the Forest Service from the South Carolina Coastal Plain.

Herbicide application. By the early 1990's, heavy willow thickets had developed on alluvial deposits and channel levees at the mouth of Pen Branch, in the north-central and northwestern parts of the delta. It was felt that an herbicide application here would be advantageous for the growth of cypress and tupelo. In late September of 1994, herbicide was applied in the delta's central planting strip (P8) and portions of the western-most planting section (P9), keeping well clear of natural regeneration near the fringe. The spray area was marked for high visibility from the air with large, square plastic flags attached to the top of bamboo poles. Each line was marked with a different color. The contractor (Rutland Air, Ridge Spring, SC) and aircraft were the same as in the previous year. The tank mixture was the same as that of the previous year, with two exceptions. Rodeo was applied at the rate of 4.7 ha^{-1} (4 pts ac^{-1}) or 3.0 kg ha^{-1} of glyphosate; and the surfactant was Timberland 90™. The stream was not sampled, but white drift cards were placed in the spray area, along the edges, and in adjacent control strips.

Herbicide results. The treatment was 90 to 100% effective against willows in the central planting strip. In the more poorly drained western planting section, however, the herbicide was less effective. Poor drainage may have diminished the herbicide's efficacy or the coverage may have been uneven. In this area, the aircraft was forced to fly about 30 to 50 m above the canopy to avoid cypress snags. The pilot also reported difficulty finding landmarks in this area to judge the location of previous spray strips. The spray cards indicated only very minor drift into control areas (Bush and Taylor, 1994). Aerial photos and ground reconnaissance showed an abrupt, clear boundary of willow mortality at the edge of the intended spray area.

Delta planting. The target planting density for most of the delta was 1078 trees ha^{-1} (436 ac^{-1}) on a square spacing of 3 m (10 ft). In the southeastern delta, however, 4.9 ha were conceded to the contractor as unplantable by a normal hand-planting crew. This area—part of P7—was later planted by Forest Service personnel at an approximate spacing of 3 x 6 m (10 x 20 ft) and density of about 500 trees ha^{-1}. It was characterized by deep, unconsolidated muck soils and standing water. Some parts were reached using snow shoes, and favorable microsites were chosen for planting. Because of its exceedingly poor drainage, this area will probably support only a sparse tree canopy with some open water. About 35,000 trees were planted on a total of 34.6 ha in the delta. Estimated percentages of the 3 species planted were water tupelo (60%), bald cypress (30%) and green ash (10%). The ash were confined to better drained willow ridges.

The planting was performed under contract by Sweat Co., Lakeport, CA with a crew of 4 to 8 from mid-January to mid-February of 1995. (The same contractor also replanted the corridor.) Seedlings were inserted directly into the muck or dibble planted with a shovel. Adequate spacing was maintained through continuous inspection, as in previous years—though fewer inspection plots were taken in the delta due to the severe muck conditions. Spacing was monitored closely, and densities usually exceeded 100% of the target. For example, the average density on 6 inspection plots taken in P7 was 1376 trees ha^{-1}, 28% above the target of 1078. This average is not necessarily indicative of the entire delta.

Replanting of the upper corridor. Feral hog herbivory and other sources of mortality left only 230 of the 747 trees ha^{-1} originally planted in the upper corridor by the start of the first growing season. This density, especially with future mortality, was inadequate for the development of a closed canopy forest. Therefore, the upper corridor was interplanted with an additional 1078 trees ha^{-1} on a square spacing of 3.0 m (10 ft). Assuming that the target planting density was achieved, a total of 19,800 trees were added. The actual total was probably larger as the average density of newly planted seedlings on 33 inspection plots taken in this section was 1220 ha^{-1}, 13% above the objective. Estimated percentages for 8 species planted were cherrybark oak (26%), water oak (17%), green ash (5%), sycamore (9%), pignut hickory (2%), shumard oak (13%), water hickory (11%), and swamp tupelo (17%).

Replanting of the lower corridor. Although 476 of the 747 trees ha^{-1} originally planted in the lower corridor remained after the first growing season, an additional 549 were added to compensate for future mortality and bring stocking in all areas to similar levels. Assuming that the desired density was planted, a total of 6,300 seedlings were added. The density of newly planted seedlings on 23 inspection plots in this area averaged 627 ha^{-1}, 14% over the objective. Estimated percentages of the 5 species planted were bald cypress (7%), green ash (13%), cherrybark oak (6%), water tupelo (13%), and swamp tupelo (61%).

Seedlings. All seedlings were 1-0 bare-root, except for 6,000 2-0 bald cypress. The 2-0 cypress were purchased from inventory of the Flint River Nursery that had been unsold the previous year, and were from a southern Georgia seed source. These larger seedlings were purchased to accommodate deep water areas and the severe herbaceous competition of the delta. All of the shumard oak and about 1/4 of the cherrybark oak planted were from the Deltaview Nursery, Leland MS, and a seed source in the Mississippi delta. The remaining seedlings originated from seed collected on the South Carolina Coastal Plain (contract described the following section) and grown at the Georgia Forestry Commission's Flint River

Nursery. Seedlings were transported to the work site in the bed of a pickup truck and were well covered by a reflective tarp.

Summary

Site preparation and planting schedules are summarized in Table 2, and the relative abundances of each species planted in Table 3. The percentages of each species planted in all years given in Table 3 are probably not indicative of the eventual, or even present, composition of the stands. This is true particularly in the upper corridor, where virtually all of the oaks planted in 1993-94 were lost to herbivory. We also anticipate differential survival among the species, which will strongly affect the ultimate stand composition.

Table 2. Site preparation and planting summary.

Location	Site Preparation*	Planting
Upper Corridor	Aerial herbicide application to control willows in September of 1993. Burned to improve access for planting crews in November of 1993.	Planted 747 trees ha^{-1} (303 ac^{-1}) in December of 1993 and January of 1994. Planted an additional 1078 trees ha^{-1} (436 ac^{-1}) to compensate for mortality in January of 1995.
Lower Corridor	None.	Plant 747 trees ha^{-1} (303 ac^{-1}) in February and March of 1993. Planted an additional 549 trees ha^{-1} (222 ac^{-1}) in January and February of 1995.
Delta	Herbicide application to control willow on levees and alluvial deposits (12 ha) in September of 1994.	Planted 1078 trees ha^{-1} (436 ac^{-1}), with 4.9 ha planted at about 500 ha^{-1} due to deep muck and standing water in January and February of 1995.

* Planted sections only.

Table 3. Estimated abundances of species planted as of December, 1995.

Upper Corridor

Species	1992-93 %	1992-93 No.	1993-94 %	1993-94 No.	1994-95 %	1994-95 No.	All Years No.	All Years %
Cherrybark Oak	-	-	16	2,200	26	5,100	7,300	22
Water Oak	-	-	20	2,700	17	3,400	6,100	18
Water Hickory	-	-	18	2,500	11	2,200	4,700	14
Swamp Tupelo	-	-	2	300	17	3,400	3,700	11
Green Ash	-	-	14	1,900	5	1,000	2,900	9
Shumard Oak	-	-	0	0	13	2,500	2,500	7
Swamp Chestnut Oak	-	-	17	2,300	0	0	2,300	7
Sycamore	-	-	0	0	9	1,800	1,800	5
Persimmon	-	-	7	1,000	0	0	1,000	3
Bald Cypress	-	-	4	500	0	0	500	1
Pignut Hickory	-	-	0	0	2	400	400	1
Water Tupelo	-	-	2	300	0	0	300	1
Totals				13,700		19,800	33,500	

Lower Corridor

Species	1992-93 %	1992-93 No.	1993-94 %	1993-94 No.	1994-95 %	1994-95 No.	All Years No.	All Years %
Swamp Tupelo	0	0	-	-	61	3,800	3,800	25
Green Ash	33	2,900	-	-	13	800	3,700	25
Swamp Chestnut Oak	30	2,600	-	-	0	0	2,600	17
Bald Cypress	19	1,600	-	-	7	500	2,100	14
Water Tupelo	11	1,000	-	-	13	800	1,800	12
Cherrybark Oak	7	600	-	-	6	400	1,000	7
Totals		8,700				6,300	15,000	

Delta

Species	1992-93 %	1992-93 No.	1993-94 %	1993-94 No.	1994-95 %	1994-95 No.	All Years No.	All Years %
Water Tupelo	-	-	-	-	60	21,000	21,000	60
Bald Cypress	-	-	-	-	30	10,500	10,500	30
Green Ash	-	-	-	-	10	3,500	3,500	10
Totals						35,000	35,000	

SEED COLLECTION

The geographic origin of seeds for commercially available hardwood and cypress seedlings is often uncertain and/or beyond the desired range. Moreover, supplies for some species of seedlings are limited and unreliable. Therefore, in 1992 and 1993, the Forest Service contracted with a private firm (Canal Environmental Services, Florence South Carolina) to have seeds of desired species collected. All seeds were collected from the Coastal Plain of South Carolina (Figure 6). Counties of origin varied by species (Table 4).

In its reports to the Forest Service, Canal Environmental Services (1992 and 1993) described methods of seed collection and storage (paraphrased here). Seed was collected by picking it up from the ground or collecting it in nets suspended under the tree. In the 1992 collection, ash seed was collected by taking it from trees cut during logging operations or for firewood. In 1993, ash was collected from standing trees using a bucket truck. All seeds were stored in refrigeration—the oaks after float testing to remove bad acorns. Acorns and hickory nuts were stored in plastic bags in refrigeration, until delivered to the Forest Service. Ash samaras, with wings left on, and cypress seeds were spread out on screen racks to air dry while refrigerated. Ash samaras were not dewinged. Seeds of water and swamp tupelo were mechanically macerated to remove pulp, recovered by flotation, then air-dried while in cold storage.

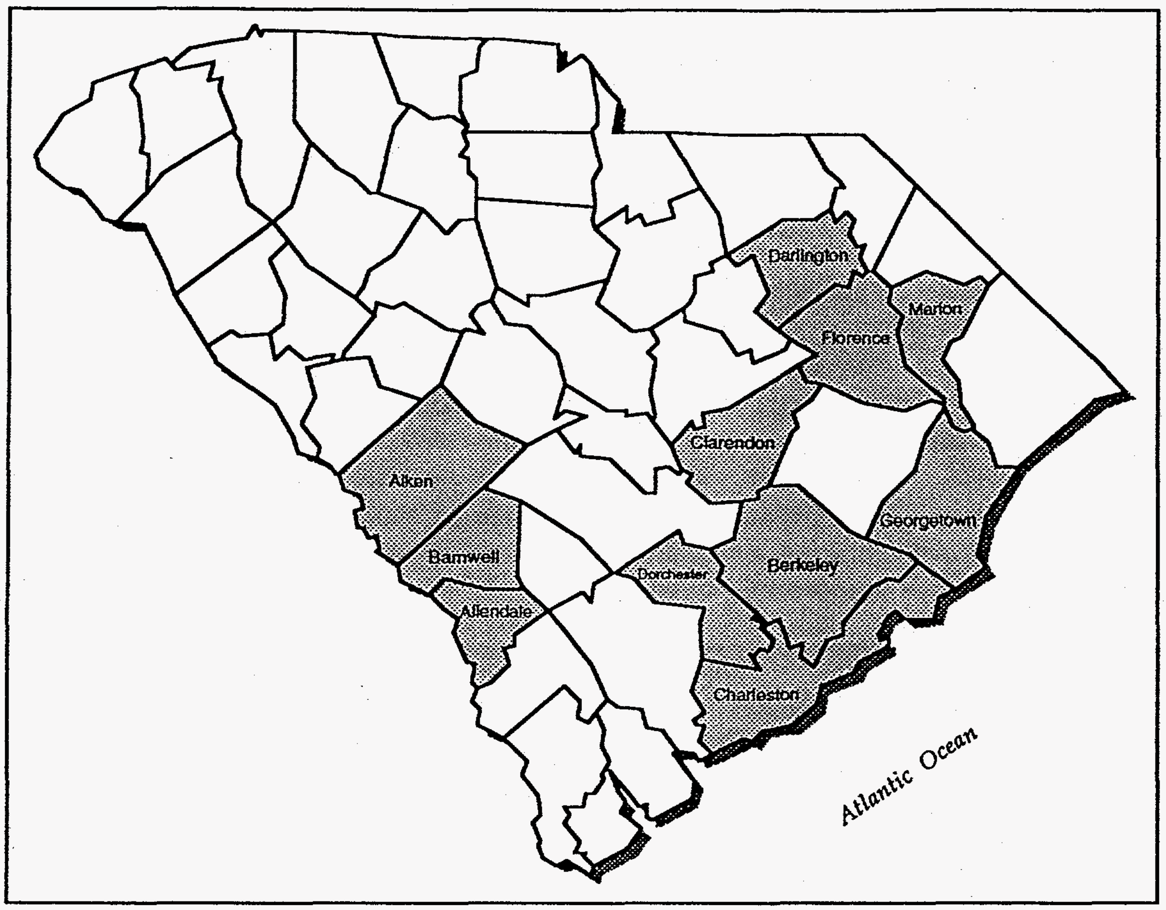

Figure 6. Counties in South Carolina from which seed was collected under contract by Canal Environmental Services in 1992 and 1993.

Table 4. Seeds collected under contract by Canal Environmental Services. Only species planted in the Pen Branch Restoration are shown. Seeds weights are after pulp removal and processing. (Adapted from Canal Environmental Services, 1992 and 1993).

Fall 1992 Collection

Species	County	Weight (kg)	(%)	No. of Trees
Cherrybark Oak	Marion	0.7	5	1
	Darlington	13.4	95	6
	Totals >	14.1	100	7
Swamp Chestnut Oak	Allendale	6.1	6	1
	Florence	51.5	56	6
	Marion	3.4	4	1
	Charleston	10.0	11	2
	Georgetown	14.1	15	5
	Clarendon	3.6	4	1
	Dorchester	3.4	4	1
	Totals >	92.1	100	17
Water Tupelo	SRS	5.3	94	3
	Marion	0.3	6	1
	Totals >	5.6	100	4
Green Ash	Marion	10.0	100	4
	Totals >	10.0	100	4

Fall 1993 Collection

Species	County	Weight (kg)	(%)	No. of Trees
Cherry Bark Oak	Charleston	2.6	92	1
	Berkeley	0.2	8	1
	Totals >	2.8	100	2
Water Hickory	Marion	4.1	46	2
	Berkeley	4.9	54	5
	Totals >	9.0	100	7
Pignut Hickory	Berkeley	6.4	100	1
	Totals >	6.4	100	1
Water Tupelo	Florence	10.0	14	1
	Berkeley	70.0	86	12
	Totals >	80.0	100	13
Swamp Tupelo	Florence	0.3	3	1
	Berkeley	10.7	88	8
	Charleston	1.1	9	2
	Totals >	12.1	100	11
Bald Cypress	Berkeley	10.0	100	4
	Totals >	10.0	100	4
Green Ash	Marion	1.1	100	1
	Totals >	1.1	100	1

MONITORING

HYDROLOGY

At the start of the project, K-Reactor pumps were still adding to Pen Branch flow by discharging non-heated water. The influence of this additional flow on the hydrology of the Pen Branch floodplain, as well as the floodplain's long-term hydrology, was uncertain. The feasibility of restoring Four Mile Creek and Steel Creek—the other 2 thermally impacted stream systems— was also being considered. Therefore, shallow water-table wells and staff gauges were installed throughout the 3 creek systems.

The primary objectives of the hydrologic monitoring were to

1) determine the influence of pumping on site hydrology,

2) characterize the hydrology of the site as reactor pumping diminished, and

3) aid in determining suitable tree species and management alternatives based upon the expected long-term hydrology.

Methods

In the summer of 1990, 7 transects were established across the Pen Branch corridor and in the delta (Map Insert 1). Additional transects were established in the summer of 1991 on Four Mile Creek and Steel Creek (Appendix A). The transects contained both shallow ground water wells and staff gauges at stream crossings. Wells were located at intervals determined by a 6 in change in elevation.

The well casings were made of PVC pipe, 2 in in diameter and 5 ft in length. A 3 ft interval below the soil surface had holes 0.5 in in diameter at 6 in intervals and was covered with plastic screen wire. A 2 ft length of closed well casing was left above the soil surface. Depth to water table and stream stage were measured manually at variable time intervals between January 1991 and April 1994.

Implications for Management and Future Monitoring

In 1990, when the Pen Branch transects were installed, reactor outflows had been reduced to a minimal rate (Figure 2), improving soil drainage and access to the corridor. However, pumping was increased again in 1991 and 1992, raising stream stage (Figures 7 and 8), flooding much of the corridor, and rendering many wells inaccessible (Figures 9 and 10).

By July of 1992, K-Reactor outflows were again reduced and water table depths at most locations began a cyclical pattern of lowering during growing season and rising closer to the surface in winter. Stream stage at some locations varied in similar cycles. Water-table depths in the floodplain were apparently related to seasonal variations in streamflow; however, transpiration by the developing willow cover may have enhanced summer water-table draw down.

Hydrologic monitoring facilitated the selection of tree species for planting, but interpretations were limited by the uncertainties of reactor outflow rates. Flooding due to high discharge rates in 1991 and 1992 demonstrated that the suite of tree species suitable for the corridor could be determined, in part, by reactor operations. Additions to streamflow, even at ambient stream temperatures, could limit the survival and growth of less flood tolerant tree species, which would otherwise be suitable for the area.

The original hydrologic characterization had several notable limitations. No transect was established in the upper half of the restoration site. Though most of this area was undoubtedly better drained than the lower corridor, the hydrology was not characterized. Many of the wells also filled partially with sediment, so that in better drained areas during the growing season, water-table depths were often beyond the measurement range. The wells' design depth was 91 cm, but many filled to 50 cm or less with sediment (e.g., Figure 9). Another limitation was the low temporal resolution of the data, which did not allow for characterization of brief flood peaks—even of a week or more—which could strongly influence species suitability. Still, two conclusions were apparent from the hydrologic record.

1) Pumping of non-heated water from K Reactor caused flooding and saturation of soils throughout Pen Branch corridor as late as the summer of 1992. Such pumping, if resumed, will limit the number of trees species suitable for the corridor.

2) Future long-term monitoring can be achieved adequately with a small number of continuous water-level recorders. The initial monitoring showed strong spatial correlations in water-table depths among many of the well locations, and continuous recording will enable characterization of all flood events.

In 1995, water-level recorders were installed at five stations in the Pen Branch area (Map Insert 2). The recorders are WL-40 capacitance probes (Remote Data Systems, Wilmington, NC) which store data digitally and are downloaded with an infrared transmitter. The recording interval can be varied. The initial recording interval was set at 3 hrs.

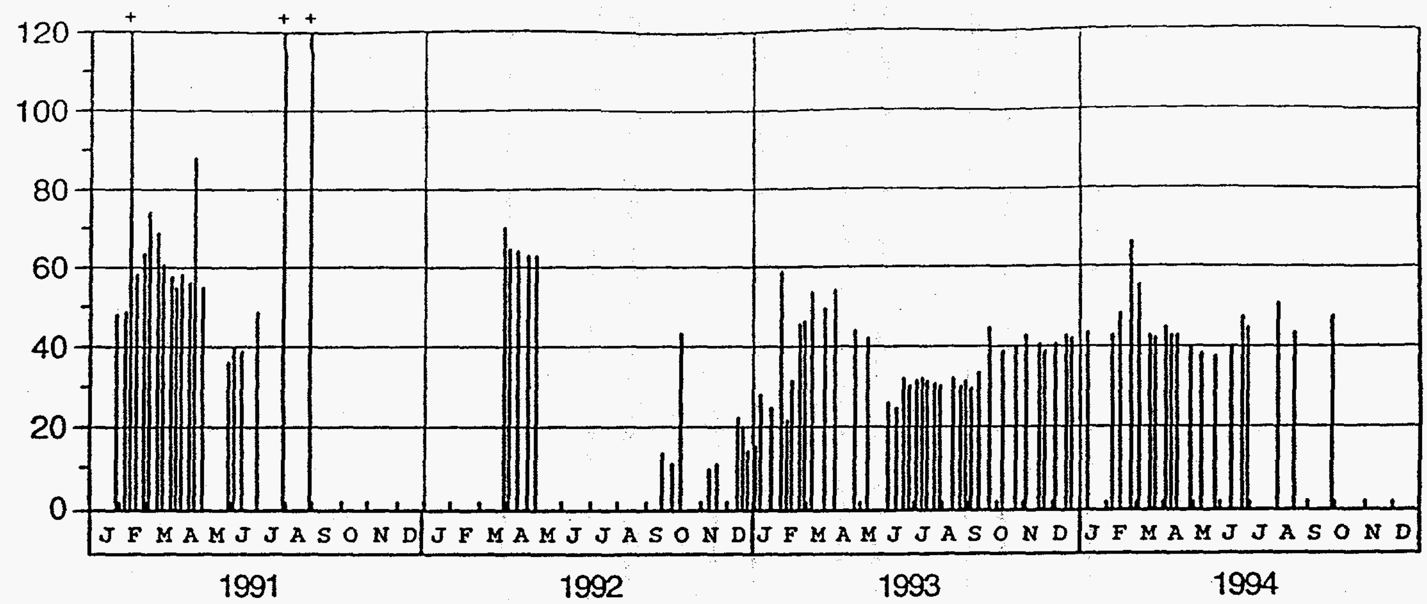

Figure 7. Stream stage (cm) at a staff gage (Transect 1 - Gage 2) in the middle Pen Branch corridor. "+" symbol indicates that the gage was underwater at the time of measurement.

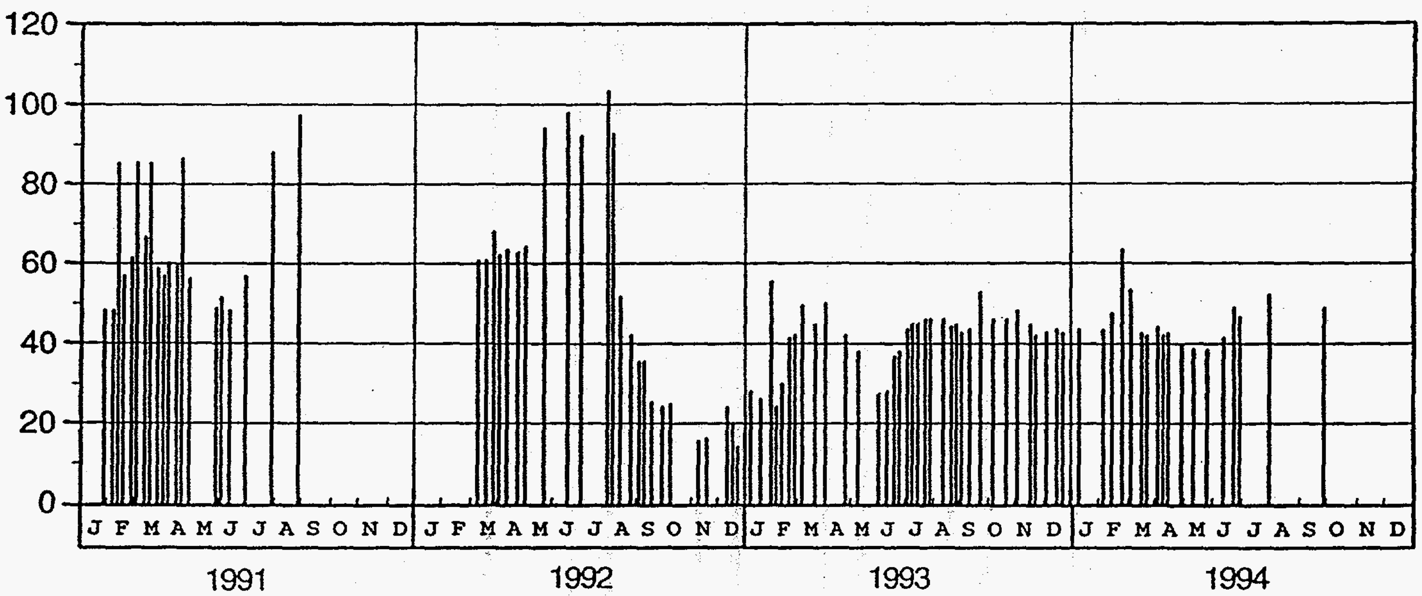

Figure 8. Stream stage (cm) at a staff gage (Transect 2 - Gage 1) in the middle Pen Branch corridor, showing high flows in early 1992.

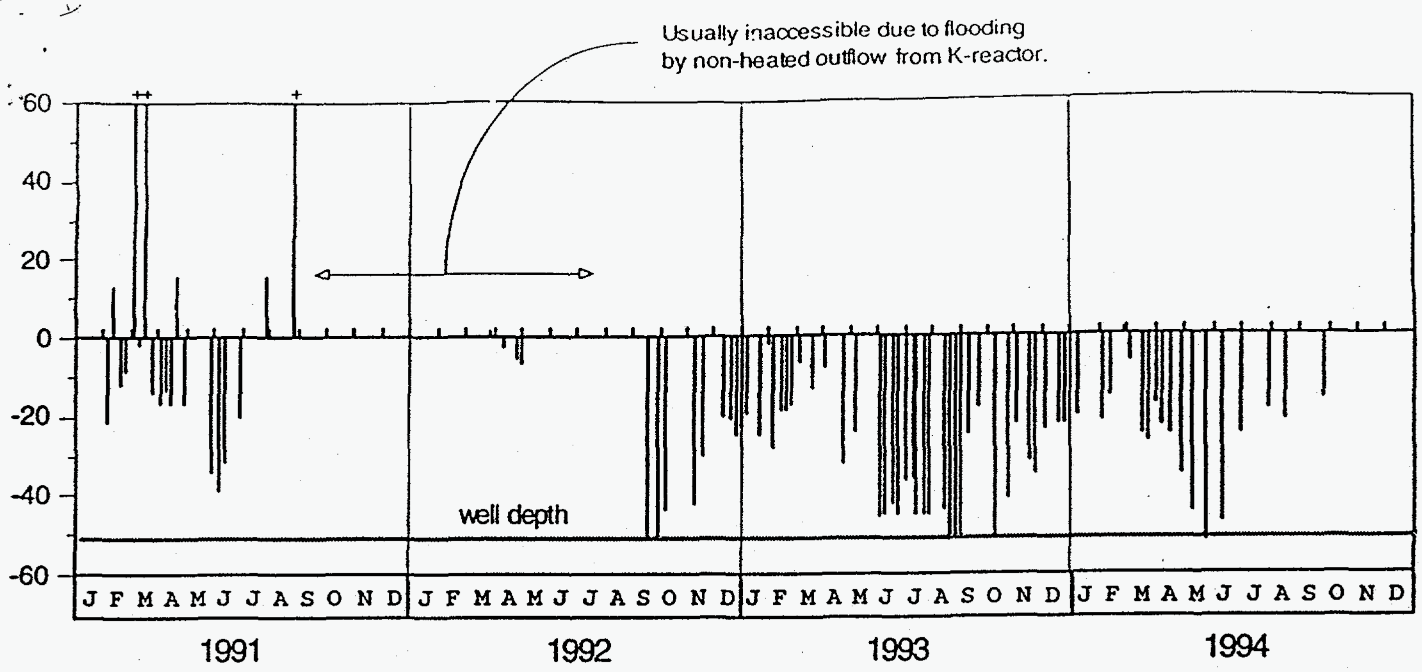

Figure 9. Water-table depths (cm) at a well location (Transect 1 - Well 4) in the middle Pen Branch corridor. Values equal to the well depth indicate that the water table is at or below this depth. "+" symbol indicates well casing was underwater at time of measurement and there were at least 60 cm of water above the soil surface.

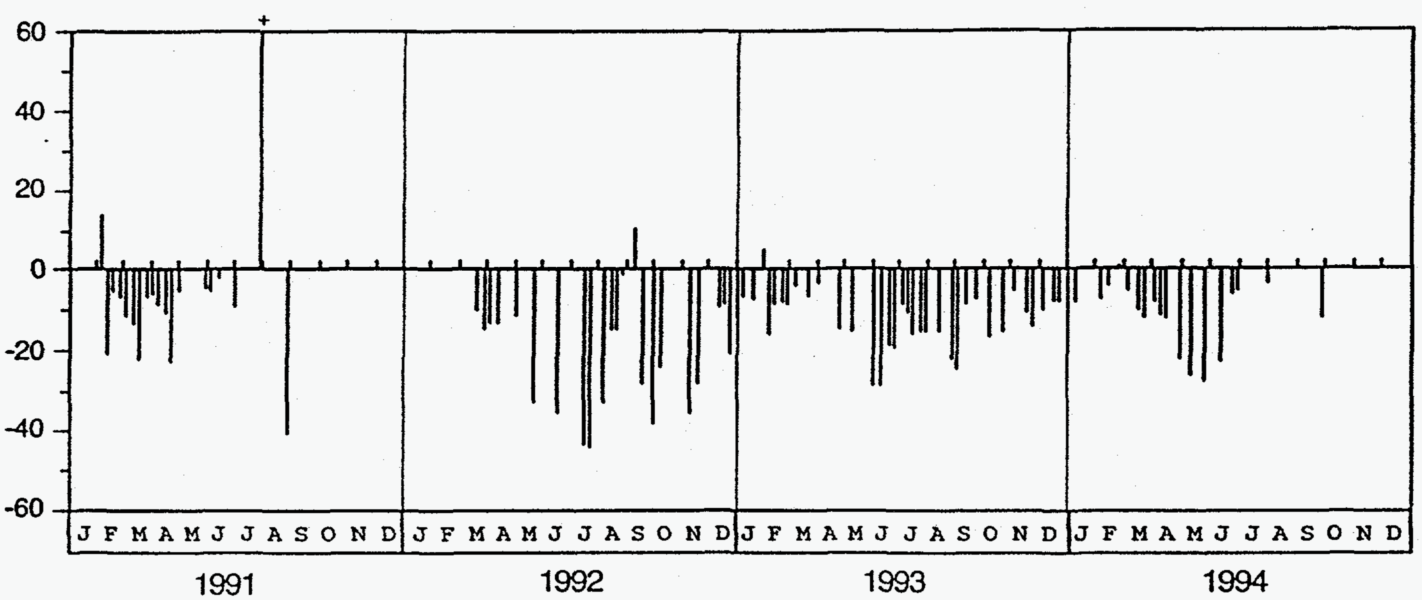

Figure 10. Water-table depths (cm) at a well location (Transect 3 - Well 1) in the lower Pen Branch corridor. "+" symbol indicates well casing was underwater at time of measurement and there were at least 60 cm of water above the soil surface.

REGENERATION OF DESIRABLE SPECIES: 1994 SURVEY

The limited objective of this monitoring effort was to quantify the abundance and size of *desirable* regeneration, artificial or natural, in the planted and control areas. Desirable species were defined as those typically present as large canopy trees in bottomland-hardwood and cypress-tupelo forests. Specifically excluded were black willow, black alder, button bush, and wax myrtle, which were present at undesirably high densities. Others species such as sumac were excluded because they are minor or atypical components in mature bottomland-hardwood forests.

Methods

Plot establishment. Sixty-six circular plots, 0.04 ha (0.1 ac) in area, were established randomly throughout the upper and lower corridor—with four plots in each control section and variable numbers in the planted sections, depending upon their areas (Map Insert 1). No plots were established in the delta, as it had not yet been planted at the time of the survey. The coordinates of each plot, for relocation with the Global Positioning System, are given in Table 5.

The vegetation plots were measured once in the spring of 1994. On each plot, all planted trees were marked with red pin flags. Volunteers of desirable species were marked with blue and white, striped flagging tape. The periphery of each plot was marked with blue or, for a few plots in the upper corridor, yellow flagging. The plot center was marked with an aluminum pole, 3 cm in diameter and 3 m in height. The top of each pole was painted orange, and a metal tag with the plot number was attached to each pole.

Measurements and analysis. The number of planted and volunteer trees on each plot was recorded by species. The current height and estimated height at the time of planting were recorded for each species. Abundance of desirable regeneration by treatment area, species, and origin--planted or volunteer--was calculated with the FREQ procedure of SAS statistical software (SAS Institute, 1990). Mean height-growth and densities by treatment area and species were calculated with the MEANS procedure.

Implications for Management

The spring 1994 survey revealed severe losses to feral hog herbivory in planted sections of the upper corridor (Figure 11). The mean density of 285 planted and volunteer trees per hectare was probably insufficient to support the development of a closed canopy forest—especially when allowing for future mortality. About 17% of the upper corridor had no remaining planted trees (Figure 12). These results lead to our decision to replant this area in 1995.

This survey also showed that sparse natural regeneration of a few desirable species was a small, but potentially important contribution to stand development. There were approximately 37 red maple stems ha^{-1} in planted sections of the upper corridor, and another 17 stems ha^{-1}, consisting of sweet gum, sycamore, red bay, laurel oak, and loblolly pine. All of these occur to some extent in bottomland forests and will complement the suite of planted species. Natural regeneration was less abundant in planted sections of the lower corridor, which were more poorly drained. Virtually all volunteers in the lower corridor only 20 ha^{-1} total were red maples, with a few scattered pines. No other desirable species were found in the lower corridor.

The volunteer trees will probably hasten the development of vertical forest structure. About 35% of the volunteers found in this survey were over 2 m in height, many as tall as 8 m. These trees, now released from competition, should begin to establish canopy dominance and suppress the willows and other less desirable species.

Note on Control Section 2 for future surveys: In future surveys, it should be noted that portions of control section 2, about 1/4 of the area on the northern and western sides were inadvertently planted. (The contractor planted across the cleared boundary line.) The exact extent of this area is not known. Mostly green ash were planted in this area, with a few swamp chestnut oak, swamp tupelo, and persimmon.

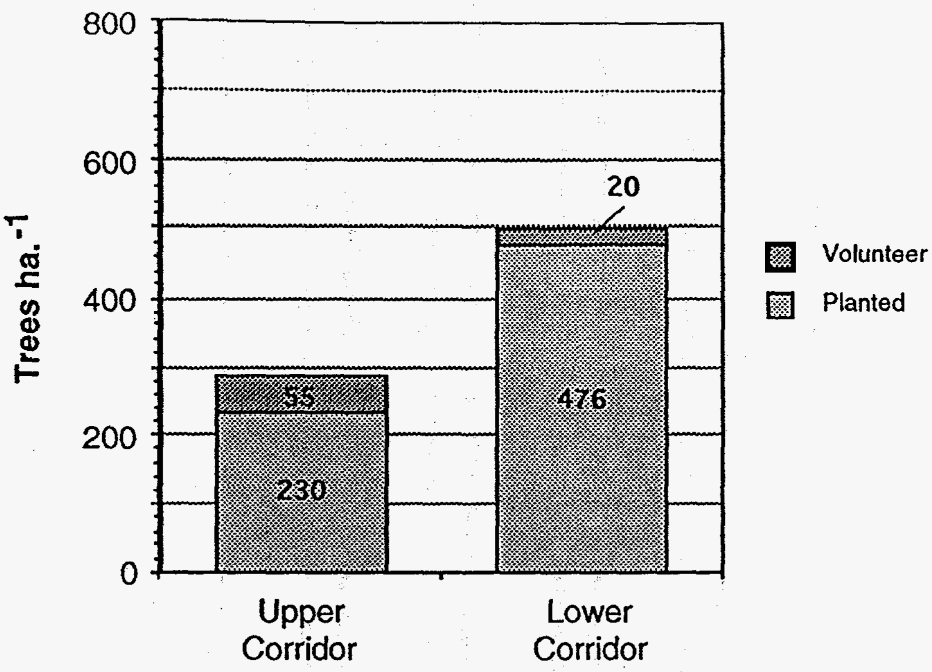

Figure 11. Mean densities of desirable regeneration in planted areas (spring, 1994). The original planting density was 747 trees/ha.

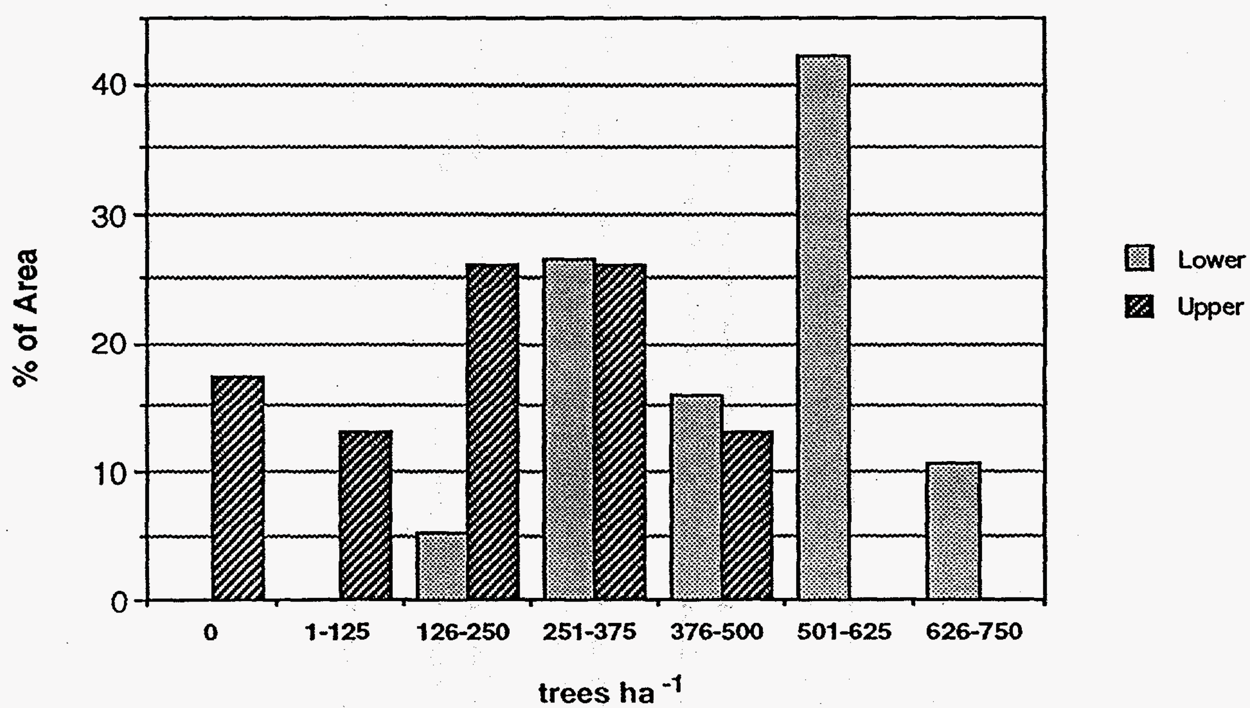

Figure 12. Frequency distribution showing artificial regeneration densities in planted areas (Spring, 1994).

Table 5. Latitudes and longitudes (NAD 27) of vegetation monitoring plots.

	Longitude			Latitude		
Plot No.	Deg.	Min.	Sec.	Deg.	Min.	Sec.
1	-81	41	36.68	33	8	43.05
2	-81	41	37.88	33	8	43.84
3	-81	41	37.11	33	8	42.42
4	-81	41	38.70	33	8	43.63
5	-81	41	36.96	33	8	40.66
6	-81	41	39.66	33	8	42.18
7	-81	41	38.42	33	8	40.29
8	-81	41	41.17	33	8	39.70
9	-81	41	39.73	33	8	36.78
10	-81	41	43.47	33	8	36.68
11	-81	41	45.00	33	8	38.01
12	-81	41	42.79	33	8	34.57
13	-81	41	45.61	33	8	36.39
14	-81	41	41.03	33	8	32.95
15	-81	41	45.34	33	8	35.28
16	-81	41	42.45	33	8	31.18
17	-81	41	43.81	33	8	32.31
18	-81	41	46.37	33	8	34.37
19	-81	41	41.97	33	8	28.52
20	-81	41	47.32	33	8	32.09
21	-81	41	46.28	33	8	32.50
22	-81	41	46.66	33	8	29.85
23	-81	41	48.23	33	8	30.81
24	-81	41	46.86	33	8	28.77
25	-81	41	50.36	33	8	30.76
26	-81	41	47.16	33	8	27.67
27	-81	41	49.82	33	8	28.51
28	-81	41	50.42	33	8	29.52
29	-81	41	49.95	33	8	25.53
30	-81	41	52.28	33	8	27.14
31	-81	41	52.94	33	8	27.91
34	-81	41	35.48	33	8	46.42
35	-81	41	36.80	33	8	45.87
36	-81	41	34.25	33	8	45.92
37	-81	41	34.15	33	8	46.88
38	-81	41	28.66	33	8	47.95
39	-81	41	34.58	33	8	49.92
40	-81	41	33.07	33	8	49.86
41	-81	41	31.84	33	8	50.27
42	-81	41	35.39	33	8	50.63
43	-81	41	32.11	33	8	53.76
44	-81	41	36.41	33	8	53.09

Table 5. Continued.

Plot No.	Longitude Deg.	Longitude Min.	Longitude Sec.	Latitude Deg.	Latitude Min.	Latitude Sec.
45	-81	41	35.82	33	8	54.24
46	-81	41	36.10	33	8	57.18
47	-81	41	34.37	33	8	58.08
48	-81	41	36.62	33	8	58.78
49	-81	41	36.01	33	9	1.23
50	-81	41	35.78	33	9	2.19
51	-81	41	34.65	33	9	4.55
52	-81	41	36.43	33	9	4.69
53	-81	41	36.60	33	9	8.05
54	-81	41	36.28	33	9	7.23
55	-81	41	34.55	33	9	6.00
56	-81	41	31.16	33	9	9.62
57	-81	41	27.09	33	9	12.47
58	-81	41	29.16	33	9	13.89
59	-81	41	30.09	33	9	14.39
60	-81	41	30.45	33	9	15.14
61	-81	41	22.09	33	9	19.68
62	-81	41	24.64	33	9	22.20
63	-81	41	21.41	33	9	24.23
64	-81	41	21.27	33	9	25.66
65	-81	41	19.42	33	9	27.74
66	-81	41	14.70	33	9	27.21
67	-81	41	16.53	33	9	28.10
68	-81	41	13.22	33	9	28.32

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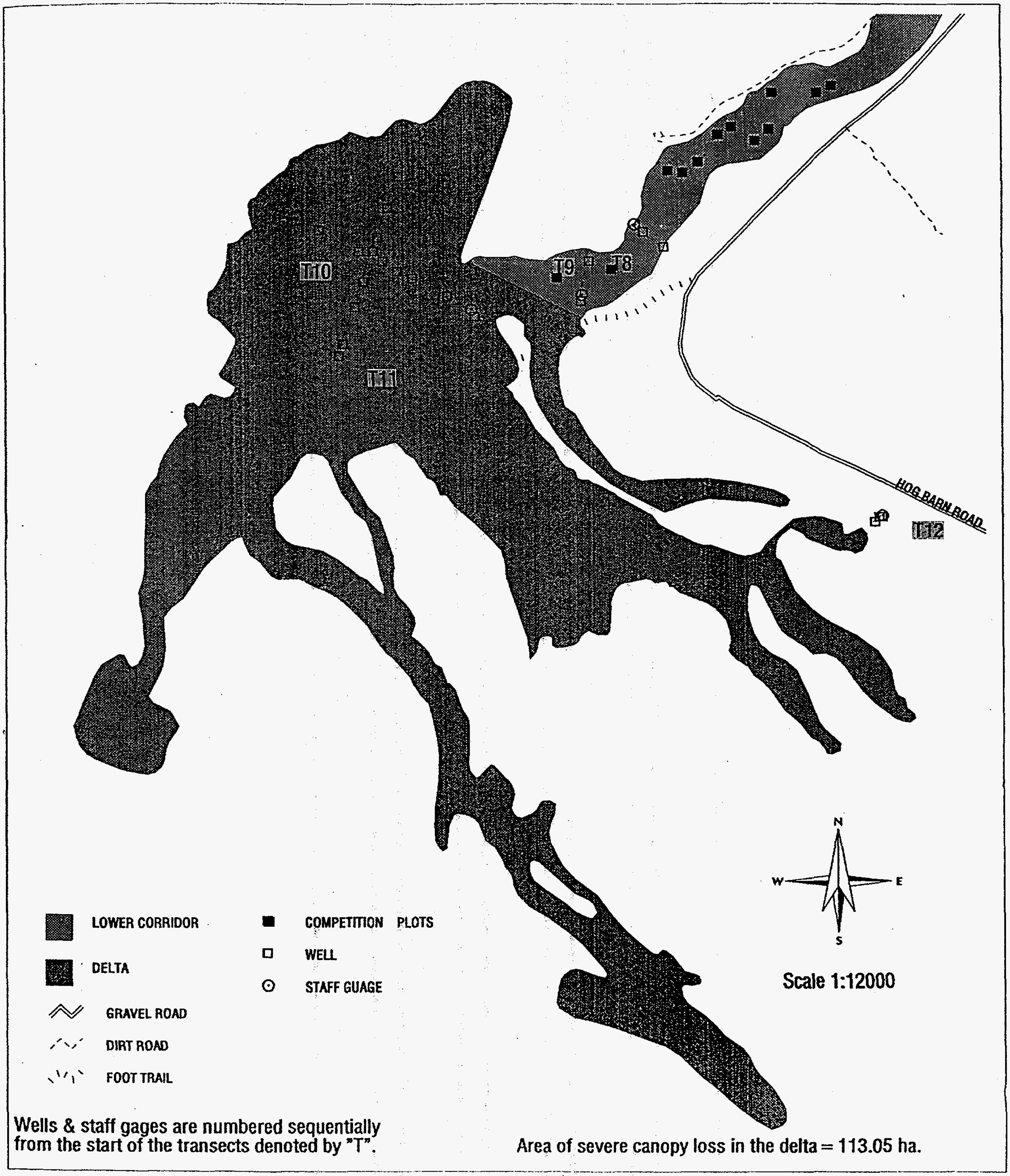
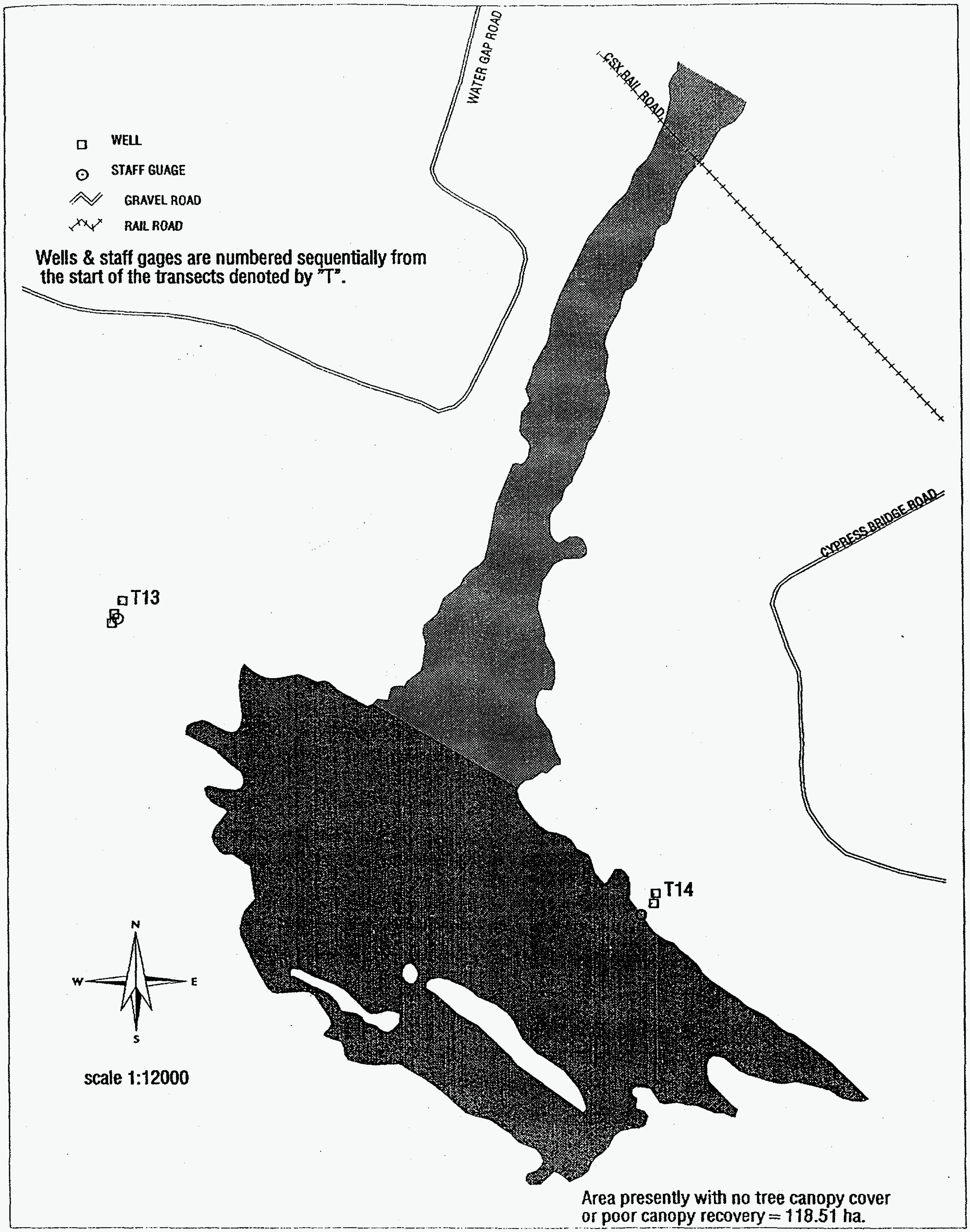
APPENDICES

Appendix A

Maps of Four Mile Creek and Steel Creek



Four Mile Creek lower corridor and delta



Steel Creek lower corridor and delta

APPENDIX B

COMMON AND SCIENTIFIC NAMES OF PLANT SPECIES IN THIS REPORT

Common Name	Scientific Name
bald cypress	Taxodium distichum
black alder	Alnus serrulata
black willow	Salix nigra
blackberry	Rubus spp.
bulrush	Scirpus spp.
button bush	Cephalanthus occidentalis
cattail	Typha latifolia
cherrybark oak	Quercus pagodaefolia
green ash	Fraxinus pennsylvanica
laurel oak	Quercus laurifolia
loblolly pine	Pinus taeda
persimmon	Diospyros virginiana
pignut hickory	Carya glabra
red bay	Persia borbonia
red maple	Acer rubrum
sand pine	Pinus clausa
shumard oak	Quercus shumardii
sumac	Rhus spp.
swamp chestnut oak	Quercus michauxii
swamp tupelo	Nyssa sylvatica, var. biflora
sweetgum	Liquidambar styraciflua
sycamore	Platanus occidentalis
water hickory	Carya aquatica
water oak	Quercus nigra
water tupelo	Nyssa aquatica
wax myrtle	Myrica cerifera

APPENDIX C

FOREST SERVICE RESOURCES AND DATA SETS RELATED TO THE PEN BRANCH REFORESTATION

Data Sets and Records

Item	Description	Location
Pen Branch Geographic Information System	An ARC/INFO GIS with all plots, treatment areas, and significant features associated with this project. For map output and analyses.	Center for Forested Wetlands Research (CFWR), Charleston, SC. Contact Cindy Bunton, GIS administrator.
Artificial-regeneration survey data	Field data in spread-sheets, summary graphs and tables available.	CFWR. Contact Neil Dulohery or Carl Trettin.
Hydrology monitoring data	Field data in spreadsheets and summary graphs available Also three annual reports (see literature section of this appendix).	CFWR. Contact Neil Dulohery or Carl Trettin.
Planting and site-preparation contract records.	Contract specifications, daily diaries, etc.	Savannah River Forest Station (SRFS). Contact Rick Davalos.
DOE site use applications and permits for all activities.	Applications and permitting required for activities on the Savannah River Site.	SRFS and CFWR. Contact Bob Crais, John Blake, or Rick Davalos at the SRFS, or Neil Dulohery at the CFWR.
Study plans for CFWR monitoring and research roles.	Rationale, locations, and methods of research.	CFWR. Contact Carl Trettin or Neil Dulohery at the CFWR.
Aerial Photography	Black and white, 1951; color infrared and natural color, early 1990s	CFWR, SRFS. Contact Neil Dulohery, Rick Davalos, or John Blake.

Reports not Previously Cited

Item	Description	Location
Department of Energy, 1990. Final environmental impact statement, continued operation of K-, L-, and P-Reactors, Savannah River Site, Aiken, South Carolina, DOE/EIS-0147, December 1990.	Environmental impact statement	SRFS and WSRTC.
Dulohery, C.J. 1993. Expected glyphosate concentration in stream water versus toxicity values. Center for Forested Wetlands Research, USDA-FS, Charleston, SC.	Appendix to DOE Site Use 92-70-R.	Contact Bob Crais at the SRFS or Neil Dulohery at the CFWR.
Dulohery, C.J., W.H. McKee, Jr., and John W. Taylor. 1993. Rehabilitation alternatives for thermally impacted stream corridors of the Savannah River Site. Center for Forested Wetlands Research, USDA-FS, Charleston, SC.	Risk assessment and recommendations concerning silvi-cultural alternatives for the reforestation.	Contact Neil Dulohery at the CFWR.
McKee, W.H., Jr., S.M. Ross, and D. Niquette. 1991. Measurement of stream water levels and soil water depths on lower Pen Branch creek and delta during spring and summer of 1991. Center for Forested Wetlands Research, USDA-FS, Charleston, SC.	Field data, methods, results, and summary graphs of hydrology measurements during this period.	CFWR. Contact Neil Dulohery or Carl Trettin.
McKee, W.H., Jr., S.M. Ross, J. Gay, and R. Moseley. 1992. Measurement of stream water levels and soil water levels on lower Pen Branch and Four Mile Creek corridors and deltas during the 1992 growing season. Center for Forested Wetlands Research, USDA-FS, Charleston, SC.	Field data, methods, results, and summary graphs of hydrology measurements during this period.	CFWR. Contact Neil Dulohery or Carl Trettin.
McKee, W.H., Jr., S.M. Ross, J. Gay, R. Moseley. 1993. Measurement of stream water levels and soil water levels on Steel Creek, lower Pen Branch Creek, and Four Mile Creek corridors and delta during the 1993 growing season. Center for Forested Wetlands Research, USDA-FS, Charleston, SC.	Field data, methods, results, and summary graphs of hydrology measurements during this period.	CFWR. Contact Neil Dulohery or Carl Trettin.
Trettin, Carl C. and M. Paller. 1995. Research proposal: Development of an assessment framework for forested wetland restoration on the Savannah River Site.	Proposal describing research activities to be undertaken at Pen Branch after 1995	Contact Carl Trettin at the CFWR or Mike Paller at WSRTC.