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Proceedings of The 21st Annual Conference on Wetlands Restoration and Creation

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PROCEEDINGS OF
THE TWENTY FIRST ANNUAL CONFERENCE ON WETLANDS RESTORATION AND CREATION

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HILLSBOROUGH COMMUNITY COLLEGE
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INTRODUCTION

The Annual Conference on Wetlands Restoration and Creation provides a Forum for the exchange of results of scientific research in the restoration, creation, and management of freshwater and coastal systems. The conference is designed to be of particular benefit to governmental agencies, planning organizations, colleges and universities, corporations, and environmental groups with an interest in wetlands. These proceedings are a compilation of papers and addresses presented at the Twenty First Annual Conference.

As in years past, this year's conference would not have been possible without the assistance and cooperation of Mr. Roy R. "Robin" Lewis, III. Mr. Lewis has been an important contributor since the very first conference twenty one years ago. We are grateful for his help and participation. Appreciation is also extended to Charles Duesner for providing administrative support for the conference.

The following people also deserve acknowledgment for contributing to the conference and assisting in the preparation of the proceedings for publication: Elaine Baskin, Tami Catanzarita, Sanjeev Choudhry, Lydia Dehoyos, Donna Foley, Janet Giles, Charles Mason, and Sandra Upchurch. A very special thanks to Johnnie Hurst for her untiring assistance in handling the many details of conference planning and to Patrick Cannizzaro for his assistance in coordinating this year's Conference.

Thanks are extended to the staff of **LEWIS ENVIRONMENTAL SERVICES** and the **SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT - SWIM PROGRAM** for arranging and conducting very successful field trips to wetland restoration sites.

These proceedings could not have been completed without the time and efforts of the authors and reviewers.

To all these people, thank you.

SITE SELECTION CRITERIA FOR SUCCESSFUL WETLAND MITIGATION PROJECTS

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ABSTRACT

Construction of a 240 Megawatt natural gas fired cogeneration facility in Plattsburgh, New York, entailed filling 2.3 hectares (5.8 acres) of federal and New York State Department of Environmental Conservation (NYSDEC) regulated wetlands with additional impacts from associated utility corridors and facilities. It was anticipated that between 4 to 8 hectares (10 to 20 acres) of wetland mitigation would be necessary to obtain federal and state permits. The selection process for the mitigation site was integrated into the alternatives analysis for the cogeneration site, and involved an examination of sites within 1.6 kilometers (one mile) of the thermal host. Because the study included the analysis of many alternative sites, a methodology to screen these sites for mitigation suitability was developed. These sites were screened for a variety of factors including: 1) the physical site conditions, 2) land uses, and 3) compliance with state and federal mitigation guidelines.

Of the twelve candidate sites reviewed, most were unsuitable as mitigation sites due to factors such as small size, existing wetlands, potential hazardous waste contamination, and inappropriate land uses. The site ultimately chosen for the mitigation wetland had the advantage of being within the same watershed as most of the impacted wetlands, having an adequate water supply and being adjacent to a large natural wetland. Further studies ultimately confirmed the original site selection.

INTRODUCTION

The Saranac Cogeneration Project is located in Plattsburgh, New York (Clinton County), a city near the Canadian border (Figure 1, Project location map). The project involved the construction of a natural gas fired 240 Megawatt cogeneration facility. This cogeneration facility supplies electrical energy to the local power grid, and steam to a Georgia Pacific paper products factory, which serves as the thermal host, also located on the north side of the City of Plattsburgh.

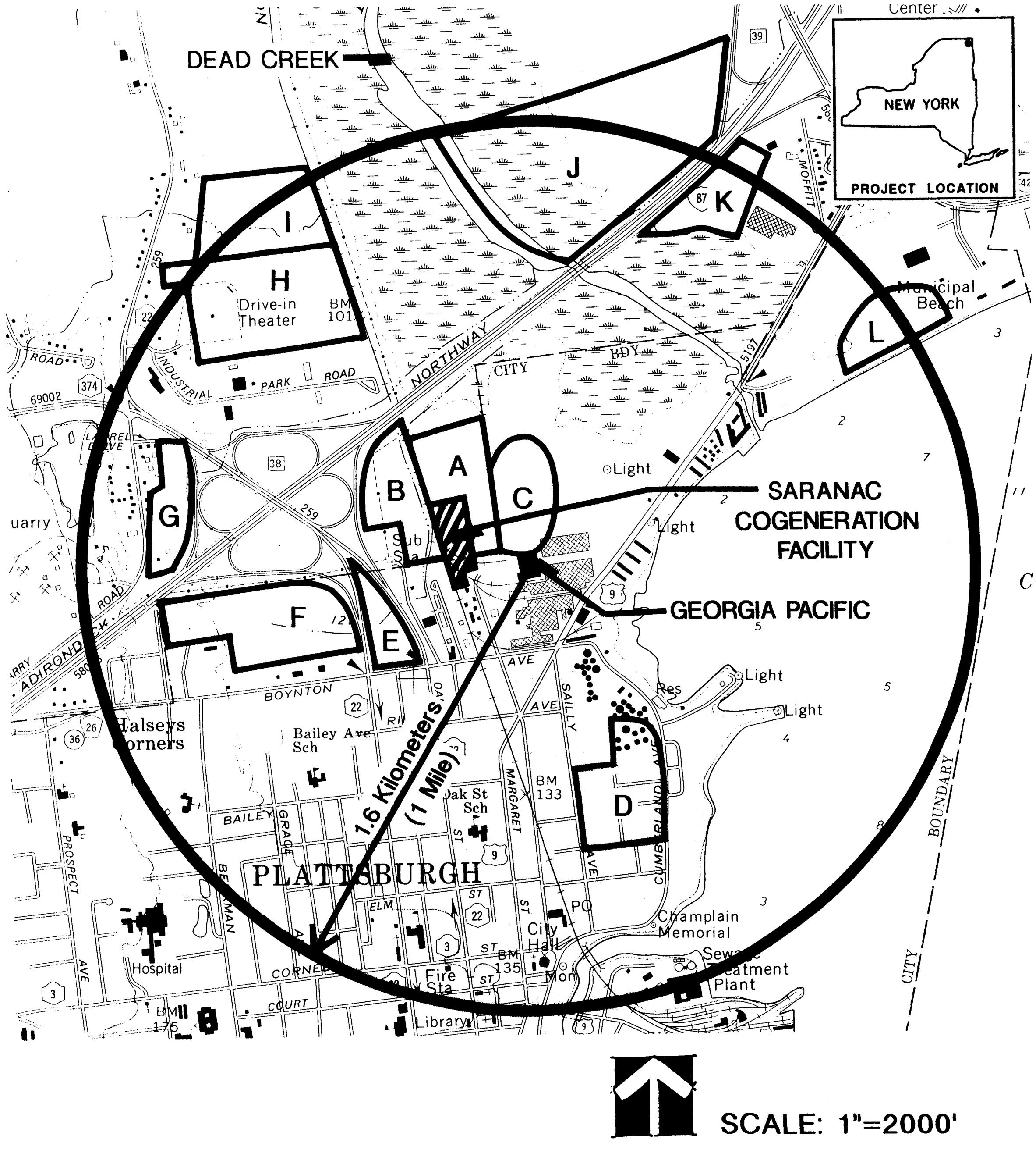

Figure 1 - Project location map from USGS 1966 Plattsburgh quadrangle, New York - Vermont, 7.5 minute series (topographic) illustrating the location of the Saranac Cogeneration Facility, Georgia Pacific, the thermal host, and the twelve alternative mitigation sites which were examined in a one mile radius from the thermal host.

Associated with the construction of the cogeneration facility were two electric substations with minor wetland impacts; a natural gas metering station with 0.4 hectare (one acre) of wetland impact; 34 kilometers (21 miles) of natural gas pipeline which traversed north to the Canadian border and approximately 18 kilometers (11 miles) of electric transmission line up to 46 meters (150 feet) wide, with a total of 8.8 hectares (22.3 acres) of canopy clearing and 3.3 hectare (8.4 acres) of permanent clearing of forested wetlands. The entire project was reviewed through the individual permit process by the US Army Corps of Engineers (ACOE), and under two New York State permit processes (the pipeline was reviewed by the New York State Public Service Commission, and the rest of the project was reviewed by the NYSDEC).

At the time of the mitigation site selection process, negotiations were in process with the state and federal wetland permitting agencies, and the exact amount of wetland mitigation which would be required for issuance of the permits was not known, but anticipated at 4 to 8 hectares (10 to 20 acres).

STUDY AREA

The cogeneration facility is located just north of the City of Plattsburgh on the edge of the city's industrial area (Figure 1). The cogeneration facility site contained a federally regulated wetland, comprised of wet meadow and shrub/swamp communities, with hydric clay soils and a perched water table to the surface during the winter and spring (Experimental Laboratory, 1987). There was not any open water on the site, and the site served mainly as habitat for small birds and mammals. The NYSDEC also mapped the cogeneration site as Class I state wetlands due to a hydrological connection to the adjacent and larger Dead Creek wetland system.

Dead Creek is a tributary to Lake Champlain located east of the site, and the valley in which it is located contains large areas of wooded wetlands and numerous dairy farms. The NYSDEC classifies most of the wetlands within the Dead Creek System as Class 1 (highest classification for classes 1 through 4) (6 NYCRR 664). This classification is due to the wide diversity of covertypes of this system, and the high percentage of land area which the system covers in Clinton County. Open water is fairly limited in this wetland system due to the dense overstory of wooded vegetation. The NYSDEC is concerned about degradation to this wetland system, as it is an important tributary to Lake Champlain which provides functions for sediment and pollutant retention and nutrient transformation from the adjacent farmed lands, and some waterfowl resting areas during migration.

METHODS

As part of the 404(b)(1) guidelines alternatives analysis required for the ACOE permit, an examination of all open sites within a 1.6 kilometer (one mile) radius from the thermal host was made to determine their potential to serve as a location for the cogeneration facility. This one mile radius was chosen as the maximum feasible distance that steam could be transported to Georgia Pacific factory. Twelve undeveloped sites were identified for investigation. The locations of these sites are shown on Figure 1.

For cost effectiveness, concurrent with the review of the sites for the alternative analysis, each site was also examined for its potential to serve as a mitigation site for all impacts associated with the cogeneration project. Screening criteria were developed to access the suitability of each site for wetland creation. Table 1 lists the physical considerations which were reviewed.

Table 2 lists the social and economic considerations which were used to evaluate these twelve sites.

These various factors can be modified to adjust for project specific or regional issues which would influence the site selection process. For example, wetlands mitigation planning in and around airports must take into consideration Federal Aviation Administration safety zones.

For the Saranac Cogeneration Project, positive criteria were determined to be a site greater than 8 hectares (20 acres) in size, with open field or sparse woody vegetation, a prior converted cropland or upland area, shallow depth to groundwater and availability of surface water, a flat site with minimal slopes, deep depth to bedrock, and opportunities to provide functions in the landscape. The site had to be compatible with adjacent land uses, have good access for construction vehicles and monitoring, and have no prior uses which would indicate hazardous materials contamination.

Table 1 - Physical Considerations and Desirable Characteristics of the Mitigation Site

- SIZE OF SITE
* Adequate area for mitigation
* Adequate area for construction and soil stockpiles

- EXISTING HABITAT
* Vegetation types - Open field better than wooded
* No unique or regionally important habitats
* No endangered, threatened, or rare species

- WETLAND REGULATORY JURISDICTION
* Prior converted cropland - first choice
* Upland - second choice
* Farmed wetland - second or third choice w/ACOE approval
* No functioning wetlands in proposed mitigation area

- WATER RESOURCES
* Shallow depth to groundwater
* Availability of on-site surface water
* Adequate watershed area to support surface water flows

- GEOLOGIC FEATURES
* Slopes and grades - flat site
* Amount of cut and fill to reach water table
* Soil types, soil permeability, and erosion hazard
* Deep depth to bedrock

- OPPORTUNITIES TO PROVIDE FUNCTIONS
* Location of site on the landscape
* Adjacent to existing wetlands

Table 2 - Social and Economic Considerations

- COMPATIBLE WITH ADJACENT LAND USES
* Zoning
* Neighbors

- ACCESS

* Construction vehicles, monitoring, public visits

- PRIOR OR CURRENT USES OF SITE
* Potential for presence of hazardous materials
* Existing right-of-way
* Archeological resources
* Prime farmland - agricultural district designation

- LAND COSTS INCLUDING BUILDING DEMOLITION

The final set of criteria for which the sites were screened were compliance with state and federal mitigation guidelines. Table 3 summarizes the requirements of New York State (6 NYCRR 663) and the federal government (Memorandum of Agreement, 1989) with regard to mitigation. The mitigation guidelines require reviewers to consider the location of the mitigation site in relationship to the impact area, both from a vicinity and a watershed standpoint. The guidelines also require an examination of the site's characteristics for its likelihood of supporting a wetland area which would replace the functions lost at the impact area.

Table 3 - Mitigation Guidelines

NEW YORK STATE

Mitigation should occur on-site or immediate vicinity of impact.

Mitigation site will be NYSDEC regulated wetland after construction.

The mitigation wetland benefits will be equal or greater than the impacted areas.

FEDERAL

Compensatory mitigation is required for unavoidable adverse impacts.

Restoration of damaged wetland preferred over creation.

Mitigation that creates the same habitats and functions as impact area is preferred over mitigation which creates different habitats or functions.

On-site mitigation, at the impact area, is preferred over off-site mitigation. Mitigation in the same watershed as the impact is preferred over mitigation in different watershed.

The mitigation wetland must replace lost functions and values. The decision to authorize project with mitigation must consider the potential for success.

The following is a brief description of the twelve sites, as shown on Figure 11, which were examined during this screening process (LA Group, 1991).

Site A (On-Site): Site A is the northern half of the 14.5 hectare (37 acre) cogeneration facility site, portions of which were proposed for the construction of a natural gas metering station and overhead transmission lines. It is a federal and state wetland area dominated by wet meadow and sapling shrub hydrophytes, with a perched seasonally high water table. The site is zoned industrial.

Site B: Site B is a 7.6 hectare (19.3 acre) parcel located immediately west of site A. It is a wet meadow with some sapling shrub vegetation, and would be classified as a federal wetland, with some portions also regulated by NYSDEC. The parcel is zones industrial and contains overhead transmission lines.

Site C: Site C is a 6 hectare (15 acre) site located to the east of Site A. It is bordered by a NYSDEC wetland associated with the Dead Creek wetlands. The site has been used as a bark dump by the adjacent industrial facilities, which raises concerns about past land use activities, as well as requiring additional costs for the removal of the bark chips.

Site D: Side D is 6.3 hectare (16 acre) site located within the City of Plattsburgh. The soils are filled udorthents dominated by upland plants. There are no surface water sources available. The site is bounded by oil tank farms to the north and to the south and west by residential development.

Site E: Site E is a 2.6 hectare 6.71 (acre) parcel of land bounded to the east and west by interstate highway corridors, and to the south by a main road and residential development. The site is classified as federal wetland, with hydrophytic tree and shrub vegetation.

Site F: Site F is a 11.4 hectare (29 acre) in size, and a federal wetland. A brook flowed through the center of the property. The northern portions of the site were adjacent to the interstate interchange, and the southern area is adjacent to residential housing.

Site G: Site G is a 2.1 hectare (5.24 acres) in size, and bounded by the interstate transportation corridor, by residential properties and by a quarry. A small portion of the site is federal wetlands, and the remainder of the site is steeply sloped.

Site H: Site H is a 11.4 hectares (29 acres) in size and was vegetated heavily with green ash, American elm and dogwood shrubs. The site was a federal wetland and portions of the site were state regulated wetlands. Hydrology was sheet flow over a clay soil, causing a perched watertable.

Site I: Site I is a 10.2 hectare (26 acres) in size, half of which was proposed for the location of a substation for the project. The site is farmed, with eastern portions of the site containing some small pockets of federally regulated "farmed wetland" (Regulatory Guidance Letter No. 90-7). A small stream, with adjacent federal wetlands in the floodplain ran through the center of the property. The site was separated from the main Dead Creek wetlands by a railroad corridor.

Site J: This 37 hectare (94 acre) parcel of land is located on the east side of the Dead Creek wetlands nearly opposite the impact area. The western half of the site is regulated state and federal wetland, and the eastern portion of the site is open pasture area, mostly "prior converted cropland" (Regulatory Guidance Letter 90-7). The site is landlocked by the construction of the interstate, but access could be provided through adjacent property owners land. The clay soils were deep and capable of holding water. Surface water sources included adjacent agricultural lands and a NYSDOT drainage ditch. The site was located on the landscape where it could provide functions.

Site K: Site K is a 3.9 hectare (10 acre) parcel of land bounded to the north by the interstate transportation corridor, to the west by state and federally regulated wetlands, and to the south and east by industrial development. The site contained open meadow and sapling shrub vegetation and was a federal wetland area.

Site L: Site L is a 5.1 hectare (13 acre) parcel located within the City of Plattsburgh, on the shores of Lake Champlain, and adjacent to the City Municipal Center, and a city beach and park, with NYSDEC wetlands to the west. The site was filled in the past with sand, but the water table was found at 3 to 6 inches below the fill surface, and the vegetation was dominated cottonwoods and cattails, classifying it as a federal wetland.

Table 4, "Evaluation Matrix For Wetland Mitigation Site Selection, "was used to examine the twelve sites relative to the physical, social, economic and wetland policy factors for which the sites were screened. An "X" in any box indicates that the site met the criteria established for that particular factor. Some criteria, such as inadequate size, or wetlands located or sized so as to preclude other activities, disqualified a site from further consideration.

RESULTS

Of the twelve sites reviewed, Site I and J were very similar in their ratings and showed the most promise as potential mitigation areas. Site J was chosen over Site I for additional consideration because 1) Site I was the proposed location of one of the substations for the project, and Site I did not have sufficient acreage to allow for both the substation and a wetland mitigation area, 2) Site I was separated from the main body of the Dead Creek wetlands by the railroad corridor on the east side of the property, whereas Site J had no barriers between the existing wetlands and the proposed mitigation site, and 3) the physical features of the Site J were ideal for the construction of a mitigation area.

Consisting mainly of open field, Site J was an old pasture with scattered trees, and hedgerows on all sides of the site. The site was determined to be a "prior converted cropland," and while there were some scattered pockets where water would collect, the previous agricultural drainage efforts and land use activities altered the hydrology and vegetation to the extent that the site no longer functioned as a wetland. The site was 37 hectare (94 acre) in size, with half of that NYSDEC wetlands associated with Dead Creek, leaving 15.7 hectare (40 acres) of land for the mitigation and stockpile areas.

Because the site was landlocked, access was a problem. It was originally assumed that access would be made across the adjacent property owner's land in the area of a proposed natural gas pipeline ROW, however, agreements could not be reached with the adjacent landowner. With additional negotiations, an agreement was made with New York State Department of Transportation to move construction vehicles in and out of the site from the interchange on-ramp.

Table 4 - Evaluation Matrix for Wetland Mitigation Site Selection

CONSIDERATIONS/SITES	A	B	C	D	E	F	G	H	I	J	K	L
SIZE OF SITE						X		X	X	X		
EXISTING HABITAT	X	X		X		X			X	X	X	
WETLAND JURISDICTION				X					X	X		
WATER SOURCES	X	X	X		X	X			X	X		X
GEOLOGIC FEATURES	X	X			X	X		X	X	X	X	X
OPPORTUNITY FOR FUNCTION	X	X	X			X				X		
COMPATIBLE ADJ. USES					X	X		X	X	X	X	X
ACCESS	X	X	X	X	X	X		X	X		X	X
PRIOR USES OF SITE	X				X	X		X	X	X		X
ARCHEOLOGY	X	X	X	X	X	X	X	X		X	X	X
LAND COSTS	X	X						X	X	X		
MEETS STATE MIT. GUIDE									X	X		
MEETS FED. MIT. GUIDE									X	X		
TOTALS	8	7	4	4	6	9	1	7	11	12	5	6

Additional studies were conducted on Site J to confirm its use as the mitigation area. Preliminary mitigation plans were prepared showing the relationship of the wetland with the NYSDEC wetland line, and on-site features, as well as the proposed configuration and percentage covertypes of the mitigation area including open water, shallow emergent marsh and shrub swamp, mixes of vegetation and the vegetative communities which would be planted, and where communities would be located. Utilizing the information known about the existing conditions at the cogeneration site, and the proposed mitigation site plans, a Wetland Evaluation Technique or WET analysis (Adamus et al., 1987) was performed to compare the wetland ecosystem at the cogeneration facility with the proposed ecosystem at the mitigation site. WET is a computer program which analyzes the opportunity and effectiveness of a particular wetland ecosystem to provide specific functions typically associated with wetlands.

Table 5, "WET II Analysis, Impact Area Versus Mitigation Site" demonstrates that the mitigation area had a higher overall potential and would be more effective at providing functions associated with wetlands than the cogeneration site. Its greater vegetation diversity and complexity, and open water area allowed the wetland to provide better habitat diversity and open water functions. The mitigation wetland had a larger watershed, and was better designed to provide cleansing functions to pasture and road runoff which would ultimately end up in Dead Creek.

The WET Analysis documented that the mitigation site would provide equal or greater functional benefits as the impacted area. This analysis, as well as other items reviewed during the screening process, documented compliance with New York State and federal wetland mitigation guidelines:

1. While mitigation was not feasible on-site, it was located in the same watershed and the same vicinity as the impacted area.

2. The applicant documented that the area would be a state regulated wetland after the project was complete.

3. The WET analysis demonstrated that the mitigation wetland would provide wetland benefits equal or greater than the impacted area.

4. The wetland mitigation was proposed to provide compensatory mitigation for unavoidable impacts.

5. The mitigation involves restoring a site which probably functioned as a shrub wetland area in the past.

6. The wetland mitigation was proposed as shrub swamp and wet meadow, similar to the mitigation site, with some additional open water and shallow emergent marsh for habitat diversity.

In order to confirm that the hydrology would function on the site, ten monitoring wells were established using 10 foot sections of PFC pipe. The soil boring data was analyzed and groundwater data was collected for a year. The groundwater data and the soil investigation determined that the water table was perched and that the soils had very low hydraulic conductivity. Using this data, an estimate for the required depth of excavation was made to maintain extended periods of inundation. Since groundwater as a sole source of water was questionable, a surficial source was important. A roadside ditch existed adjacent to the interstate highway. By tapping into this ditch, the upstream watershed feeding into the wetland site was expanded from 32.7 hectares (83 acres) to 192 hectares (488 acres). A water budget was then calculated to confirm that the proposed wetland hydrology would function as proposed.

Table 5 - WET II Analysis
Impact Area Versus Mitigation Site
Saranac Cogeneration Project

RESULTS FOR IMPACT AREA

	Social Significance	Effectiveness	Opportunity
Ground Water Recharge	M	L	*
Ground Water Discharge	M	M	*
Floodflow Alteration	L	M	H
Sediment Stabilization	M	L	*
Sediment/Toxicant Retention	M	H	L
Nutrient Removal/Transformation	M	H	L
Production Export	*	L	*
Wildlife Diversity/Abundance	M	*	*
Wildlife D/A Breeding	*	L	*
Wildlife D/A Migration	*	L	*
Wildlife Wintering	*	L	*
Aquatic Diversity/Abundance	M	L	*
Uniqueness/Heritage	H	*	*
Recreation	L	*	*

Table 5 - WET II Analysis (Cont.)
Impact Area Versus Mitigation Site
Saranac Cogeneration Project

RESULTS FOR MITIGATION AREA

	Social Significance	Effectiveness	Opportunity
Ground Water Recharge	M	U	*
Ground Water Discharge	M	M	*
Floodflow Alteration	H	H	M
Sediment Stabilization	H	L	*
Sediment/Toxicant Retention	M	H	H
Nutrient Removal/Transformation	M	H	H
Production Export	*	L	*
Wildlife Diversity/Abundance	H	*	*
Wildlife D/A Breeding	*	H	*
Wildlife D/A Migration	*	H	*
Wildlife Wintering	*	L	*
Aquatic Diversity/Abundance	M	M	*
Uniqueness/Heritage	H	*	*
Recreation	L	*	*

Note: "H" = High, "M' = Moderate, "L" = Low, "U" = Uncertain, and "*"'s identify conditions where functions and values are not evaluated.

In addition, detailed studies were conducted to thoroughly examine Site J for the presence of hazardous waste and archeology resources.

By this point in the permitting process, the amount of wetland mitigation area was finalized at 6.9 hectares (17 acres) of created wetlands, with deep water marsh, emergent marsh, and shrub and tree swamp, and 3.2 hectares (8 acres) of a wetland "restoration area," which would be planted with wetland shrubs and saplings and would receive a greater flow of water from the created wetland area.

Engineering and final mitigation design was completed for the mitigation site, and included a grading plan, with deep water marsh areas having 1.2 to 1.5 meters (four to five feet) of water when full, and excavation of 53,550 cubic meters (70,000 cubic yards), which was to be stockpiled at the site. Water movement through the site was designed to be as serpentine as possible, to slow the water, and retain it for maximum sediment and nutrient removal. The planting plan used natural wetland plants common to the Plattsburgh area, with many species having been present at the cogeneration site. These plants included red maple, green ash, silky dogwood, red osier dogwood and arrow-wood in the shrub swamp areas, rich cutgrass, soft rush, smartweed and bulrushes in the emergent areas, and wild celery and common hornwort in the deep water area. The restoration wetland was planted with red maple, green ash, and black willow. The planting beds were composed of a variety of species to create diverse habitat and provide waterfowl food value, which was important to the NYSDEC.

Construction occurred from September to November of 1993. The site was allowed to settle during the winter, and was planted in May of 1994. Monitoring of the site will continue over the next five years to determine plant survival and coverage rates, use of the site by various animal species, and functioning of the wetland for floodflow alteration, sediment and toxicant removal and nutrient removal and transformation.

DISCUSSIONS AND CONCLUSIONS

There are many benefits to a thorough and methodical site selection process for wetland mitigation:

1. The process assures that all available sites within a defined geographical region or watershed are reviewed, increasing the likelihood that a suitable site will be chosen, and that the wetland mitigation plan will succeed.

2. The process quickly eliminates problem sites, allowing financial and personnel resources to be focused on sites with the highest potential for success.

3. The process provides a method for documenting compliance with federal (and, if present, state) wetland mitigation guidelines, potentially resulting in a faster review of the mitigation proposal by the regulatory agencies.

4. The process increases the resources expended on a site concurrently with an increasing level of confidence, based on analyses, that the site will function as proposed.

5. The process decreases the risk of "surprises" during the construction phase, when delays are most costly, increasing the likelihood that the project will come in on budget.

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ECONOMIC ANALYSES OF WETLANDS MITIGATION PROJECTS IN THE SOUTHEASTERN U.S.

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ABSTRACT

Economic analyses were conducted of numerous wetlands mitigation projects to determine the real costs of successful projects. The work was part of a study conducted by the Maryland International Institute for Ecological Economics. Private consultants were contacted who provided itemized cost data on their projects in spreadsheets or hard copy. The present paper is an analysis of the data relating to various wetlands within the U.S., emphasizing the southeastern U.S. Analyses included preconstruction, construction, and postconstruction costs.

As expected, there was much variation between project costs in the U.S., with a range of between $77,900 per acre and $18,000 per acre (Mean $38,275; S.D. $13,456). Freshwater wetlands were generally much more costly than saltwater wetlands, and construction costs far exceeded pre- and postconstruction costs. Complex or mixed wetlands also showed generally higher costs.

Southeastern wetland types analyzed were predominantly freshwater, but they provide accurate guidelines for the region. In the southeastern U.S., the average wetland cost $23,874 (S.D. $11,410) to construct and succeed. Land costs doubled the mitigation costs. For longer term, successful projects, the cost of maintenance was the major component of postconstruction costs.

INTRODUCTION

Thousands of wetlands mitigation projects have been constructed in the U.S. since wetlands regulations came into effect. Originally the costs of these projects was not given adequate attention during the permitting process, the applicant often agreeing to provide whatever mitigation was necessary to obtain a permit, without realizing the potential for high costs associated with the work. As a result, mitigation projects were often not begun or completed. Agencies began requiring proof of sufficient financial resources for projects, including project budgets and dedicated funding. Budgets for mitigation projects are now necessary in many states, and mitigation costs have been itemized and standardized. The analysis of these itemized budgets was the primary goal of the present research. To determine itemized costs, budgets were obtained for "successful" projects throughout the U.S., successful meaning that they had met the permitting criteria and had been in compliance for over two years. This paper contains a summary of project costs, with itemizations, for the entire U.S., and with emphasis on the southeastern states of Florida, Georgia, and South Carolina.

METHODS

A number of data bases were used to derive mitigation costs. The University of Maryland Center for Environmental and Estuarine Studies collected data in 1993 for approximately 1,000 projects; the itemized data for 90 projects were collected directly by the Center (the primary data base) and the remainder were collected by other sources. Coastal Science Associates, Inc. (CSAi) collected itemized data from about thirty projects they were responsible for in the southeastern U.S., adding those to the regional list. Projects were itemized within the categories preconstruction, construction, and postconstruction, and dollar amounts were separated into the categories labor, materials, equipment, and other. Preconstruction costs were design and permitting; construction costs were land (omitted), earthwork, and planting; and postconstruction costs were maintenance and monitoring. Cover sheets and blank budget sheets were submitted to various firms and agencies for completion of the primary data base. Databases were entered onto spreadsheets software for analysis.

Databases for eight categories of created/restored wetlands were generated, as follows:

(1) Aquatic Bed Projects, tidal or nontidal submerged plants;
(2) Complex Projects, three or more wetland types in a project;
(3) Freshwater Mixed Projects, nontidal projects with both forested and

emergent vegetation;

(4) Freshwater Forested Projects, woody vegetation (forest or shrub);
(5) Freshwater Emergent Projects, emergent (herbaceous) vegetation;
(6) Freshwater Tidal Wetlands Projects, tidally influenced, often mixed emergent/woody vegetation;
(7) Saltmarsh Projects, dominated by marine emergent vegetation; and
(8) Mangrove Projects, mangrove dominated wetlands.

Table 1. Summary of various mitigation costs and cost components for the southeastern states of Florida, Georgia and South Carolina (N=30; S.D. shown for larger date sets).

Parameter	Mean/S.D. Cost $/acre
States	
Florida	24,899/10,919
Georgia	23,200/11,467
South Carolina	20,247/12,409
Wetland Type	
Aquatic Bed	20,140
Freshwater Mixed	20,540
Freshwater Emergent	31,793
Freshwater Forested	20,696
Salt Marsh	34,145
Mangrove	16,652
Construction Phase	
Preconstruction	3,109/1,280
Construction	15,954/4,354
Postconstruction	4,932/1,608
Maintenance, by Type	
F.W. Emergent	4,654
F.W. Forested	3,021
Mixed	4,740
Plant Source Costs	
Nursery	32,857
Forestry Department	3,070
Wild Stock	28,688

Figure 1. Mitigation costs - nationwide.
(1993 data; sans land; n=90)

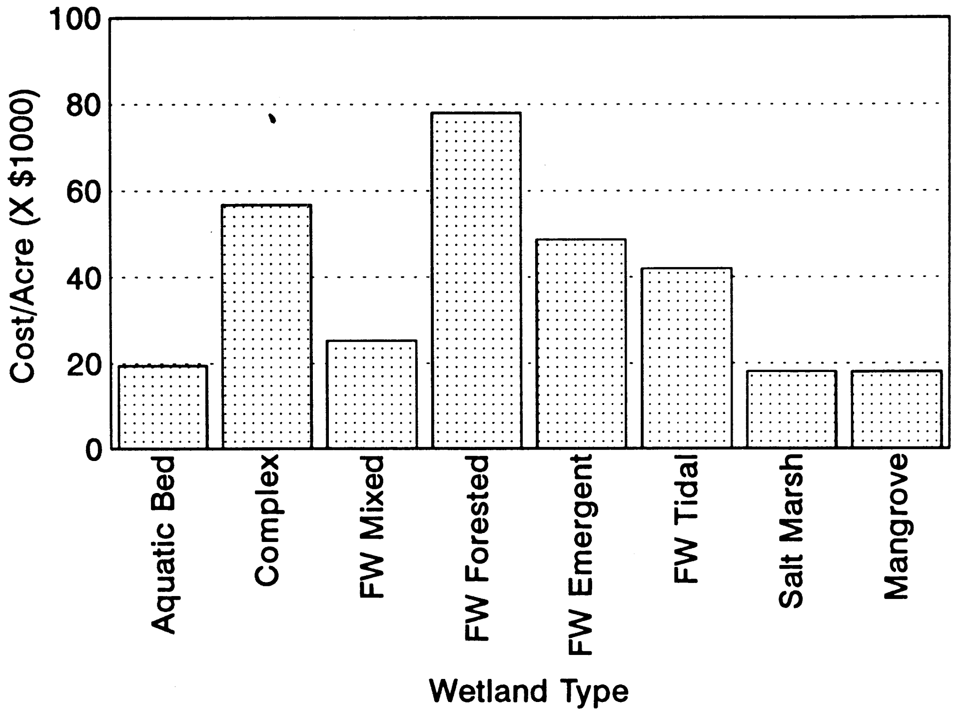
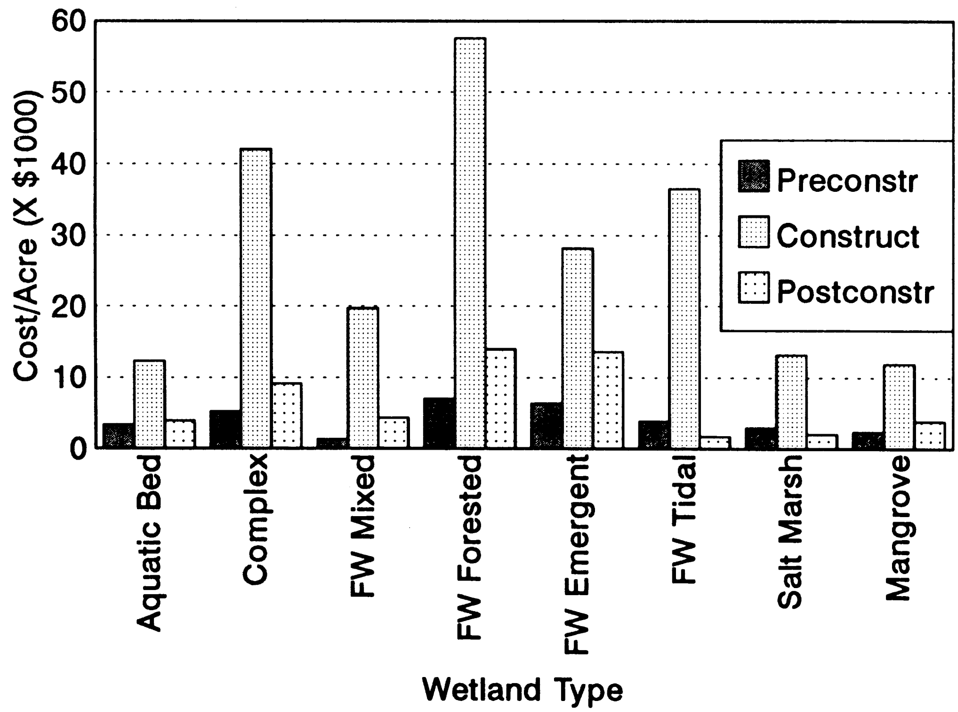


Figure 2. Project costs by phases - nationwide.
(1993 data; sans land; n=90)



RESULTS

In database evaluation, some weaknesses were seen in the inability to separate costs into categories, the differing intended functions of the created wetlands, and the use of volunteers in various projects which complicated costing. The cost of land was another complicating factor because it was lacking or inconsistent. Agricultural conversion (or reversion back to wetland), common in the midwestern U.S. but rare in the southeast, was used only to a limited extent in the nationwide analysis.

Using the primary nationwide database, without land costs, gave consistent costs for various categories (refer to King and Bohlen, 1994a, for original data). A summary of cost per acre by wetland type is depicted in Figure 1 and shows freshwater forested wetlands were most expensive, averaging approximately $77,900 per acre. Mangrove and salt marsh projects were least expensive, averaging approximately $18,000 per acre. Obvious differences exist between costs for freshwater vs saltwater projects using nationwide statistics gives an average of $48,475 per acre for freshwater and $18,050 per acre for saltwater; however, the variability of the data precluded meaningful statistical analyses. A breakdown of these costs is given for each project type in Figure 2. As shown, the majority of costs are associated with construction, with postconstruction costs appearing to be higher in freshwater projects. To further analyze these costs, a breakdown of construction vs postconstruction costs is given in Figure 3. As shown, freshwater emergent (marsh) types have the closest totals, with construction costs comprising 58 percent, and postconstruction costs comprising 28 percent, of the total. The highest disparity, an 83 percent difference between construction and postconstruction costs, was seen with freshwater tidal wetlands. The complex and mixed wetlands showed slightly larger disparities than other categories.

The 1993 data for 30 southeastern U.S. projects provide similar comparisons, and more details were collected by the authors which allowed further analyses. Overall mitigation costs for three southeastern states are given in Figure 4. Without land costs, cost-per-acre averages of $24,899 (S.D. $10,919), $23,200 (S.D. $11,467), and $20,247 S.D. ($12,409) were obtained for Florida, Georgia, and South Carolina, respectively (overall mean $23,874; S.D. $11,410). These averages were derived by the number of projects. This method factored in the cost-per-acre differences between large and small projects. If total project costs are divided by total acreage, the overall mean is much lower, $14, 869 per acre. Land costs, computed solely for Florida, but based on only seven projects, added $26,179 to the mitigation cost (per acre), doubling the average cost.

Figure 3. Construction vs postconstruction costs - U.S.
(1993 data; sans land; n=90)

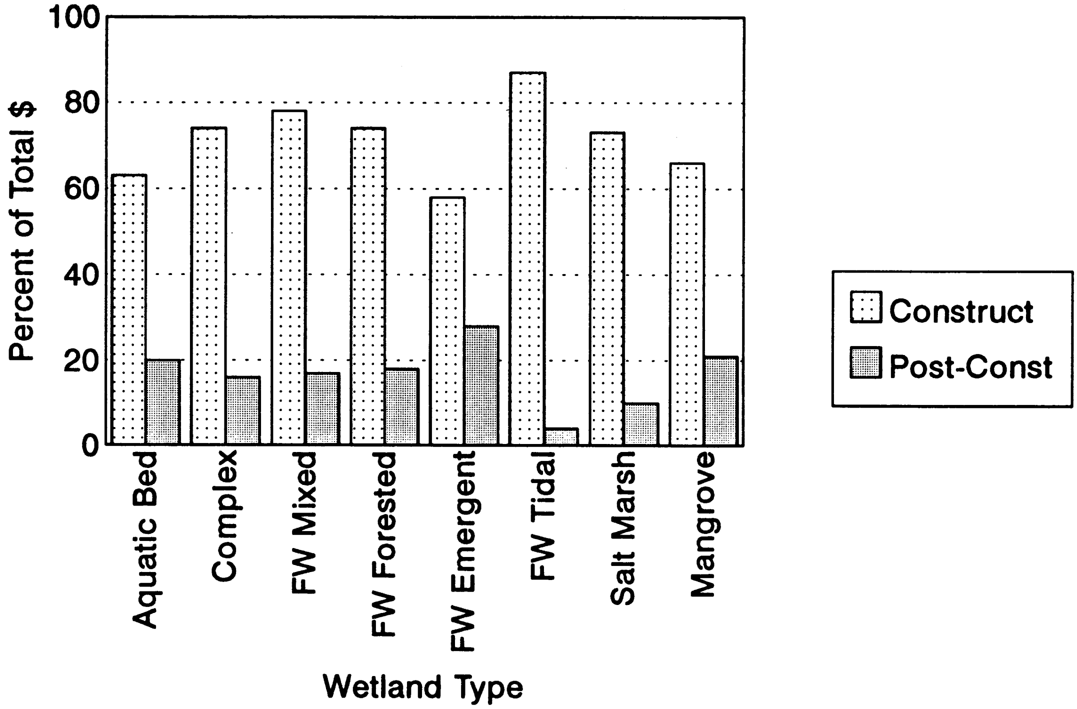


Figure 4. Cost comparison between three states.
(1993 data; sans land; n=30)

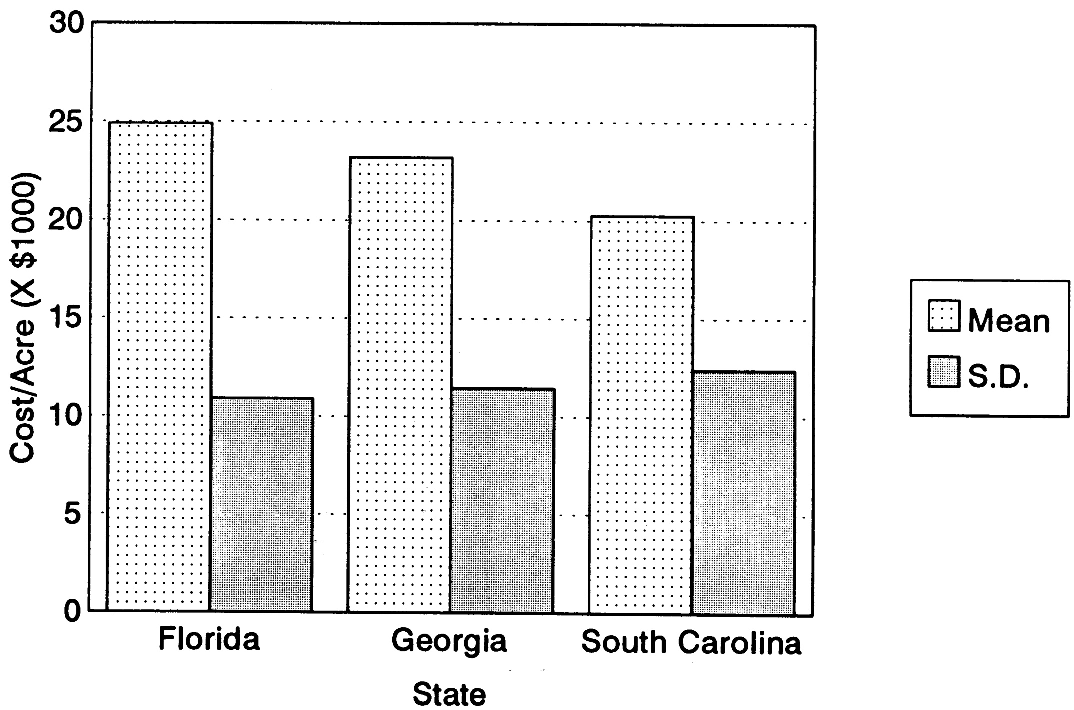


Figure 5. Mitigation costs - nationwide vs southeast.
(1993 data; sans land; n=90)

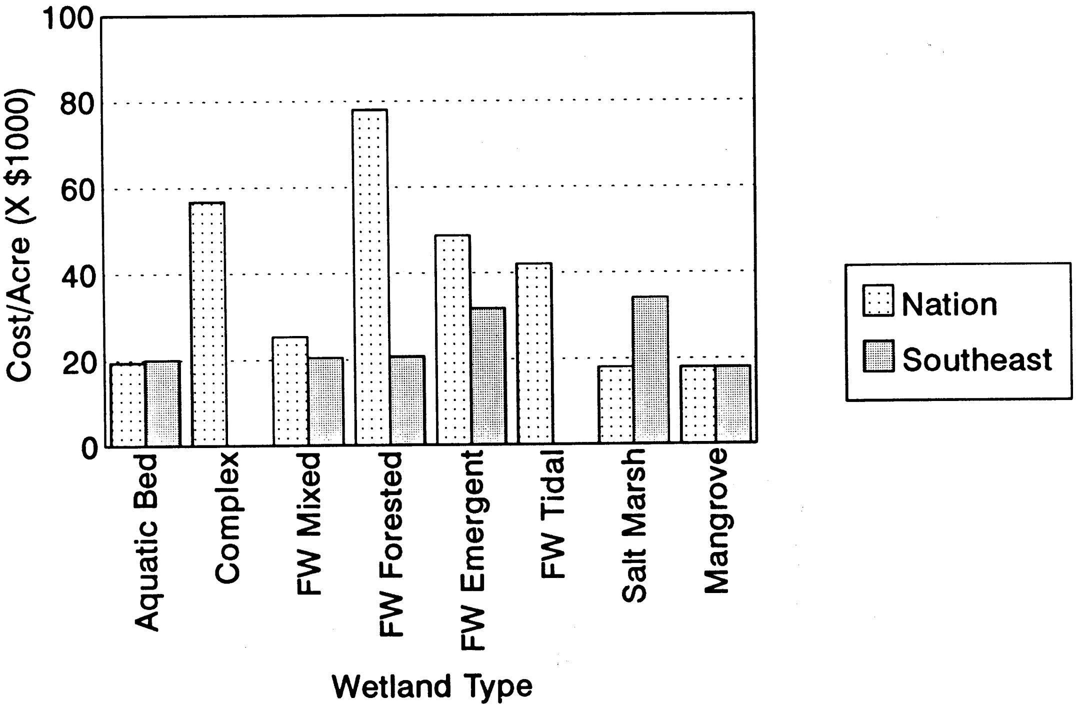
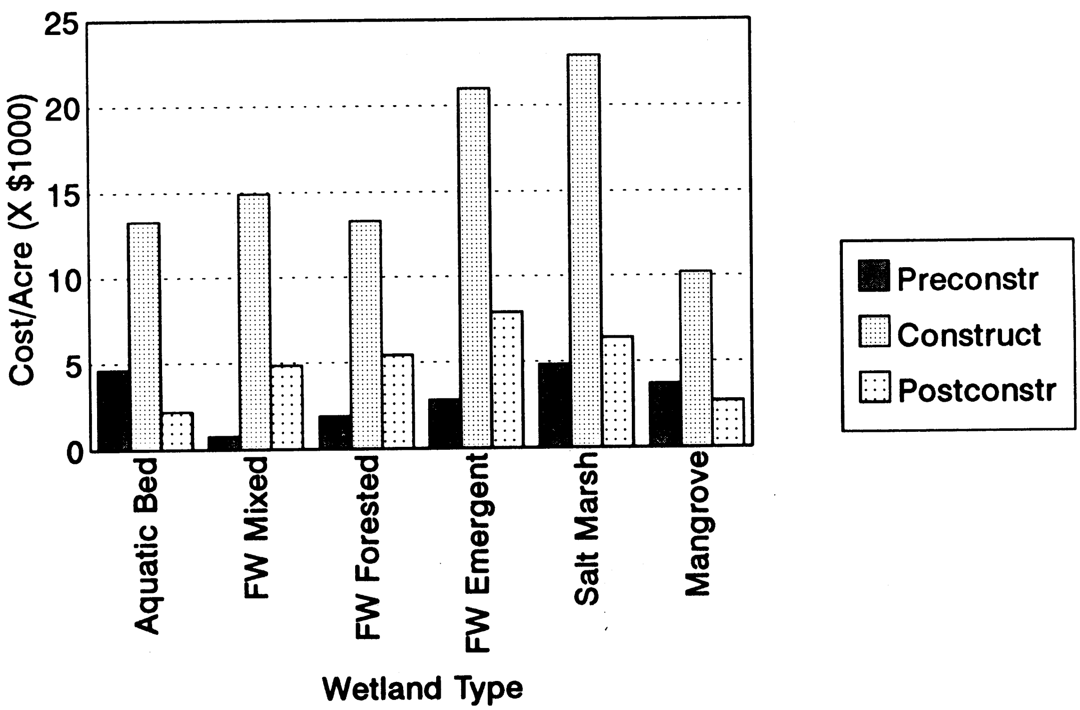


Figure 6. Project costs by phases - southeast.
(1993 data; sans land; n=30)



Southeast breakdowns of costs by wetland type were similar in some cases to the nationwide costs given above, but there were distinct differences. As shown in Figure 5, and as compared to Figure 1, costs in the southeast were much smaller for freshwater forested wetlands and freshwater emergent wetlands, and much larger for salt marsh. However, the relatively small number of project for each type precluded statistical comparisons. King and Bohlen (1994b) found that total cost differences between nationwide and southeastern projects were significant, using Analysis of Covariance (ANCOVA). Southeast project costs, by construction phases, are given in Figure 6, and these are also similar to nationwide costs previously shown in Figure 2. Differences, such as with freshwater forested types, indicate that construction costs were the main variable.

A summary of various other cost comparisons for the region is given in Table 1. Construction phase costs indicated the same trend as nationwide, with actual construction costs being approximately twice the total of pre- and postconstruction. A large component of postconstruction costs was maintenance, which involves weed control, hydrology maintenance, and replanting. As shown, forested wetlands required the least maintenance, presumably because of less competition by weedy vegetation relating to the larger starting tree size. Herbaceous wetlands develop emergent weeds such as cattails which are difficult and costly to control, and starter plants are usually bareroot and/or small in size. Mixed wetlands are costly by virtue of the different methods needed for the variety of species and wetlands created.

Plant source costs provide insight into this important cost component. Nursery stock costs are Freight On Board from various Florida producers. Their larger size and better root structure aided in survival. However, they were not used in enough projects to increase the average overall project cost of $24,849. Forestry Department refers to state tree suppliers. Trees are bareroot and 3-4 feet tall. Since these trees were used often in southeastern projects, they kept project costs low. However, they required more maintenance and replanting (recent plans require larger and/or potted plants). Wild stock were removed from the wetland to be impacted, or from adjacent or area wetlands. Plants were "heeled in," potted, or planted directly into the mitigation site. Although these plants are "free," the costs of digging, heeling/potting, and installation are considerable, making these plants nearly as costly as nursery stock.

CONCLUSIONS

Analyzing a large and selective data base has provided an indication of mitigation costs in the U.S. and southeastern region. Caution is advised in applying and using this information, however. Data were collected in 1993 for projects constructed in, or before, 1990. In addition, new practices such as wetland banking were not taken into account, and refinements in wetland techniques have occurred since these projects were constructed. The size of the database, as well as that of the statistical analyses of the data, precluded their inclusion. The reader is referred to King and Bohlen (1994a,b) for such detailed information.

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RESTORING ENVIRONMENTALLY DAMAGED LANDS FOR PUBLIC USE AND CONSERVATION

by
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ABSTRACT

The Maryland-National Capital Park and Planning Commission (M-NCPPC) has completed over a dozen restoration projects on environmentally damaged lands in Prince George's County, Maryland, utilizing non-traditional funding sources and innovative methods. The majority of projects involved the reclamation of abandoned sand and gravel mines, and included the recreation or creation of freshwater non-tidal wetlands. Among the techniques used in the restoration or recreation of wetland areas are site assessment and evaluation of existing natural features prior to restoration, through hydrology and soil studies, and the use of a self-operated native wetland plant nursery. Most projects utilized volunteers during and after construction, and all projects had public use and wildlife habitat improvement as a goal.

INTRODUCTION

The Maryland-National Capital Park and Planning Commission (M-NCPPC) is responsible for parks, recreation, and planning in Prince George's County, Maryland, a rapidly urbanizing county of metropolitan Washington, D.C. Rich sand and gravel deposits located throughout the county have been extensively mined for more than two hundred years. Historically, there were very few controls on the surface mining of sand and gravel, and until recently, sites were often left in a scarred and degraded condition from mining operations. Marginal or mined out sites were often abandoned with little or no attempt at reclamation.

For many reasons, the M-NCPPC acquired a large number of these abandoned mine sites as park property. Most often they were acquired because they were located in or near stream valleys and river floodplains and, thus were included in stream valley and river park land acquisition programs.

In the 1970s, as a result of agency commitment and citizen advisory panel encouragement, the M-NCPP began reclamation efforts on a number of these sites. To date, we have completed about fifteen projects with varying degrees of success. Projects have ranged from simple stabilization, complete re-contouring and replanting, and pond construction to freshwater non-tidal wetland creation and restoration.

Sites varied considerably in location, elevation and condition, but there were several features common to all. Most sites were obtained at little or no cost. Most sites were relatively small in size, namely one to ten hectares. Most sites were mined to or below the water table. This mining practice resulted in excellent potential for wetland creation and restoration. Even the most scarred sites often had remnant native plant populations and seed banks including those of wetland species.

Looking back over the twenty years that our agency has been reclaiming environmentally damaged sites, we note that our methods have changed substantially. In the 1970s, we were pioneers in wetland restoration projects in our area. Often there were no guidelines or accepted practices, and few permits were required. Many of the early projects were simply trial-and-error that sometimes worked and sometimes did not.

STUDY SITES

Three representative examples of sites that the M-NCPPC has restored on the Patuxent River, approximately equidistant from Annapolis, MD, Baltimore, MD, and Washington, D.C., illustrate the challenges of attempting to restore environmentally damaged lands for public use and conservation. These sites are the:

- **Phelps property** (now known as the **Patuxent River Izaak Walton League Center**),
- **Fleming property** (now known as a portion of the **Patuxent River Natural Resource Management Area** of the State of Maryland), and
- **Myrtle Henry property** (now known as the **Fran Uhler Natural Area*** of the Patuxent River Park).

The Phelps property/Izaak Walton League Center was a 30 hectare site seriously degraded by thirty years of sand and gravel mining. Subsequent post-mining uses for gravel-washing, asphalt-batching, and rubble-filling added to degradation. The topography was very scarred and numerous spoil piles were scattered across a desert-like site. Rubble was dumped in a helter-skelter fashion among the rusting remains of an asphalt batching plant and gravel separation operation. A relatively undisturbed small stream with undisturbed stream banks bisected the property and was not included in the project. The successful restoration of this site and the creation of non-tidal freshwater wetlands typified some of the best examples of our restoration projects.

In the early 1980s, we learned that the Maryland State Highway Administration was looking for mitigation sites due to wetlands destroyed by highway construction and that they had funding in hand. We also learned that the Maryland State Department of Natural Resources was looking for model surface mine reclamation projects and also had funding available. By combining state agency funding with our own in-kind services (planning, engineering, heavy equipment support), we were able to package about $350,000 of outside funding with our own in-house efforts to complete two separate restoration projects involving 12 hectares of upland and 4 hectares of wetland restoration and creation. Contributing to the success of the project was that we were able to expedite the permit process by having state agencies involved, and that we were able to move very quickly in the design and completion of the project. The participating state agencies were extremely pleased with the results and we established ourselves as a reliable partner in wetland restoration projects. Because of the success of this project, we have subsequently completed a number of other wetland mitigation and mine reclamation projects, and have often combined inter-agency funding.

An interesting lesson to the Phelps property restoration was that it illustrated a principle that is sometimes questioned by wetland practitioners, namely "don't be afraid to take a chance." Some will quibble, but this has been the key to some of our best successes. In this particular project, for example, State Highway Administration engineers insisted that created wetlands on the site would not hold water. We believed they would because of the presence of a number of remnant wetlands remaining from mining operations and the presence of numerous groundwater springs. Eventually we had to sign a waiver exempting them from responsibility. The site held water beautifully, and the State Highway Administration eventually won a national award for the project. We have learned that a poorly planned approach is no substitute for a good hydrology study, but we also know that common sense and past experience can be a reliable indicator as to the eventual success of creative ideas in restoration projects.

Throughout the course of the restoration, members of the Hyattsville chapter of the Izaak Walton League of America (IWLA) assisted in management, security, and restoration aspects of the project. The IWLA have leased a portion of the site to conduct environmental education programs and club activities. They participate in the monitoring and management of this site and regularly assist park staff in presenting fishing clinics, environmental education programs, and other programs.

The Fleming Property, now known as a **Patuxent River Natural Resource Management Area** of the Maryland Department of Naural Resources, was a 2 hectare restoration site consisting of an abandoned sand and gravel mine and gravel separation plant. Several head walls remained from the mine, and a number of a large spoil piles and cobble piles remained on the site. A .5 hectare pond created by beavers was located at the edge of the decertified mine site, and had a surprisingly high quality diversity of plant and animal life.

The project consisted of a 3 hectare restoration plan which included 1 hectare of non-tidal freshwater wetlands. The total project cost was approximately $300,000 which was principally funded by State Highway Administration mitigation funds. A design goal of this project was to incorporate environmental education an nature interpretation themes into the final restoration plan. A perimeter trail was built around the recreated wetlands and interpretive signs and benches were used extensively in the replanting of recontoured hillsides and Compro (a digested sewage sludge compost) was applied liberally to the upland soils of the reclaimed site.

The beaver pond was left intact and carefully connected to the created wetlands. Native emergent and sub-emergent wetland plan species quickly re-colonized the new wetlands.

The third representative project was the reclamation of **the Myrtle Henry Property**, now known as the **Fran Uhler Natural Area** of Patuxent River Park. The restoration of this 12 hectare site is noteworthy in several ways in that the purchase price of $52,000 was donated by Francis M. Uhler, a retired federal wildlife biologist, and that the reclamation involved the removal of 800 tons of trash from the site, the majority of which was collected and consolidated by volunteers of the Prince George's Audubon Society.

The Myrtle Henry site presented a unique challenge to our agency. Long identified as an illegal dump site and suffering many types of abuse because of absentee ownership, this degraded property was a glaring example of the inability of government to prevent inappropriate and environmentally destructive uses of river floodplain's Clean Lot Ordinance and threats of lien on the property, the property owner negotiated the sale to the M-NCPPC who agreed to perform restoration in an as environmentally sensitive manner as possible.

Enlisting the help of the Prince George's Audubon Society in the National Audubon Society's Adopt-A-Refuge program, the M-NCPPC spearheaded a clean-up which took approximately three years to complete. The careful removal of trash from the site and restoration of the worst of the surface mine scars restored the property to a surprising and refreshingly pristine condition. The volunteers of the Audubon Society now conduct bird and nature hikes, wildflower walks, compile plant and bird lists, and participate in regular clean-ups and trail maintenance projects.

An important factor in the restoration of environmentally damaged lands by a public agency is that there are often no funds appropriate purely for restoration and reclamation purpose. Land acquisition may be relatively simple and inexpensive, but funding for restoration is nearly impossible to obtain. Given that set of circumstances, M-NCPPC staff set out to find non-traditional funding sources to initiate restoration projects and bring them to completion. Over the past decade, we have been extremely successful in identifying sources of funds such as state demonstration grants, highway mitigation funds, surface mine reclamation funds, and other creative sources. In almost all cases we used multiple sources of funds to complete larger restoration projects. The proposal to combine funding from different agencies was not an impediment to the participation of those agencies, and in fact was sometimes an inducement.

MATERIALS AND METHODS

Methods varied widely for restoration according to the specifics of the individual sites. The most common pattern for restoration projects of environmentally damaged sites consists of the following:

- **Initial site evaluation** including wildlife surveys, identification of special features (springs, wildlife habitat areas, presence of rare and endangered plants, scenic views, etc.)

- **Initial site topographic survey**

- **Hydrology study**

- **Soils Analysis**

- **Preparation of Conceptual Design Plan**

- **Permit Review** (and grant submissions, if needed)

- **Preparation and Review of Final Engineering Plan**

- **Release for Contract or Self-Construct**

Generally, in the reclamation of environmentally damaged sites, we have attempted to do a cut and balanced fill wherever possible, and to minimize the import/export of material from the site. The initial site evaluation and conceptual design phases attempt to work with the features of the site. In our experience conditions have varied widely. Site evaluation must be flexible and realistic, and timetables should not be hurried.

RESULTS

As a result of our agency commitment to engage in the practice of wetland restoration and creation, we note the development of several trends. More an more, for example, we are involving the cooperation of mine owners and operators in restoration projects. Sand and gravel mine sites generally used to be regarded as waste sites. Often the "reclamation" process consisted of turning the site into a sludge disposal area or rubble fill at the end of mining operation. More and more, however, the highest and best use of an abandoned sand and gravel mine site is perceived as one that is used for conservation and, where possible, public recreation. Not only does this practice enable mine owners and operators to give something back to the community owners and operators to give something back to the community which they impacted, but it shows a good faith commitment on their part when they apply for permit extensions or new permits. We now see mine owners and operators getting involved in projects up front as cooperators as opposed to walking away form sites that they have left in a degraded condition.

As a park and recreation agency, we have always made excellent use of volunteers, and now we see them as indispensable in both the restoration process and the long-term eventual management of sites for public use and conservation. The payoffs are numerous, both to the participating volunteers and to the agencies who use them. An added benefit is that they reduce the total cost of contracted services and they help to develop public policy for the long-term protection and management of wildlife habitat areas on reclaimed sites. An important consideration about volunteers is that they become your most effective constituency for the publicly supported funding of wetland restoration and reclamation.

We have seen that there is a fundamental need to develop advocates for wetland and wetland restoration. We have found that there is intense public interest in wetlands restoration, and there is often a corresponding public relations benefit that accompanies successful restoration projects. Both public and private owners of created or restored wetlands can tap into the favorable publicity and many benefits that accrue from an appreciative audience.

Among the steps that enable you to capitalize on successful restoration projects are the following:

- **Publicize your successes.** Invite local newspapers or TV news operations to visit sites. Especially provide them with before and after photographs.

- **Have dedication ceremonies,** and give everyone credit including politicians who did not even know about your project before they saw it completed. They will be more likely to support future requests for restoration funding.

- **Give everyone involved credit.** Nominate your designers and contractors for awards. At a minimum they will appreciate the nomination, and if you win, you have an "award-winning project."

- **Whenever possible, utilize volunteers.** Volunteers reduce project costs, act as a constituency, and provide instant public relations. They usually help in management after restoration is complete.

- **Incorporate education and interpretation into the final project design.** Set aside small portions of total project cost for interpretive and educational signage, and factor in public accessibility wherever possible.

An unexpected result of our commitment to public restoration has been the development and operation of a wetland plant nursery. Stimulated by the desire to make restoration dollars go further and accomplish more, staff of the M-NCPPC plant seeds from park properties. Seeds were germinated and propagated experimentally. Once we established methods for successfully and economically propagating about 30 wetland species, we entered full production stage, and now produce between 20,00-50,000 plants annually for restoration projects. Several agencies put up seed money (no pun intended) and now draw from the plant bank for their own projects. Plants grown from the locally collected native seed have the added advantage of being climate and soils adapted and, thus have a much higher success rate after transplantation.

CONCLUSION

In summary, the Maryland-National Capital Park and Planning Commission has proven that public agencies can effectively and economically reclaim environmentally damaged lands for public use and conservation. The methods employed by the M-NCPPC have proven that non-traditional funding sources, creative design, and practical experience based on both accepted procedures and trial-and-error methods, can produce high quality created or restored wetlands. Environmentally damaged properties which wind up in the public domain are satisfactorily restored to original or better condition, have the added benefits of creating a public constituency for wetland restoration projects. Intergovernmental cooperation and the support of volunteers are critical to the success of such projects. Education, interpretation and public accessibility should be a design goal of wetland restoration projects whenever feasible and practical.

ACKNOWLEDGEMENTS

Wesley R. Johnson, Planning Coordinator for the Park Planning and Development Division of the Maryland-National Capital Park and Planning Commission in Prince George's County is gratefully acknowledged for his contributions to this paper and his leadership in wetland restoration projects of the M-NCPPC.

FISHERY VALUE OF A SARASOTA BAY, FLORIDA HABITAT ENHANCEMENT PROJECT

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ABSTRACT

A system of restored intertidal marshes and newly-created saltwater ponds was monitored by seining each of the five ponds in the 1.8-ha project twice a month over a nine-month period. Distinct differences between the individual ponds were found with respect to fish abundance and community structure. Differences appeared to be attributable mostly to bathymetry and hydrology. Three shallow ponds were dominated by marsh species that live only in very shallow environments during their entire life cycle, while the two deepest ponds were dominated by juvenile stages of estuarine species (including commercially and recreationally valued species) that utilize deeper, open-water habitats as adults. The results of the study and information from studies of natural estuarine habitats indicate that with careful design, habitat restoration projects can make valuable contributions to fisheries, whereas projects lacking such design may have negligible fishery value.

INTRODUCTION

Habitat loss and degradation recently has been recognized to be an important general problem in many bays and estuaries. The most extensive and arguably most important losses have been to shallow and fringing intertidal environments. For example, losses including 78% of natural shorelines (Roat and Alderson, 1990), 35% of seagrass area (Duke and Kruczynski, 1992) and 46% of wetlands (Estevez, 1992), have been documented for Sarasota Bay, Florida. Similar losses have occurred in order bays and estuaries in the region. About 44% of Tampa Bay's intertidal marshes and mangroves and 81% of its seagrass meadows have been lost since the 1800's (Lewis *et al.*, 1985). Between 1945 and 1982, 51% of Charlotte Harbor's saltmarshes and 76% of its intertidal flats were lost (Harris *et al.*, 1983).

Estuarine habitat loss has long been known to be a major cause of fishery declines (Lindall and Saloman, 1977). Losses of salt marshes, mangroves and interfacing shallow subtidal habitats can have significant negative impacts on fishery productivity and carrying capacity. Losses of intertidal and shallow subtidal habitats are particularly critical relative to fisheries by virtue of the importance of these environments as essential nurseries for recreationally and commercially valuable fish and invertebrates (Weinstein, 1979, Edwards, 1989).

Creation or restoration of intertidal wetlands habitat recently has received considerable attention. Initially these endeavors were generally justified because of the extent to which many systems had experienced wetlands habitat losses. More recently, habitat restoration/creation efforts are being specifically justified by their potential contribution to fisheries through production of fish and other organisms (Lewis, 1992). In most bays or estuaries that have experienced large habitat losses, the amount of shoreline available for wetlands habitat creation, restoration or enhancement is very limited and is restricted to that which is publicly owned, that which can be publicly-acquired at a reasonable cost, or that which can be publicly-owners are willing to provide. In these circumstances, it follows that if habitat restoration is to make a significant contribution to fisheries, each project must be highly-effective and productive or as close to optimally-productive as is reasonably possible. Unfortunately, with regard to fish and fisheries, techniques for creating optimally productive habitat have yet to be developed and tested.

In this light, an experimental habitat restoration in Sarasota Bay was implemented in early 1989 as a Priority Action Plan Demonstration Project of the Sarasota Bay National Estuary Program (NEP), with funding form the U.S. Environmental Protection Agency and the Florida Department of Environmental Regulation (FDER). The project concept involved creation of wetlands habitat that was ecologically complex, diverse and highly integrated, in the hopes that such habitat would be highly productive with regard to valuable fisheries species. Project construction and initial planting was completed in December 1990. Since one of the strongest justifications for the project included a monitoring component which was designed to assess the degree to which the intertidal wetlands creation was sufficient to result in high levels of fishery productivity.

METHODS

Study Site

The study site was a 1.8-ha area adjacent to Sarasota Bay on City Island (CI) and consisted of a series of five created, interconnected saltwater ponds and associated planting of a diverse community of wetland and ecotonal upland vegetation (Fig. 1). The system of ponds is connected to the bay through one main outlet. Bathymetry of the ponds is shown in Fig. 2.

Sampling Techniques

Sampling stations were established such that approximately the same area of water was sampled in each pond with a 0.6-cm mesh (bar) seine 1.8 m deep, 9.1 m long, with a 1.8 m x 1.8 m bag. Fish and macroinvertebrates were identified, counted, measured, and released. The ponds were sampled 18 times between January, 1991 and April, 1992 during the highest high tides and lowest tides of each lunar month, as specified by FDER. Additionally, the ponds were completely sampled to determine the number of juvenile snook residing in each pond on 10/30/92. Pond 1 and Pond 2 were each sampled with four seine hauls that covered the entire area of each pond. Ponds 3, 4 and 5 were sampled with single hauls that took in each pond entirely.

RESULTS AND DISCUSSION

Total Fish Abundances

A total of 6,282 fish comprising 23 species or taxa were collected during the monitoring (Table 1). The totals for individual ponds ranged from 956 (Pond 1) to 1,753 (Pond 2).

Species Composition

Sheepshead killifish (*Cyprinodon variegatus*) was the most abundant species, accounting for 1,795 (29%) of the fish collected at all stations and all events. Mojarras (*Eucinostomus* sp.) (993, 16%), silversides (*Menidia* sp.) (628, 10%), longnose killifish (*Fundulus similis*) (513, 8%), sailfin mollie (*Poecilia latipinna*) (511, 8%), spot (*Leiostomus xanthurus*) (449, 7%), Gulf killifish (*Fundulus grandis*) (445, 7%) also were numerically important. Together, the above species accounted for 85% of all fish collected. Five species of local commercial or recreational value were collected: striped mullet (*Mugil cephalus* - 196 individuals), red drum (*Sciaenops ocellatus* - 22), snook (*Centropomus undecimalis* - 14), black drum (*Pogonias cromis* - 10), and permit (*Trachinotus falcatus* - 1). All specimens of Brevoortia in the reference collection were identified as gulf menhaden (*B. patronus*) and all *Menida* were identified as tidewater silversides (*M. penninsulae*). Macro-invertebrates were not abundant; only 58 individualswere collected, including 34 portunid crabs, 8 cariden shrimp and 5 penaid shrimp.

Temporal Patterns

Figure 3 shows the total catch from each pond at each sampling event during the monitoring period. Several species showed distinct seasonal patterns of abundance. Snook first appeared in the samples in November (sampling event 8) at a size of around 50 mm standard length (SL). They either had been in the pond for a month or more and were missed in prior collections, or they had metamorphosed into juveniles (at around 25 mm SL or less [Edwards and Henderson, 1987; McMichael *et al.*, 1989]). One early-juvenile red drum (31 mm SL) was collected in December, but the rest were collected after January. This corresponds well with red drum spawning and recruitment patterns found in Tampa Bay (Petes and McMichael, 1987) and the Manatee River estuary (Edwards, 1991). Juvenile black drum were collected early (August - December) in the monitoring period; their sizes (84-124 mm SL) indicated that they were young of the year that entered the ponds sometime after their late winter early spring spawning period (Murphy and Taylor, 1989). Juvenile striped mullet, spot and pinfish also are winter spawning species and began to be collected as small early juveniles after mid January. Several other species including silversides, gulf killifish, and mojarra appeared to demonstrated bimodal patterns with peak abundances occurring in the fall, followed by low abundances during winter and increasing abundance in late winter/early spring. Gravid adult silversides were collected in November, indication that this species can complete it's life cycle in the ponds. Bay anchovies were present after late september, but their abundance was highest after November. Juvenile menhaden were most abundant in the early fall, after which time they were present but not abundant. Sheepshead minnow and longnose killifish did not show distinct seasonal patterns of abundance, probably because these species are permanent residents with protracted spawning periods.

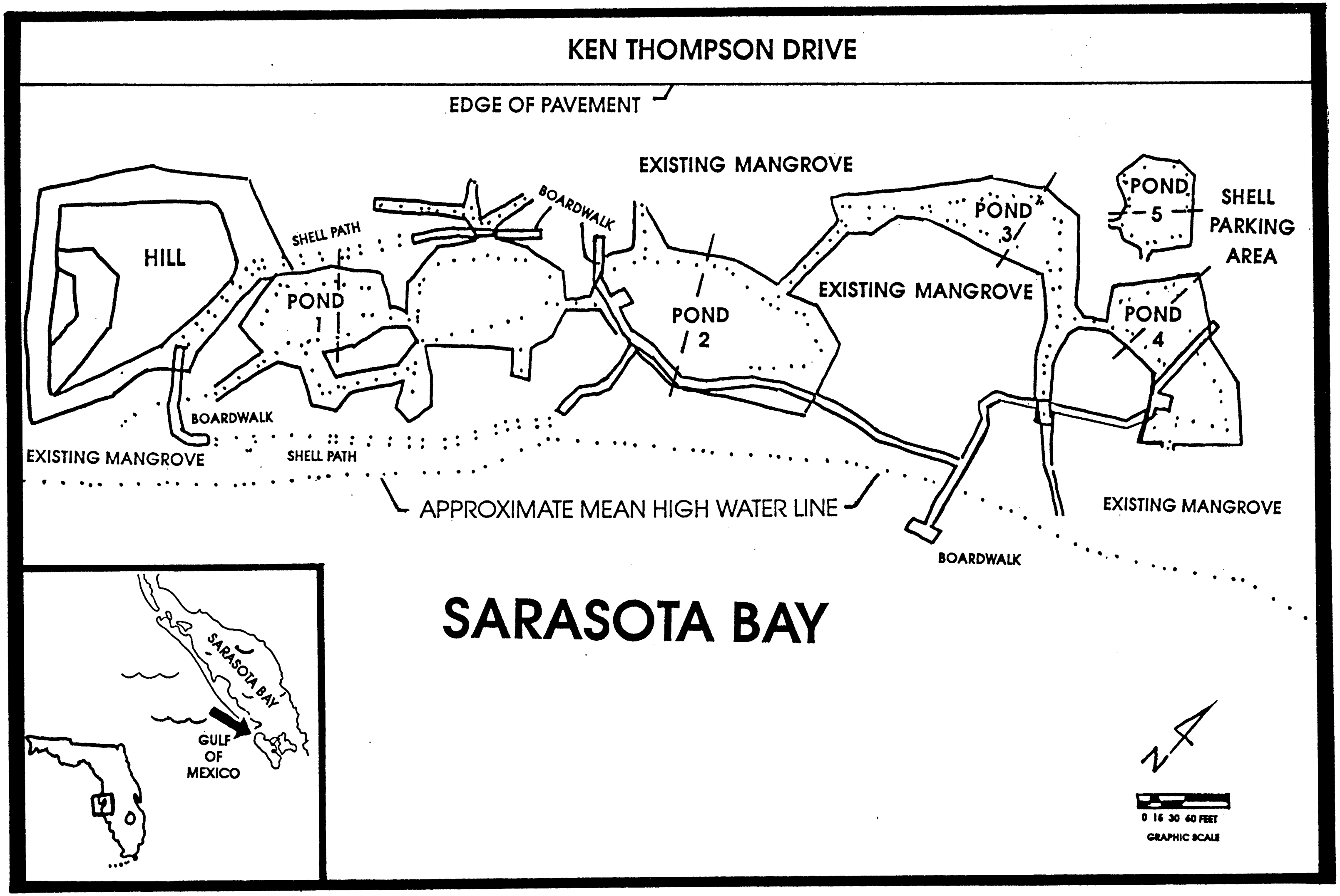

Figure 1. Study site and bathymetry transects (dashed lines).

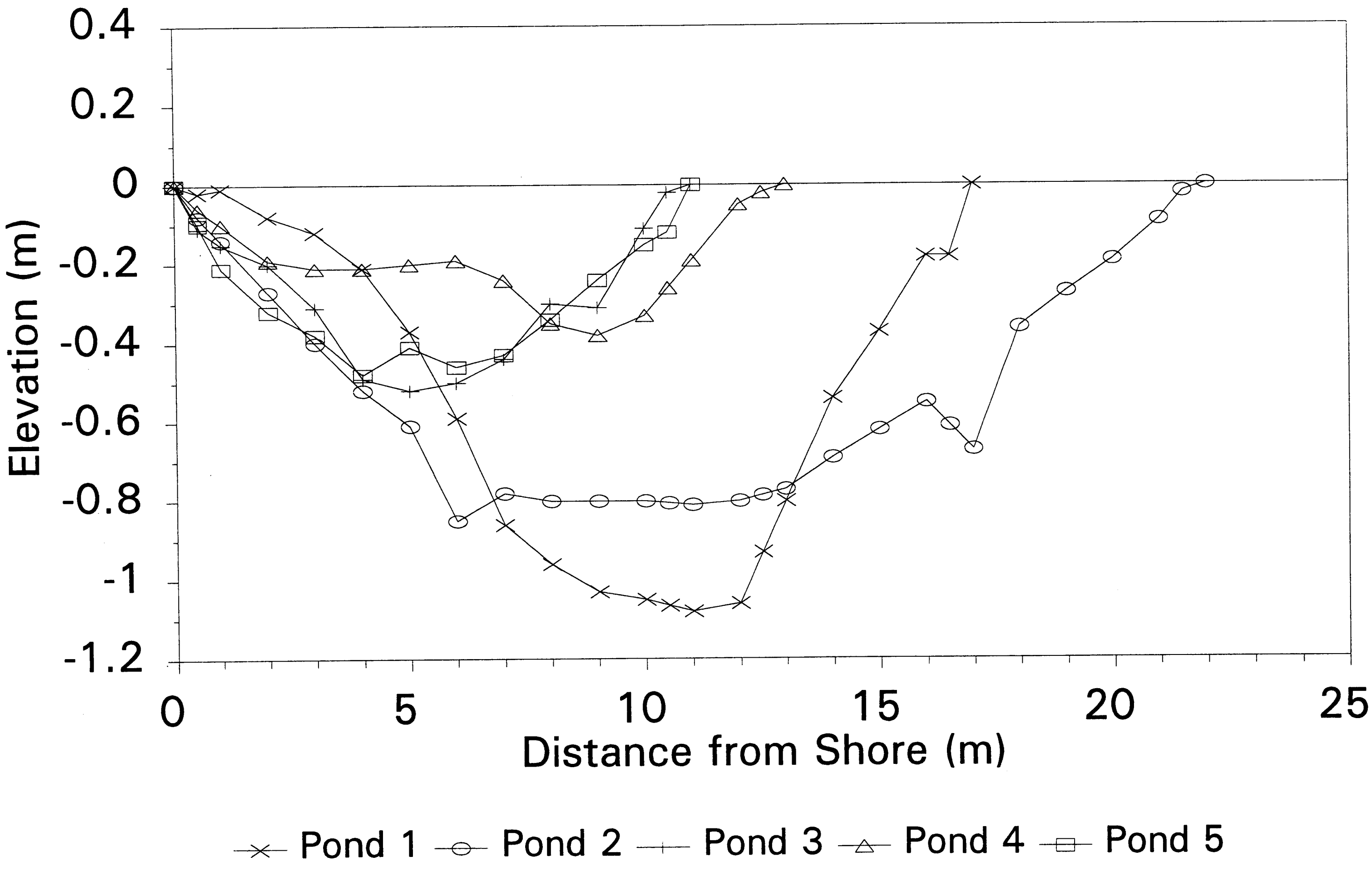

Figure 2. Relative bathymetry of the City Island ponds.

Table 1. Total fish abundance (all ponds) for each species at each sampling event.

Species	Sampling Event																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	TOTAL
Anchoa mitchilli	0	0	1	0	8	8	1	1	3	12	16	18	8	2	10	55	4	18	165
Brevoortia sp.	16	53	7	8	1	7	2	0	1	8	4	2	5	0	1	13	10	11	149
Chloroscombrus chrysurus	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Centropomus undecimalis	0	0	0	0	0	0	0	2	1	2	0	2	0	2	1	0	1	3	14
Cyprinodon variegatus	168	118	137	104	25	148	65	99	84	137	58	41	48	52	66	124	139	182	1795
Diapterus plumieri	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
Eucinostomus sp.	48	23	61	209	18	110	42	24	48	43	17	5	7	4	12	100	18	204	993
Fundulus confluentus	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	15	17
Fundulus grandis	21	31	25	29	0	161	0	29	10	20	7	11	6	7	8	28	45	7	445
Fundulus similis	28	44	54	37	16	74	4	49	11	41	31	14	22	3	24	30	29	2	513
Hippocampus sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Lagodon rhomboides	0	3	4	2	0	1	2	0	0	3	0	0	1	8	9	89	32	179	333
Leiostomus xanthurus	0	0	0	0	0	0	0	0	0	1	0	0	0	12	28	128	126	154	449
Microgobius gulosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
Menidia sp.	42	5	6	169	69	178	22	42	4	1	6	0	2	3	10	19	38	12	628
Mugil cephalus	0	0	1	1	0	0	0	1	0	1	3	1	30	10	10	16	72	50	196
Mugil curema	1	10	0	0	1	0	0	0	0	0	0	0	0	0	0	15	0	0	27
Orthopristis chrysoptera	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Poecilia latipinna	160	26	0	64	0	59	3	0	17	44	4	15	10	24	3	28	18	36	511
Pogonias cromis	4	0	0	3	0	1	1	0	0	1	0	0	0	0	0	0	0	0	10
Sciaenops ocellatus	0	0	0	0	0	0	0	0	0	1	0	5	2	3	2	2	3	4	22
Strongylura sp.	2	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Trachinotus falcatus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TOTAL	490	315	297	630	140	748	142	247	181	316	146	114	141	130	184	648	535	878	6282

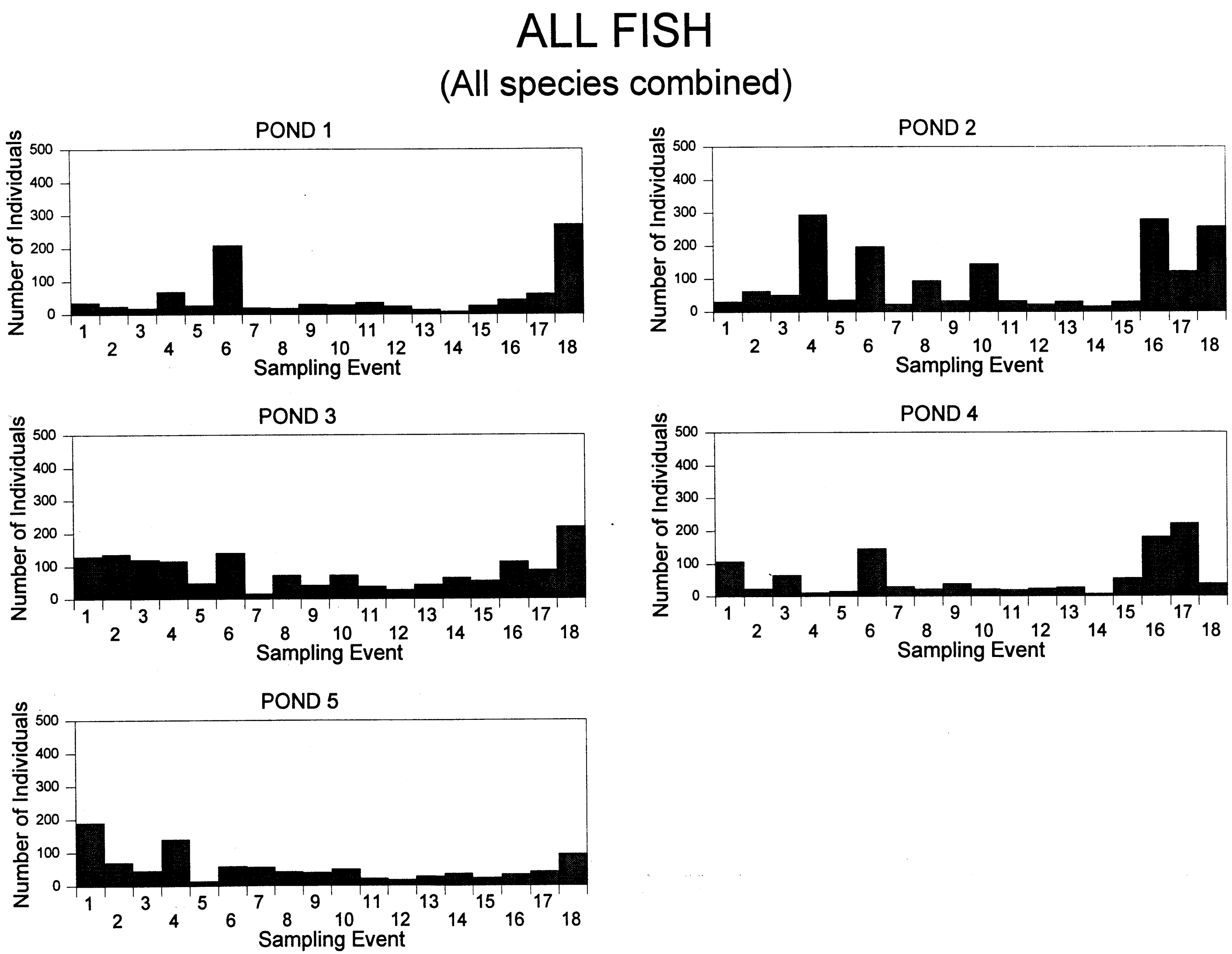

Figure 3. Number of fish (all species) at each station.

Community Structure

Distinct differences in fish community structure were apparent between ponds. In order to facilitate analysis, the fish community was divided into five groups: 1) marshes fishes - fishes that typically are found only in or near marshes and other intertidal habitat (*Fundulus grandis*, *F. similis*, *F. confluentus*, *Cyprinodon variegatus*, and *Poecilia latipinna*); 2) planktivores - fishes that feed primarily on zooplankton and phytoplankton, although detritus may be trophically important as well (*Anchoa mitchilli*, *Brevoortia* sp., and *Menidia* sp.); 3) mojarras - benthic fishes of the genera *Eucinostomus*), 4) spot and pinfish (*Leiostomus xanthurus* and *Lagodon rhomboides*), and 5) commercial and recreational species - fish that are of direct value in local commercial and recreational fisheries (*Mugil cephalus*, *Centropomus undecimalis*, *Sciaenops ocellatus*, *Pogonias cromis*, and *Trachinotus falcatus*).

Using these categories, the total catch from each of the ponds (plus all ponds combined) is depicted in Fig. 4. Pond 1 was dominated by planktivores; although marsh fishes, mojarras, and spot + pinfish were also abundant. Pond 2 had a similar distribution, except that mojarras dominated and planktivores were second. Ponds 3, 4, and 5 were dominated by marsh fishes, which accounted for 71, 72 and 95% of the respective totals for each pond. The spot + pinfish category, which accounted for 14% of the fishes in Pond 3 and 14% in Pond 4, was the only other large category for Ponds 3-5.

Valued Species

Commercially and recreationally valued fishes were collected from all of the ponds. However, the bulk (81%) of the valued fish were striped mullet. Snook and red drum together accounted for 77% of valued fishes other than striped mullet. Snook were collected from Pond 1 (71%) and Pond 2 (29%) only. Red drum were collected from Pond 2 (32%), Pond 3 (32%) and Pond 4 (36%) only. However, all except one of the red drum were collected during a period in which little or no connection or tidal exchange into Ponds 1 and 2 existed (see below). Therefore, the red drum results may reflect the ponds' accessibilities to early-juvenile red drum more than the ponds' habitat.

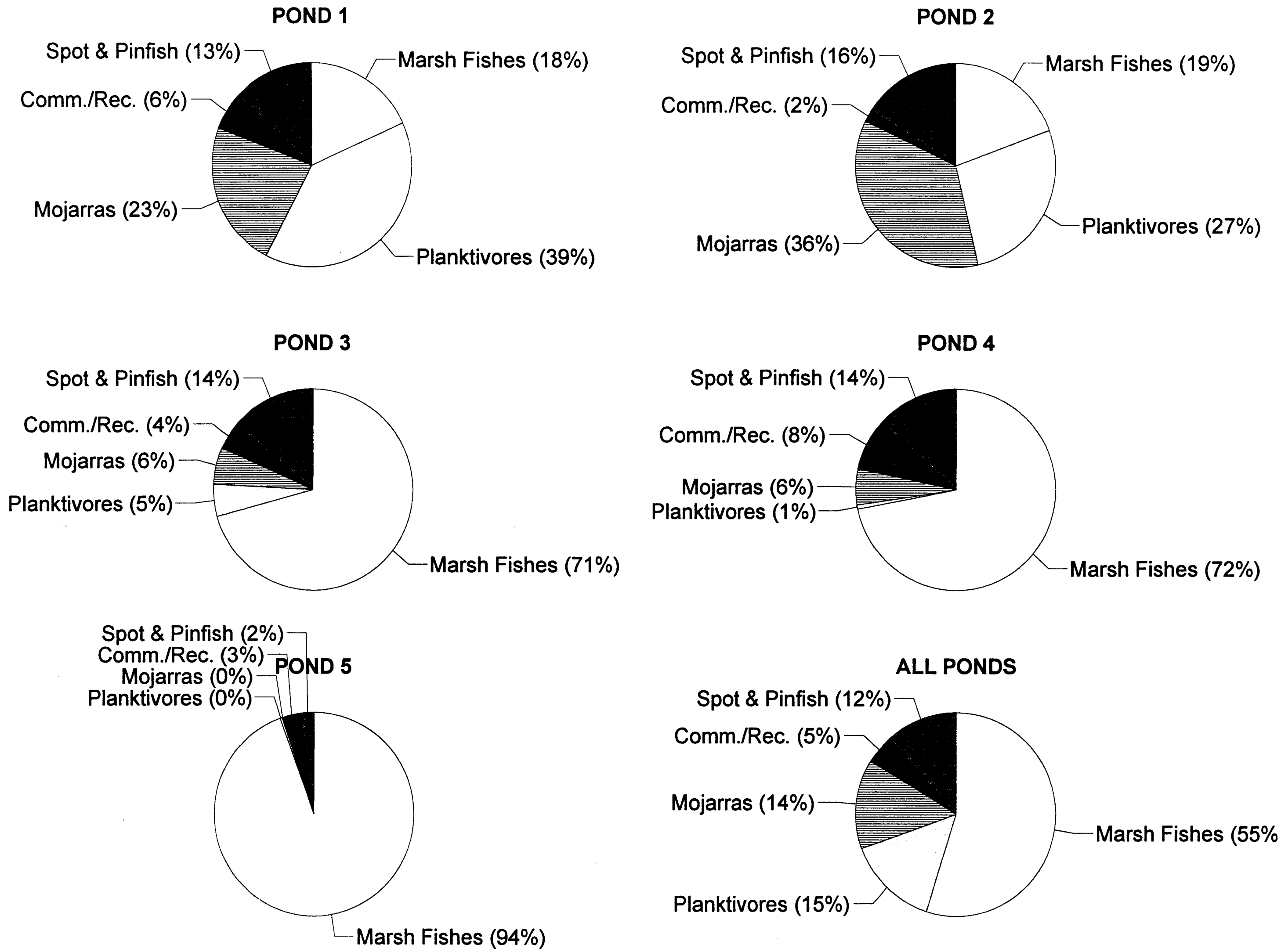

Figure 4. Fish community structure based on total catch from the City Island ponds.

Snook Abundances

A total of 12 snook (9 early juveniles < 125 mm SL, and 3 juveniles > 125 mm SL) were collected from Pond 1, and 3 early juvenile snook were collected from Pond 3 on 10/30/92. Based on experience and assessments of seining efficiency in similar ponds (Allen, *et al.*, 1992), it can be roughly estimated that about half of all snook in Ponds 1 and 2 were collected. The other ponds were sampled thoroughly and no snook were collected. Because Ponds 3-5 are smaller and were sampled more effectively, it is unlikely that any snook were missed in the sampling. Therefore, it can be roughly estimated that there were about 30 juvenile living in the ponds. Most if not all of the juveniles from the 1992 summer spawning could be expected to have been already recruited and present in the ponds y the end of October (McMichael *et al.*, 1989).

CONCLUSIONS

Effects of Design Features on Fishery Value

Depth (Fig. 2) is probably the most obvious difference between the ponds that could account for the differences in fish communities. Pond 1 is generally deepest, followed in order by Pond 2, Pond 3, Pond 4 and Pond 5. Differences in vegetation probably are of secondary importance and are themselves influenced by bathymetry and shoreline slope. Pond 5 was also affected by periodic stormwater runoff that reduced salinity and imported fine-grained sediments, and these factors probably greatly influenced the fish fauna. The two deeper ponds (1 and 2) appeared to be deep enough for a planktonic food web to be developed and thus support planktivorous feeders. These two deep ponds had a generally more-balanced and diverse fish community (Fig. 4). On the other hand, Ponds 3 and 4 may be too shallow to serve as habitat for many of the species that were abundant in Ponds 1 and 2 and were dominated by marsh fishes that are typical of shallow environments.

Overall design of the ponds did not maximize marsh/water interface, shoreline length, or structural heterogeneity - features that increase value and productivity of fish habitat (Weinstein, 1979; Edwards, 1991). Such features could be added to this or other restoration projects at very little additional cost, and could greatly increase the fishery habitat value of the projects. Although Ponds 3 and 4 are productive in terms of marsh fishes, they could maintain that asset and additionally be productive of other types of fishes if some deeper areas were present (e.g., holes or "fingers" of deeper water). Conversely, Ponds 1 and 2 might be more productive of marsh fishes if the shoreline were more irregular and included islands or peninsulas of marsh vegetation.

Tidal exchange between the ponds and the bay is another design feature that probably influenced fish community structure and abundances. Exchange in the CI system is limited by the small size and shallowness of the creek that connects it to the bay, and by the connections between ponds. Connection between Ponds 1 and 2 and the bay were non-existent during March and April due to seasonal changes in tidal levels (Provost, 1973), precluding recruitment of larvae and juveniles. This is an important factor that should be considered in future project designs.

Estimates of Total Abundance of Snook, Red Drum, and Striped Mullet

Although juvenile snook abundance was estimated on 10/30/92, similar complete sampling was not performed during the period (late winter) when juvenile red drum and striped mullet were using the ponds, total abundance of these species can only be estimated. During the monitoring period, 22 red drum, 196 striped mullet and 14 snook were captured. Based on the ratio of 14 snook captured during the regular sampling to 30 estimated in October, an approximated ratio of 2 can be applied to the totals for red drum and striped mullet. In this way the total abundance of red drum can be estimated at 44 and total abundance of striped mullet at 392. These admittedly very rough estimates were derived for the following analysis.

Project Valuation Estimations with Regard to Valuable Fishes

Total cost of the CI project was over $200,000. Although it is very difficult and sometimes misleading to attempt to directly calculate values for natural resources (Bell, 1989),the following analysis can put part of the project's value into perspective. First, a cost-benefit break-even point for an almost perpetual investment such as is the CI project, an return on the investment. For example, if the $200,000 had been invested for a very long term, a return rate of 10% (selected for ease of calculations in this illustration) might be reasonable and would yield an annual return of 20,000. It is against this potential return that the project's annual benefits should be compared.

The benefits of the restoration are numerous (including sociological, esthetic, and ecological benefits) and difficult to directly value. The many ecological values would be almost impossible to directly qualify. However, rough estimates can be obtained for valued species produced by the ponds. Looking only at the three most important species (snook, red drum and striped mullet), annual "returns" were calculated as follows: the numbers of each of these species produced annually in the restoration site (estimates developed in the preceding section) were multiplied by estimated values for individuals of each species to obtain annual values, which are summed.

Although the value of a snook, red drum or striped mullet is hard to estimate, FDER has developed a list of fish values (Chapter 17-11 F.A.C., Fish Value Rule) for use in economic impact statements (EIS). The most recent FDER EIS values for these species are $67.20/snook, $33.60/red drum and $6.70/striped mullet. Although these values may seem exceedingly high, recent economic analyses (e.g., Bell, et al., 1982) have demonstrated that the recreational economic value of species like red drum is several times its retail food-fish values. Therefore, the above estimates may serve as upper limits to values. Additionally, use of these values is particularly meaningful in restoration projects funded from FDER's Pollution Recovery Trust Fund (PFTF), which in some cases may have used the fish values in levying fines that contribute to the PRTF.

Using these values and estimated total number of each species in the City Island ponds results in an annual value (return) of $6,120.80 for the number of snook, red drum and striped mullet produced by the project. If more-conservative values, $20.00/snook, $10.00/red drum and $1.00/striped mullet were applied, the annual return would be $1,432.00. Actual values may be even less.

The above analysis does not purport to accurately calculate the value of the CI project, but it does provide some perspective. Based on the estimates, from 7% to 31% of the project's break-even return could be attained from production of three commercially and recreationally valued species.

Potential Fishery Value and Production

Another way to access the fishery value of the project is to compare the numbers of valued species collected in the best seine hauls and to compare those numbers found in natural habitats. For example, the maximum number if snook collected in any one seine haul was three. This compares with up to 14 snook collected in Manatee River estuary (Edwards, 1991) and 113 juvenile snook collected in Alafia River seine hauls (McMichael *et al.*, 1989). Similarly, the maximum number of juvenile red drum collected from the CI ponds was five, as compared to 40-60 in better seined hauls from the Manatee River (Edwards, 1991) and seine hauls of hundreds to over 2,000 juvenile red drum from the Alafia River (Peters and McMichael, 1987). The best seine hauls for juvenile striped mullet collected 28 and 50 individuals, but no more than 15 were collected in the rest. This compares to top seine hauls from the Manatee River of around 40 to 60 individuals (Edwards, 1991).

Based on the above comparisons, it is concluded that production of snook and red drum could be increased more than ten-fold and production of mullet could be increased several fold if the CI ponds could approach production levels found in the best natural habitats. Also, mullet production could probably be increased substantially. If these levels were to be attained, the annual return from this production would account for most, if not all, of the return necessary for the CI project investment to have a positive net economic impact.

Future Directions

Unfortunately, techniques and design criteria for creating optimal fishery habitats do not yet exist. At present, all that can be relied upon is observation and experience gained from studies of natural habitats. Available information indicates that specific subtidal habitat characteristics are extremely important in determining the abundance of fishes in areas adjacent to intertidal wetlands (Edwards, 1991). Wherever possible, subtidal habitat considerations should be included in designs of wetlands restoration projects. Important factors to be considered include geomorphological complexity, edge effects, ecotonal effects, marsh access, low-tide refugia, proximity of subtidal habitats and integration of intertidal and subtidal habitats by inclusion of marsh creeks, lagoons, deep edges, overhanging vegetation and similar features of the proper scale, bathymetry and configuration. Wetlands creation projects should include the participation of fish ecologists and fishery scientists in the design phase. Once implemented, projects should include thorough monitoring of fish and important invertebrates so as to identify habitat features that result in high production of fishery organisms, to allow these features to be repeated in future projects or retrofitted to existing habitat restorations. With such efforts, it is likely that intertidal habitat restoration can significantly contribute to restoration of estuarine and coastal fisheries. Without directed efforts to include creation of highly-productive fish habitat, it is likely that wetlands creation and restoration will be of marginal value to fisheries.

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LOST LAKE - RESTORATION OF A CAROLINA BAY

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ABSTRACT

Carolina bays are shallow wetland depressions found only on the Atlantic Coastal Plain. Although these isolated interstream wetlands support many types of communities, they share the common features of having a sandy margin, a fluctuating water level, an elliptical shape, and a northwest to southeast orientation. Lost Lake, an 11.3-hectare Carolina bay, was ditched and drained for agricultural production before establishment of the Savannah River Site in 1950. Later it received overflow from a seepage basin containing a variety of chemicals, primarily solvents and some heavy metals. In 1990 a plan was developed for the restoration of Lost Lake, and restoration activities were complete by mid-1991. Lost Lake is the first known project designed for the restoration and recovery of a Carolina bay.

The bay was divided into eight soil treatment zones, allowing four treatments in duplicate. Each of the eight zones was planted with eight species of native wetland plants. Recolonization of the bay amphibians and reptiles is being evaluated by using drift fences with pitfall traps and coverboard arrays in each of the

treatment zones. Additional drift fences in five upland habitats were also established. Hoop turtle traps, funnel minnow traps, and dip nets were utilized for aquatic sampling. The presence of 43 species common to the region has been documented at Lost Lake. More than one-third of these species show evidence of breeding populations being established. Three species found prior to the restoration activity and a number of species common to undisturbed Carolina bays were not encountered. Colonization by additional species is anticipated as the wetland undergoes further succession.

INTRODUCTION

Carolina bays are natural, shallow depressions of upland interstream areas of the southeastern Atlantic Coastal Plain. They share the common features of a complete or beached sandy marginal rim, an elliptical or ovoid shape, and a northwest to southeast orientation of the long axis (Schalles *et al.*, 1989). Since these depressions commonly have an impervious clay layer beneath the surface soil, their hydrologic regime depends on local precipitation patterns (Lide, 1991; Kirkman, 1992). Although individual bays may be seasonally or continually flooded, they tend to have deeper water levels in winter than in summer (Kirkman and Sharitz, 1993).

Carolina bays contain hydric or mesic communities ranging from shallow lakes to marshes, herbaceous bogs, and swamp forests (Wharton, 1978). In addition to providing forage and water for upland wildlife, bays are particularly important as sites of amphibian reproduction and larval development (Patterson, 1978; Bennett *et al.*, 1979; Sharitz and Gibbons, 1982; Pechmann *et al.*, 1989). Semiaquatic fauna are characteristic of Carolina bay wetlands (Sharitz and Gibbons, 1982).

Although Carolina bays are a relatively common feature of the Atlantic Coastal Plain landscape, most bays have been severely altered by human activities. The most common disturbance has been ditching and draining of bays, usually accompanied by cultivation. However, since 1950 few Carolina bays have been actively disturbed on the Savannah River Site, a Department of Energy industrial facility in South Carolina, and most altered bays have undergone successional recovery (Schalles *et al.*, 1989). Lost Lake is a Carolina bay on the Savannah River Site that has been negatively impacted by industrial pollutants and is the target of a wetlands restoration effort.

STUDY SITE

Lost Lake, an 11.3-hectare Carolina bay located on the Savannah River Site along the Savannah River in South Carolina, was ditched and drained for agricultural production from prior to 1943 until the early 1950s. After the Atomic Energy Commission removed the land from farming in the early 1950s, the cultivated area around the bay was planted in slash pine (*Pinus elliottii*) and loblolly pine (*Pinus taeda*), and Lost Lake began to refill and function as a wetland (Bennett *et al.*, 1979; Gladden *et al.*, 1992). However, impacts to the watershed continued as an industrial facility was installed nearby. Until 1984, overflow from a seepage basin contaminated the bay with a variety of chemicals, primarily cleaning fluids, solvents and heavy metals. By that time Lost Lake supported no emergent or submerged aquatic macrophytes (Bennett *et al.*, 1979). One aspect of a closure plan for the nearby settling basin was the restoration of the degraded bay to a "natural wetland system" (Gladden *et al.*, 1992).

During 1990, in cooperation with the Department of Energy Savannah River Office, a task team from Westinghouse Savannah River Company, Savannah River Forest Service, Savannah River Ecology Laboratory, and Soil Conservation Service developed a plan for the restoration of Lost Lake. Vegetation in the bay was burned, and the residual ash was removed to the settling basin and compacted. Soils from the lake basin were excavated to a depth sufficient to remove the contaminants and were then backfired into the settling basin. The basin was then capped and closed as a hazardous waste disposal unit. Monitoring of the Lost Lake restoration project is being funded through the South Carolina Universities Research and Educational Foundation (SCUREF), a university consortium promoting research by qualified professionals and student technicians. This is the first known project designed for the restoration and recovery of a Carolina bay.

MATERIALS AND METHODS

In January 1991, the bay was divided into eight soil treatment zones, allowing four soil treatments in duplicate. Each of the eight zones was planted with eight species of native wetland plants, and four sizes of experimental plots were established to monitor vegetation recovery. A description of these treatments and the results of this monitoring were reported by Ornes *et al.*, (1994).

In May 1993, monitoring of the bay for recolonization by amphibians and reptiles was initiated. Four collecting methods were used in each of the eight treatment zones:

(1) One 30m drift fence with pitfall traps (Gibsons and Semlitsch, 1982) was established 30 meters from and parallel to the water's edge. (Five additional drift fences were established 100 meters from the water's edge in surrounding upland habitats). Ten-gallon buckets, which function as pitfall traps, were sunk to ground level at the ends and at 10m intervals along both sides of each fence.

(2) Artificial cover boards (Grant *et al.*, 1992) of sheets of plywood or galvanized roofing tin, each measuring 0.66m x 1.33m, were individually numbered. Arrays consisting of four cover boards (two each of tin and plywood) were placed at the water's edge and at intervals of 20m, 50m, and 90m along a line perpendicular to the water's edge.

(3) Two hoop net turtle traps (Plummer, 1979) baited with sardines were placed parallel to the water's edge at a depth of 1.0 - 1.5m.

(4) Three funnel-throat minnow traps baited with sardines were placed at depths sufficiently shallow so as not to become submerged.

Drift fence pitfall traps and coverboards were checked daily (twice daily during summer months) for a year. Turtle traps and minnow traps were set for a one-week period during each month and checked daily. Hand-collecting and the use of D-framed dipnets for aquatic sampling supplemented the primary sampling methods.

Amphibians which were collected by trap or by hand were toe-clipped, but not for individual recognition, and released. Animals captured along a drift fence were released on the opposite side of the fence. Demographic data were recorded for each captured reptile before individually marking and releasing. Lizards were marked by toe-clipping, snakes were marked by clipping ventral scales, and turtles were marked by notching marginal scutes. Data gathered for turtles were included in ongoing studies begun by SREL in the 1960s (Gibbons, 1990; Gibbons *et al.*, 1990). Recaptured animals were noted and removed from all calculations of numbers collected.

RESULTS

A total of 43 species of amphibians and reptiles was collected or observed during this study (Table 1). The general herpetofaunal groups were represented by the following percentages by species: frog and toad species - 32.6%, snake species - 30.2%, lizard species - 16.3%, salamander species - 11.6%, turtle species - 7.0%, and crocodilian species - 2.3%.

Table 1. Amphibian and reptile species collected or observed at Lost Lake, Savannah River Site, South Carolina, May 1993 - April 1994

Species		Number Collected
CLASS AMPHIBIA		
Order Caudata - Salamanders		
Family: Ambystomatidae		
[2] *Ambystoma opacum*	marbled salamander	15
[1,2] *Ambystoma talpoideum*	mole salamander	452
[1,2] *Ambystoma tigrinum*	tiger salamander	71
Family: Salamandridrae		
[1,2] *Notophthalmus viridescens*	eastern newt	1,392
Family: Plethodontidae		
[2] *Plethodon glutinosus*	slimy salamander	20
Order Anura - Frogs and Toads		
Family: Pelobatidae		
[1,2] *Scaphiopus holbrooki*	eastern spadefoot toad	13
Family: Bufonidae		
[2] *Bufo quercicus*	oak toad	1
[1,2] *Bufo terrestris*	southern toad	12,432
Family: Hylidae		
[1] *Acris gryllus*	southern cricket frog	497
[2] *Hyla chrysoscelis*	Cope's gray treefrog	- observation only
[1,2] *Hyla cinerea*	green treefrog	155
[1,2] *Hyla gratiosa*	barking treefrog	1,842
[1] *Hyla squirella*	squirrel treefrog	43
[2] *Pseudacris crucifer*	spring peeper	4
Pseudacris nigrita	southern chorus frog	2
[1] *Pseudacris ornata*	ornate chorus frog	13
Family: Microhylidae		
[2] *Gastrophryne carolinensis*	narrow-mouthed toad	559
Family: Ranidae		
[1,2] *Rana catesbeiana*	bullfrog	1,000
[2] *Rana clamitans*	greenfrog	2
[1,2] *Rana utricularia*	southern leopard frog	330

Table 1. (Cont.)

Species			Number Collected
CLASS REPTILIA			
Order Crocodilia - Crocodilians			
Family: Alligatoridae			
	Alligator mississippiensis	American alligator	2
Order Chelonia - Turtles			
Family: Kinosternidae			
	Kinosternon subrubrum	eastern mud turtle	4
Family: Emydidae			
	[1] *Trachemys scripta*	slider turtle	40
	Deirochelys reticularia	chicken turtle	8
Order Squamata - Lizards and Snakes			
Suborder Lacertilia - Lizards			
Family: Iguanidae			
	[2] *Anolis carolinensis*	green anole	29
	Sceloporus undulatus	eastern fence turtle	- observation only
Family: Teiidae			
	Cnemidophorus sexlineatus	six-lined racerunner	3
Family: Scincidae			
	Eumeces fasciata	five-lined skink	1
	Eumeces inexpectatus	southeastern five-lined skink	1
	Eumeces laticeps	broadheaded skink	3
	[2] *Scincella lateralis*	ground skink	30
Suborder Serpentes - Snakes			
Family: Colubridae			
	[2,3] *Cemophora coccinea*	scarlet snake	1
	[2,3] *Coluber constrictor*	racer/black racer	34
	[2,3] *Diadophis punctatus*	ringneck snake	1
	[2] *Elaphe obsoleta*	rat snake	1
	[1,3] *Heterodon platirhinos*	eastern hognose snake	10
	[1,2] *Nerodia fasciata*	banded water snake	134
	[3] *Storeria dekayi*	brown snake	1
	[2,3] *Storeria occipitomaculata*	red-bellied snake	6
	[2,3] *Tantilla coronata*	southeastern crowned snake	7
	Thamnophis sirtalis	common garter snake	10
Family: Viperidae (=Crotalidae)			
	[3] *Crotalus horridus*	canebrake rattlesnake	4
	[3] *Sistrurus miliarius*	pygmy rattlesnake	3

[1] Successful reproduction documented by presence of larvae, recent metamorphs, hatchlings or newborns.

[2] Species reported by Bennett (draft ms).

[3] Species is normally terrestrial in periphery of bays and other aquatic habitats.

Successful reproduction was documented for fifteen species (Table 1). Evidence of successful reproduction included the presence of larvae or recent metamorphs (amphibians) and hatchlings or newborns (reptiles). Males of four additional species of frogs were heard calling from the bay and gravid females of one lizard species were collected. However, these observations indicate only breeding activity and not successful reproduction.

DISCUSSION

Our results indicate significant recolonization of Lost Lake by amphibians and reptiles. Successful reproduction was documented for more than one-third of the species encountered. However, many of the species, particularly those most abundant, inhabit a wide variety of wetland habitats, including ones that have been heavily disturbed.

Bennett (draft ms) conducted a similar study of Lost Lake herpetofauna in the summers of 1978 and 1979 prior to restoration in which he utilized drift fences with pitfall traps and coverboards on a smaller scale and did not use turtle or minnow traps. He documented only 27 species (Table , but those included three species not encountered in the present study. The eastern coral snake (Micrurus fulvius) is a secretive animal associated with turkey oak-pine habitats , and few have been collected on the Savannah River Site (Gibbons and Semlitsch, 1991). One specimen was collected in a pitfall trap in 1978-1979. Two specimens of the smooth earth snake (Virginia valeriae) were collected in 1978 -1979. This secretive animal inhabits forested areas in the periphery of some Carolina bays and may be captured in pitfall traps. Further sampling may verify the presence of these species since upland forests, though now at some distance , still surround Lost Lake. The dwarf salamander (Eurycea quadridigitata), which is commonly found in leaf litter in the margins of undisturbed bays, was present in 1978 -1979 but not encountered in the present study in spite of intensive sampling. It is possible that this species was extirpated from Lost Lake during the excavation activity or that the sparse vegetation now surrounding the bay does not provide adequate cover or shade for these animals.

Schalles *et al.* (1989) and Gibbons and Semlitsch (1991) list amphibian and reptile species collected or observed in other Carolina bays on the Savannah River Site. A comparison with our results reveals numerous common species not encountered at Lost Lake (Table 2). The absence of many of these species is not surprising since the bay is in a very early successional stage. There is little emergent or submerged vegetation, and the area surrounding the bay is dominated by "old field" successional plant species rather than trees.

Table 2. Amphibian and reptile species collected or observed in Carolina bays on the Savannah River Site, South Carolina (Schalles *et al.*, 1989; Gibbons and Semlitsch, 1991) but not collected or observed at Lost Lake in this study.

Species	
CLASS AMPHIBIA	
Order Caudata - Salamanders	
Family: Amphiumidae	
Amphiuma means	two-toed amphiuma
Family: Sirenidae	
Siren intermedia	lesser siren
Siren lacertina	greater siren
Family: Plethodontidae	
Eurycea cirrigera	two-lined salamander
Eurycea longicauda	long-tailed salamander
Eurycea quadridigitata	drawf salamander
Order Anura - Frogs and Toads	
Family: Hylidae	
Hyla avivoca	bird-voiced treefrog
Hyla femoralis	pine woods treefrog
Family: Ranidae	
Rana areolata	crawfish frog
Rana grylio	pig frog
Rana palustris	pickerel frog
Rana virgatipes	carpenter frog
CLASS REPTILIA	
Order Chelonia Turtles	

Table 2. (Cont.)

Species	
Family: Chelydridae	
<u>Chelydra</u> <u>serpentina</u>	common snapping turtle
Family: Kinosternidae	
<u>Kinosternon</u> <u>bauri</u>	striped mud turtle
<u>Sternotherus</u> <u>odoratus</u>	skinkpot
Family: Emydidae	
<u>Pseudemys</u> <u>floridana</u>	Florida cooter
<u>Chrysemys</u> <u>picta</u>	painted turtle
<u>Clemmys</u> <u>guttata</u>	spotted turtle
Order Squamata - Lizards and Snakes	
Suborder Serpentes - Snakes	
Family: Colubridae	
*<u>Elaphe</u> <u>guttata</u>	corn snake
<u>Farancia</u> <u>abacura</u>	mud snake
<u>Farancia</u> <u>erytrogramma</u>	rainbow snake
*<u>Lampropeltis</u> <u>getulus</u>	common kingsnake
<u>Nerodia</u> <u>floridana</u>	Florida green water snake
<u>Nerodia</u> <u>erythrogaster</u>	red-bellied water snake
<u>Regina</u> <u>rigida</u>	glossy crayfish snake
*<u>Rhadinaea</u> <u>flavilata</u>	yellow-lipped snake
<u>Seminatrix</u> <u>pygaea</u>	black swamp snake
*<u>Thamnophis</u> <u>sauritus</u>	eastern ribbon snake
*<u>Virginia</u> <u>valeriae</u>	smooth earth snake
Family: Viperidae (=Crotalidae)	
<u>Agkistrodon</u> <u>piscivorus</u>	cottonmouth

*Species is normally terrestrial in periphery of bays and other aquatic habitats.

We predict that as the wetland undergoes further succession, suitable habitats will allow recolonization by additional species. Our sampling design will allow us to test the correlation of relative abundances of amphibian and reptile species with any vegetational differences that may occur between the eight soil treatment zones. Continued monitoring of the herpetofauna of Lost Lake will significantly enhance our understanding of the recovery of this unique Coastal Plain ecosystem.

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MITIGATING AN OIL SPILL IN TIMBALIER BAY, LOUISIANA: NOAA'S DAMAGE ASSESSMENT AND RESTORATION PROGRAM IN ACTION

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ABSTRACT

The National Oceanic and Atmospheric Agency (NOAA) is responsible for assessing and claiming damages associated with the accidental discharge of oil of hazardous material. This paper presents a case history describing the use by NOAA of the Habitat Restoration Analysis technique to determine the amount of wetlands that would be created to adequately compensate for the 1992 Greenhill Petroleum well blowout and oil spill Timbalier Bay, Louisiana. This mitigation project was constructed during the November 1993 - June 1994 period. The wetland creation project is described and initial indicators of success provided.

INTRODUCTION

The National Oceanic and Atmospheric Agency (NOAA) is designated under numerous legislative acts to serve as a federal trustee for living marine resources, including marine fishery resources and their supporting ecosystems, anadromous and catadromous fish, selected threatened and endangered species, marine mammals, and tidal wetlands and other critical habitats. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) provides a mechanism authorizing NOAA to respond to hazardous waste contamination for NOAA to address discharges of oil from a vessel or a facility into navigable marine waters. These two acts authorize NOAA to assess and claim damages for injuries to natural resources caused by discharges of oil or the releases of hazardous substances.

NOAA fulfills portions of its trustee responsibilities through its Damage Assessment Center (DAC), the Office of General Counsel (GC), and the National Marine Fisheries Service's Restoration Center (RC). DARP was established in fiscal year 1991 to provide an effective mechanism for assessing damages and restoring coastal and marine habitats and resources under NOAA's trustee authority. Prior to DARP, there was no central federal office of authority to direct the restoration or compensation process for marine fishery injury cases.

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DAC works with NOAA's GC and co-trustees such as state departments of natural resources, environmental quality and wildlife and fisheries to develop claims against parties responsible for marine natural resource damages. Those NOAA/state departments assisting in a case assessment and settlement are hereafter referred to as "Trustees." DAC analyzes information about oil spills and releases of hazardous substances to determine whether the discharge may have injured NOAA trust resources. The DAC provides technical information to the GC and to the Department of Justice to assist in the litigation of natural resource damage claims. The RC, in collaboration with National Marine Fisheries Service (NMFS) Regional and Branch Offices and Science Centers, assists in the development of a restoration project and oversees the restoration of damaged habitats after settlement and resolution of a case. NOAA natural resource responsibilities and the role of the RC in restoration planning is described in greater detail in Pease *et al.* (1994).

DARP traditionally uses the National Resource Damage Assessment (NRDA) process, originally outlined in CERCLA and adopted by OPA, to pursue a natural resource damage and restoration case. The process is composed of three phases: 1) case selection and preliminary case assessment; 2) damage assessment; and, 3) a mitigation phase including post-assessment settlement, restoration planning, and project implementation.

NOAA is not required to follow the official NRDA process in its activities under CERCLA and OPA. Though these Acts provide the authority and framework for responding to natural resource injury, how the Trustees choose to handle the case is their option. They may omit or combine steps in the damage assessment and restoration planning process. They may choose negotiation-based settlement over litigation-based settlement, in-kind compensation over monetary compensation. This flexibility allows for innovation and improvement in implementing the statutory mandate to "restore, replace, or acquire the equivalent of" injured natural resources.

The following case history provides a demonstration how the combination of flexible legislation and the initiative of a few trustee representatives produced an improved method for achieving natural resource restoration. This case history is subdivided into a description of the oil spill, preliminary case assessment, damage assessment, and settlement plan. Also provided is a narrative detailing project implementation and a preliminary assessment of compensation success.

INCIDENT SUMMARY

On September 29, 1992, a natural gas and petroleum platform in Timbalier Bay, Louisiana, began discharging light crude oil from a ruptured well pipe. That evening, Greenhill Petroleum (GP), the owner of the platform, reported approximately 260 U.S. gallons of crude had entered the bay. By the following morning, the estimate had risen to approximately 29,400 U.S. gallons. Containment efforts, including booms and skimmers were already underway.

Attempts to cap the well on the morning of October 1 resulted in the ignition of the oil and natural gas spewing from it. Patches of burning oil disintegrated the containment boom. For the next week, the well continued to burn complicating plans to cap it. However, by October 10, the well was successfully capped and the fire was extinguished.

It was estimated that approximately 96,000 U.S. gallons of oil entered the marine environment, resulting in the oiling of approximately 122 acres (49.410 ha) of intertidal marshes on East Timbalier, Timbalier, Brush, Calumet, and Casse Tete Islands. Most of the oiled marsh grass, composed primarily of Spartina alterniflora, died or experienced significant impacts to growth and productivity, increasing the vulnerability of the impacted areas to erosion.

PRELIMINARY CASE MANAGEMENT

The GP incident was not a textbook oil spill allowing a standard regulatory response. Under normal circumstances, DARP would have followed guidelines outlined in OPA or CERCLA, depending on when the spill occurred. In this case, the OPA regulations passed in 1990 were not yet fully implemented. Therefore, DARP would have used the CERCLA damage assessment and restoration process. CERCLA specifies two types of damage assessments: Type A and Type B. Type A is a simplified assessment which uses a computer model to simulate natural resource injuries and calculate damages. The model includes variables such as spill type, location, date, habitat, and resource uses through submodels of physical fates, biological effects, and economic damages. The model estimates the value of damages by using standard scientific and economic values involved in a typical spill on a typical wetland. However, the Type A model can only simulate an acute spill in which the oil is released all at once. In addition, the model considers habitat loss in terms of particular species and services only; it does not value losses to aquatic vegetation. Because the GP case involved a prolonged oil release and the main injury was loss of marsh grasses and the aggregate services provided by the marsh, it was determined that the Type A model was inappropriate for use in this case.

The Type B damage assessment is designed for major oil spills. It involves studies of each potentially impacted resource, followed by a calculation of damages for each injured resource. Because the GP blowout resulted in a relatively minor spill and a Type B assessment would likely have cost more than the damages that DARP would have used it to calculate, it was determined that this model also was inappropriate for this case.

Because both damage assessment methods were determined to be inadequate, the Habitat Replacement Analysis (HRA) was selected as the most viable alternative for proceeding with the GP case. Rather than concentrating on the dollar value of specific components of a habitat, it focuses on the ecological services of a habitat as a whole. The HRA attempts to determine the amount of wetland acreage that would need to be created such that the ecological services provided by the created area over its functional lifespan are equal to the services lost due the injury.

The HRA wetlands compensation methodology is depicted graphically in Figure 1. The level of ecological services produced by one acre of wetlands during a single year is referred to as one "acre-year" of services. Thus, the triangle identified as "L" represents the total acres-years lost due to oiling. The acre-years of services lost in the first year following the spill is the total acres oiled (A_o) times the percentage of services lost initially upon oiling (p.) A value of $0<p<1$ is used to indicated that the

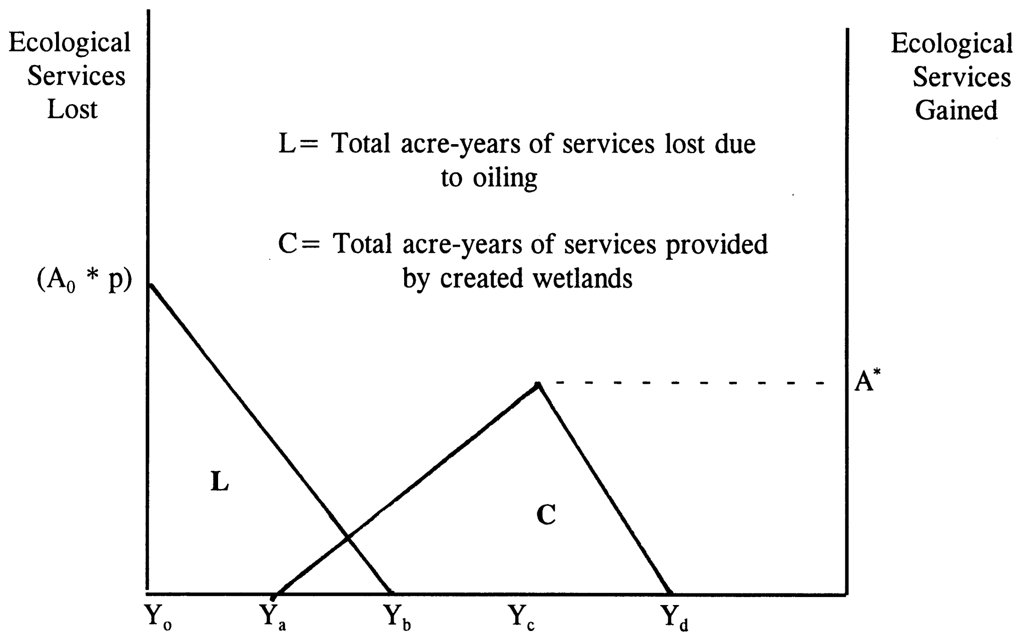

Figure 1. General methodology for calculating acres of wetlands to be created.

less heavily oiled areas may remain functional to some extent, even immediately following the spill. The extent of the impact decreases over time as the marsh recovers from the oiling and because the island was expected to erode even without the impact. The triangle identified as "C" represents the total acre-years of services produced through the creation of A^* acres of wetlands in year Y_a. In the years prior Y_c, the created area produces less than A^* acre-years of services per year because the wetland created requires (Y_c, -Y_a) years to reach full maturity and provide a full flow of services. In the years following Yc, the created area produces less than A^* acre-years of service per year due to the rapid erosion of the created area. These wetlands will continue to provide a diminishing level of services until the year Y_d, at which point the island, or at least the created marsh area, is assumed to have eroded completely. The compensation analysis calculations and assumptions are used to determine the appropriate level of A^* such that the area of triangle C is equal to the area of triangle L. That is, the total acre-years of services provided by the created wetland from the point of initial oiling until full recovery.

Although the well blowout was not as detrimental as anticipated early in the incident, there were several justifications for DARP to adopt the case. This incident was one of the first oil spills to occur after the OPA was passed, thereby presenting NOAA with an opportunity to exercise its new authority under OPA. It also offered DARP its first opportunity to build a working relationship with the State of Louisiana, which is steward of over 40% of the coastal wetlands in the contiguous United States. Most importantly, the nature of the case made it a prime candidate for a restoration-based settlement using the HRA. For these reasons, the GP case was officially adopted by DARP in December 1992.

DAMAGE ASSESSMENT

The HRA calculates the number of acre-years of service lost to injury and the created acreage needed to replace those acre-years of service through a number of steps, each of which requires scientific or quantitative assumptions. Throughout the GP analysis, DARP case team members consulted with scientific experts and reviewed scientific and economic literature to develop technically defensible assumptions.

The characterization of oiled areas was a two-step process with the first step involving the identification of impacted areas based on oil distribution (e.g., continuous, broken, patchy, sporadic, or trace). Each category of oil distribution had a percentage range assigned to it. The second step involved characterization of areas based on the average thickness of the oil on the vegetation. The final characterization of areas was based on the interaction between the oil distribution and average thickness variables. Thus, an area designated as "heavy" under the first process because of 91-100% coverage may have been downgraded to "moderate," if the average thickness of the oil was very low.

The case team first estimated the level of services lost due to the spill and the expected time needed for the area to fully recover. If all the affected acres were heavily oiled, a 100% loss of services would be assumed and the acre-years of services lost in the year following the spill would be equal to the total number of acres oiled. However, since the majority of the 122 acres (49.41ha) impacted were moderately (as compared to heavily) oiled, the acre-years of services lost in the first year are equal to (122 * p), where p is equal to the average percent of wetlands' functionality initially lost. The average percent of wetland services lost was estimated to be 37% based on a weighted average of the percent oil coverage of the acres identified as moderately oiled marsh in the first stage of the oiling characterization process. By calculating the weighted average, using only the moderately oiled acreage figures, the average thickness of oil as well as the oil distribution is implicitly taken into account. We believe that 37% is an extremely conservative estimate of the percentage of initial services lost. The oil spilled was a relatively toxic light grade crude that was able to easily penetrate the interiors of the vegetative stands, potentially impacting biomass and organisms both above and below ground. Thus, significant services may be lost even after visible signs of oiling have disappeared.

The literature on oil spill recovery in marsh areas suggests the average recovery time was from one to more than five years (Bender et al. 1980; Baca et al., 1983; Winifield et al. 1992). Due to the toxic nature of the spilled oil and the hurricane-induced vulnerability of the barrier island, the recovery time was estimated to be three years.

The total acre-years of service lost was then calculated by multiplying the percent of services lost in each year by the initial level of services lost, discounting each year's lost services, and adding these figures over the expected life span of the marsh (Table 1). The discount rate is the consumers' rate of time preference, reflecting society's willingness to trade off current services for future services. In the context of the HRA, the discounting procedure allows comparison of different service flows by calculating the equivalent level of services at single points in time, given the chosen consumer rate of time preference (i.e. discount rate). This discounting is done according to the formula:

$$\text{Total Discounted Acre-Years of Services} = \sum_i \frac{A_i}{(1 + r)^n}$$

where A_i is the raw acre-years of services provided (or lost) by the wetland in period i, r is the discount rate and n is the number of years between period i and the initial injury. Assuming a 3% discount rate and a three year linear recovery of the marsh, the total discounted acre-years of services lost due to oiling was calculated to be 43.4 acre-years.

Table 1. Calculation of total acre-years of wetland services lost.

Year	Percent of Wetland Services Lost (Beginning of Period)	Percent of Wetland Services Lost (End of Period)	Percent of Wetland Services Lost (Average of Period)	Raw Acre-years of Wetland Services Lost	Discounted Acre-Years of Wetland Services Lost
1	36.9	24.6	30.7	37.6	36.5
2	24.6	12.3	18.4	6.93	6.53
3	12.3	0.0	6.1	0.43	0.39
4	0.0	0.0	0.0	0.0	0.0
Total discounted acre-years of wetland services lost					43.43

Translating this information into the number of marsh acres to be created required that the service flows produced by a created wetland be modeled according to the following four parameters: 1) the amount of time elapsed between the spill and the beginning of wetland creation; 2) the number of years until the created wetland reaches full maturity and provides all expected services; 3) the relative productivity of created versus natural wetlands; and, 4) the lifespan of the created wetland. In view of the time needed to prepare a restoration plan, reach a settlement, obtain permits, and finalize construction, the DAC case team assumed that marsh creation would begin two years after the spill had occurred.

It was assumed that once created, the marsh would reach full maturity in five years. This estimate is highly optimistic when compared with recent research suggesting that a marsh may take fifteen to thirty years to develop the soil nutrient levels and macroorganic matter characteristic of a mature marsh (Craft *et al.* 1988). Biologists have observed that created marsh plots frequently have lower levels of overall productivity than existing natural stands after years of establishment (Moy and Levin 1991; Minello and Zimmerman 1992). Therefore, to replace lost natural marsh services, a relatively higher number of created acres must be created. The Trustee restoration team conservatively estimated that created wetlands in the East Timbalier area would by 50% as productive as natural marsh in the same area.

The barrier islands that characterize Louisiana's gulf coastline, including Timbalier and East Timbalier Islands, are eroding rapidly, thereby reducing the number of years during which created wetlands can provide ecological services. Experts at the U.S. Geological Survey and the Louisiana Geological Survey had estimated that East Timbalier Island would erode away completely by 1997 (McBride *et al.* 1991). The Trustees estimated that wetland creation on the island would extend its functional life to 2004, meaning the created marsh would continue to provide ecological services for five years after reaching maturity, at a linearly declining rate due to erosion.

By incorporating all these parameters, the flow of services produced by the created wetland can be modeled and the acreage necessary for compensation can be calculated. The details of this calculation are provided in Tables 2 and 3. Using assumptions identified above, it was determined that GP would have to create 21.7 acres of Spartina alterniflora marsh to adequately compensate for the ecological services lost due to the oil spill.

Table 2. Calculation of Acre-Years of services provided by created wetlands prior to reaching full maturity. (Function increases as created wetlands approach full maturity).

Number of Years (Following Initial Creation of Wetlands)	Percent of Full Service Flows Provided (Beginning of Period)	Percent of Full Service Flows Provided (End of Period)	Percent of Full Service Flows Provided (Average of Period)	Raw Acre-Years of Services Provided[1]	Discounted Acre-Years Of Services Provided
1	0	20	10	1.05	0.99
2	20	40	30	3.15	2.88
3	40	60	50	5.25	4.67
4	60	80	70	7.35	6.34
5	80	100	90	9.46	7.92

Total Acre-years of services provided prior to created wetland reaching full maturity 22.80

[1]Assuming created wetlands are 50% as productive as natural marsh

Table 3. Calculation of acre-years of services provided by created wetlands after reaching full maturity. (Function decreases as East Timbalier Island erodes).

Number of Years (Following Full Maturation of Created Wetland)	Percent of Full Service Flows Provided (Beginning of Period)	Percent of Full Service Flows Provided (End of Period)	Percent of Full Service Flows Provided (Average of Period)	Raw Acre-Years of Services Provided[1]	Discounted Acre-Years Of Services Provided
1	100	80	90	9.46	7.69
2	80	60	70	7.35	5.81
3	60	40	50	5.25	4.03
4	40	20	30	3.15	2.35
5	20	0	10	1.05	0.76

Total Acre-years of services provided prior to created wetland reaching full maturity 20.62

[1]Assuming created wetlands are 50% as productive as natural marsh

CASE SETTLEMENT

In December 1992, the DARP case team received approval to pursue a restoration-based settlement with GP. The basic terms of the final agreement signed in November 1993 were identical to those initially requested. GP agreed to use dredged spoil to create 19.72 acres (7.987 ha) of new marsh on East Timbalier Island and plant both the created area and 1.98 acres (.802 ha) of existing emergent unvegetated sand flats, called "cast-over" areas, with Spartina alterniflora. Planting the cast-over areas was determined to be acceptable in lieu of marsh creation with dredged material because they were at an intertidal elevation but did not contain marsh vegetation and none was expected to colonize these areas in the near future. In view of the high tidal energy of the barrier island, it was felt that, without planting, these areas would rapidly erode.

East Timbalier Island was selected as the project site because it was the barrier island most impacted by oiling, is closest to a potential source of dredged material, and is already permitted for dredging and spoil placement. This island is approximately 4 miles (6.44km) long and between 0.1 and 0.4 miles (.161 and .644km) wide. The island is currently experiencing shoreline retreat rates of 23.1 meters per year (McBride et al. 1991) and, with the tremendous loss of area caused by Hurricane Andrew, was estimated to be lost by the year 1997. This island is tremendously important as a wave barrier for fragile mainland marshes north of the island and its loss would also result in increased inundation periods for marshes in the Timbalier Bay area. Therefore, spoil disposal on this island is expected to increase the longevity of this barrier island system, benefitting wetlands on both the island and on mainland marshes.

The Trustees provided GP with several criteria to assist them in selecting appropriate sites for marsh creation. These criteria included the following: the sites had to be greater than 2 acres (.81ha) in size; accessible to marine organisms; subject to tidal flushing; have minimal human disturbance; be sheltered from wave action; and likely to increase the longevity of the island as a whole. The sites finally selected by GP, after much negotiation and several on-site field trips, were found to meet these criteria. The GP proposal calls for the use of approximately 275,000 cubic yards (210,375m3) of material to be hydraulically dredged from access canals adjacent to East Timbalier Island and deposited within open water areas within the widest portion of the island (Figure 2). The proposal includes the construction of retainment dikes at strategic locations to allow the spoil to stack to elevations such that, after consolidation and compaction, intertidal elevations are created. These retention features will also ensure the spoil is not tidally flushed from the project area before compaction and consolidation occurs and before the created area is planted.

In addition to compensating for marsh functions lost by the oil spill, the marsh creation project benefits GP needed to dredge from a series of petroleum's oil facility and will protect the facility from wave action and storm surge. The project also provides a disposal site for material that GP needed to dredge from a series of petroleum access canals that had been partially filled by Hurricane Andrew and other storms. However, GP likely would have bucket dredged this material due to the lower cost of bucket versus hydraulic dredging.

The Greenhill Petroleum Natural Restoration agreement requires reimbursement to the Trustees for past administrative costs and anticipated future oversight expenses, satisfactory completion of all phases of the restoration plan, and performance monitoring of the site for a period of 5 years. Success, as identified in the restoration and monitoring plan, is 80% coverage by smooth cordgrass, Spartina alterniflora, of the 21.7 acres (8.789 ha) within two years after dredging. The settlement/restoration plan also contains stipulations allowing for future actions if the mitigation project is not successfully completed, and does not hold FP responsible for the loss of project wetlands in the case of a hurricane.

Contractors for GP surveyed the elevation range of existing healthy and robust smooth cordgrass at 4 sites on East Timbalier Island. From these surveys, it was determined that the lower elevation for best growth varied from 0.15m to 0.49m NGVD. Vibracores were taken from the restoration area and the dredged fill source area to allow for an analysis of grain size and to determine the amount of compaction and settling which would occur after dredging and filling. Based on the results of these analyses, it was estimated that settlement and compaction would range from 11.4 cm for 0.6m of fill to approximately 33 cm for 2.4 m of fill. Using these figures, a final conservative dredge to fill ratio of 1.3:1.0 was estimated. Based on a survey of the deposition site, and knowledge of the intertidal elevation and dredge-to-fill ratio, it was estimated that it would require approximately 150,000 cubic meters of material to create the required number of acres of substrate at an elevation suitable for the growth and survival of smooth cordgrass. Any additional spoil would be used to fill contingency areas, labelled DC on Figure 2, to ensure having at least 21.7 acres (8.789ha) of emergent marsh after 2 years.

Requirements concerning planting were provided in the restoration and monitoring plan. All plant materials were required to be acclimated to Louisiana climatic and habitat conditions for at least 90 days and hardened to 20 parts per thousand salinity. Material to be planted on the project site would be sprigs of Spartina altereniflora (var. vermillion) consisting of one of more stems on a single rhizome. Sprigs were to be planted on spacings no greater than five-foot centers. Denser plantings could be undertaken on the shore near the water's edge or as necessary to meet the plan objectives. Trade gallon size containers could be planted at the edges of the project site in areas vulnerable to wave energy.

The retainment features were created using marsh buggy backhoes during November and December, 1993. Initially, winter storms frequently breached the retainment dikes as water attempted to flow through the island. Finally, however, the retainment dikes were sufficiently fortified and GP began hydraulic dredging on December 28, 1993. The use of visqueen to cover the earthen dikes helped protect them from tidal and wave erosion.

Although it was initially estimated that dredging would require 40 days, the actual duration of dredging lasted approximately 100 days and the total cost of the project to FP was approximately $2.5 million.

The high cost of this project is completion in December and January necessitated by the frequent rebuilding of containment dikes and the extra spoil that had to be dredged to provide the necessary fill after the fill already deposited was flushed from the marsh creation areas after levee breaching.

During construction, several changes from the original plan were incorporated. The containment levee north of DP1 (Figure 2) was moved approximately 30 m south to avoid a deep pit and lengthened to tie into an existing levee and prevent breaching. a channel developed between connecting DP4 and DP5, necessitating the creation of a dike to plug this channel. Another channel developed connecting DP4 with the canal north of the site and allowed spoil to be exported from that area. This channel was plugged. An additional disposal area was created at Site 5, north of DC2 (Figure 2) to ensure that at least 21.7 (8.789ha) acres of intertidal marsh were created. The creation of this disposal area also closed a breach through the island and helped ensure spoil flowing from DC2 was not lost to tidal flows.

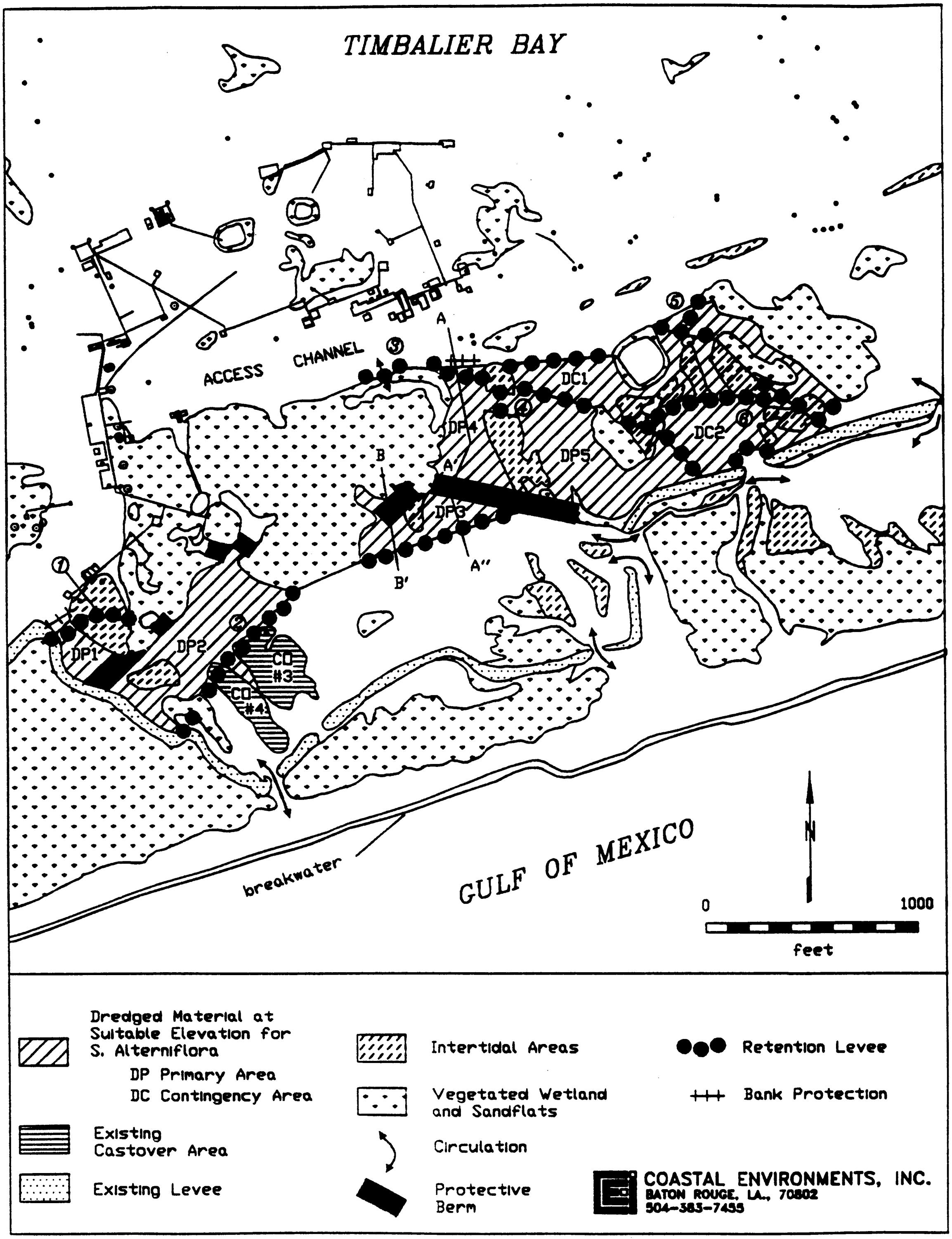

Figure 2. Features of the Greenhill Petroleum marsh creation project on East Timbalier Island in Louisiana.

By early April, the filling of Sites DP1-5 and DC1 was completed and the areas were left to dewater. DC2 and the area north of it, although receiving some sediment, was not filled to emeregent elevations. The rate of dewatering and compaction differed between areas. It appeared as if the spoil in DP1 and DP2 was composed of a higher percentage of sand than DP3-5 and dewatered relatively quickly. It was possible for someone to walk on DP1 and DP2 less than a week after deposition, even in areas that had previously been water 2 m deep.

In May, bulldozers were used to create a berm between DP1 and DP2 that was approximately 4 m wide and 0.7 m higher than the adjacent spoil area. This berm was created to serve as extra protection for the disposal sites by preventing tides from passing through the sites and creating another channel.

By mid-May, GP believed the project area was ready for planting. However, a site visit to East Timbalier island showed that not all areas had subsided to intertidal vegetation. Much of DP1 and DP2 was visibly higher than the adjacent marsh elevation and was not expected to subside appreciably in the near future. Surveys taken of the site showed that about 70% of the project area was approximately 15 to 20 cm higher than average high water levels. GP was informed of this problem and agreed to grade the area to the correct elevation. The spoil bulldozed from the deposition area was pushed into the berm and into the open water area south of DP2. Following this effort, planting of all sites was initiated in mid-June.

It was expected that marsh bordering the spoil containment areas would prevent the export of dredged material from the project area. However, the amount of spoil deposited on the marsh adjacent to DP2 and its impacts outside of the containment areas were unexpectedly severe. Adjacent to DP2, at least 15 to 20 cm of spoil was deposited on the existing smooth cordgrass marsh. This graded to 7 to 10 cm in depth 25 meters away from the borders of the deposition areas. This severe deposition of spoil on intertidal marsh killed the smooth cordgrass bordering DP2. Further away from the deposition site, some marsh plants were also killed, but enough survived to make us believe that the area would recover. Black mangrove trees in the marsh areas most severly impacted by spoil survived with little apparent impact. It is too early to determine if this addition of spoil will result in some areas becoming non-tidal and losing their marsh characteristics.

During the May site visit, it was determined that the spoil elevation in eastern deposal sites was adequate. Portions of DC1 and DP5 were inundated by 5-7 cm of water during high tide, and areas not inundated showed signs that led us to believe that they would subside several more centimeters. In addition, where the disposal site bordered marsh vegetation, the smooth cordgrass appeared healthy and was colonizing the deposition area. It appeared as if the spoil deposited in the eastern sites had a much higher percentage of silts and clay than DP2; this may explain the greater subsidence and the adequacy of the soil elevations.

In addition to the creation of marsh within the spoil containment dikes, the flow of dredged material from disposal areas resulted in the creation of marsh elevations outside of the designed disposal areas south of DP2 (Figure 2). In addition, a few marsh ponds near DP2 and surrounded by smooth cordgrass also were filled. It is expected that marsh vegetation will rapidly colonize these areas.

Even with project implementation, it was expected that East Timbalier Island would disappear within 15 years. Because of its importance as a barrier to waves and storm surges, another project to create over 80 acres (32.4 ha) of marsh on the island was funded under the auspices of the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) (Public Law 101-646). The MNFS is the Federal sponsor for this project, which will fill 3 areas of the island severely breached by hurricane Andrew. Another project on East Timbalier designed to completely restore the central 40% of the island which is now almost completely sub-aqueous, is sponsored by the NMFS and proposed for funding under CWPPRA in 194.

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A SURVEY OF WETLAND RESTORATION AND CREATION PRACTITIONERS

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The North Carolina Water Resources Research Institute undertook a project to develop a technical handbook for the creation and restoration of six coastal wetland types. This handbook has provided the North Carolina Division of Coastal Management with guidance to create and restore wetlands in the Southeastern United States.

One phase of the project was to acquire more information directly from the "practitioners" about techniques they utilize to restore and create wetlands. A questionnaire was developed with the assistance of a survey and wetland experts. There were 29 questions that were organized into the following six areas: organization/classification, record keeping sources of information, material needed in handbook, personal, and plant/soil/hydrology information. Approximately 400 questionnaires were mailed and 50 percent were returned.

The survey found most of the participants had biological training and were employed by a federal agency. Most organizations specialized in freshwater wetland types, and most respondents cited cost as the most limiting factor in restoration and creation efforts. Key informational sources were two federal agencies and journal articles. Hydrological restoration was found to be the most important topic to consider in developing a restoration and creation handbook.

INTRODUCTION

BACKGROUND

Of the estimated 110.9 million hectares of wetlands in the United States, North Carolina ranks sixth in the number of existing wetland hectares (Dahl, 1990). The original amount of wetlands in North Carolina is thought to be over 4.1 million hectares to be impacted. Impact in this case is whether the wetland is partially supporting, or non-supporting its original uses. Wet pine flatwoods and ponds, the only two wetland types that have increased by approximately 688 thousand hectares (NCEHNR, 1991). Of all the wetlands located in North Carolina over 95 percent are found in the 41 counties that make up the coastal plains. This is based on U.S. Soil Conservation Service estimates of hydric soils in each county. Steps have been taken by state and federal agencies to curb the number of hectares lost to development activities. Wetland restoration and creation are becoming a more common component of the regulatory program, and the U.S. Fish and Wildlife Service is restoring wetlands on its refuges. However, there is only one known national guidance document on wetland creation and restoration techniques. This is Chapter 13 developed by the U.S. Soil Conservation Services (SCS) in 1992 as part of their Field Handbook.

Currently, what is the number of restoration and creation projects that are being undertaken in North Carolina? To answer this question contact was made with the three main agencies involved with wetlands. These agencies are the U.S. Army Corps of Engineers (USACOE), U.S. Fish and Wildlife Service (USFWS) and the North Carolina Division of Environmental Management (NCDEM). Wetland projects fall under one of two components that include the regulatory and non-regulatory. The regulatory component involves both mitigation and enforcement actions tied to the permitting process (Section 404 of the Clean Water Act) that is regulated by the US. There are approximately 45 mitigation projects covering 186 hectares (available data from 1991-93). The North Carolina Department of Transportation (NCDOT) has 16 projects involving approximately 81 hectares, and the remaining 29 projects and approximately 105 hectares, are non-NCDOT projects. There are approximately 125 cases per year that some form of enforcement action is required by the USACOE. In 90 percent of the cases, this usually means restoring a wetland by removing the material that has been place on it and allowing the site to revegetate naturally. Current acreage figures for the wetland enforcement actions are not available (Wayne Wright, U.S. Army Corps of Engineers, Wilmington, NC and Ron Ferrell, N.C. Division of Environmental Management, Raleigh, NC, July 1993). The non-regulatory projects appear to be mainly associated with the USFWS efforts to restore wetlands to their original state on the National Wildlife Refuges, conservation easements, and private land. There are approximately 486 hectares that are actively being converted back to wetland habitat (Mike Wicker, U.S. Fish and Wildlife Service, Raleigh, NC, July, 1993).

PURPOSE

The Water Resources Research Institute has undertaken a project to develop a techniques handbook for the restoration and creation of wetlands. Funds for this project have been provided by the North Carolina Division of Coastal Management. The project is being carried out in three phases. Phase One consists of identifying techniques used for wetland creation and restoration through a literature review and consultation creation projects. Phase Two is to develop and distribute a questionnaire concerning specific restoration and creation techniques being utilized by wetland experts. Phase Three is to compile a handbook incorporating information from the literature, on-going projects, and expert opinion from the questionnaire for approximately six wetland types found in the Southeastern United States. The six wetland types are brackish/saltwater marsh, freshwater marsh, bottomland hardwood, swamp forest, pocosin and estuarine scrub-shrub.

This paper will specifically discuss the results of Phase Two. A questionnaire was developed with the assistance of a survey and wetland experts to acquire more information directly from the "practitioners" about techniques they utilize to restore and create wetlands. There were 29 questions that were organized into the following six areas: organization/classification, record keeping, sources of information/ material needed in handbook, personal, and plant/soil/hydrology information. Approximately 400 questionnaires were mailed and 50 percent were returned.

METHOD

QUESTIONNAIRE

The second phase of this project was to gain more information directly from the "practitioners" about the techniques they utilize to restore and create wetlands. A questionnaire was developed with the help of Tom Hoben, North Carolina State University - Department of Sociology and Anthropology and wetland experts. The questionnaire consisted of 29 questions covering such topics as sources of information, wetland types, handbook information needed, etc. A list of practitioners was developed from individuals attending a workshop conducted by the Army Corps of Engineers - Waterways Experiment Station on Engineering for Wetlands Restoration: A National Workshop. This workshop took place in St. Louis, Missouri on August 2-5, 1993. Participants at the workshop were asked to fill out the questionnaire and return it by the end of the workshop. Approximately 50% of the 224 attendees returned the questionnaire. A list of the individuals that did not attend the workshop was developed with the assistance of the Army Corps of Engineer's staff. Individuals on the list were mailed the questionnaire with a follow-up letter to individuals that did not return the questionnaire after one month. Other "practitioners" were contacted with the assistance of known wetland experts. In all, 400 questionnaires were sent out with 175 individuals returning a completed survey form.

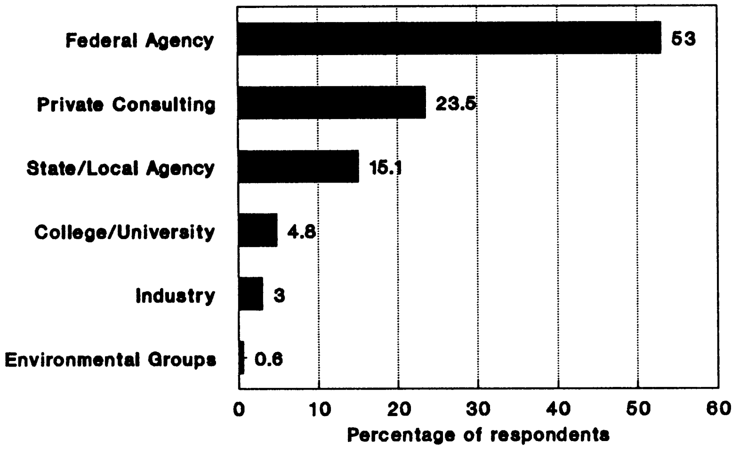
RESULTS

Results of the survey will be presented in six areas including organization/classification, record keeping, sources of information, material needed in handbook, personal and plant/soil/hydrology information. The results are presented as frequencies (converted to percentage) for 28 questions. The percentages given for each question do not always add up to 100% because of missing or incomplete information provided. Question #9 could not be expressed by frequency analysis as well as other follow-up questions and these questions were not included in this discussion.

There were five personal questions relating to type of organization, location of work, years of experience, area of training and main responsibility. There were 53.0% federal agency, 23.5% private consultants, 15.1% state or local agency, 4.8% college or university and 0.6% conservation or environmental group participants in the survey (Figure 1). This is not surprising because of the heavy involvement of many federal agencies such as Army Corps of Engineers, Environmental Protection Agency and U.S. Fish and Wildlife Service to name a few. The main location of work was one state (38.7%) followed closely by one region (28.6%). The remaining two larger areas of national and international consisted of less than 15%. Results of this question appeared to indicate that wetland practitioners were rather localized to one state or region. The most experience in wetland management (70.9%) ranged from 2 to 15 years. Training was most represented by the fields of biology (33.3%) followed by ecology (22.6%) and then engineering (18.5%). The least represented fields were administrative/business and law. Therefore, biology including botany and ecology with 62%, represented the main field of training with between 2 and 15 years of experience.

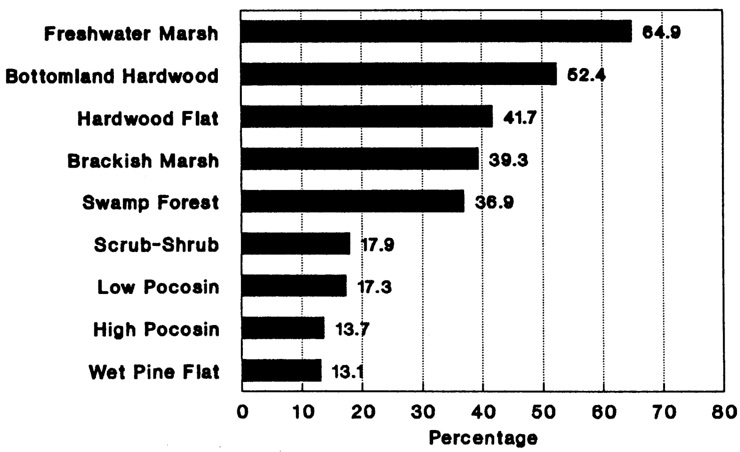
There were 10 questions dealing with the practices of the individual's organization concerning wetlands and the classification scheme utilized. Most organizations (64.5%) only spent between 0 and 20% on restoration and creation projects. When the number of projects increase between 21 to 40% the percentage of organizations only increased to 79.5%. Freshwater marsh (64.9%) was the main wetland type that was specialized in, followed by bottomland hardwood and hardwood flats (Figure 2). The least specialized wetland types (less than 18% each) were pocosin and estuarine scrub-shrub. The project stages of objectives, site selection, planning, construction and monitoring were felt to be very important. The most important function that was attempted to be restored/created was aquatic and terrestrial habitats/corridors (60.4%), water quality (39.6%) and flood and/or erosion control (31.4%). Success criteria, as defined as always established, occurred only 38.4% of the time. Far and away the most limiting factor in an organization's efforts was the

Figure 1
Employer



Survey question #25

Figure 2
Wetland specialization



Survey question #2

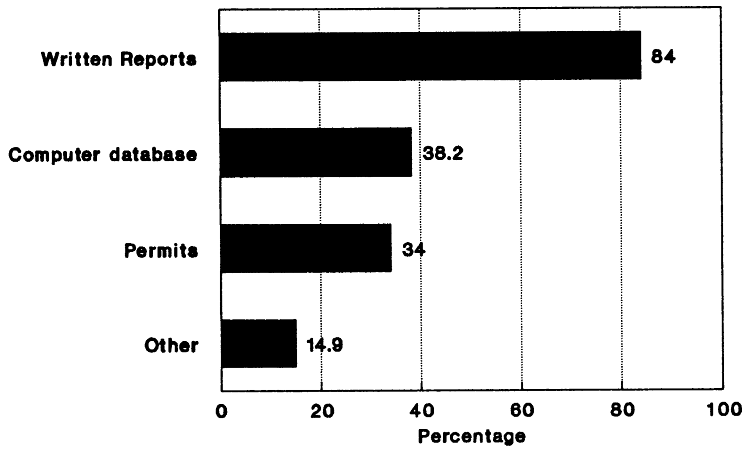
cost involved (32.3%) and a distant second was regulations. Most organizations had been involved with more than 20 restoration and creation projects (46.6%) and between 1 and 5 were attempted by 25.0% of the organizations represented in this survey. The level of success of a restoration/creation project was considered to be moderately successful 65.2% of the time and very successful 20.7% of the time. Project success was usually determined between 2 to 5 years after the project (49.6%) was completed. This success time period of 2 to 5 years was the general guideline used by the Army Corps of Engineers. Poorly suited sites for restoring/creating were required sometimes (40.0%), success was affected sometimes (41.5%) and the intended functions of a wetland was changed sometimes (53.3%). Most participants (65.%) used the Cowardin/Fish and Wildlife Service classification system while the others used a variety of other systems but most (61.8%) were based on plant communities. A comparison of three classification systems can by seen in Appendix C. The other main factors in a classification system were hydrology and hydrogeomorphology (32.3%).

There was one question that dealt with record keeping. Most organizations (86.2%) keep records on their projects and the most important information kept was plant survival rate, colonization by other plant species and wetland functions. Monitoring records were kept in 88% of the cases and between 86.1 and 91.5% of the participants would allow government agencies and wetland researchers access to their records. (Figure 3).

There were 2 questions dealing with sources of information for restoration/creation efforts. The four key sources of reference material included information from the Army Corps of Engineers, scientific/professional journals, personal communication with a consultant and the U.S. Fish and Wildlife Service. The least referred to source for information was the Environmental Protection Agency (5.8%) based on the list of nine different areas presented (Figure 4). Only 64% of the organizations disseminated information concerning their restoration/creation work. Most of the information was disseminated through project reports (82%) and conference presentations (58.4%).

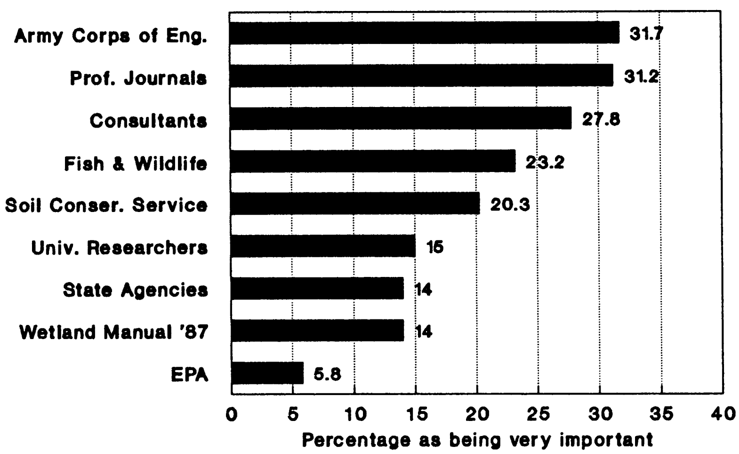
One question covered the possible topics to be included in the handbook. Planting procedures, plant selection, ecological functions of different wetland types, hydrology restoration and sources of regional expertise were felt to be the most important topics presented. The most important topic was hydrology restoration (Figure 5).

Figure 3
Form of record keeping



Survey question #11

Figure 4
Important sources of information



Survey question #13

The remaining 9 questions include plant, soil and hydrology questions. The question as to planting as opposed to natural colonization was split 50/50% but the wetland types were different. Planting included freshwater marsh, bottomland hardwoods, hardwood flats, swamp forest and brackish marsh. Natural colonization included freshwater marsh and bottomland hardwood. When obtaining plants for a site, 59.5% of the time both natural areas and nursery stocks were used but more is purchased than is taken from natural areas. The important hydrologic conditions are hydroperiod lengths and season, volume of water inputs relative to outputs, duration of inundation, frequency of inundation and near surface saturation. Only 33.3% of the organizations polled use a hydrologic model (Figure 6). The three most important soil/substrate preparation is grading (70.2%), clearing (36.3%) and importing soil (33.3%). Only sometimes (34.1%) and rarely (28.3%) is soil imported to the restoration/creation site. In most cases soil parameters are not monitored (61%). Water control structures are utilized 79.6% to regulate the site along with vegetation (73.2%) as the main erosion control technique.

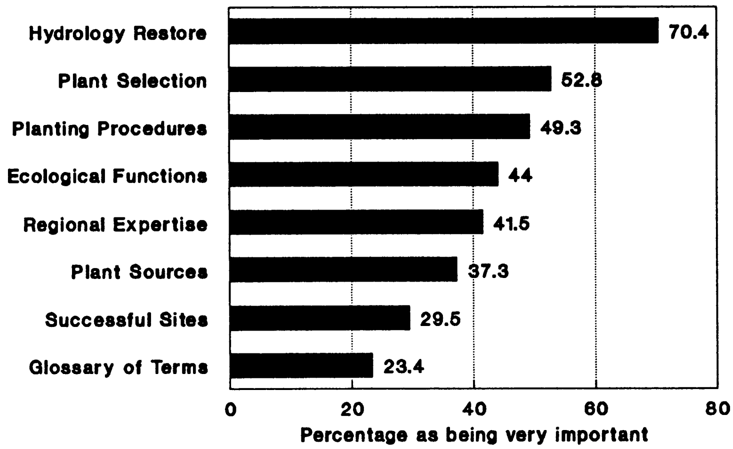
CONCLUSIONS

The majority of the questionnaire participants had biological training and were employed by a federal agency. The main wetland type their organization specialized in were freshwater types and cost the most limited factor. When poorly suited sites were selected for restoration/creation effort approximately 40 to 50% of the problems arose. These responses indicate that federal agencies are heavily involved and the factors of economics and poorly suited sites limit current efforts.

Key informational sources included two federal agencies, private consultants and scientific/professional journals. A little over one-half the organizations disseminated information concerning their project through reports and conference presentations. These comments indicate the importance of federal agencies' research efforts but the limited amount of current information available made all sources of information including the gray literature very important.

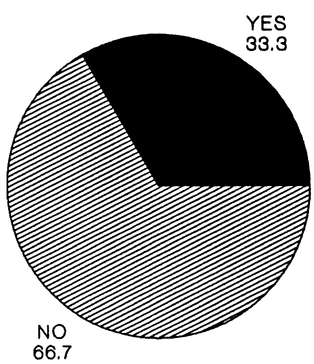
Hydrology restoration was the most important topic that should be considered in a handbook on restoration/creation techniques. However, only one-third of the organizations polled used hydrologic models. Restoration and creation efforts in wetlands have evolved from focusing on plants toward that of hydrology. Hydrology was one of the most difficult topics to deal with in wetland efforts but the most important in a project's success.

Figure 5
Information for handbook



Survey question #15

Figure 6
Use of hydrologic model (%)



Survey question #19

ACKNOWLEDGEMENTS

The author would like to thank Wesley Childres for helping to develop the questionnaire and to Dr. Tom Hoban for providing guidance in creating a more refined survey instrument. Thanks are in order for Mike Palermo and the other Army Corps of Engineers - Waterways Experiment Station staff for their help in distributing the questionnaire at their meeting. Appreciation is also expressed to all the individuals who completed and returned the survey. Without their cooperation there would be no results to report.

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Editor's Note: For additional information on wetland creation and restoration techniques the reader is referred to the publication listed below:

Kusler, J. D. and M. E. Kentula (eds.). 1990. "Wetland creation and restoration: The Status of the Science." Island Press, Washington, D.C. XXV+594pp.

MANAGING EROSION CONTROL PROBLEMS ON A LARGE MULTI-USE SITE

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ABSTRACT

Erosion, either through natural or man-induced forces, and subsequent sedimentation in downslope areas is a growing threat to the existence and integrity of wetlands. The Savannah River Site (SRS) is a U.S. Department of Energy owned and Westinghouse Savannah River Company operated site located in southwestern South Carolina that was previously used for the production of defense-related nuclear materials. Over a several-year period, the authors evaluated the deposition of fill into wetlands as a result of erosion on this 780 km^2 site. Industrial development, primarily in the early 1950s, has resulted in extensive damage to wetlands at SRS and in some cases irrevocable loss of these resources. The greatest amount of deposition occurred between 1954 and 1968, when heated reactor effluents were discharged directly into several site streams, resulting in extensive deforestation of a mature bald cypress (Taxodium distichum)-tupelo (Nyssa aquatica) forest at the point where the creeks flow into the Savannah River swamp. Deltaic fans of more than 240 ha were formed in these areas as a result of the increased flow, water temperature, and sedimentation (up to 1 m in some areas). Less extensive amounts of deposition have occurred across the site in all major watersheds. While the "delta" areas are revegetating naturally and in some cases with the assistance of selected plantings, DOE is currently evaluating the development of a comprehensive watershed management strategy to minimize future impacts. Areas of ongoing erosion are being addressed, but no effective strategy exists to remediate wetland areas where extensive deposition has already resulted in a loss of function.

INTRODUCTION

The Savannah River Site (SRS) is a 780 km^2 U.S. Department of Energy (DOE) facility constructed in the 1950s for the production of nuclear defense materials. The SRS is located in the Carolina-Georgia Sandhills Major Land Resource Area of South Carolina with the Savannah River forming the south-west boundary of the Site (Figure 1). Most of the uplands on the SRS, and many of the wetlands, were in cultivation when the land was purchased by the U.S. Atomic Energy Commission in 1950. Several small communities (including the towns of Ellenton and Dunbarton) with a total population of around 6000 people were located in this area. All houses and persons were moved prior to construction. Five small streams supply drainage for the site into the Savannah River. Facilities were located high on the watersheds to make use of these streams as discharge points for thermal or wastewater effluents. All vegetation was cleared within the planned industrial areas to construct facilities. Vegetation was also cleared for 33 m around the perimeter of security fences that surrounded these areas. Due to the lack of environmental regulations at the time of construction, impacts to wetland areas, either direct through fill or indirect through deposition of erosional materials, were not considered.

The construction of the five production reactors, chemical separation facilities, infrastructure and administrative areas occurred in a relatively short time and is still considered as one of the most massive construction projects in U.S. history. After construction of the reactors and associated facilities was completed, the U.S. Forest Service (USFS) planted the remaining open land in loblolly (Pinus teada) and slash pine (Pinus elliottii) to produce wood products and provide complete land cover for some 70,570 ha of soil.

In 1972, the SRS was designated as the DOE's first National Environmental Research Park. Currently, technology transfer, waste management, and environmental restoration activities comprise the major focus of the SRS. Ecologically, a diversity of different habitat types are currently found on the SRS. These include planted pine plantations, oak-hickory forest, mixed pine-hardwood and sandhills oak-pine in the upland areas. Wetland areas include bottomland hardwood forests, cypress-tupelo swamp associated with the Savannah River, and numerous Carolina bays scattered throughout the uplands.

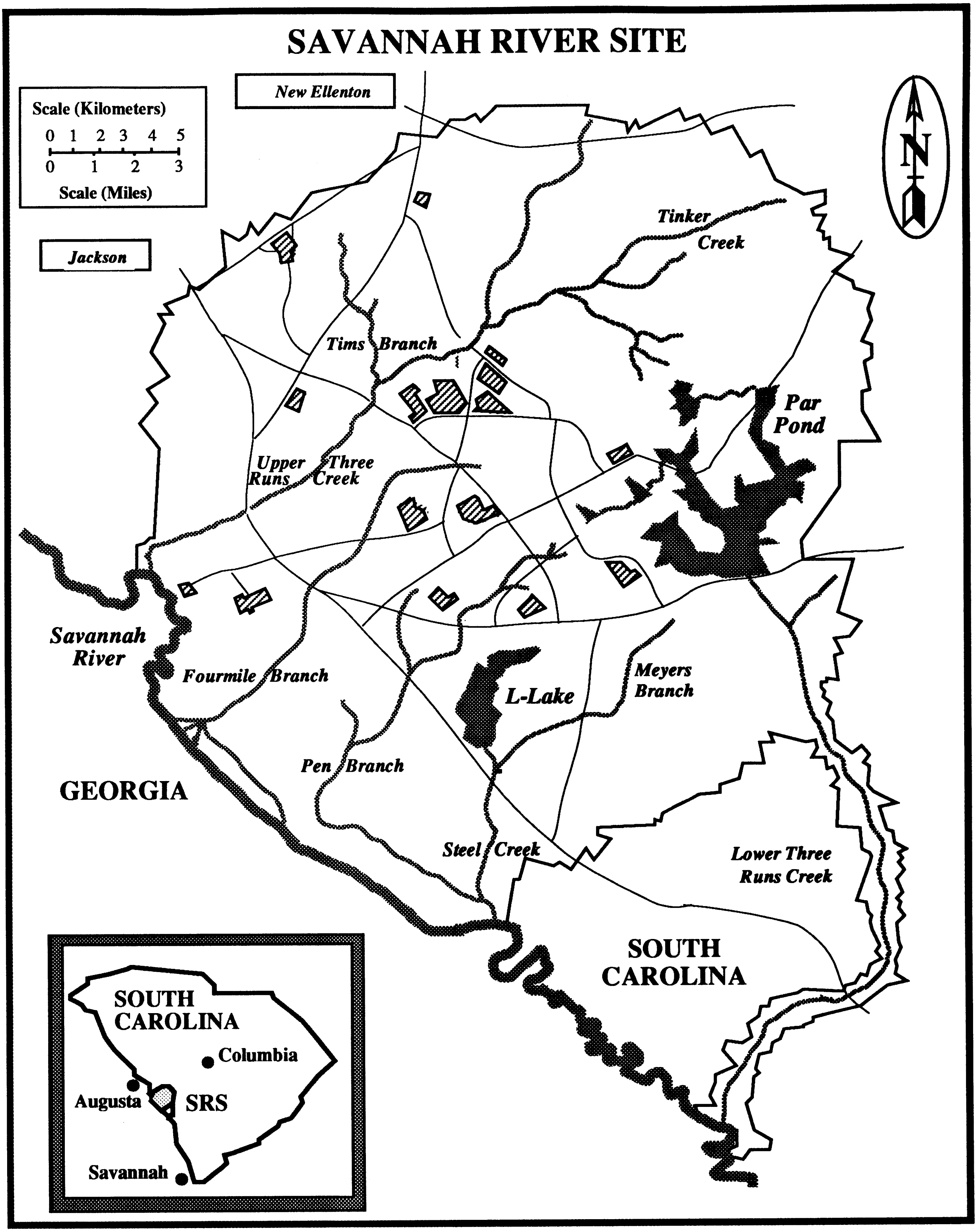

Figure 1. Location of the Savannah River Site. Developed areas are designated with hatched lines.

CURRENT STATUS

During the 40-year period that has followed initial construction, facility upgrades and industrial development have occurred on a regular basis, primarily within the confines of existing fenced areas. Currently approximately ten percent of the site's 80,130 ha is in industrial usage. During the period since initial construction, the tightening regulatory climate and passage of a myriad of environmental regulations resulted in a heightened awareness of the sites's impact on the environmental restoration activities.

The SRS consists of hundreds of facilities (which may be designated as a building or collection of buildings) each of which has a facility manager who is responsible for activities and regulatory compliance within their facility. Numerous concurrent activities and projects within the already developed areas, have played havoc with implementation of an overall approach for effective sediment and erosion control measures. Consequently within these fenced areas, control of erosion problems was haphazard and at the discretion of the facility manager(s). Problems were often discovered not at their source, but at the point of downslope impact, usually a wetland area. Often the difficulty in correcting the problems was compounded by multiple nonpoint sources within a watershed not attributable to any new construction activities.

In addition to the involvement of different facilities in contributing to erosion problems within a developed area, corrective actions were sometimes delayed due to a lack of clear lines of responsibility. The management and operation of the SRS is conducted by Westinghouse Savannah River Company (WSRC) under contract to DOE. The USFS Savannah River Forest Station (SRFS) and the U.S. Soil Conservation Service (SCS) work together on the site to provide expertise on management of SRS natural resources. A Natural Resources Management Plan was developed in 1991 to provide strategic guidance and delineate responsibilities among these organizations. The plan covered a number of different aspects of natural resource management (Figure 2) including sediment and erosion control and charged WSRC, SRFS, and SRS to enhance quality and productivity (DOE 1991). In addition, the plan delineates responsibilities within many specific areas, where they were previously unclear or overlapping. It has provided a good first step towards a unified approach to managing SRS soil resources and identifying and correcting existing problems.

Management Programs	Research Programs
Soil, Water and Air Resources Fish and Wildlife Management Timber Management Secondary Road Management Boundary Management Public Affairs (SRFS)	Environmental Research (SRFS, SREL, WSRC-SRTC) Forest Management Research
Cultural and Archeological Resources Management (SRARP)	Archeological Research (SRARP)

Figure 2. SRS natural resource management and research programs. SRFS-Savannah River Forest Station; SRARP-Savannah River Archeological Research Program; SREL-Savannah River Ecology Laboratory; SRTC-Savannah River Technology Center; SEFES-South East Forest Experiment Station.

Fill in wetlands has occurred in all watersheds of the SRS as a result of sediment that eroded from construction sites and facilities lacking proper vegetative cover. The authors traversed much of the SRS to examine impacted areas; most of the impacts to wetlands were generally less than 1 ha. In some cases depth of fill was so substantial that loss of wetland function and mortality of mature trees had occurred. In most instances, impacted areas were still functioning wetlands although the vegetation and hydrology were often designated as low priority by the facility managers because there were no regulatory noncompliances associated with them.

An extreme example of sediment deposition in wetlands on the SRS was associated with the operation of the nuclear protection reactors and subsequent discharge of thermal effluents, which exceeded 70° C at times, into the site streams. There was severe erosional impact because of the increased flow rates in the stream channels and elevated water levels sustained during reactor operation. The high water temperatures killed much of the vegetation and allowed scoring of the small stream channels and exposed floodplain during peak discharge periods. Deposition of unconsolidated sediments occurred at the point where the streams entered the Savannah River Swamp resulting in the creation of deltaic fans. The relationship between upstream scouring of the stream channels and downstream formation of the "details" is seen in Pen Branch, Steel Creek, and Four Mile Creek (Ruby *et al.* 1981).

Up to 1 m of overburden was found in some areas with up to 600 ha of impact overall in the Savannah River swamp system. This extensive amount of deposition compounded the oxygen deprivation that occurred with the thermal flooding. Researchers from WSRC-SRTC, SRFS and SREL have been working with selective plantings in the Pen Branch delta, and with the reactors no longer in operation, natural succession is slowly proceeding in the Fourmile Branch and Steel Creek deltas.

DISCUSSION

The nature of soils on the SRS add to the erosion potential because about 75 percent of the area has a sandy surface and is formed on topography with some relief or slope. In fact, over seven percent of the area has soils on strongly sloping to steep slopes. Sandy soil material erodes easily and as slope increases the potential to erode increases. The major series in the upland areas are the well drained Fuquay, Blanton, and Dothan soils (Rogers 1990). Each of these soils has a sandy surface of varying thickness.

Vegetative cover in the form of woody or herbaceous species prevent soil from moving from its position on the landscape. While water and wind are the primary forces that move soil particles from one place to another, water has been the main force that caused erosion on the SRS. Large areas were cleared of all vegetation for the construction of various facilities during the first few years the government owned the property. Major construction projects and land-clearing activities still take place but on a much smaller scales.

The average annual rainfall is approximately 121 cm and about 54 percent of this amount falls in April through September. This rainfall is often in the form of heavy thunderstorms that occur on average 55 times each year with the most severe recorded in nearby Aiken, South Carolina on April 16, 1969 when 24.6 cm of rain was measured. This volume of rainfall is capable of moving massive amounts of soil materials from the sandy upland slopes where vegetative cover has been removed to the wetlands and low lying floodplain areas. The site then loses much of its capacity to intercept rainfall which becomes stormwater runoff, higher peak discharges, and shorter lag time for the runoff to reach the stream.

Much of this sediment is deposited in the wetlands with some going into streams and adversely impacting water quality. Sedimentation, impacts to water quality include increased sediment loads, increased suspended solids, and a decrease in dissolved oxygen levels. Sediment also has an affinity for absorbed nutrients, pesticides and other materials that it transports into the streams. Sediment in wetlands equates to filling the wetland or lowering the water table which changes the hydrology of the area and creates a drier habitat for new species to establish. Wildlife can also be impacted due to loss resources on which they depend.

In developed areas, the extent of impervious surfaces are increased resulting in a greater amount of runoff from these areas during storm events. Besides the physical and biological impacts from increased runoff, sediments eroded from waste sites and the chemical separations areas on the SRS may contain high amounts of metals or radioactive constituents resulting in chemical impacts on the vegetation in depositional areas. For example, aluminum has been detected above background in a number of water samples tested in impacted wetlands downslope of some seepage basins on the SRS. Acidic water tends to leach metals from the kaolinitic subsoil material.

CORRECTIVE ACTIONS

The South Carolina Stormwater Management and Sediment Reductions became effective on June 26, 1992 which now require stormwater management and sediment control plans to be approved at the state or local level prior to any land disturbing activity. This new program is being implemented by the South Carolina Department of Natural Resources and contains provisions for enforcement actions for offsite damage due to runoff. Requirements for protecting wetlands and the quality of groundwater and surface waters are also addressed.

A Handbook for Sediment and Erosion Control was developed in 1992 by DOE in cooperation with the SRFS and the SCS to assist project sponsors, facility managers and other users in developing best management practices and assist them in control measure planning, implementation, and maintenance on the SRS. Some of the many techniques that have helped to reduce erosion at construction sites are the use of mulch, matting, silt fences, vegetative buffer zones, sediment basins, terraces, seeding, application of fertilizer and lime at time of planting, close follow-up treatments as needed, and timely plus limited removal of vegetation from the construction site (DOE 1992). A coordinated effort was made to evaluate these practices in the field and provide guidance on corrective actions where needed. The SRFS and SCS routinely hold workshops to educate site personnel on best management practices for erosion control and natural resource issues.

WSRC, DOE, SRFS, and SCS recently undertook an in-depth analysis of the erosion problems on site and identified priority areas for resolution and near term correction. Site technical personnel are also participating in an Environmental Protection Agency led effort to develop a watershed management plan for the Savannah River basin. A site-specific watershed plan is also under development. This plan is expected to provide a coordinated approach to identifying and remediating existing sediment and erosion control problem areas in a a coordinated fashion across SRS. In addition, the plan will be used to facilitate future permitting activities (e.g., National Pollution Discharge Elimination System permits).

In April 1994, the Secretary of Energy outlined a comprehensive initiative for land and facility management to redirect departmental stewardship to include a balanced ecosystem-based focus. This initiative includes a revision of land and facility use and site development planning policies and an inventory of physical site information. This comprehensive approach to SRS planning will facilitate future management of the site to minimize impacts to natural resources, identify areas for future development, and remediate areas of past impacts. Although SRS has recently made major strides towards addressing historical sediment and erosion control problems on site, this new Secretarial initiative will be the basis for minimizing the impacts of future development.

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A MESOCOSM MODEL OF THE EVERGLADES: AN EXTREME EXAMPLE WETLAND CREATION

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ABSTRACT

The Everglades mesocosm of the Smithsonian Institution is described as a high energy example of wetland creation. The mesocosm is a living model of the Everglades that was built as a prototype for the marsh biome of Biosphere 2 in Arizona. It is located in Washington D.C. in a 30.5 m (100 foot) long greenhouse. The system was constructed in 1987 and was stocked with species from southwest Florida. A number of energy sources are required to maintain the subtropical ecosystem including motors and pumps for tides and water flows, large fans for wind, a sprinkler system for precipitation, algal scrubbers for nutrient control, propane heaters and titanium heat exchangers for temperature control and a half-time technician. Thus, it is a special, extreme case of wetland creation. At present the system is being used for ecological research and educations. Data on temperature and salinity are presented which help validated the mesocosm as a model. These results indicated a general similarity between the mesocosm and literature data from southwest Florida. The utility of the mesocosm as an example of wetland creation is discussed.

INTRODUCTION

Arising out of the need to mitigate the loss of wetlands, a number of techniques are being developed to create new wetlands that replace the loss. This is practical work where success is judged by the development of an ecosystem with structure and functions similar to that of a natural wetland. The challenge is great and requires the combination of ecology and engineering. Here we report on an extreme case of wetland creation in which a living model of the Everglades is operated in a mesocosm. The experience gained from building and maintaining the Everglades mesocosm contributes to wetland mitigation technology by demonstrating how a complex system can be reproduced under controlled conditions.

SITE DESCRIPTION

The Everglades mesocosm was created in 1987 as a prototype for the marsh biome of the Biosphere 2 project in Arizona (Allen 1991). It is one of a series of ecosystems created for research and exhibit by the Smithsonian Institution's Marine Systems Laboratory (Adey and Loveland 1991). The system was created in the Smithsonian's horticultural greenhouse complex on the grounds of the United States Soldiers and Airmen's home in Washington D.C. While the Everglades mesocosm is only one fifth of the size of the marsh biome of Biosphere 2, it is a fully functioning subtropical estuarine ecosystem.

A description of the Everglades mesocosm has been given by Adey and Loveland (1991) but a summary is provided here. The mesocosm is housed in a glass 12.2 m (40 foot) x 30.5 m (100 foot) greenhouse which allows control over the energy signature of the system. The Everglades is not a single system but a gradient of estuarine subsystems organized by water flows. The mesocosm itself was modeled after a 48 km (30 mile) transect near Everglades City in southwest Florida, where collections of sediments and organisms for the system were made. To simulate the transect, the mesocosm was designed to bend the gradient around the greenhouse with the freshwater system paralleling the marine-estuarine system (Figure 1). The heart of the mesocosm is a series of seven butyl-rubber lined tanks containing the subsystems of the Everglades gradient: freshwater marsh with upland hammock (tank 7), oligohaline marsh (tank 6), white mangroves (Laguncularia racemosa) (tank 5), black mangroves (Avicennia germinans) (tank 4), red mangroves (Rhizophora mangle) on an oyster reef (tank 3), fringing red mangroves (tank 2) and the marine bay (tank 1). The tanks are connected with step up weirs which increase in elevation as one moves toward the headwaters of the estuary. These weirs not only compensate for the

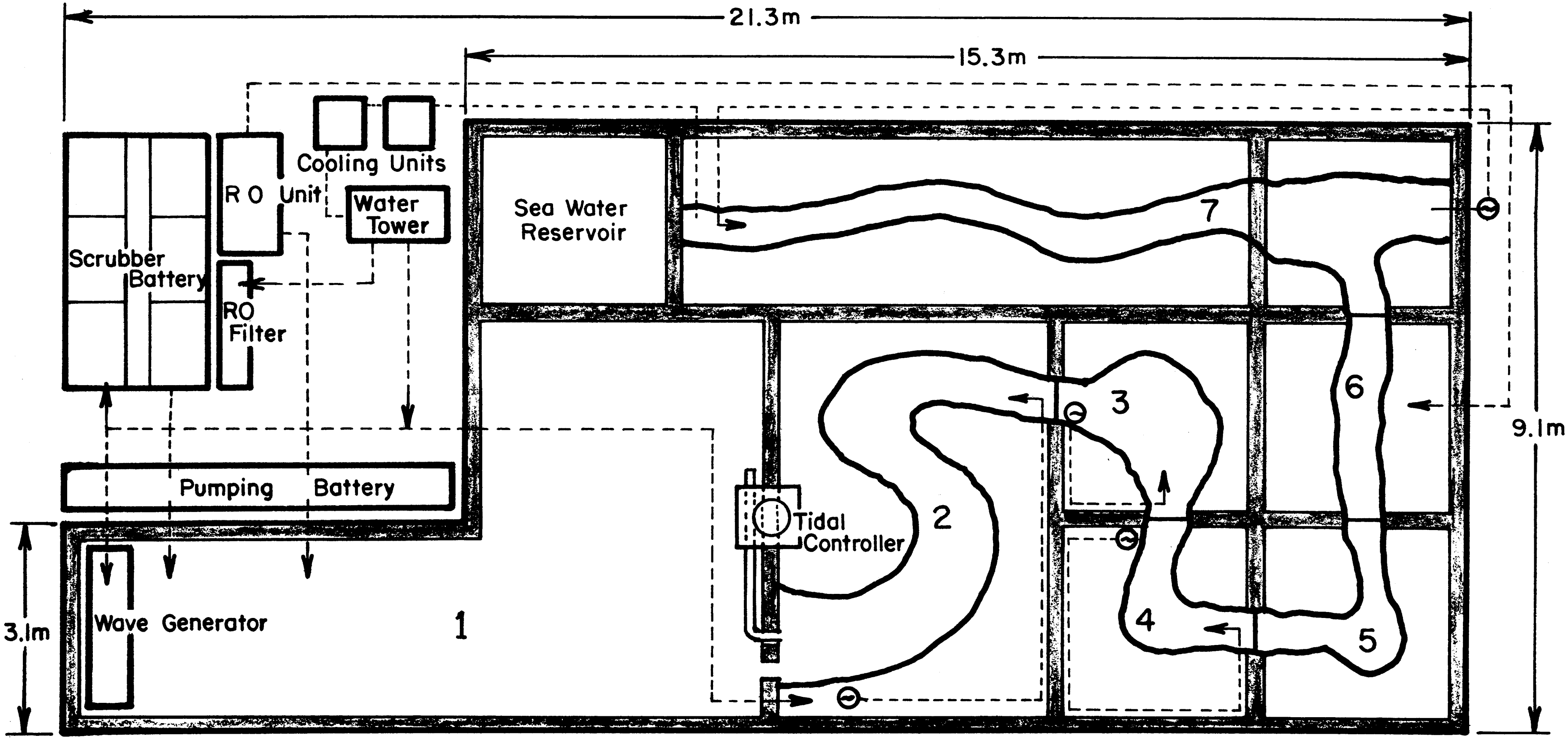

Figure 1. Floor plan for the Everglades mesocosm in Washington D.C. (redrawn from Adey and Loveland 1991). Numbers refer to subsystems along the estuarine gradient (see text for list). Dashed lines represent water flows.

elevation gradient found along the transect but also help to maintain the salinity gradient and salt water intrusion in the estuary.The water cycle of the system is mostly pressure driven but with a few recirculating pumps to maintain flow. The dynamics of the water flow is as follows: salt water is pumped from the marine tank to the water tower. A portion of the water is then pressure fed into a reservoir for the algal turf scrubbing system which is the nutrient control mechanism for the mesocosm (Adey *et al.* 1993, Jensen 1994). Algal scrubbers are mats of algae grown on screens, which receive pulses of water in the form of waves. As the water passes over the algal mat, the algae strip nutrients from the water and incorporate them into their biomass. Once a week the algal scrubbers are harvested by scraping the excess algae from the screens. The biomass can either be removed from the system if nutrients are too high or returned to the system if nutrients are too low. This action regulates nutrient concentrations and allows control over water quality of the system.

From the algal scrubbers water is returned to the marine tank. Water from the tower also flows into the wave generator of the marine and into the fringing red mangrove tank. The three part tide motor and the flexible tide return arm regulate the semi-diurnal tidal cycle by controlling the rate of return of water to the marine tank (tank 1) from the estuary (tank 2).

Freshwater flow is provided by a reverse osmosis machine which transforms saltwater into water molecules and brine. The freshwater is fed into the headwaters of the estuary while the brine is returned to the marine tank. Thus, use of the reverse osmosis machine simulates both large-scale evaporation from the marine end of the system by concentrating the brine as well as precipitation input of freshwater to the headwaters of the estuary. Additional precipitation is simulated with an overhead sprinkler system or manually with a hose.

METHODS

Preliminary data from the Marine Systems Lab's routine monitoring program are reported to demonstrate correspondence between the mesocosm and the Florida Everglades. Air and water temperature are recorded daily in the mesocosm with maximin thermometers. Salinity is measured daily throughout the system in the morning and afternoon with a refractometer. These data have been recorded, with minor interruptions, since construction on the system was completed in 1988. In 1993 a more detailed microclimate and hydrology monitoring program was initiated that includes measurements of evaporation, water inputs (simulated precipitation), water level fluctuation, relative humidity, wind speed and solar radiation.

RESULTS

Air temperature in the mesocosm matches well with data from Everglades City, Florida (Figure 2). There is a slight drop-off in temperature during the fall but generally a close correspondence exists. This matching is achieved through use of propane heaters which heat the greenhouse in the winter. In the summer, cooling is provided by use of large fans which simulate wind and titanium heat exchangers in the water circulation system. Comparison with data from Washington D.C. in Figure 2 illustrates that the mesocosm is maintained at a very different microclimate than ambient conditions.

Data on the salinity gradient of the mesocosm are shown for 1988, which was the first full year of operation, as an example in Figure 3. The only directly comparable data for the Everglades is shown for the Faka Union Canal from 1972 (Carter *et al.* 1973). Locations along the Faka Union canal for this figure were chosen to match with tanks in the mesocosm based on vegetation. Although salinity in the mesocosm is slightly lower at the ends of the gradient, the overall correspondence between the mesocosm and the Everglades is close. This matching is achieved through the tidal and water circulation plumbing system of the mesocosm.

DISCUSSION

The data described above indicate that the Everglades mesocosm has been successful in reproducing two of the important physical-chemical characteristics of the Florida Everglades estuary. Because of this success, a significant amount of the biodiversity that initially was stocked into the mesocosm has survived and reproduced. Studies are now underway on the marine food web, mangrove forest structure and function and freshwater marsh plant community composition. These and other planned studies will demonstrate the relative success of creating Everglades ecology in the mesocosm.

After background studies are completed, one of the long-term goals for the system is to use it to test issues of environmental impact and management that are relevant to the Florida Everglades (Kushlan 1987, Rader and Richardson 1992, Scheidt *et al.* 1989, Walters *et al.* 1992). For example, nutrient enrichment studies can be performed to study the effects of pollution from sugar cane agriculture below Lake Okeechobee on the downstream Everglades. It would be possible to test various levels of nutrient enrichment in the mesocosm since the algal scrubbers can be used to restore background nutrient conditions after each experiment. Another example of the experimental capability of the mesocosm

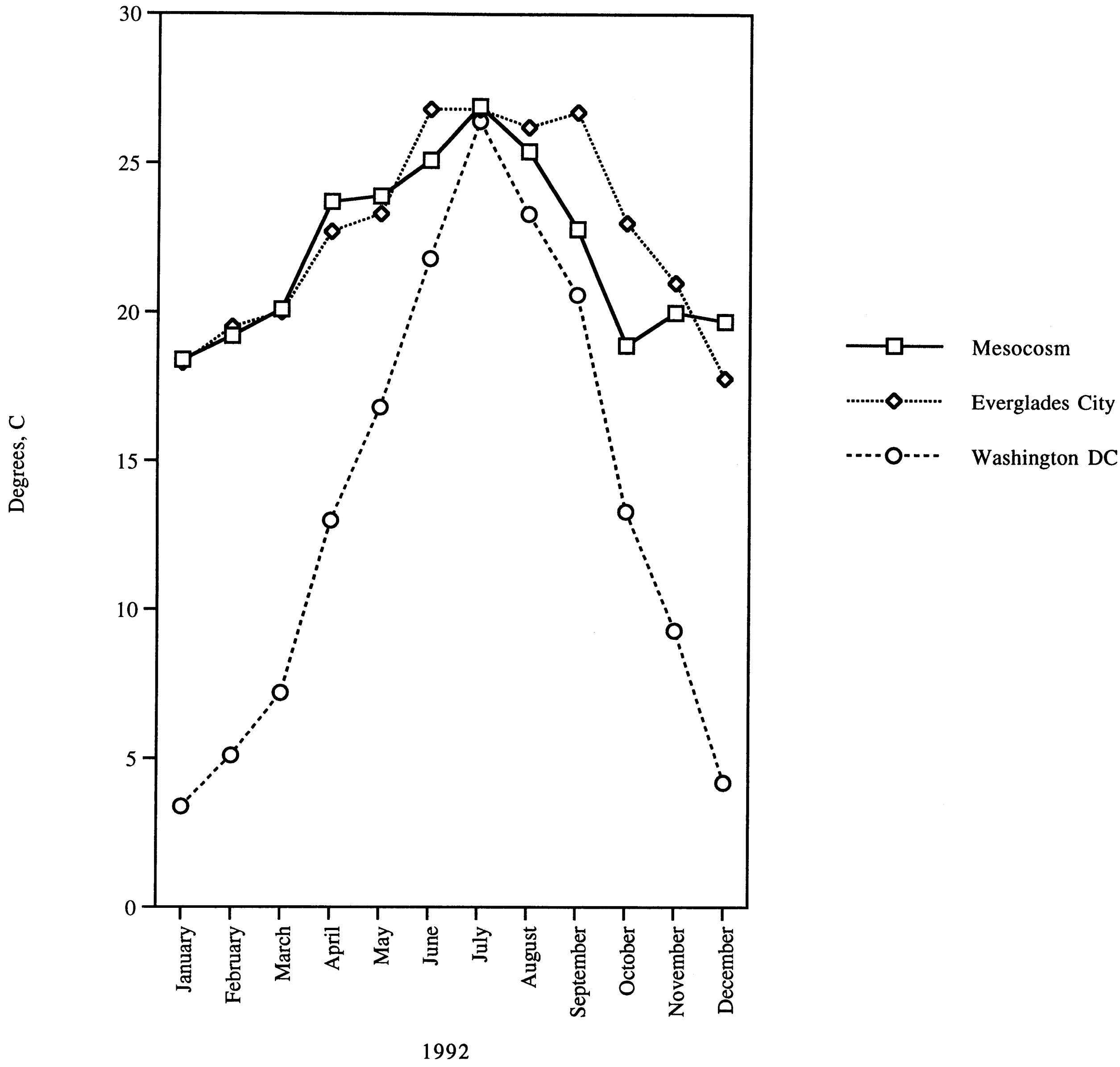

Figure 2. Temperature comparisons with the Everglades mesocosm for 1992. Data from Everglades City are from NOAA (1992a) and data from Washington D.C. are from National Airport (NOAA 1992b).

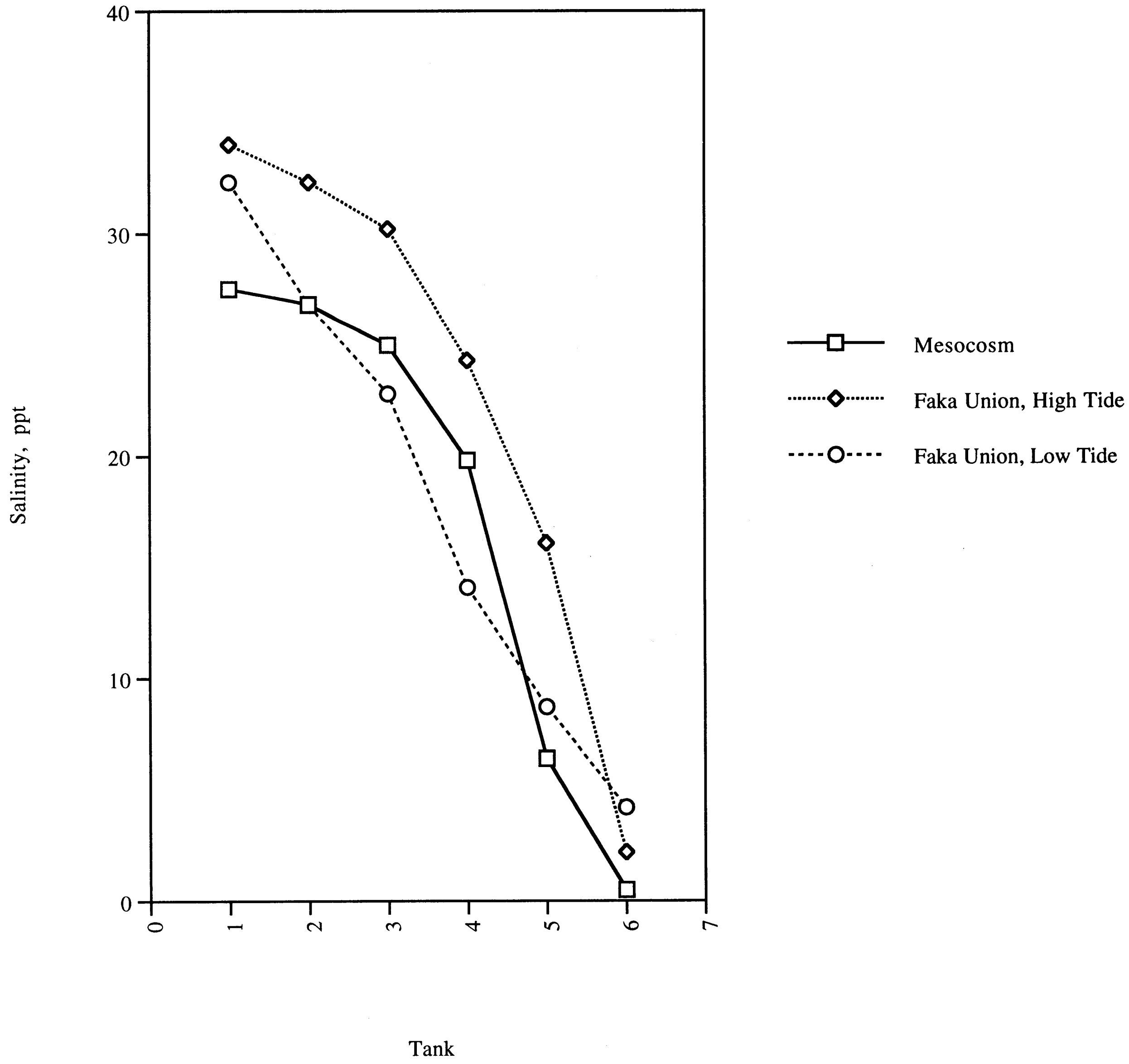

Figure 3. Comparison of salinity data along estuarine gradients in the Everglades mesocosm and southwest Florida (Faka Union Canal).

occurred inadvertently when the reverse osmosis unit broke down for a period and salinity greatly increased in the marine bay tank. This event simulated what is presently occurring in Florida Bay as freshwater input is reduced (Allen 1993, Barley 1993). The bay is becoming hypersaline with consequent changes in biota. Although the reverse osmosis problem was quickly repaired in the mesocosm, this situation demonstrated another significant environmental impact that can be studied with the system.

The Everglades mesocosm has not only been used as a research facility but also as an educational setting. A cooperative relationship has developed between the Marine Systems Lab and ecology programs at the University of Maryland to facilitate educational use. Students from several courses are given tours of the mesocosm each semester to demonstrate dynamics of a subtropical estuary and the technology used to create and maintain the system. Some courses go further and utilize the mesocosm for field work to teach ecological methods, such as litterfall collection, leaf decomposition and microclimate characteristics. A special additional activity is the utilization of students as interns with the Marine Systems Lab to help operate the mesocosm. All of these educational activities are unique opportunities for students to learn about ecological engineering and Everglades ecology that would not be available without access to the mesocosm.

In conclusion, we compare the Everglades mesocosm with a typical wetland mitigation project for perspective (Table 1). Wetland mitigation is a relatively new endeavor involving both science and policy (Jones 1993), Kusler and Kentula 1990, White *et al.* 1992). The goal of mitigation is to create wetland ecosystems in an economically efficient manner, but there is still much to learn. The Everglades mesocosm exceeds the typical mitigation project on all counts in Table 1 primarily because its cost is high. This was possible in a small-scale research facility but the relative investment is necessarily less in a typical wetland mitigation project. Thus, the Everglades mesocosm, represents an extreme case in wetland creation and is not directly comparable to most mitigation projects. The results of the mesocosm, however, can contribute to the growing knowledge on technology for wetland ecosystem creation as a special case study.

Table 1. Comparison of a typical wetland mitigation project with results of the Everglades mesocosm.

	Typical Mitigation Project	Everglades Mesocosm
Control over energy sources	weak	strong
Ecological monitoring	absent - irregular	regular
Planting success	variable	high
Relative cost	low - moderate	high

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SELECTION OF WOODY SPECIES FOR BOTTOMLAND RESTORATION

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ABSTRACT

The bottomland forest of a third order stream in the South Carolina coastal plain was slowly destroyed between 1955 and 1985 by thermal effluent. When restoration efforts began in 1990, the site was dominated by several early successional stages , ranging from broomsedge (Andropogon virginicus) on dry sites to black willow (Salix nigra) in ephemeral pool sites. Successful bottomland forest restoration depends on choosing the correct species and methods of reintroduction for a particular site. The presence of large areas of broomsedge and loblolly pine suggested that some upland as well as bottomland species might do well in this habitat. Therefore, eleven species representing a wide range of site requirements were planted as either containerized or bareroot seedlings into sites varying in apparent soil moisture. After the first growing season, a relatively dry year, survival was > 70% for species as diverse as Taxodium distichum and Quercus marilandica. The subsequent three years have been much wetter and adequate survival has been limited to T. distichum and Q. michauxii (in both wet and dry sites), Fraxinus pennsylvanica (in wet sites), and Q. nigra (in dry sites). Over the four years of the study, growth has been substantial, but beaver herbivory during recent flood events has adversely affected, while not killing, some individuals.

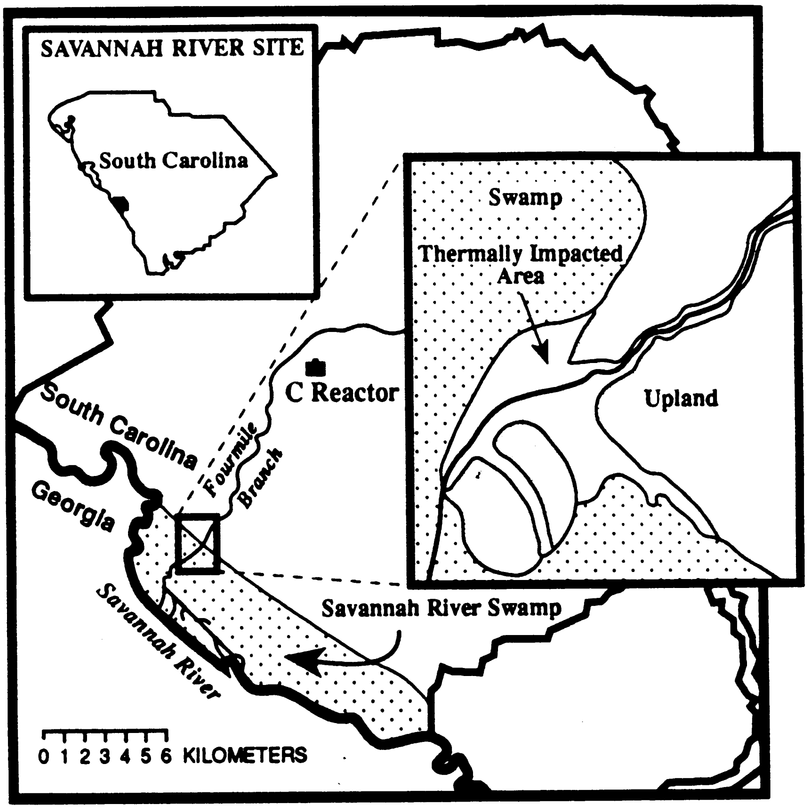
INTRODUCTION

On the Savannah River Site, nuclear production reactors were cooled by a once-through cooling cycle, utilizing wate r from the Savannah River and discharging the effluent to third order tributaries of the Savannah River. This discharge persisted for 30+ years and changed the stream environment drastically. The flow rate was increased by approximately an order of magnitude, raising the stream level 15 to 30 cm. The water temperature was raised to approximately 45°C at the delta where the tributaries merge with a bald cypress (Taxodium distichum) - water tupelo (Nyssa aquatica) swamp forest associated with the Savannah River.

In addition, the effluent caused sediment instability with erosion of the streambed in the upper reaches and deposition in the lower reaches. As a result of these discharges, large areas of bottomland and swamp forests were destroyed in three stream systems on the SRS (Sharitz, *et al.*, 1974). These losses include 90 ha of the delta of Fourmile Branch (Jensen, *et al.*, 1984), a stream impacted by C-Reactor (Figure 1).

Since this effluent persisted almost continually from 1955 to 1985, the normal seed bank and sprouting ability of the original forest was eliminated. Therefore, secondary succession, observed as a consequence of other disturbances such as blowdown of clearcutting, was not possible.

Figure 1. Location of the Savannah River Site and the thermally impacted area of the Fourmile Branch delta.



Natural recovery of the vegetation in the delta of Fourmile Branch began in 1985 when the reactor was shut down. Recovery of the vegetation is being documented through the use of permanent plots. The vast majority of woody stems belong to early successional species with few individuals of later successional species present.

Although vegetation recovery is occurring in Fourmile Branch delta, the later successional, bottomland hardwood forest would not likely be well established for at least 50 years. This later successional vegetation would provide a continuous forest canopy and good soil stabilization, along with quality wildlife habitat. Therefore, a research program was begun to investigate methods to accelerate succession and restoration of the vegetation of Fourmile Branch delta.

The restoration is limited by several factors. First, large scale soil disturbance, such as contouring of the site, is not desirable due to the potential resuspension of low level radionuclide contaminated soil. Second, the hydrology of the delta cannot be separated from the influence of the Savannah River, which is controlled by several upstream dams. Finally, it was decided that species reintroduction would be necessary to ensure that desirable species become established in the delta rapidly. Thus, the research has focused on introducing later successional species into the existing dense early successional vegetation. This manuscript reports the results of three experiments designed to determine suitability of various species and their responses to fertilization at planting.

GENERAL SITE DESCRIPTION

When this research program was initiated in 1990, three distinct habitats were observable: dry sites, dominated by _Andropogon virginicus_ (broomsedge) and _Pinus taeda_ (loblolly pine); wet sites, dominated by _Scirpus sp_. (sedges) and _Juncus_ _sp_. (rushes); and open shallow water sites, comprised of pools and segments of the braided stream with only overhanging vegetation. The initial studies attempted to utilize these apparent site differences to establish a broad suite of species.

The Fourmile Branch delta is atypical of Southeastern stream bottoms. The sediments have a layer of recently deposited sands on the surface. Therefore, without frequent rainfall, the soils of the delta can be droughty, even though a permanent water table exists at approximately one meter. Surface flooding can occur due to local rainfall or when the Savannah River water levels are high.

The general climate of the area includes warm summers and mild winters (see Aiken station of the South Carolina Climatological Data (NOAA, 1992)). The coldest and warmest months are January (mean daily temperature of 7.9°C) and July (mean daily temperature of 26.8°C), respectively, with a mean yearly temperature of 17.9 C. Precipitation averages 121 cm per year with fairly equal distribution throughout the year. Maximum and minimum monthly rainfalls are 13.6 cm (March) and 5.6 cm (October), respectively. Winter rainfall is primarily from frontal activity, while summer rainfall usually results from convective thunderstorms.

MATERIALS AND METHODS

EXPERIMENT I. The objectives of this experiment are twofold: 1) to determine site suitability of nine tree species for a relatively dry area of the delta, and 2) to determine whether fertilization would enhance survival and growth. Nine species (*Quercus alba*, *Q. coccinea*, *Q. margaretta*, *Q. marilandica*, *Q. michauxii*, *Q. nigra*, *Q. rubra*, *Q. stellata*, and *Taxodium distichum*), which represent a wide range in both flood and drought tolerance, were used. The "dry" habitat in which these species were outplanted was defined by the dominance of *Andropogon*. Plants for this experiment were grown from locally collected seed and were two years old at planting. The containerized seedlings were planted on 2x2 m centers, with seven plants per species/treatment in each of two replicated plots. Half of the seedlings received a starter fertilizer tablet (23/2/0 plus 1% Mg), placed at the bottom of the planting hole. Species/fertilization treatment was randomly assigned to planting locations.

Each spring and autumn following planting, survival and health were determined. Dead seedlings were examined to determine the cause of death, if possible. Any signs of herbivory were noted, especially those that might have contributed to seedling death. Height was determined in the autumn of each year. Data were analyzed by one and two way analysis of variance using SAS (1990).

EXPERIMENT II. This experiment is similar to Experiment I, but trees were planted in wet sites to contrast species response to the hydrology of the planting site. "Wet" sites were defined as having the vegetation dominated by *Scirpus* species and *Juncus* species. Four of the species planted in the previous experiment (*Quercus alba*, *Q. michauxii*, *Q. nigra*, and *Taxodium distichum*) were used in this planting. Details of spacing, fertilizer treatments, observations and measurements were the same as in the preceding experiment.

EXPERIMENT III. The last of the three experiments planted in the winter of 1990 differed by using bareroot seedlings of three species (*Fraxinus pennsylvanica*, *Quercus michauxii*, *Q. shumardii*). Bareroot stock was obtained through the Southeast Forest Experiment Station in Charleston, SC. The objectives of this experiment were similar to Experiment II. Differences between these two experiments include type of planting stock and species, with only Q. michauxii in common with the previous two experiments. Sample size per species/fertilization treatment was 30, with only a single wet site plot used.

DESCRIPTION OF THE PLOT ENVIRONMENT. From random locations in each of the five plots in the delta of Fourmile Branch, 12 soil samples were taken for nutrient and textural analysis. These analyses were conducted at the University of Georgia Soil and Plant Analysis Laboratory in Athens, GA. Following planting, the relative elevation of each planting location was determined during a flood event by measuring the depth of water at each location. The plots are fairly small and these measurements were taken in a short time period during which the overall after level remained constant. At a central location on the delta, and automated meteorology station collected various climatic and hydrologic data.

RESULTS

SOILS. While some minor trends might be indicated by the soils data (Table 1), the variance within each plot is so large that it made interplot comparisons insignificant. Considering then the entire data set as characteristic of the soils in the delta, several facts are apparent. First, the soils are composed primarily of sands, characteristic of the Coastal Plain and also indicative of the deposition of materials in the delta as a result of the increased stream flows. The organic matter and nutrient concentrations of the soil are low, but localized areas of higher concentrations exist, as indicated by the high variance. Also characteristic of Coastal Plain soils is the low pH. The elevation of the planting locations within each plot did not vary greatly, but note that while plot four was dominated by the "wet" site vegetation, it was considerably higher in elevation than the other "wet" plots.

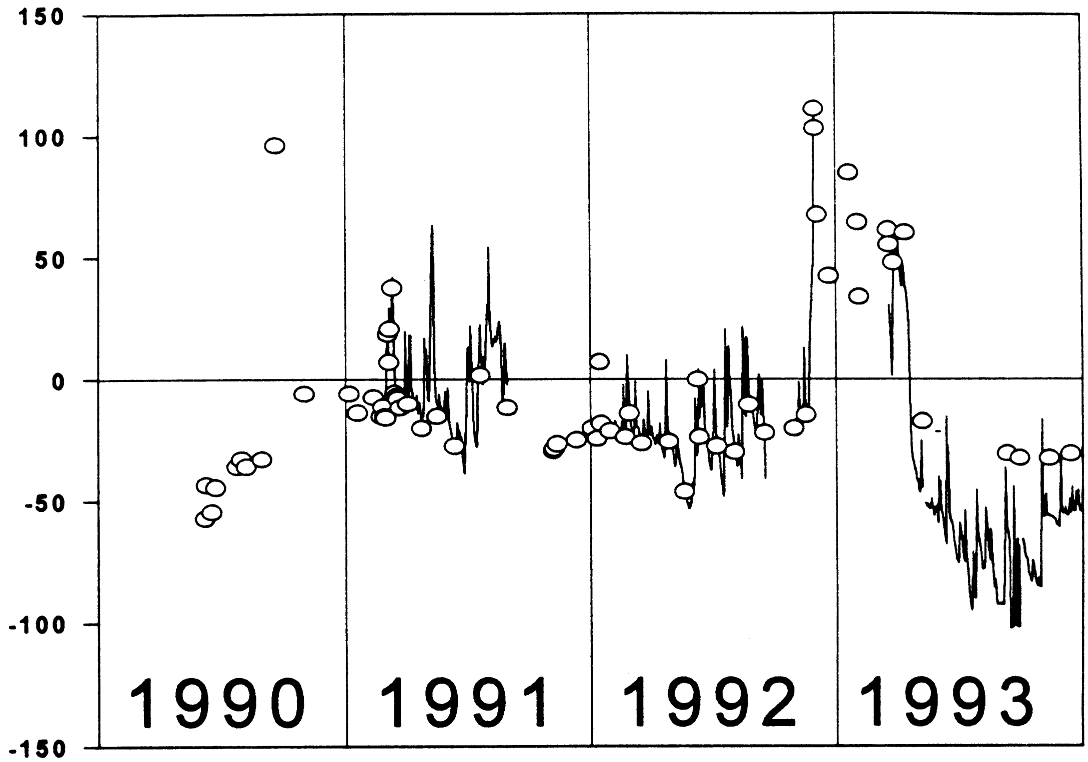
CLIMATE AND HYDROLOGY. The growing seasons of 1990, 1991 and 1993 were warmer than normal, while 1992 was cooler than normal except for the month of July. The growing seasons of 1990 (the first growing season of this study) and 1993 had below normal rainfall, but the rainfall was generally adequate during the other two growing seasons.

The delta of Fourmile Branch is located within the floodplain of the Savannah River, which has three flood-control dams upstream of the site. Releases from these dams affect the hydrology of the delta, independent of the rainfall within the Fourmile Branch watershed. Thus, the rainfall and the water releases from Clarks Hill Dam (the closest reservoir, 130 km upstream) on the Savannah River have combined to produce very different hydrologic conditions during the growing seasons of the last four years. Little flooding occurred during the 1990, 1992, and 1993 growing seasons, but 1991 had several events in which floodwater accumulated on the delta, especially during spring (Figure 2).

Table 1. Relative elevation, soil nutrient levels and soil texture (0-30 cm depth) of experimental plots. Plots 1-4 were used in Experiments I and II, while plot 5 was used in Experiment III. Sample size is 12. Values are mean ± (1 S.D.).

PLOT	1 (Dry)		2 (Dry)		3 (Wet)		4 (Wet)		5 (Wet)	
Relative elevation (cm)	22.1	(5.4)	25.3	(6.3)	3.3	(7.1)	15.9	(6.9)	0.0	(4.9)
Organic Matter(%)	1.3	(1.8)	0.6	(0.5)	4.7	(5.7)	2.3	(4.4)	3.0	(5.7)
pH	4.7	(0.2)	4.8	(0.2)	4.6	(0.2)	4.9	(0.3)	4.7	(0.2)
Total N (%)	0.07	(0.08)	0.04	(0.02)	0.16	(0.10)	0.09	(0.12)	0.09	(0.10)
P (mg/kg)	8.6	(2.7)	8.6	(2.7)	8.6	(2.0)	6.5	(3.3)	8.9	(2.7)
K (mg/kg)	8.1	(3.9)	5.0	(3.6)	9.0	(4.4)	12.0	(8.5)	18.5	(6.0)
Ca (mg/kg)	100.0	(71.2)	52.0	(20.2)	165.3	(72.5)	101.3	(91.5)	131.7	(95.3)
Mg (mg/kg)	13.4	(12.5)	3.9	(2.2)	26.8	(12.2)	13.3	(16.1)	19.4	(16.8)
Sand (%)	87.7	(14.1)	96.5	(2.4)	56.7	(36.4)	81.3	(30.2)	78.8	(33.5)
Silt (%)	6.8	(8.8)	2.2	(1.6)	13.8	(9.5)	7.7	(11.3)	6.9	(7.9)
Clay (%)	4.7	(5.3)	1.3	(1.3)	10.7	(5.4)	3.6	(5.7)	7.2	(16.4)

Figure 2. Hydrology of Fourmile Branch delta from May 1990 to December 1993. Solid line is data from a permanently recording pressure transducer, while the circles are from a staff gauge. Positive values indicate centimeters of water over the soil surface, while negative values are below the soil surface.



While growing seasons of 1992 and 1993 had little flooding, the fall and winter of 1992/93 had extensive flooding. Water depths in our plots exceeded one meter and were continuously flooded from mid-November until mid-April. The trees were dormant and not strongly affected by this flooding. In March and April of 1993, the plants began to leaf out underwater. Fortunately, the flood waters receded below the soil surface by mid-April. However, it was an unusual hydrologic year, with an extensive, prolonged winter and early spring flood, followed by low rainfall and an increasing depth to the water table over the growing season.

EXPERIMENT I. In autumn of 1990, all nine species had survival greater than 70% in "dry" areas of the delta (Table 2). After this first growing season, no fertilizer effect was observed in survival or height growth ($p = 0.22$) within an individual species.

By 1991 the site hydrology had returned to a more typical situation and survival had been drastically changed. Only three species (Taxodium distichum, Quercus michauxii, and Q. nigra) had survival greater than 35%. This has not greatly changed in the last 2 years. While T. distichum did not have the best initial survival, this species currently has much better survival (68%) than any other species.

Over the four years, growth in height of the three surviving species has been substantial, with T. distichum, Q. michauxii and Q. nigra all tripling from their initial height (Table 3). Of the surviving individuals of the two oak species, 70% were classified as in good health, with the remainder either in poor health or with the top leader dead or broken. Over 65% of the surviving saplings of T. distichum were in good health, with the remainder having had the main stem cut by beaver during the winter of 1992/93. These six saplings were vigorously resprouting with 11 to 38 new stems emerging per sapling (mean of 25).

Table 2. Percent survival in the autumns of 1990 to 1993 of containerized seedlings planted in dry sites in the Fourmile Branch delta.

SPECIES	1990	1991	1992	1993
Quercus alba	90	11	14	04
Q. coccinea	86	00	00	00
Q. margaretta	93	04	04	00
Q. marilandica	96	00	00	00
Q. michauxii	71	46	50	36
Q. nigra	82	36	36	32
Q. rubra	93	00	00	00
Q. stellata	89	25	18	14
Taxodium distichum	71	68	68	68

Fertilizer treatments were combined, due to lack of significant effects.

TABLE 3. Mean seedling height (cm) in the autumns of 1990 to 1993 of containerized seedlings planted in dry sites on the Fourmile Branch delta.

SPECIES (initial height)		1990	1991	1992	1993
Quercus alba	(12.1)	15.7	34.0	34.0	36.0
Q. coccinea	(8.2)	12.8	NA	NA	NA
Q. margaretta	(9.2)	13.6	23.2	12.0	NA
Q. marilandica	(10.1)	15.8	NA	NA	NA
Q. michauxii	(25.1)	32.2	63.5	75.2	76.4
Q. nigra	(23.6)	38.4	65.1	76.9	84.4
Q. rubra	(11.5)	18.9	NA	NA	NA
Q. stellata	(10.6)	16.4	36.9	39.3	34.7
Taxodium distichum	(70.9)	78.7	127.7	159.7	214.7

Fertilizer treatments were combined, due to lack of significant effects.
NA = Not applicable, all seedlings dead.

EXPERIMENT II. Survival in 1990 for the four species planted in "wet" areas exceeded 70% (Table 4). Fertilization was not responsible for any changes in survival or height growth (p = 0.12). Since then, survival of *Q. alba* and *Q. nigra* have declined to very low levels. *Taxodium distichum* and *Q. michauxii* have survived well and both of these species have higher survival in "wet" than "dry" sites (Table 2). While *Q. alba* had poor survival in either sites, *Q. nigra* had better survival in "dry" than "wet" sites.

Height growth of the *T. distichum* and *Q. michauxii* in the "wet" plots (Table 5) was greater than in the "dry" plots (Table 3). These species increased height by three and five times that of the original height, respectively. Health of these two species was very similar to that observed in the "dry" plots. Deer and beaver herbivory were less in the "wet" plots.

Table 4. Percent survival in the autumns of 1990 to 1993 of containerized seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES		1990	1991	1992	1993
Quercus alba		75	04	00	00
Q. michauxii	82	64	64	50	
Q. nigra		86	25	14	04
Taxodium distichum	93	79	79	79	

Fertilizer treatments were combined, due to lack of significant effects.

Table 5. Mean seedling height (cm) in the autumns of 1990 to 1993 of containerized seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES (initial height)		1990	1991	1992	1993
Quercus alba	(11.3)	16.4	NA	NA	NA
Q. michauxii	(26.1)	34.8	80.3	110.4	129.8
Q. nigra	(26.4)	40.5	91.5	110.0	77.0
Taxodium distichum	(70.2)	80.3	123.1	180.2	235.3

Fertilizer treatments were combined, due to lack of significant effects.
NA = Not applicable, all seedlings dead.

EXPERIMENT III. The larger bareroot planting stock used in this experiment generally did not survive as well as the smaller containerized stock used in Experiments I and II. After the initial growing season, only *F. pennsylvanica* had good survival. Survival of *Q. michauxii* and *Q. shumardii* was < 55% (Table 6). Again, fertilization had no effect on survival or growth ($p = 0.51$).

By the end of the second growing season (1991) and a return of more typical hydrology, survival of the two oaks was < 20%, while survival of *F. pennsylvanica* was 97%.

Height of *F. pennsylvanica* and *Q. michauxii* saplings, had tripled by autumn of 1993 (Table 7), but only seven of the latter species were still surviving. Over 74% of the remaining *F. pennsylvanica* saplings were in good health, with 17% in poor health and 9% having the top leader dead or broken.

TABLE 6. Percent survival in the autumns of 1990 to 1993 of bareroot seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES	1990	1991	1992	1993
Fraxinus pennsylvanica	97	95	100	97
Quercus michauxii	53	17	13	12
Q. shumardii 42	07	02	00	

Fertilizer treatments were combined, due to lack of significant effects.

TABLE 7. Mean seedling height (cm) in the autumns of 1990 to 1993 of bareroot seedlings planted in a wet site on the Fourmile Branch delta.

SPECIES (initial height)	1990	1991	1992	1993
Fraxinus pennsylvanica (57.1)	62.7	88.4	110.9	149.9
Quercus michauxii (34.7)	38.9	69.1	87.0	130.3
Q. shumardii (57.3)	58.7	58.1	26.5	NA

Fertilizer treatments were combined, due to lack of significant effects.
NA = Not applicable, all seedlings dead.

DISCUSSION

The hydrology of the site is exceptionally important in determining the survival of the various tree species. Each species will be profoundly affected both during establishment and subsequent growth into adult trees. However, the climate and hydrology of any individual year may not be typical. Therefore, the results of any particular experiment must be evaluated in light of the climate and hydrology which existed during the experiment to determine how the results could be extrapolated to other climatic years.

Based on the species' responses after the first and subsequent growing seasons, very different recommendations would have been made for replanting. A broad range of species was indicated to be potentially suitable following the results of the relatively dry, first growing season. But, once the typical hydrology of the site returned in 1991, only flood-tolerant species (Taxodium distichum and Fraxinus pennsylvanica) continued to have excellent survival. Thus, other woody species with similar flood tolerance might also be successful, such as Nyssa aquatica, and N. sylvatica var. biflora.

The degree of flood tolerance may also play an important role in selecting species for "dry" and "wet" sites, as slight elevation differences did lead to differential survival among the 11 species. This difference might be exploitable by planting Quercus michauxii and Q. nigra in the "drier" end of the gradient.

Since flood-tolerant species are not usually very drought tolerant, the success of these species indicates that drought conditions did not exist even when the rainfall was slight and the surface soils were apparently dry. The water table (Figure 2) and its associated capillary fringe did not recede below the rooting depth of these species. Thus, it is unlikely that the drought tolerance of species, once established, would ever become an important characteristic.

Although Clewell and Lea (1989) indicated that fertilization is usually necessary for successful restoration, it had no effect in our studies. This result may be due to the type or rate of fertilization or possibly to the fact that the existing vegetation may have been able to exploit the fertilizer before our seedlings could use it.

Herbivory was not a critical factor during floods of typical years. But during the winter of 1992/93 when the entire delta was under water, beaver had access to all plantings and definitely had an impact. Fortunately, the resprouting ability of the species can prevent mortality. Herbivory, other than from beaver, was not influential.

RECOMMENDATIONS FOR RESTORATION

Future restoration plantings should involve multiple species, with possible differentiation of planting sites by elevation. Drier sites could be planted with several Quercus species, while wetter sites could be planted with flood-tolerant species, such as *Taxodium distichum* and *Fraxinus pennsylvanica*. This mixed species approach to restoration is desirable for diversity and is accomplishable in the Fourmile Branch delta. This certainly does not mean that small scale monospecific patches will not occur or are undesirable. In fact, in some wet areas, there are so few species that can tolerate these conditions that only communities of low tree diversity can be expected to develop.

ACKNOWLEDGEMENTS

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UTILIZING PLANT MATERIAL FROM A DONOR WETLAND: *A PERSPECTIVE OF MITIGATION PRACTICES IN NORTHWEST FLORIDA*

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ABSTRACT

Plant material consisting of Spartina patens, Juncus roemerianus, and Cladium jamaicense were removed from an adjacent wetland area to be filled for residential development. The mitigation site is located at Gulf Breeze in Santa Rosa County, Florida.

A 1.47 (.595 ha) acre wetland has been installed at a site previously classified as an upland. The former site consisted of a Pinus elliotii - Sabal minor plant association. The 1.47 (.595 ha) acre site was clearcut and graded to approximately 0.8 ft (24.4 cm) above MSL. Eight inches of organic soil was placed on top of the primarily mineral soils. Water depth of approximately 0.25 ft (7.62 cm) is occurring throughout the mitigation site.

Plant material was excavated from the adjacent wetlands to be filled, and was delivered in clumps of 4' (121.92 cm) x 6' (182.88 cm) x 12" (365.76 cm) to the mitigation site. A front-end loader with a fork attachment was used for plant removal. Each clump was manually chopped into 12" (30.48 cm) x 12" (30.48 cm) squares and planted in densities ranging from an average of one to two feet (30.46 to 60.96 cm) on center. After four months, the site appears as a natural marsh with overall coverage currently exceeding 60%.

This success seems to be based on the utilization of the stock of herbaceous plant materials from the adjacent lands destined for fill placement. Plant diversity and density of planting benefit from this approach. Also, usual permit specifications, such as survivalship or coverage, should be expedited.

INTRODUCTION

The enactment of the Swamp Land Acts of 1849, 1850 and 1860 attests to the fact that historically man has had a negative perception of wetlands as useless, mosquito-infested wastelands. These acts essentially granted all swamps and overflow lands to be reclaimed by draining and filling. The results of this early perception served the population by creating additional land for farming and development, thus eliminating an apparent nuisance.

Today man's view of wetlands has changed, and many important economic and environmental contributions are attributed to wetland functions. As appreciation of wetlands increases, so does the number and scope of federal and state mandates that protect these wetland resources. In addition to these, other specific wetland regulations are mandated by counties as a part of their growth management agenda.

Despite these programs to protect wetlands, development pressures are increasing because most of the remaining undeveloped lands contain wetlands. It is within this setting that conflicts between developers and preservationists inevitably occur.

Recently, mitigation practices through creation, enhancement, or preservation have achieved popularity as a way of allowing development while at the same time ensuring no net loss in wetlands. The mitigation strategy utilized depends largely on the type of project, the size of the property, the size, condition, type, and position of the wetlands, as well as the regulatory environment. Generally, the larger the project the greater the mitigation flexibility.

MITIGATION STRATEGIES

The first strategy for developers to consider is avoidance; the benefits of this simple strategy are numerous. Permit acquisition is quicker due to fewer regulatory demands such as mitigation strategy, monitoring, and various regulatory hurdles encountered when wetland impacts are considered. Also, costs of avoiding the wetland are less than creating a replacement wetland. Finally, creation of a wetland in what otherwise would be a viable upland piece of real estate seems contradictory. If wetland impacts are unavoidable, then a number of mitigation strategies become options. Creation usually involves the clearing and grading of an upland system to the elevation of a surrounding wetland, providing suitable substrate for the establishment of hydrophytes and provisions for erosion control during the period of plant establishment. The complexity of these variables introduces considerable risk of failure, and care must be taken to duplicate accurately these complex intrinsic factors. For example, created and natural wetlands may contain a similar assembledge of plant species, but the created wetland may not possess the ecological settings of a naturally occurring wetland. Ideally, the created wetland should provide the same functions, such as flood control or groundwater recharge, as the destroyed wetland.

The Florida Department of Environmental Protection (FDEP) recognizes creation, if all practical modifications to the project have been considered. If at that time the proposed development has no other alternatives, the FDEP will consider proposals designed to offset the remaining adverse impacts to a wetland.

The basic goal of mitigation proposals is to offset expected adverse environmental impacts to the point at which projects can meet permit qualifications. These proposals must include the following criteria: a description of the mitigation area, a planting plan, monitoring plan, description of construction methodology, mitigation cost estimates, and contingency plans.

In evaluating mitigation proposals, FDEP takes into consideration the applicant's prior record with development in wetlands, the success probability, whether there is sufficient legal interest on behalf of the applicant; and the financial resources to guarantee that the mitigation will be successful.

Permits will specify the criteria used for determining the success of the mitigation activities performed. FDEP's criteria for success are dependant upon the types of wetlands being created. These criteria usually define the minimum amount of plant cover required and minimum amount of exotic plants allowed at the mitigation site. Currently the FDEP has established a ratio for created wetlands that is equal to the amount of wetlands destroyed. This one-to-one ratio is usually based on creating the same type of wetland as the one that is impacted.

Restoration is another mitigation strategy that is looked upon favorably by the FDEP. This methodology does not have a fixed ratio; although, most restoration ratios are considerably greater than the one-to-one ratio established for creation. This is partly due to the fact that restorations occur on established wetland sites and require less effort. Such strategies usually involve restoring the natural hydrology by filling drainage ditches, or removing other stresses from the ecosystem, thus allowing natural succession to proceed. Many designs may call for the transplantation of species already present in the stressed system to speed up the successional processes. The success of restored wetlands depends on numerous factors including type and location of wetland, size and scope of the particular project, and project planning and management.

Enhancement is also used within the mitigation framework where an undesirable component detracts from the function and value of the natural system. An obvious enhancement strategy would be to remove all exotic invaders thus gaining the desirable attributes of an undistributed wetland system. The FDEP also has no standard ratio for enhancement projects, but typically value enhancement activities less than restoration techniques. Finally, a last mitigation strategy is preservation. Here, the State is essentially given a conservation easement and clear title to the land, thus prohibiting future development and conservation easements which would preclude development in these areas. This approach yields ratios sometimes approaching 100 acres of preservation for 1 acre of wetlands to be filled.

Wetland mitigation strategies offer some degree of economic development to occur in wetlands while ensuring that wetlands will be created, enhanced, and restored. As the result of FDEP permits issued between October 1, 1989 and September 30, 1990, 1,291 acres (522.855 ha) of wetlands were lost, 1,941 acres (786.105 ha) of wetlands were created, 1,580 (639.900 ha) acres of wetlands were enhanced, and 4,227 (1711.935 ha) acres of wetlands were preserved (Batts 1991).

CASE STUDY

The following is a case study that utilized wetland creation strategies to offset the loss of 1.47 acres of coastal marsh to a waterview residential development in Northwest Florida (Figure 1). In January 1994, after all attempts at avoiding coastal wetland impacts were exhausted, plans to minimize the impact on wetland resources within the subdivision boundaries were submitted to the FDEP and COE for approval. A small (0.13 acre/.053 ha) area of palustrine emergent wetlands were needed to access the interior uplands, and a larger 1.34 acre (.543 ha) estuarine march was to be converted into residential lots. The wetlands community was a North Florida coastal strand and consisted primarily of Juncus roemerianus, Spartina patens, Scirpus robustus, Distichlis spicata, and Schizachyrium maritimus. The FDEP and COE agreed that a 1:1 creation of similar floralistic composition would be acceptable for permitting the impact to the wetland areas.

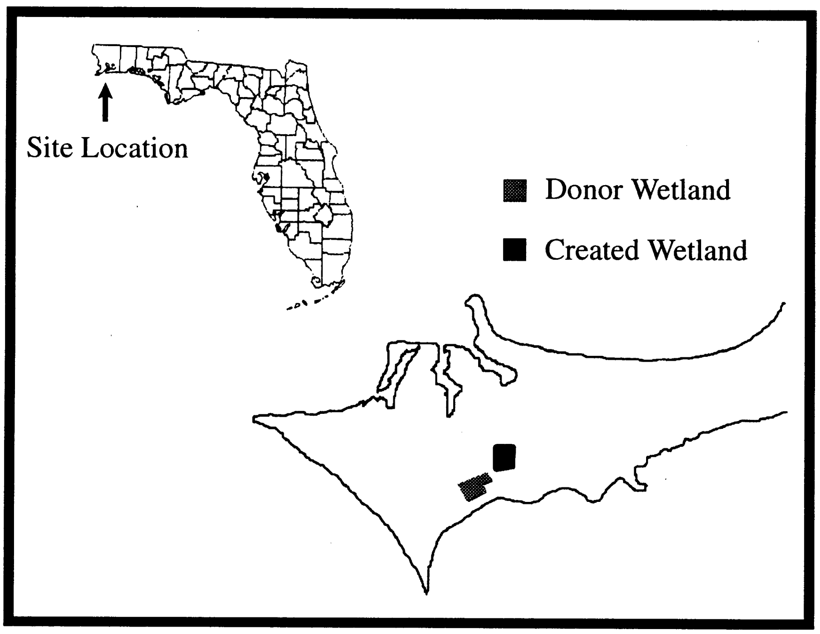

Figure 1. Location of wetland mitigation site, Santa Rosa County

The donor wetland was selected to provide the substrate materials and associated seed bank, as well as the plant material for the creation project. An adjacent parcel of uplands consisting of Quercus virginiana var. maritima, Serenoa repens, Ilex vomitoria and Pinus elliottii, was designated for the creation site (Figure 2). The site chosen was ideal for the creation purpose due to the fact that a natural wetland would be contiguous to the created wetland -- this orientation expectedly aiding in the natural dispersion of plant species as well as other associated biota. The upland habitat was cleared and final contour grades made equal to the elevation of the adjacent marshlands. Hydrologic indicators were immediately apparent and the surface of the creation site was flooded.

Figure 2. The upland site prior to clearing and grading.

Using a front-end loader, the existing marsh was carefully removed from the site proposed for fill, and the plant material and associated organic sediments were transported to the creation site and carefully unloded, with the plants in an upright orientation. The entire process of removing the plant material from the donor wetland, placing the organic sediment from the site proposed for dredge and fill activities, and transplantation lasted two weeks. The plant material was divided into manageable sizes ($0.3m^2$) and placed on 0.6m centers or closer (Figure 3).

Coverage of the created wetland immediately exceeded 60%. After two months, it became apparent that the seed bank was viable and many seedlings were beginning to appear. Vegetative reproduction also was quite vigorous, and the required State standards of 80% coverage within one year was expected to be achieved easily.

MONITORING

The permits required post-creation monitoring for a period of five years to ensure 80% coverage and the elimination of exotic plant species. To achieve these goals, three permanent transects will be established and monitored annually for species diversity and coverage.

Figure 3. Spacing of transplants within the created wetland. (Meter stick placed for reference)

Another monitoring requirement is fixed point references for photographic documentation, a practice that would aide in examining changes over time.

Certainly the distance of the wetlands to be filled from that to be created from the wetland that is permitted to be filled would dictate the feasibility of such undertakings. With the degree of success of these projects being measured in terms of coverage instead of survivorship, those creating wetlands will have to acquire considerable more plant material to achieve these standards (Figure 4).

Figure 4. Overview of created wetland 2 months after transplantation.

In summary, if possible, wetland plant material should be utilized from the wetlands that are permitted to be filled. This methodology will provide the project with: plant material that will be regionally adapted, higher diversity due to the limited commercial availability of many plant species, increased coverage rates, seed banks which provide excellent potential to establish in the open areas, and considerable savings with bare root material selling for .20 to .70 cents per plant from commercial nurseries.

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A SOUTHERN SOLUTION TO A NORTHERN PROBLEM - A LOW IMPACT WAY TO REPAIR PIPELINES IN VERY WET PLACES

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ABSTRACT

Linear utility corridor projects often result in impacts to many wetland systems during their construction, repair, and maintenance. A recurring issue during permitting of these projects is whether or not to perform active wetland restoration or allow natural processes to repair the temporary alterations caused by construction activities. The anticipated impacts can be minimized through judicious use of the most appropriate construction or repair technology and methods. Therefore, permit requirements to actively restore an impacted wetland are often determined in the planning stage of a project.

During the repair of a 10-inch diameter natural gas pipeline in Vine Brook Swamp, a freshwater emergent marsh, in Burlington, Massachusetts, was used to minimize disturbance of the wetland system. Previous attempts to repair the pipe had failed because of the extremely wet and deep muck soils. A "marsh buggy" backhoe from Louisiana was used to excavate, replace and backfill approximately 800 m of pipe.

The use of the "marsh buggy" resulted in minimal damage to the marsh and reduced the need to actively restore the wetland. Special construction practices for work in wetlands were followed and the hydrology was restored. Additional plantings were done to increase species diversity. Within weeks following completion of work, natural revegetation was occurring and it is anticipated that following one growing season, vegetative cover will be greater than 75 percent.

INTRODUCTION

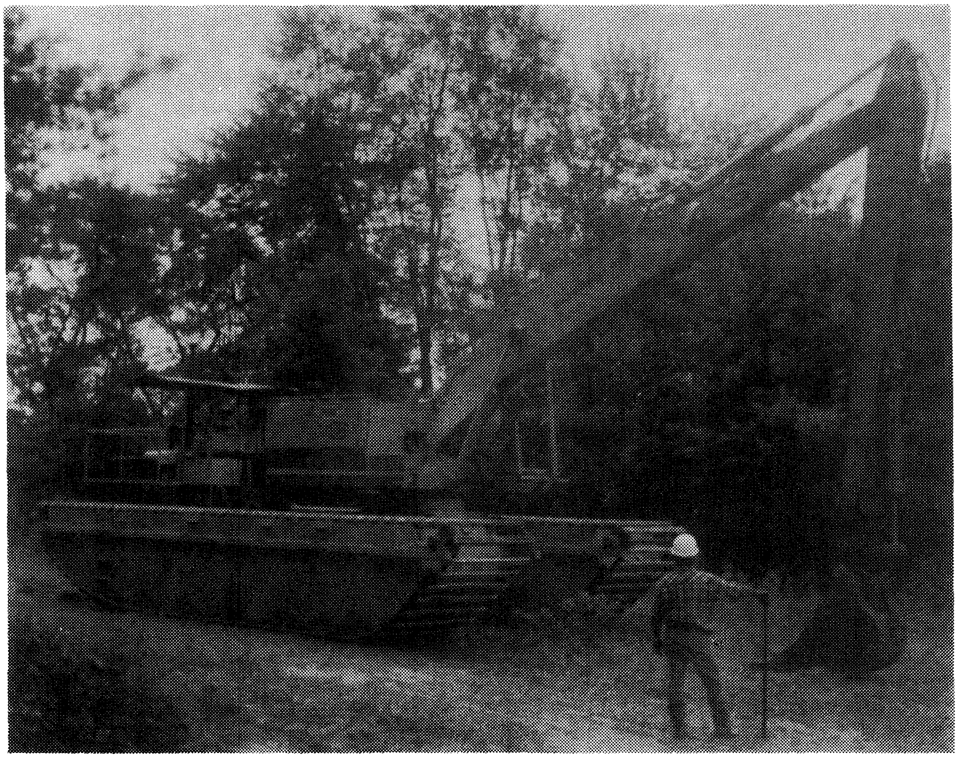
Natural gas pipeline distribution systems undergo periodic safety inspections (SIPS) to assess the integrity of the pipe and determine the location and severity of any corrosion. In 1988, the safety inspection of the Arlington Lateral, a Tennessee Gas Pipeline Company delivery line located in several northern suburbs of Boston, Massachusetts, revealed a number of locations where corrosion had resulted in a loss in the pipe wall thickness. Typical construction equipment and methods were used to repair or replace the identified sections of pipe. Because of the extremely wet conditions and the deep organic muck soil encountered in one wetland, Vine Brook Swamp, maintenance repairs were unable to be completed following an incident in which a backhoe excavator working on "marsh mats" was temporarily mired and emergency measures were needed to rescue it from the wetland.

Vine Brook Swamp is held in high regard by local resource agency personnel and townspeople. The Swamp is one of the largest tracts of undeveloped land in the Town of Burlington, Massachusetts, representing a natural area oasis amid the asphalt and lawns. In addition, several of the Town's drinking water supply wells are located in the wetland down gradient from the pipeline right-of-way. The Swamp is regarded by the local conservation commission (the local regulatory group responsible for permitting and upholding state wetland regulations) as being highly important for storm water runoff and flood control, aquifer recharging, and wildlife habitat.

Even though the wetland is highly regarded for its important wetland functions, according to Massachusetts' Wetlands Regulations (CMR 310.40), the repair and maintenance of utility systems is exempt from the normal permitting process for projects that involve impacts to wetlands. Similar exemptions exist under the Federal Energy Regulatory Commission (FERC) permits for utility systems. Such exemptions are seen as necessary because of the many wetlands that exist on utility right-of-ways and the assumed minor impacts that occur to wetland systems from maintenance activities. However, most utilities have a good neighbor policy and take some kind of effort to inform municipalities of construction activities that will be occurring within lands in their jurisdiction.

When SIP testing in 1993 revealed additional severe corrosion that necessitated a second attempt to repair the pipe in Vine Brook Swamp, Tennessee Gas Pipeline Company notified the Town of Burlington of the anticipated work. Concerns expressed over excavating the pipe across the swamp with traditional equipment led to the decision to use a specialized type of backhoe excavator. Additionally, instead of digging up isolated locations and repairing them individually, the decision was made to cut out and replace all 800 m of pipe within the wetland.

The specialized excavator is called a marsh buggy backhoe and was developed for work in the bayous of Louisiana and Mississippi. Essentially the top half of an excavator is mounted on a pair of pontoons. The pontoons are essentially flat on all sides with upturned ends, approximately 1.4 m wide by 1.7 m high by 10m long. The pontoons provide enough buoyancy to float the excavator. A diesel engine drives large tracks around the outside of the pontoons (Photograph 1). This self-propelled excavation vehicle can work in the wettest of wetlands with no fear of sinking into the muck.



Photograph 1
Marsh Buggy Backhoe

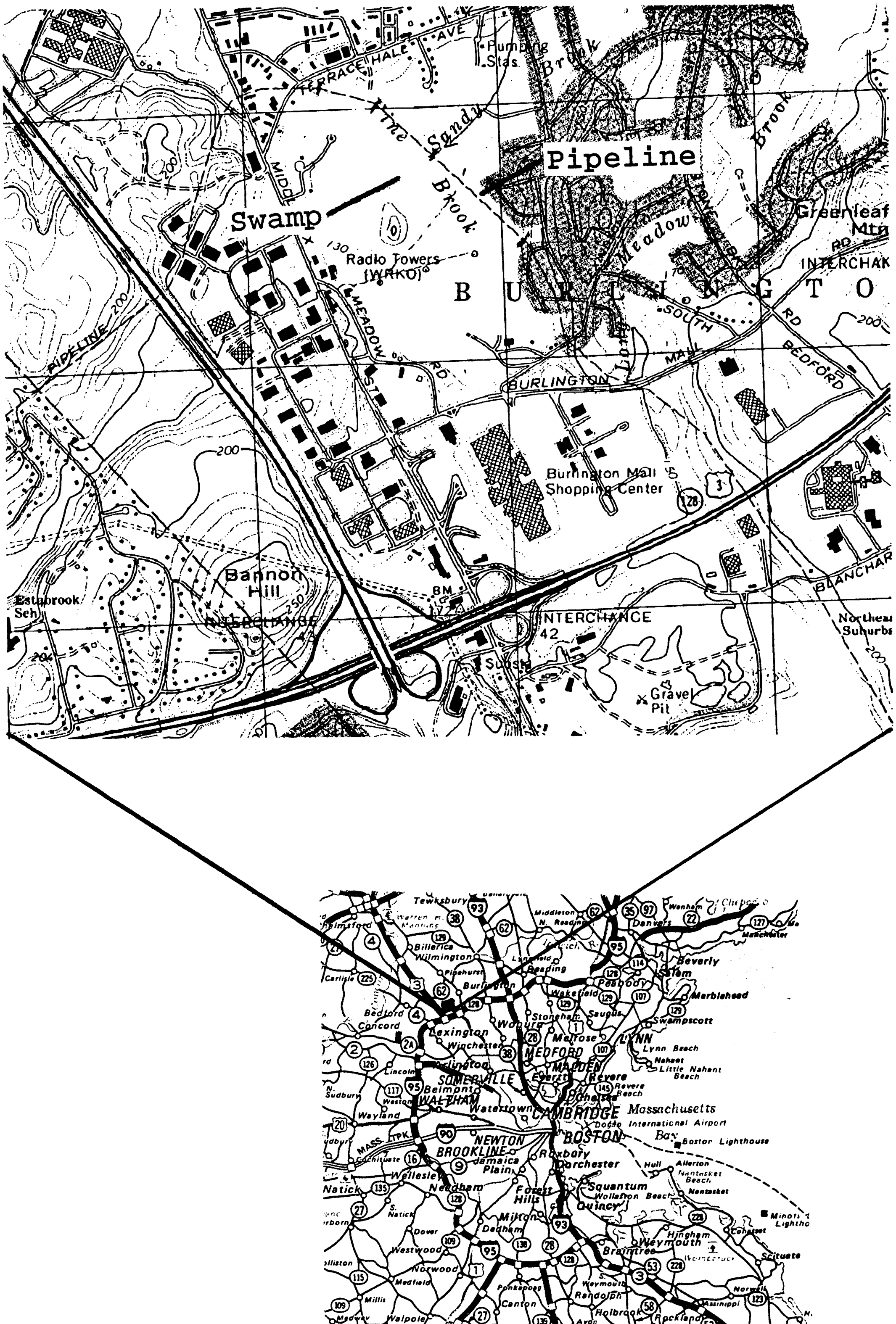
In addition to the use of the marsh buggy, a variety of other wetland impact minimization and restoration practices were incorporated into the project. Additional information on the overall project is provided by Fournier (1993).

STUDY SITE

The project site is located in Burlington Massachusetts, a northern suburb of Boston (Figure 1). The approximately 81-hectare wetland system is bounded on all sides by residential or industrial and commercial property.

The permanently maintained pipeline right-of-way is 10 m wide while crossing 800 m of Vine Brook Swamp. The gas flows from the northwest to the southeast,

Figure 1
Site Location



corresponding to a flow from "upstream" to "downstream" along the pipeline. The upstream side of the wetland begins as a red maple swamp (approximately 100 m) abutting an old sand borrow area. The central portion of the wetland is an emergent cattail and purple loosestrife marsh, approximately 400 m wide. Sand Brook flows in a southerly direction across the right-of-way until joining Vine Brook approximately 100 meters from the pipeline. Two small pools of standing water (12m diameter, average of 1 m deep) are located on the right-of-way within the marsh. The pipeline then crosses through 100 m of shrub swamp and finally exits the wetland after another 200 m of red maple swamp (Figure 2).

Throughout the emergent marsh, standing water varies from several centimeters to nearly 1 meter deep during most of the year. The soils are a deep (over 3 meters) organic muck throughout the marsh portion of the wetland. A 20-to-40-cm thick organic layer lies on top of a sandy subsoil in the forested portions of the wetland.

Vegetation surveys of the undisturbed swamp and right-of-way were performed in 1988 (the BSC Group, 1988) prior to the 1988 repair effort and again in 1993 prior to construction. Similar species were found in the 1988 and 1993 surveys; however, differences in survey methods probably account for the differences in total species numbers. Table 1 shows the number of species (grouped into broad vegetation type categories) identified in the undisturbed swamp outside of the right-of-way.

Table 1
Undisturbed Area of Vine Brook Swamp
July 1988 Inventory of Plant Species

Trees	2 species
Shrubs and Woody Vines	12 species
Ferns, Mosses and Lichens	5 species
Grasses, Sedges and Rushes	2 species
Forbs	14 species
TOTAL	35 species

Vegetation types identified in the 1988 survey within the undisturbed portion of the right-of-way are shown in Table 2. Species are similar to the undisturbed swamp but do differ in total numbers from the 1993 survey results.

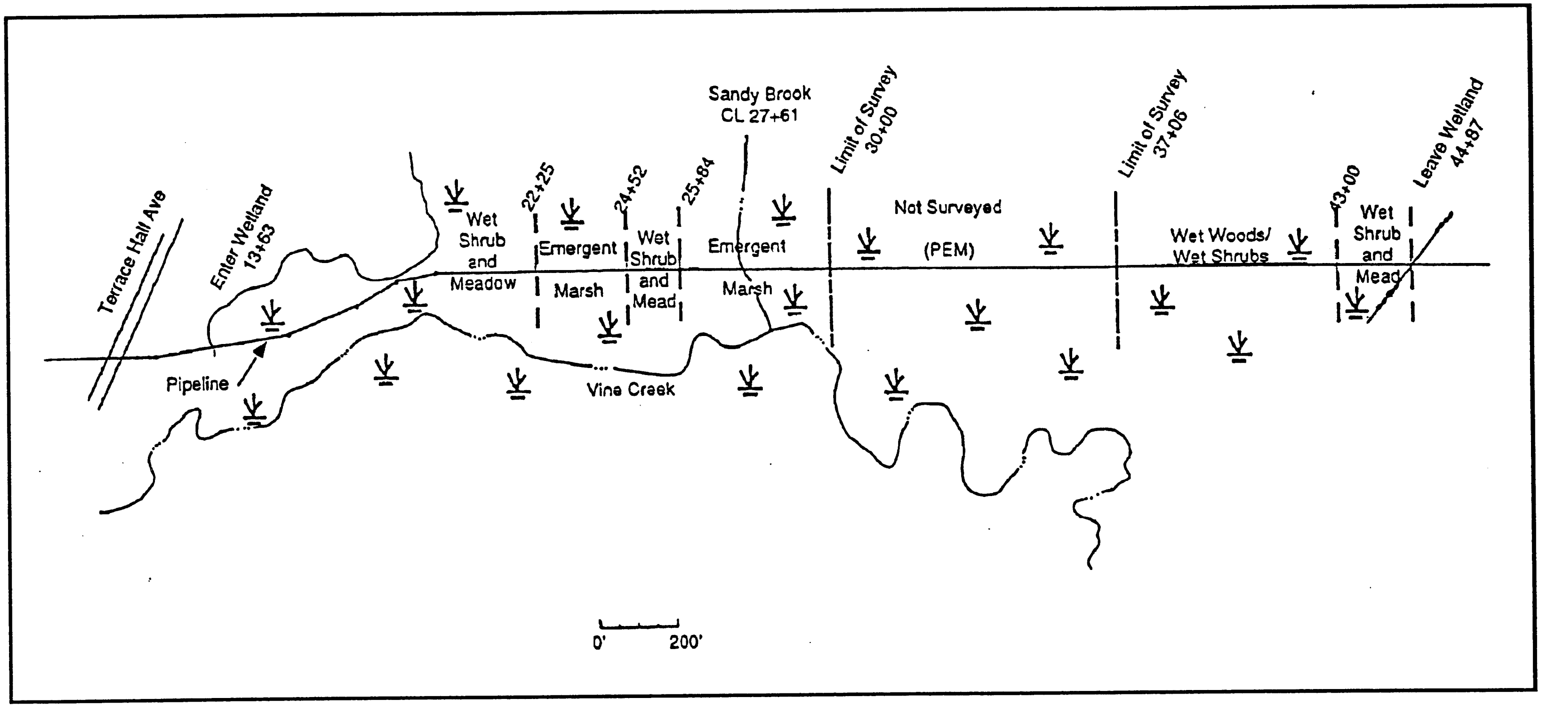


Figure 2
Wetland Habitat Boundaries and Stream Locations
Vine Brook Swamp

Table 2
Undisturbed Area of the Right-of-Way
July 1988 Inventory of Plant Species

Trees	1 species
Shrubs and Woody Vines	10 species
Ferns, Mosses and Lichens	5 species
Grasses, Sedges and Rushes	3 species
Forbs	13 species
TOTAL	32 species

Additional follow-up survey work in Vine Brook Swamp occurred in 1989 (Rury, 1990). Data presented by Dr. Rury indicate that from July of 1988 to November of 1989 the number of species from outside the right-of-way, from the undisturbed right-of-way, and from the disturbed right-of-way went from 39:36:7, respectively, to 51:42:57, respectively.

To document wetland conditions prior to disturbance in 1993, a pre-construction vegetation survey was performed in July, one month prior to the start of construction. Species diversity was high because of the variety of wetland types within the wetland boundaries (Table 3). Within the marsh there was a predominance of cattail, tussock sedge, and purple loosestrife. Forested wetlands were dominated by red maple, silky dogwood, and cinnamon fern.

Table 3
Vine Brook Swamp
July 1993 Inventory of Plant Species

Trees	12 species
Shrubs and Woody Vines	13 species
Ferns, Mosses and Lichens	8 species
Grasses, Sedges and Rushes	16 species
Forbs	34 species
TOTAL	83 species

MATERIALS AND METHODS

In addition to the use of the marsh buggy, construction impact minimization procedures used on the project included: installing sediment and erosion control devices prior to any ground disturbing activities; limiting the clearing and width of the temporary construction right-of-way; constructing during the driest time of the year; limiting crossings of the wetland by careful planning of project components; minimizing the duration of construction in the wetland by careful planning and scheduling of construction activities; separation of topsoil form subsoil during trench excavation and backfilling and; restoration of pre-construction grades and hydrology.

There were essentially four components to the wetland restoration plan: proper backfilling and grading; supplemental live plantings; seeding with wetland species; and pre-existing fill removal.

During the backfill operation, the subsoil was placed in the bottom of the ditch. Once the subsoil was in place, the topsoil and removed vegetation was placed back on the top of the ditch. Care was taken to scrape all soils off the ground next to the ditch without removing the underlying vegetation or topsoil. This is particularly important to avoid altering the grade. Placement of the excavated soils on top of vegetation in the temporary work space allowed for easier detection by the marsh buggy backhoe operator of the boundary between the excavated material and the underlying topsoil. In conjunction with the backfilling, the right-of-way was graded. A flat bar welded across the teeth of the backhoe bucket allowed the marsh buggy backhoe to perform the grading. Microtopographic relief was provided by leaving small pits and mounds and not grading to a smooth surface.

Following grading, a contractor was brought in to install approximately 1,000 plants. Four species were chosen to increase the diversity of the right-of-way, but not to provide any significant degree of areal cover. The plantings were performed in the marsh portions of the right-of-way, a total area of approximately 3,000 m^2. Approximately equal numbers of blue flag iris (Iris versicolor), cardinal flower (Lobelia cardinalis), burreed (Sparganium americanum), and softstem bulrush (Scirpus validus) were planted in areas of appropriate water depth.

In addition to the plantings, a wetland seed mix was used to increase species diversity and provide coverage of the drier portions of the wetland, predominantly the wooded areas. Fox sedge (Carex vulpinoidea), Joe-pye-weed (Eupatoriadelphus fistulosus), smartweed (Polygonum sp.), and boneset (Eupatorium perfoliatum) seeds were mixed together, hand broadcast across the disturbed soil, and hand raked to a shallow burial depth. The species chosen for the plantings and seed mix were determined based on appropriateness for the site conditions, ability to provide some wildlife benefits, and to a lesser extent for aesthetic reasons.

The final restoration activity involved the removal of fill from a portion of the marsh. A combination of building debris and fill was removed to restore approximately 90 m2 of emergent marsh. The debris was hand removed and hauled offsite. Approximately 20 to 30 cm of sandy gravel fill was removed from the edge of the marsh and placed as subsoil backfill in the pipe trench. This created a slight excess of organic material from the pipe trench which was then spread over the restoration area to aid in the establishment of wetland soil conditions.

RESULTS

The use of the marsh buggy backhoe in conjunction with the other wetland impact minimization methods employed on the project was deemed a great success by the pipeline company and regulatory personnel. The entire project occurred on schedule, with no equipment failures, and no unanticipated wetland or water quality impacts. The use of the marsh buggy backhoe had indeed minimized impacts to the wetland. The temporary work space was kept to a minimum width (average of 22 m instead of the normal 32 m), the disturbance of the topsoil and vegetation layer was minimal (only the 5 m width over the ditch as opposed to the normal 15 m for ditch plus marsh mat width), and the duration of excavation and backfill activities was reduced by several days.

Construction activities at the site were completed in early October of 1993. By the end of 1993, the short fall growing season had allowed for some natural revegetation to occur, primarily cattails and tussock sedges.

In early May 1994, the site was re-visited to determine how the right-of-way had survived the winter and to determine how well natural revegetation was progressing. Although the growing season had commenced only a few weeks earlier, it was evident that numerous species were sprouting along the right-of-way, including broadleaf cattail (*Typha latifolia*), tussock sedge (*Carex stricta*), rushes (*Juncus spp.*), arrow arum (*Peltandra virginica*), skunk cabbage (*Symplocarpus foetidus*), sensitive fern (*Onoclea sensibilis*), cinnamon fern (*Osmunda cinnamomea*), jewelweed (*Impatiens capensis*), purple loosestrife (*Lythrum salicaria*), Phragmites (*Phragmites communis*), speckled alder (*Alnus rugosa*) silky dogwood (Cornus amomum), and red maple (Acer Rubrum). It was also evident that the grading had restored the hydrology since water levels on the right-of-way were similar to those in adjacent undisturbed areas. The banks and stream channel for Sandy Brook were restored properly and appeared stable. Erosion was not apparent anywhere on the right-of-way.

DISCUSSION

The use of the marsh buggy backhoe on this project represents the first time that such a specialized piece of wetland construction equipment has been used in New England. In learning from companies that regularly do a majority of their work in marshes, swamps and bayous, it has been possible to perform work in a very wet marsh with minimal impact to the wetland resources and a high degree of personnel safety. Additionally, working with this type of equipment can reduce and possibly eliminate the need to perform active wetland restoration following construction, thereby potentially saving thousands of dollars.

The marsh buggy worked well in the marsh, but it does have limitations for working in other types of wetlands. Wetlands with numerous trees, boulders, and stumps pose a problem in both reducing the marsh buggy maneuverability and potentially damaging the tracks or pontoons. Also, to move from one wetland overland to another wetland on a long linear project requires that the marsh buggy be broken down, loaded onto flatbed trucks, hauled to the new wetland, and reassembled. This is both costly and time consuming.

In the future, during project planning phases, the possibility and feasibility of using a marsh buggy backhoe for construction in very wet wetlands or for ecologically sensitive or important wetlands should be considered.

ACKNOWLEDGEMENTS

Stone & Webster Environmental Services would like to thank Tennessee Gas Pipeline Company for allowing the presentation and publication of this information. We would also like to thank the resource personnel from the Town of Burlington and the Massachusetts DEP who provided valuable input into the planning and execution of this difficult construction project.

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PLANTING UNCONSOLIDATED SEDIMENTS WITH FLOOD-TOLERANT SPECIES

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ABSTRACT

Restoration of severely disturbed swamp forests often necessitates the use of innovative methods due to unconsolidated sediments and almost continuous flooding. Because of the difficulty of working in this habitat, methods such as planting saplings by simple insertion are highly desirable. Saplings of three flood-tolerant tree species (*Fraxinus pennsylvanica*, *Nyssa aquatica* and *Taxodium distichum*) were root pruned to three severities (moderately root pruned, severely root pruned and cutting) and out planted by insertion into unconsolidated sediments of a severely disturbed stream delta. Survival was greater than 80% for *T. distichum* and *N. aquatica* when the roots were either moderately or severely pruned, but less than 33% for cuttings. *Fraxinus pennsylvanica* did poorly with moderately root-pruned saplings having the greatest survival (20%). There was no difference in height and diameter growth between treatments with good survival. *Taxodium distichum* and *N. aquatica* can be successfully reestablished by these methods using either moderately or severely root-pruned saplings.

INTRODUCTION

Innovative methods are often required for the vegetative restoration of severely disturbed swamp forests. The wide range of existing microsites dictates that planting techniques must be adaptable. Thus, many different methods or variations of replanting may be used to restore an entire site.

One soil type commonly found in wetland restoration projects is unconsolidated sediments. They are often referred to as muck, mire or loose soil and may be either organic or inorganic. The unconsolidation or looseness makes it difficult to walk or work in the sediments, yet may constitute a significant portion of a restoration area. The soft nature of unconsolidated sediments does not allow a planting hole to be dug, so alternative methods of plant establishment need to be developed. In addition, these sediments are often permanently to seasonally flooded even during the planting season, so appropriate species for reintroduction are limited by their flood tolerance.

Some successful planting methods have included root pruning of the saplings so they may be simply inserted into the soil. In replanting Louisiana swamps, Conner and Flynn (1989) successfully planted Taxodium distichum saplings in which the lateral roots were pruned to 2.5-5.0 cm in length. One-year-old cuttings or whips of selected hardwood species have also been successfully outplanted in restoration projects (Clewell and Lea 1989). Although root-pruned saplings have been tried before, there has been a direct comparison of different root pruning methods on the growth and survival of outplanted saplings. The objective of this study was to test the feasibility of establishing differentially root-pruned saplings, outplanted in an area of unconsolidated sediments.

SITE DESCRIPTION

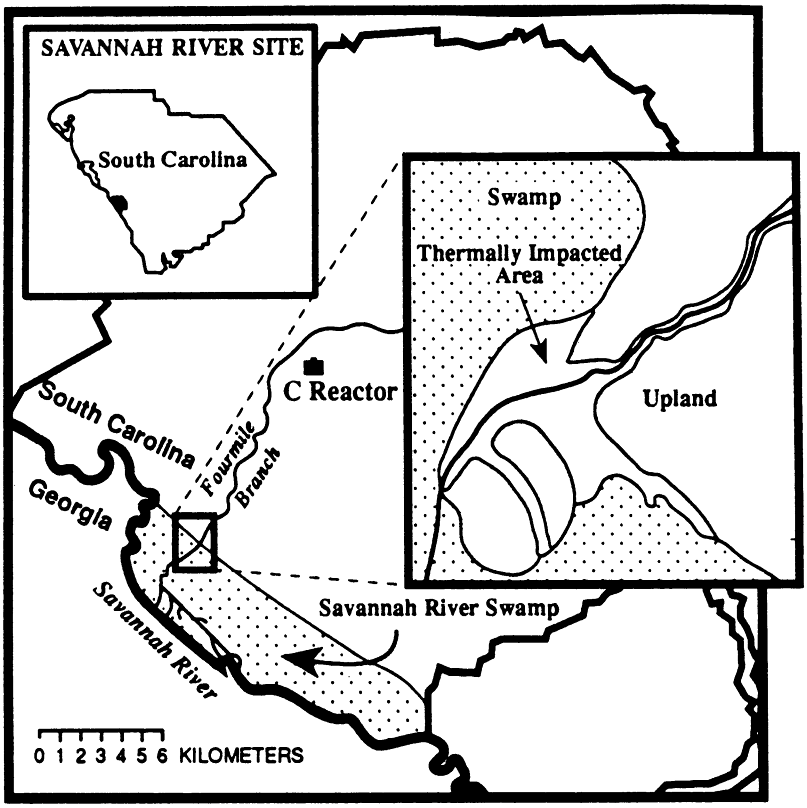
The Savannah River Site is a nuclear materials production facility located adjacent to the Savannah River in the upper coastal plain of South Carolina. During the production of nuclear materials, waters for cooling the production reactors was drawn from the Savannah River. The resulting thermal effluent was then discharged into several streams that drain into the Savannah River. Since 1953, thermal effluent has been released into the streams and through a bald cypress-water tupelo swamp, leaving the corridors and deltas of three streams denuded of existing forest vegetation (Sharitz *et al* 1974).

Fourmile Branch is one of three streams that was deforested during reactor operations between 1953 and 1985 (Figure 1). During this time, water volume increased from 1.0 to 11.3 m^3s^{-1}, eroding the upstream sediments and redepositing them in the stream delta within the Savannah River Swamp (Jensen *et al* 1984). As the base flow returned to pre-reactor levels, a terrestrial habitat emerged containing within it a braided stream with isolated sloughs and pools. Since 1985, the stream corridor and delta have been naturally revegetated with early successional vegetation. Later successional species are generally absent from the site. In 1990, an attempt to restore Fourmile Branch delta by accelerating succession through the introduction of saplings of later successional species was implemented. This manuscript reports one aspect of those species' introductions.

MATERIALS AND METHODS

Three bottomland tree species (Fraxinus pennsylvanica (green ash), Nyssa aquatica (water tupelo) and Taxodium distichum (bald cypress)) were outplanted into muck soils, following three different degrees of root pruning. These species were chosen because of their range in flood tolerance from moderately tolerant (F. pennsylvanica)

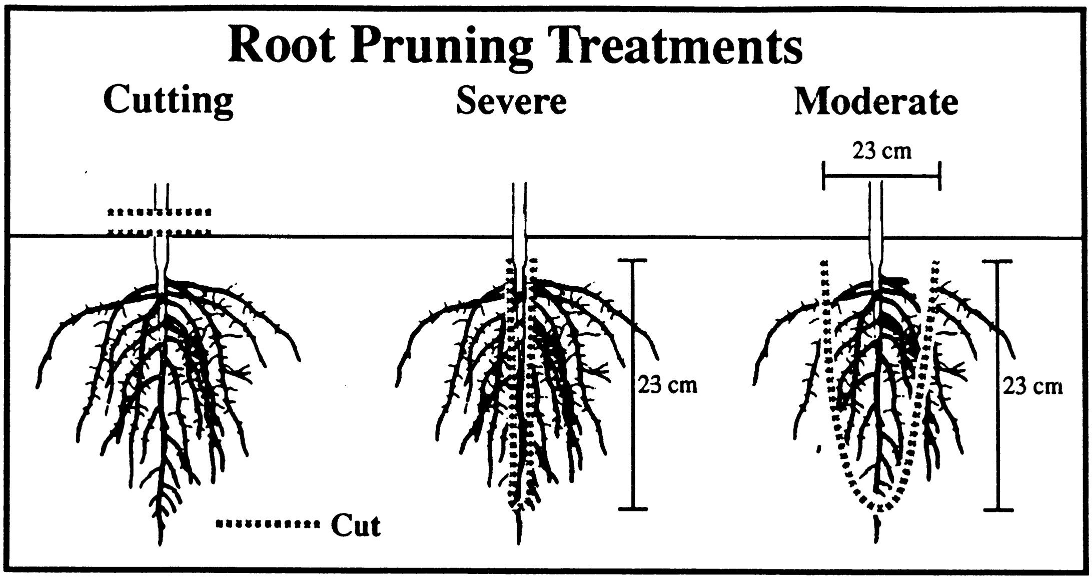
Figure 1. Location of Fourmile Branch and the Savannah River Site in South Carolina.



to very tolerant (N. aquatica and T. distichum) (Hook 1984). Bareroot stock of F. pennsylvanica and T. distichum were obtained from a commercial nursery. Nyssa aquatica was containerized stock grown in small tree pots from seed collected locally. Both N. aquatica and T. distichum were two-year-old stock, while F. pennsylvanica stock was three years old. Initial height of the F. pennsylvanica saplings was greater than 2.0 m, while T. distichum averaged 1.3 m and N. aquatica 0.9 m.

Saplings were root pruned to three different severities (moderately, severely and cutting) (Figure 2). The least severe treatment, (moderately pruned), had lateral and tap roots pruned to a 23 cm spread. The moderately pruned saplings were the most difficult to plant by simple insertion because they retained the most roots. Tap roots were shortened to 23 cm and all lateral roots were removed from the severely pruned saplings. Both the moderately and severely pruned saplings were inserted into the sediment to the root collar. The cutting treatment was the most severe with all roots removed.

Figure 2. Root pruning treatments.



Cuttings were made by severing the sapling at the one-year-old wood. Rootone F (a mixture of synthetic auxins) was applied before the cuttings were inserted 20 cm into the sediment.

Treated saplings were randomly assigned to planting locations with 1.0 m spacing. Each treatment contained 15 saplings of each species. Following planting on March 17, 1992, each sapling was enclosed in 1.0 m staked Tubex tree shelter. Shelters were used to deter herbivory. All planting locations had soft sediments, and were flooded by less than 20 cm of water.

Height and diameter measurements were taken at planting and then annually for height and biannually for diameter. Height was measured from the soil surface to the tallest leader. Diameter measurements were taken at permanent marks on the stem that were 20 cm from the soil surface. All data were analyzed by using SAS (1990).

Survival of the plantings was assessed weekly at the beginning of the experiment until budbreak, then biweekly for the remainder of the first growing season and bimonthly during the second year. Trees with at least one leaf were considered to be surviving. The fullness of foliage was also noted for each sapling. If the sapling had a normal healthy amount of foliage, then it was considered in full foliage. But if the sapling was defoliating, (an indicator of stress), that was also noted.

During the survival assessments herbivory of the saplings was also recorded. Potential causes of herbivory included grazing (deer), stem breakage (deer or birds) and main stem cut (beaver).

Hydrological data were collected beginning in the spring of 1990 at a location near the center of the delta. Water-table depth was measured using a pressure transducer located in a 1.0 meter deep well or by a staff gauge. Temperature was measured with a model 207 probe, and was collected hourly by a Campbell Scientific, Inc. 21x Micrologger.

RESULTS

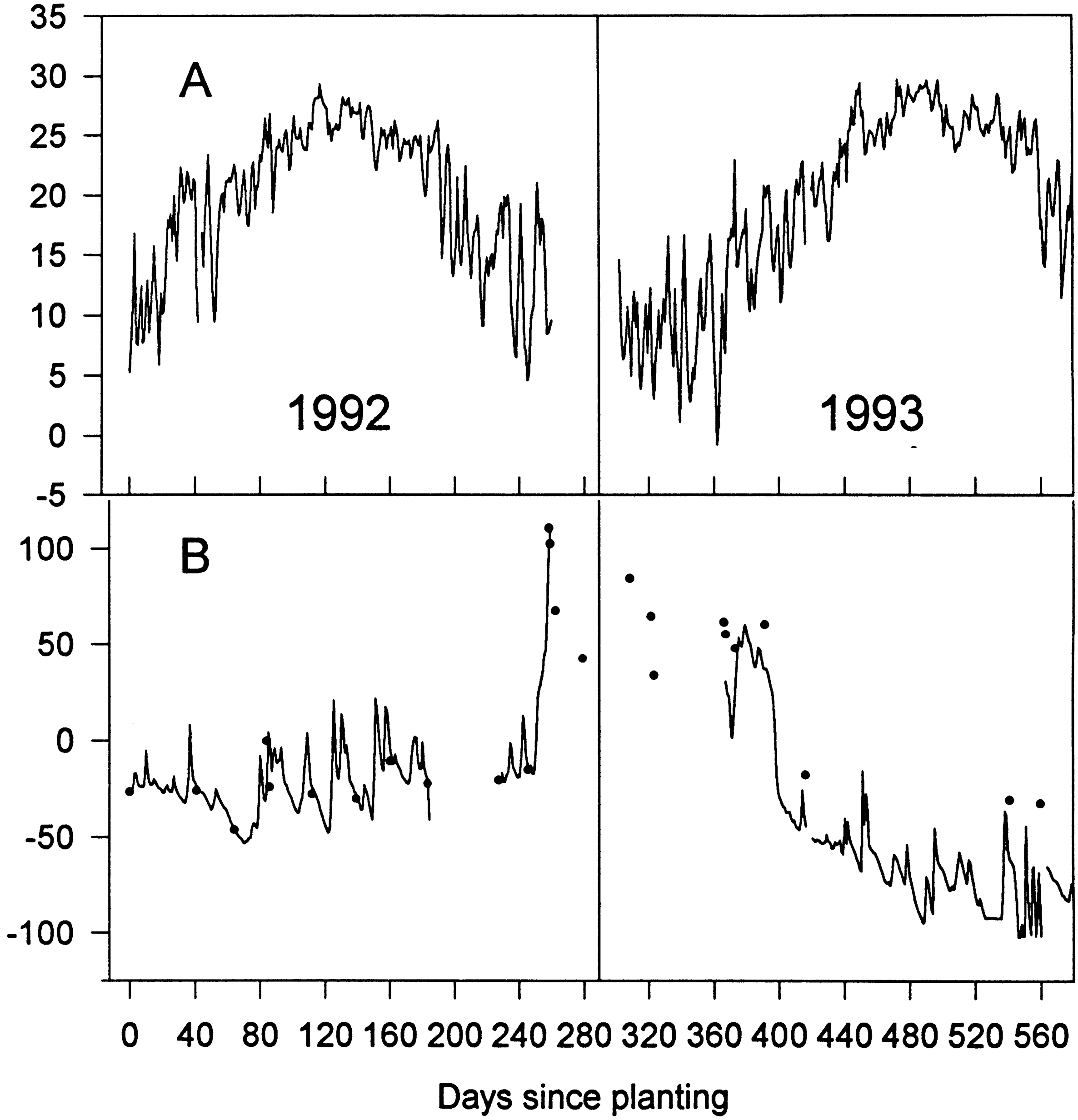
The site was generally wet during the 1992 growing season, with the driest period being between day 60 to 90 (May 16th through June 16th) (Figure 3). The end of the first growing season had a deep flood, greater than 1 meter, that extended from day 280 to day 410 (November 1992 to April 1993). The remainder of 1993 was droughty, with infrequent rain and a low water table. Summer mean daily temperatures were normally above 25 °C (Figure 3).

Taxodium distichum and N. aquatica had 100% budbreak in all treatments. in contrast, only the moderately pruned F. pennsylvanica saplings had 100% budbreak, while severely pruned saplings and cuttings had 53 and 87% budbreak, respectively.

Of the trees that broke bud, we determined the number of saplings in leaf at each assessment date. For F. pennsylvanica, the moderately pruned treatment saplings were not 100% in leaf until July (day 97) (Figure 4). The percent in leaf declined until 20% remained at the end of 1993 (day 567). The severely root-pruned saplings were never 100% in leaf at any assessment. Some of the saplings in leaf on one assessment would defoliate before the next assessment and be replaced by another sapling in leaf. But by May (50 days since planting) survivorship began a constant decline with only a few saplings surviving to the start of the second year. These remaining saplings died by autumn of 1993. Cuttings of F. pennsylvanica that broke bud were 100% in leaf by the first assessment. By early May (day 40), survivorship had dropped sharply until all saplings had died by fall of 1992 (day 185).

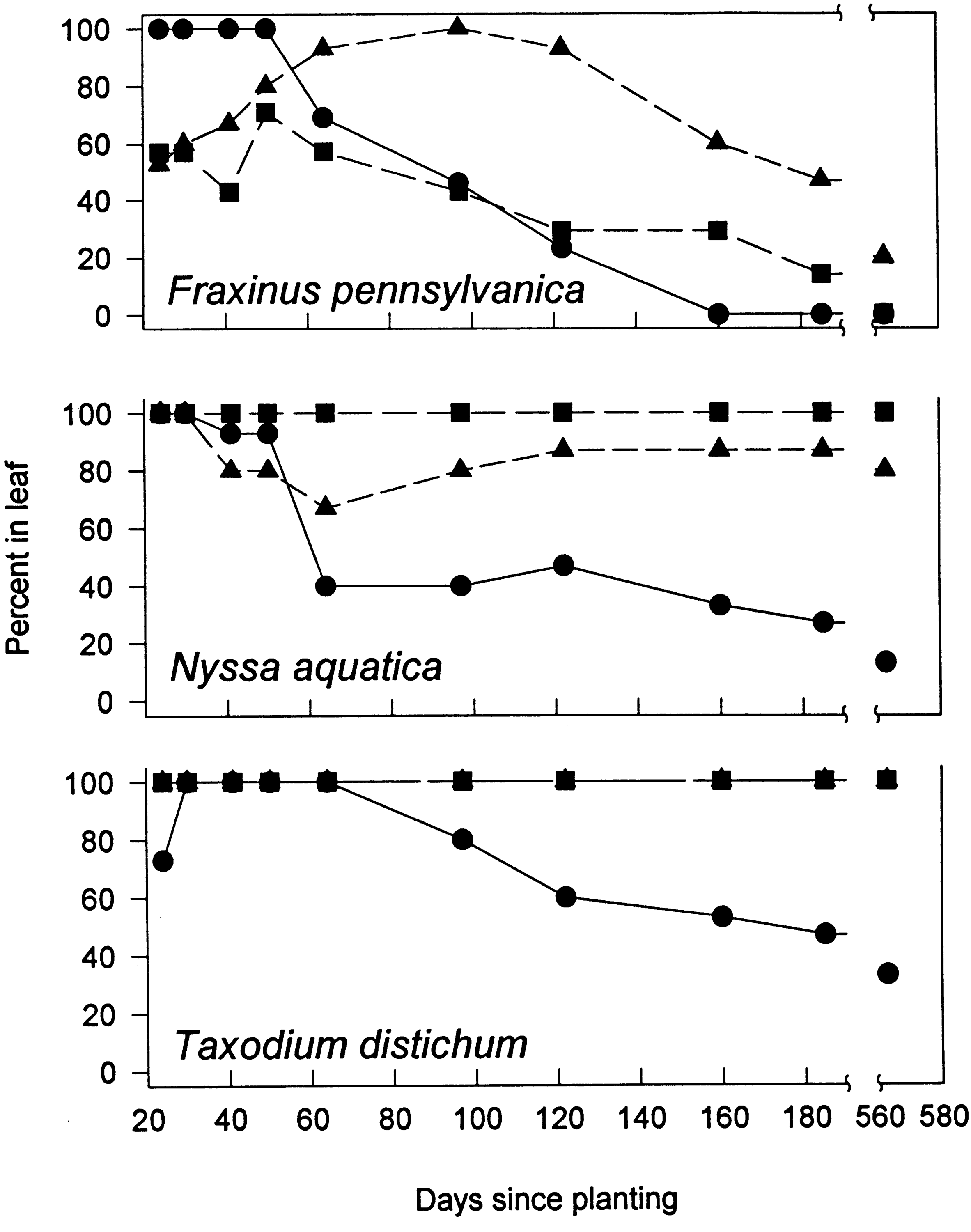
Nyssa aquatica saplings in the moderately pruned treatment of were 100% in leaf during the entire experiment (Figure 4). In the severely pruned treatment, 30% of the saplings had either died or defoliated by May (day 64), but a few saplings resprouted in July (day 97). The percent in leaf then remained almost constant for the remainder of the experiment with 80% in leaf at the end of the 1993 growing season. Nyssa aquatica cuttings respond similarly to the F. pennsylvanica cuttings. During May (starting on day 50), survival sharply declined and only 13% were alive at the end of the experiment.

Figure 3. (A) Mean daily air temperature (°C) and (B) depth of water (cm) at the meteorological station. Solid line is data from a permanently recording pressure transducer, while the ● are from a staff gauge. Positive values indicate standing water above the soil surface, while negative values indicate the water table is below the soil surface.



Both the severely and moderately pruned _T. distichum_ saplings were 100% in leaf during the 1992 and 1993 growing seasons (Figure 4). Like the other two species, survival of _T. distichum_ cuttings also began to decline starting in May (day 64), but 47% were still in leaf by the fall of the first year. More saplings died the second year until only 33% remained alive in the autumn of 1993.

Figure 4. Percent in leaf for the three species at each sampling date during the 1992 growing season and the autumn 1993. ● = Cutting, ■ = Severe and ▲ =Moderate.



All species had damage from herbivores (deer/beaver) or birds. Herbivory did not occur within the tree shelters, but instead was restricted to the portion of sapling emerging from the top. Herbivory from beaver was limited to a deep flood event during the winter of 1992/93 when flooding depth was greater than the height of the tree shelters. Most damage was from birds breaking the main stem above the tree shelters and deer browsing the exposed tops of the trees.

Both *F. pennsylvanica* and *T. distichum* had minimal herbivory (< 5%). *Nyssa aquatica* had the most herbivory, with saplings in the moderately and severely pruned treatments having 88% and 50% herbivory, respectively. *Nyssa aquatica* cuttings had no herbivory.

The amount of foliage and health of the trees surviving in the autumn of 1993 varied for each species, but was not affected by treatment. The three remaining moderately pruned *F. pennsylvanica* saplings all had sparse foliage. All severely pruned or cutting *F. pennsylvanica* saplings were dead. *Nyssa aquatica* had 55, 50 and 100% in full foliage for the moderately pruned, severely pruned and cutting treatments, respectively. All *T. distichum* were in full foliage. Although both the *N. aquatica* and *T. distichum* cuttings were 100% in full foliage, only a few saplings were still alive.

Due to the effect of herbivory in decreasing the height of saplings, only trees without herbivory were used in the growth analysis. Poor survival of the cutting treatments and *F. pennsylvanica* excluded them from this analysis.

Nyssa aquatica increased in height, but only two moderately and four severely pruned saplings were not affected by herbivores. Height growth for the two treatments increased by an average of 6 cm with a rage of -19 to 35 cm. Diameter also increased for both treatments an average of 6 mm.

The moderately and severely pruned *T. distichum* had a mean height growth of 56 cm for both treatments. No significant differences were noted between the moderately or severely pruned treatment for either *N. aquatica* or *T. distichum*.

DISCUSSION

The site was flooded at the beginning of the first growing season. The sediment, with the exception of brief periods, was constantly saturated, and often had standing water. Because of this inundation, saplings of all three species in the cutting treatment and all the *F. pennsylvanica* saplings did not appear to have produced new roots and subsequently had poor survival. Even though a late spring partially delayed budbreak, the increasing temperatures and depth to the water table in the summer of the first year also hastened the death of the cuttings and of all of the treatments of F. pennsylvanica.

The winter of 1992/93 had a very deep flood of over one meter, topping most of the plantings. Survival was not significantly affected by being deeply flooded, because the trees were dormant. The drought during the summer of 1993 (second growing season) also did not affect survival.

None of the three root pruning treatments were appropriate for F. pennsylvanica. Of the three species, F. pennsylvanica is more readily propagated by woody cuttings (Dirr 1987) than the other two species, but our results indicated that the cuttings of F. pennsylvanica did poorly, probably due to less flood tolerance. The ecotype of F. pennsylvanica obtained for the experiment (F. pennsylvanica var. subintegerrima) may have been less suitable for such a wet site than F. pennsylvanica var. pennsylvanica (Wharton 1973). In all likelihood, neither ecotype would have had good survival. Saplings in the moderately and severely pruned treatments had almost equal survival and growth for the N. aquatica and T. distichum. These species were well suited for the area and long-term survival should remain high.

Beaver had access to the tops of the trees above the tree shelters during the winter flooding of 1992/93. While the beaver cut the tree tops, survival was not reduced. Deer browsing almost completely defoliated many of N. aquatica saplings and the main stems were often broken, probably by wading birds landing on them to access adjacent pools. Herbivory did not greatly affect either F. pennsylvanica or T. distichum. While damage from animals reduced growth, all trees survived and resprouted.

Restoring unconsolidated sediments is possible using either moderately or severely root-pruned saplings which allow for planting by simple insertion. With the proper species or ecotype selection and root pruning severity, unconsolidated sediment can be restored using this planting method.

ACKNOWLEDGEMENTS

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INVESTIGATIONS INTO A CASE OF TREE STRESS AND MORTALITY IN WETLANDS

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ABSTRACT

The Savannah River Site (SRS) is a U.S. Department of Energy owned and Westinghouse Savannah River Company operated site located in southwestern South Carolina that was previously used for the production of defense-related nuclear materials. In 1992, a study was initiated to identify the cause of stress and die-out of mature wetland species in a first order drainage of Fourmile Branch. Upslope, approximately 350 m from this area were three seepage basins constructed in the 1950s to receive low level radioactive waste effluents generated from one of the chemical separations processes on site. The basins comprised approximately 2.7 ha and received in the mid-eighties an average of about 400 cubic meters of wastewater per day to decay and to slowly release into the soil. This waste consists mainly of sodium hydroxide, nitric acid, low levels of various radionuclides (primarily tritium) and some metals. The basins were closed (capped) in 1990 when investigations revealed that they were releasing faster than desired.

In the summer of 1992, transects were established that traversed the width of the wetland area with data for soil sediment deposition and status of tree canopy collected every 3.5 m across the transect. Samples for tritium analyses were collected at locations established around the edge of the seepline which is the transition from wetland to uplands. Tritium was selected because it tracks so closely with contaminants moving from the basins as a ground water plume. Conductivity and pH data were also collected at these locations. Quarterly sampling was subsequently conducted to verify the results and detect any change in water chemistry. Sampling for metals was initiated in January 1993. Data collected thus far indicates that tree stress and death were related to the amount of overburden, with stress noted at 10 cm of sediment.

INTRODUCTION

The Savannah River Site (SRS) is a 780 km^2 U.S. Department of Energy (DOE) facility constructed in the 1950s for the production of nuclear defense materials. The construction of the five production reactors, separation facilities, infrastructure and administrative areas occurred in a relatively short time and still is considered one of the most massive construction projects in U.S. history. In 1972, the SRS was designated as the DOE's first National Environmental Research Park. Currently, technology transfer, waste management, and environmental restoration activities comprise the major focus of the SRS.

The SRS is located in the Carolina-Georgia Sandhills Major Land Resource Area of South Carolina with the Savannah River forming the south-west boundary of the Site (Figure 1). Most of the uplands on the SRS, and many of the wetlands, were in cultivation when the land was purchased by the U.S. Atomic Energy Commission. After construction of the reactors and associated facilities was completed, the U. S. Forest Service (USFS) planted the remaining open land in loblolly (Pinus taeda) and slash pine (Pinus elliottii) to produce wood products and provide complete land cover for some 70,570 ha of soil (USDA 1990).

Three seepage basins were located in the central area of the SRS south of the site's chemical separations facilities (F Area; Figure 1). From 1955 to 1988, these basins routinely received wastewater from the F-Area facilities. This acidic waste consisted mainly of sodium hydroxide, nitric acid, low levels of various radionuclides, and some metals (Killian *et al.* 1985). Tritium was the major radionuclide constituent in the wastewater (ca. 99%), and the basins served to delay tritium release to surface water by using infiltration through the soil column (Murphy *et al.* 1993). Groundwater monitoring since 1955 has characterized the groundwater plume of tritium from one of the basins to a headwater tributary of Fourmile Branch which is located about 600 m downslope of the basins.

In the early 1980s, it was observed by using over-flight photography that there was localized tree mortality as well as stressed vegetation in the wetland areas bordering headwaters of Fourmile Branch downslope from the F Area seepage basins. An investigation was conducted in 1989 to determine the cause; the approach was taken that the stress and mortality was a result of chemicals that leached from the seepage basins into the wetlands (LeBlanc and Loehle 1990). Chemical data were not conclusive but it was hypothesized that aluminum was high enough to prove toxic to trees in one of the wetlands. High levels of aluminum, manganese, cadmium and sodium were present in the soil of one wetland (Killian *et al.* 1987). But since groundwater contamination had occurred around 15 years before evidence of localized forest stress was noted, data was inconclusive (LeBlanc and Loehle 1990). These authors concluded that an

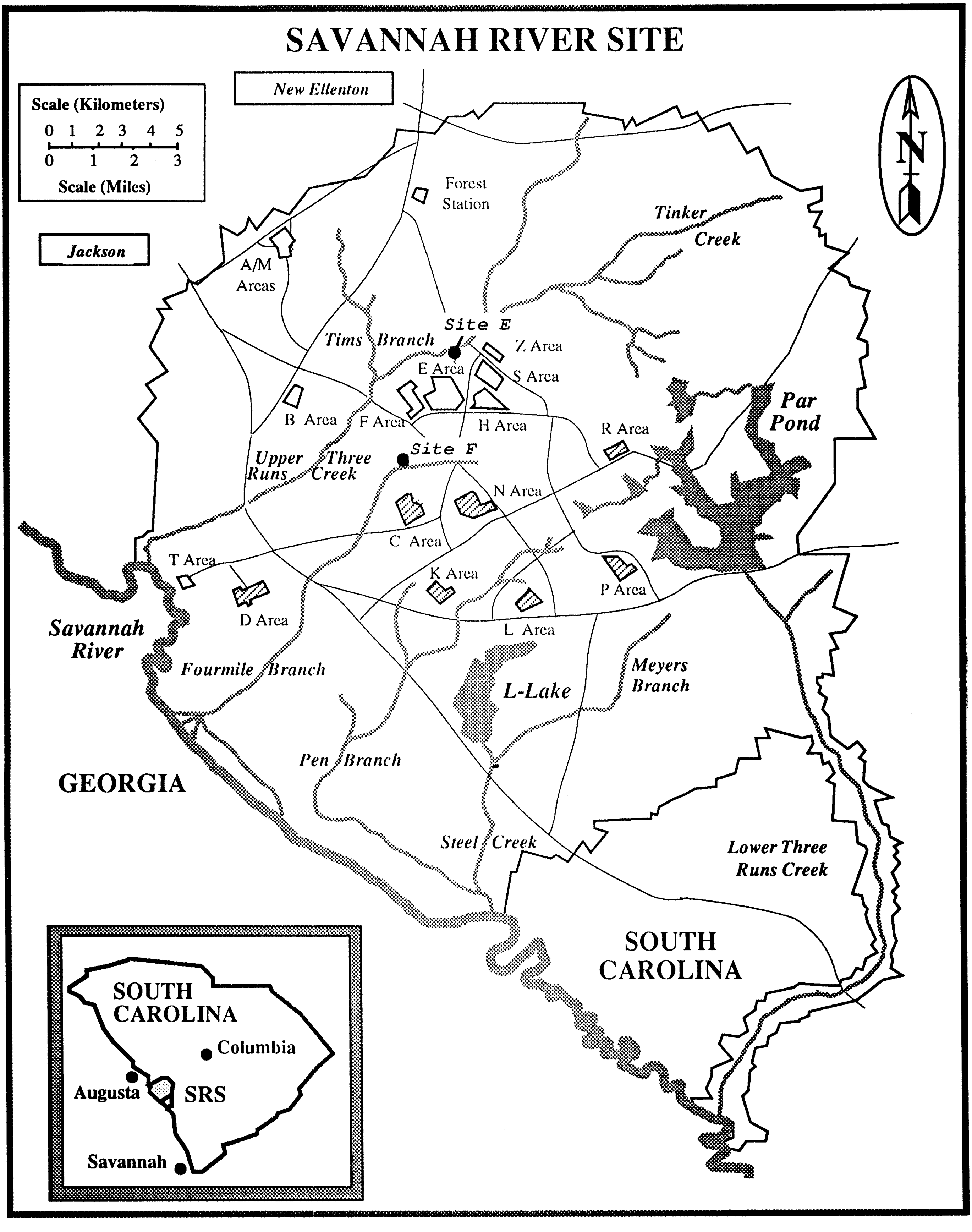


Figure 1. Location of the Savannah River Site and our study sites

interactive effect between drought and contaminants may have caused the localized tree mortality. However, another wetland with tree mortality and stress which was located about 244 m west and about 200 m south of the severely impacted wetland did not show extremely elevated aluminum levels. This wetland (Site F) was selected as one of the study sites.

In 1993 with the aid of infrared aerial photography (1:6400) an additional wetland area (Site E) with localized tree mortality was identified about 3 km north of the F Area seepage basins. By evaluating historical overflight photography, it was determined that this area had been affected during approximately the same time period as the wetlands south of the basins. Further study showed no evidence of soil contamination based on tritium, conductivity, and pH analyses (Haselow *et al.* 1992).

Photo interpretation also indicated that tree mortality was progressing with time in the direction of Fourmile Branch. The only obvious common factor in both areas of localized tree mortality was the presence of considerable overburden in the wetlands. This sediment eroded from construction areas on the adjacent upland soils. It was hypothesized that sediment deposition could be a major contributor to stress and mortality of the trees in these two wetland areas.

STUDY SITES

Two jurisdictional wetlands (Site E and Site F) with localized tree mortality were the subject of this investigation. Site E was 0.8 ha and Site F was about 1.4 ha in size. The soils in this area occur mostly on excessively drained ridges with slopes of 2 to 15 percent. Soil was classified as Osier series on both sites. Osier has a sandy profile, low organic matter, and only the A horizon is well developed. Osier soils are classified as Siliceous thermic Typic Psammaquents. Because of the well developed A horizon, field investigators were able to determine the precise amount of sediment (overburden) on top of the original A horizon.

The mean monthly precipitation during the growing season ranged between 10 and 13 cm (USDA 1990). Through meteorological records kept in F Area the storms that contributed most to the sediment deposition were tracked to give an estimate of the time of occurrence. Normal hydrology characteristic to these wetlands comes from rainfall seeping out of sandy soils on the surrounding upland slopes. Daily wastewater effluent helped to charge the ground water prior to capping the basins in 1990.

The two wetlands in this study are long irregularly shaped depressions that route drainage water without defined channels to perennial streams on both sides of the sandy upland divide. These wet depressions are primarily vegetated with an overstory of swamp tupelo (Nyssa sylvatica var. biflora), sweet gum (Liquidambar styraciflua), tulip poplar (Liriodendron tulipifera) sweet bay (Magnolia virginiana), red maple (Acer rubrum), holly (Ilex opaca), and water ash (Fraxinus caroliniana). The under-story consisted mainly of green briars (Smilax spp.), and various canes, ferns, and saplings.

METHODS

Transects were established traversing both of the study sites and sampling points were established along the outside boundary of each wetland. Twenty ml water samples were collected to analyze tritium activity. Conductivity and pH were recorded in situ by placing pH and conductivity electrodes in the seepline water which slowly flowed into a 10 by 18 cm hole made with a soil auger. Samples were also collected for the analysis of metals such as aluminum, arsenic, barium, copper, and sodium. Since rainfall would influence the concentration of contaminants sampled in the seepline water, no samples were collected for at least 72 hr after measurable precipitation. Sample collection and analyses were conducted as described by Dixon and Rogers (1992).

A sampling pattern was selected to give an even distribution on all sides of the study area plus have at least one point at the head of the incoming drainage. Eight transects were used to determine the amount of overburden or material deposited over the original A horizon at Site F and five transects were used for Site E. Sample locations were marked with plastic stakes and the thickness of sediment was determined with an 8 cm soil auger. Observations were made each 3.5 m along transect lines. At each soil observation a visual tally was made of the over-story canopy for a distance of 3.5 m and 360 degrees from the point of soil observation. The tally included healthy trees, dead trees and stressed trees that showed chlorotic leaves, deformed leaves, die back of twigs, or lack of normal leaf development for each species. The three dominant species selected to tally were N. sylvatica, L. styraciflua, and L. tulipifera because they were either dead or showing stress in the field.

RESULTS

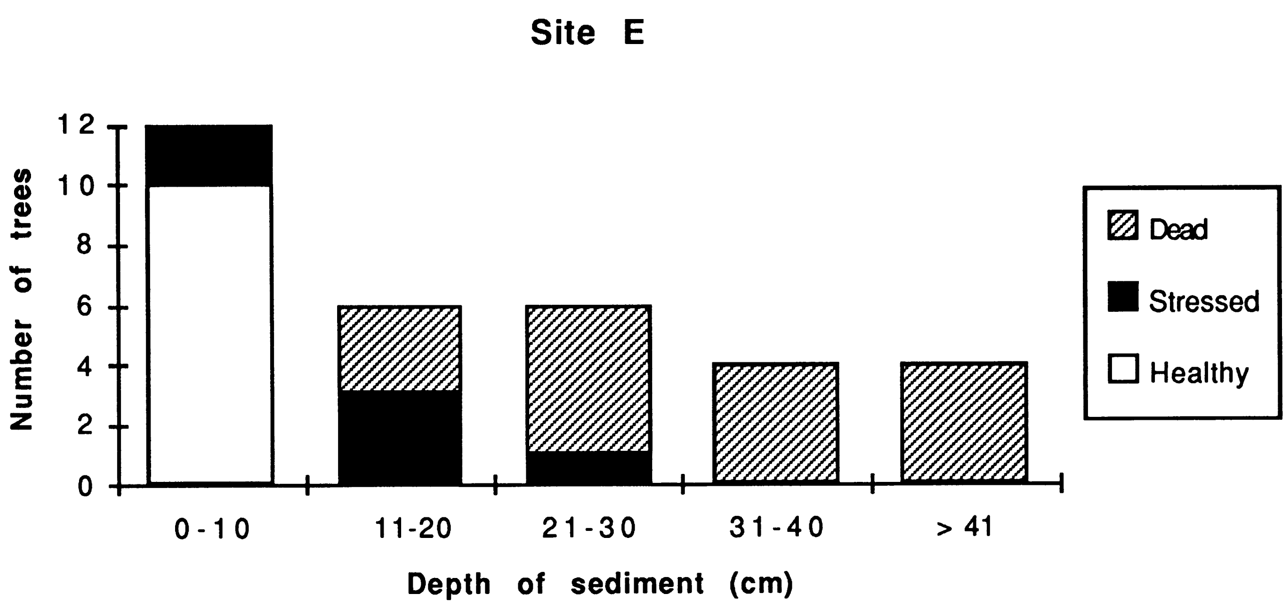
The tritium activity ranged from 208 to a high of 3,715 pCi/ml in the F site. Specific conductivity ranged from 26 to 578 us and pH ranged from 4.0 to 5.7. Metals were near or below detection limits in samples collected from Site F. Tritium activity for Site E in September 1991 ranged from 17 to 89 pCi/ml. All metals except iron were below detection limits. Conductivity and pH readings were comparable to Site F. Tritium data was not corrected for the amount of normal decay which would be a reduction of about 12 percent.

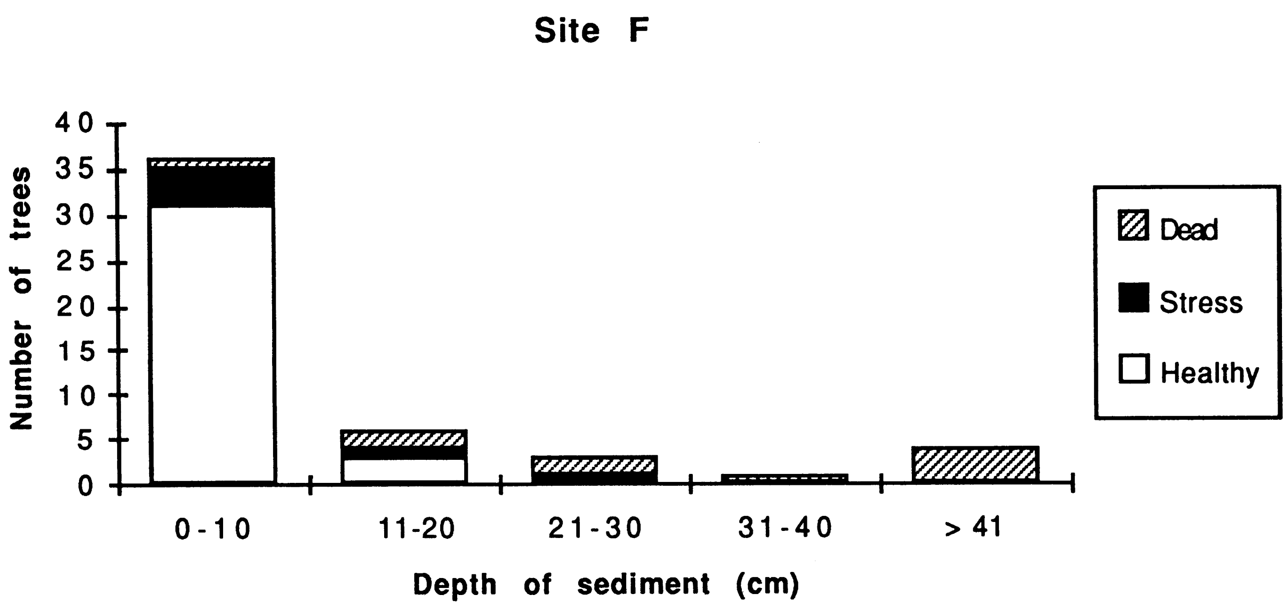
The number of trees that were dead, stressed, or in healthy condition at each study site as a function of the depth of sediment deposited on the original soil surface is presented in Figure 2. Transects showing sedimentation compared very closely with the vegetation stress and die back areas. The upper 75 percent of the wetlands visually appeared to have greater vegetative stress and die out. As the amount of sediment decreased down gradient in the wetlands at each site there was an observed reduction in dead trees and a gradual decline in stress and mortality. As the thickness of sediment decreased below about 8 cm, there was no evidence of tree stress. Site E had no healthy trees where there was more than 10 cm of sediment. Site F had three healthy trees in the 11 to 20 cm thickness range. Each site had complete mortality where there was 30 cm or more sediment. In areas where there was no sediment, there were no visual indicators of tree stress. In general saplings appeared to be healthy.

DISCUSSION

The metabolic adaptations of N. sylvatica to survive with siltation are moderate with problems noted at 7.5 cm of sediment according to Teskey (1977). This is consistent with the findings of this study. From recorded large rainfall events, the length of time from major sediment deposition until stress symptoms appeared was about four years. Mature trees showed greater impact than saplings. Sediment deposition differentially affected the tree species in our study sites with N. sylvatica the most susceptible of the species in this study. While more data is needed to support this project, it appears that as little as 8 to 10 cm of sediment deposited on the hydric soils of the study sites can induce stress or even mortality in mature or near mature trees of certain species. Impact appeared to vary with the tree species and age. Healthy tree species observed were M. virginiana, A. rubrum, I. opaca, and F. caroliniana.

Figure 2. Number of dead, stressed and healthy trees relative to cm of sidement deposition in Sites E and F.





These data suggested that mature N. sylvatica was subject to stress in these wetlands and subjected to as little as 10 cm of sediment on the surface of the A horizon. It also indicated that tree mortality was likely to occur if there was as much as 21 cm of sediment. There were areas on some of the transects that had as much as 31 cm of sediment and in these areas all of the mature trees were dead. A couple of transects at Site F had about 8 cm of sediment and stressed or dead trees. These sample locations also showed evidence of recent erosion indicating that perhaps the sediment was previously 10 cm or more for an extended period of time. For this reason the break between healthy and stressed trees was set at 10 cm thickness rather than 8 cm.

There was a possibility of mortality and stress being related to pathological-biological factors. While this option could not be completely ruled out, it is presumed that tree mortality and stress would have also occurred in the wetland areas immediately beyond the zone of sediment deposition if there were a disease-related cause. There was not sufficient data to establish if sediment weakened the trees and allowed disease to invade and cause mortality.

Chemical impact was ruled out for both sites because the metals and salt content were close to background for each of the study sites. An area with localized mortality near Site F had no sediment deposition and there was a high amount of dissolved aluminum (>64 mg/L) in the soil-water solution (Haselow *et al.* 1990). Data from the Haselow report was taken prior to closure of the seepage basins and represents conditions at the time of tree kill and stress. Data collected after closure of the basins showed aluminum to be less than 1 mg/L (Dixon and Rogers 1993). This trend indicates the soil-water chemistry has improved after closing the basins. Kaolinitic clays are high in aluminum and extremely acid water in the seepage basins caused large amounts of aluminum to be released into solution and seep from the soils to this wetland. Natural concentrations of aluminum in groundwater range from less than 5 to 1000 ug/L (Dragun 1988).

Tritium was analyzed in this study because it was not an expensive test plus it was an excellent chemical to track contaminant plumes in this area as a part of the groundwater. Tritium has not proven toxic to vegetation even in much higher concentrations than present in these wetlands.

Organic matter was not analyzed; however, a field estimate was made and only a trace amount was observed. There was about five percent organic matter in the buried A horizon. The lack of organic matter in the sediment was a clue to where the old A horizon occurred. The sediment was made up of fine to medium sand, silt and clay. There was a higher percentage silt and clay at the outlet (lower elevation) of each site. There was not sufficient data to prove different impacts for clayey texture versus the more sandy texture.

CONCLUSIONS

In this investigation the most susceptible species to stress or mortality were N. sylvatica, L. styraciflua, and L. tulipifera. For the species tallied, 31 cm of sediment was a lethal thickness with about 8 to 10 cm being the thickness that stress and occasional mortality began to occur. With less than 8 to 10 cm of sediment trees appeared to be healthy. Based on aerial photos and rainfall data about 3 years was required for stress to appear and 4 to 5 years for mortality to occur. Mature and near mature trees were more susceptible to stress or mortality than younger trees.

The results of this investigation so far do not adequately support the hypothesis that sediment deposition was the single causal factor of localized tree mortality and stress in Sites E and F. However, preliminary analysis of soil and groundwater in these two wetlands have not revealed levels of toxic metals such as aluminium, manganese, or salt concentrations, or other constituents that would cuase stress or mortality to trees growing in this area. Aluminum, nitrates, and sodium were at such high concentrations in a wetland east of Site F that chemical contamination likely was the cause of tree mortality in that location.

Data collection and analysis is ongoing to test the hypothesis that soil materials eroded from construction areas up slope and deposited into these wetlands was the sole cause of tree mortality and not contaminants from the groundwater as had been earlier proposed.

ACKNOWLEDGMENTS

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DEVELOPMENT OF A HYDROLOGIC MODEL USED TO EVALUATE A WETLAND MITIGATION BANK DESIGN

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ABSTRACT

A hydrologic model was developed to evaluate the feasibility of constructing of a proposed wetland mitigation banking design. Hydrologic data was collected from a monitoring network located in northwest Hillsborough County, Florida. The model was restricted to the upper 15 feet of unconsolidated clastics belonging to the surficial aquifer.

A water balance equation was used to estimate net gains and net losses occurring under existing hydrologic conditions between February 1993 and march 1994. An unsaturated zone model was developed to predict the volumes of water which would be required to fully saturate the project site based on estimated soil porosities obtained from moist and dry bulk density estimates.

Water balance results indicate net losses exceeded net gains within the system.

Unsaturated zone model results predict that the invert structure elevations, as designed, will not provide adequate water volumes to fully saturate the proposed bank site soils during the critical growing season between May and November under existing precipitation conditions.

INTRODUCTION

Specific conditions within the issued permit (SWFWMD, 1993) required collection of hydrologic data for a period of one year prior to project construction. The preconstruction data base is to be compared against post-construction monitoring to substantiate successful restoration of wetland hydrologic conditions.

SITE DESCRIPTION

The proposed site is located in northwest Hillsborough County, Florida within Section 9, Township 28 South, Range 18 East. The site consists of approximately 90 acres of combined upland and hydrologically altered wetland cypress dome systems.

HYDROLOGY. Figure 1 shows the general landscape features and location of the monitoring network stations. The section located south of the Tampa Electric Company easement represents the proposed bank site. Surface and ground water hydrology appears to be directly correlated to rainfall patterns, fluctuating in direct response to frequent precipitation events. Figures 1 and 2 are water table contour maps which represent typical wet and dry patterns.

Evaporation and evapotranspiration were considered to play important roles in the hydrologic balance. High humidity, ambient temperatures, and dense vegetation were considered as drawdown sources of surface and water table levels during the entire monitoring period.

The study area is located south and west of county owned, undeveloped tracts. To the north is a wastewater treatment facility, and to the east is a potable water treatment and storage facility. Expanding residential development is occurring approximately one mile to the east. Vacant land occurs to the west and south of the study area.

Ditches rim the north, east, and west boundaries of the study area. The south boundary consists of a large wooded cypress dome and pine forest upland. Several borrow pits and ditches occur within the interior study area and are surrounded by large expanses of secondary faculative and faculative wetland forest and shrub species.

TOPOGRAPHY. The landscape gently slopes from the north towards the south. The higher elevations (20.25 feet MSL) occur north of the Tampa Electric Company (TECO) power line easement. South of the utility easement, topographic elevations range between 18 and 23 feet above mean sea level. These elevations correspond to the Pleistocene Pamlico terrace sand deposits.

GEOLOGY. Surface soils encountered on the site consisted of dark brown, gray brown, and gray sands to silty sands. The subsurface layer consisted of brown, dark brown, light to dark gray, brown gray sands to silty sands. The substratum layer consisted of gray to tan sands. Sandy clay was encountered in 5 out of 7 of the 15 foot soil borings, and appeared to represent the clay residuum layer associated with

Figure 1. May 1993 water table contour map.

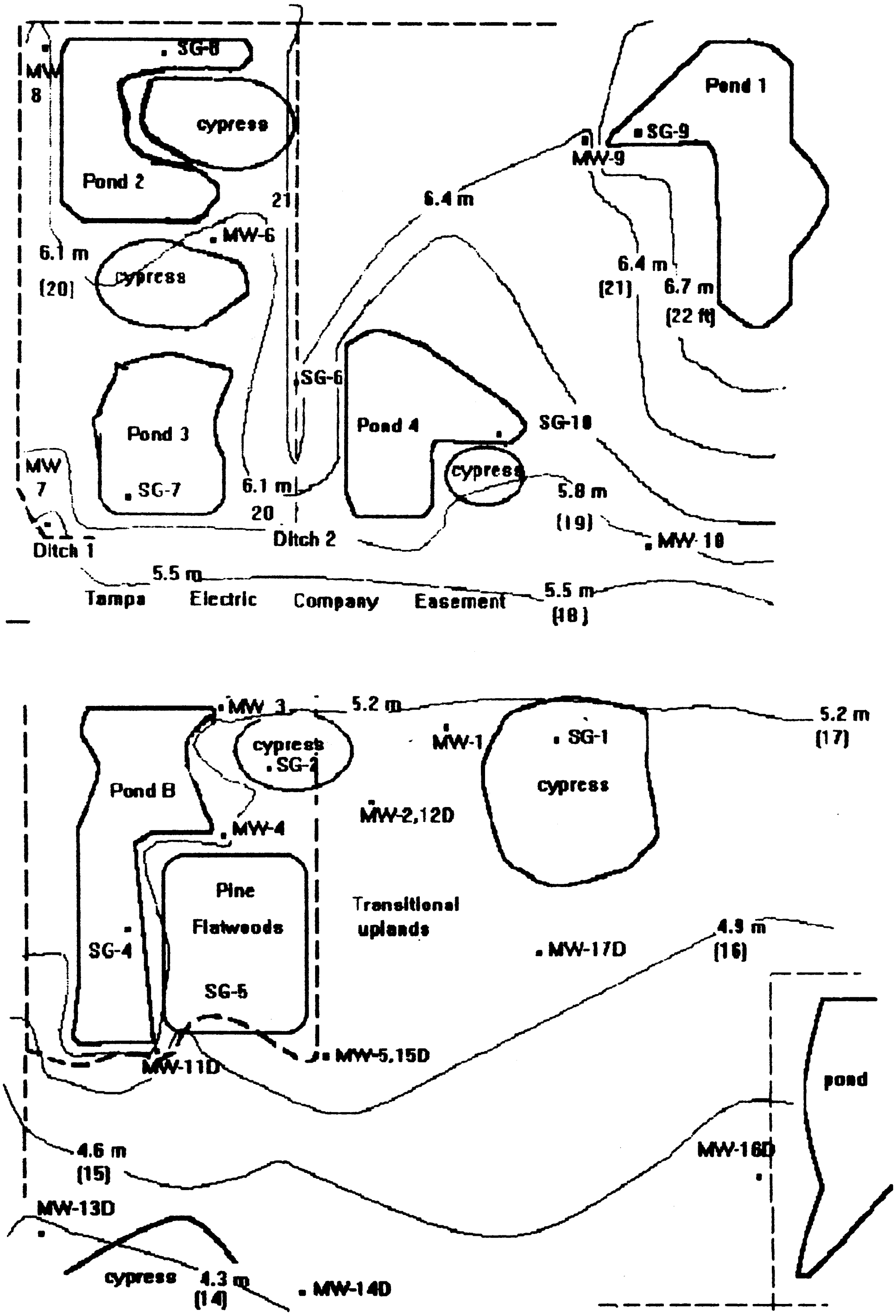
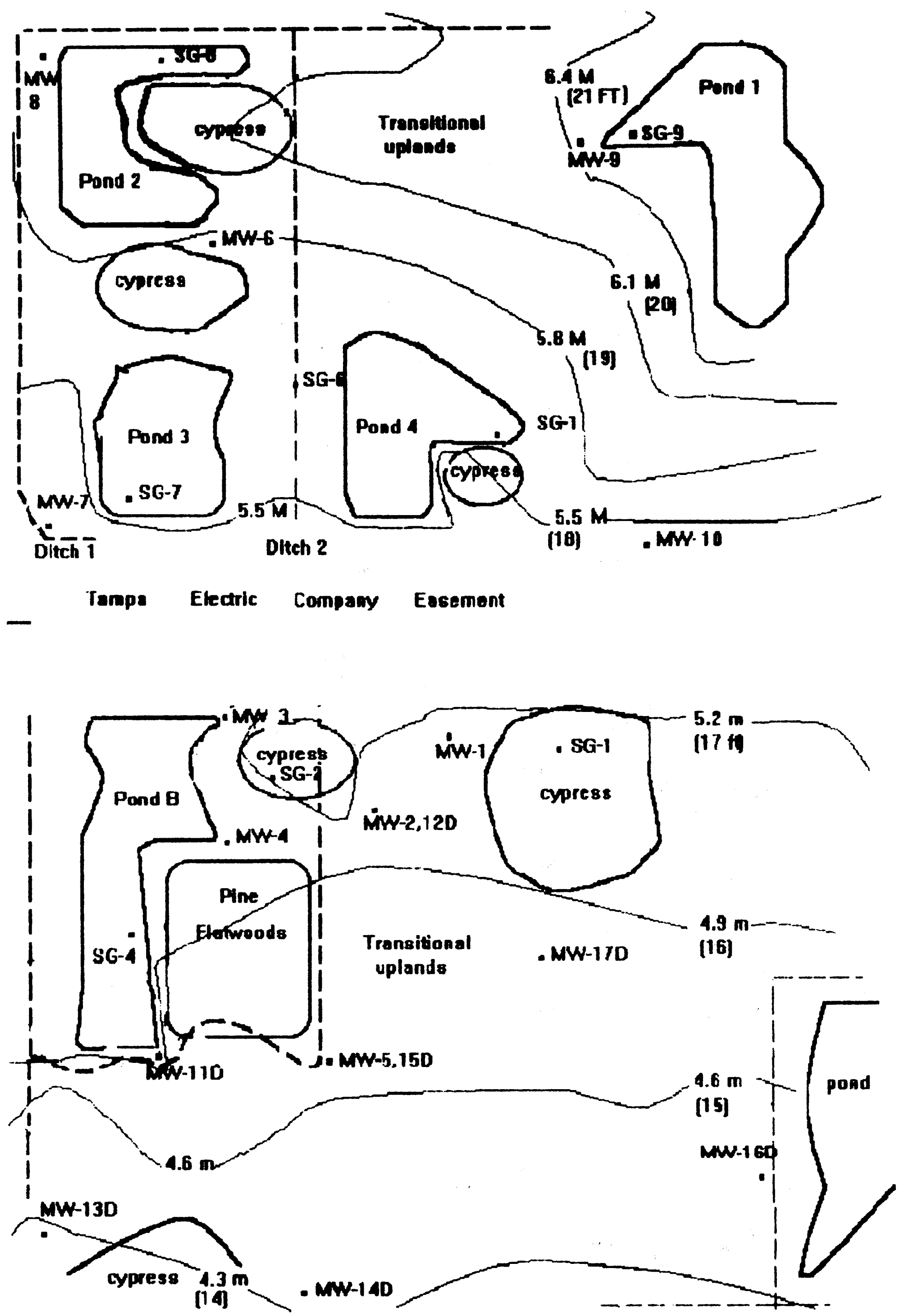


Figure 2. August 1993 water table contour map.



the surface of the Tampa limestone. Soil logs were compared with the Hillsborough County Soil Survey (USDA - SCS, 1986) to confirm soil types occurring in the study area. Soil descriptions corresponded with the Basinger, Holopaw, and Samsula series within the cypress domes, and Malabar and Myakka soils within the flatwood areas.

WATER TABLE RECHARGE. Recharge to the water table occurs from Pond 1, and in the vicinity of MW-9. During periods when recharge mounding occurs near MW-9, ground water gradients reverse and flow back into Pond 1. This phenomenon was particularly evident during February, March, September 1993, and during January 1994.

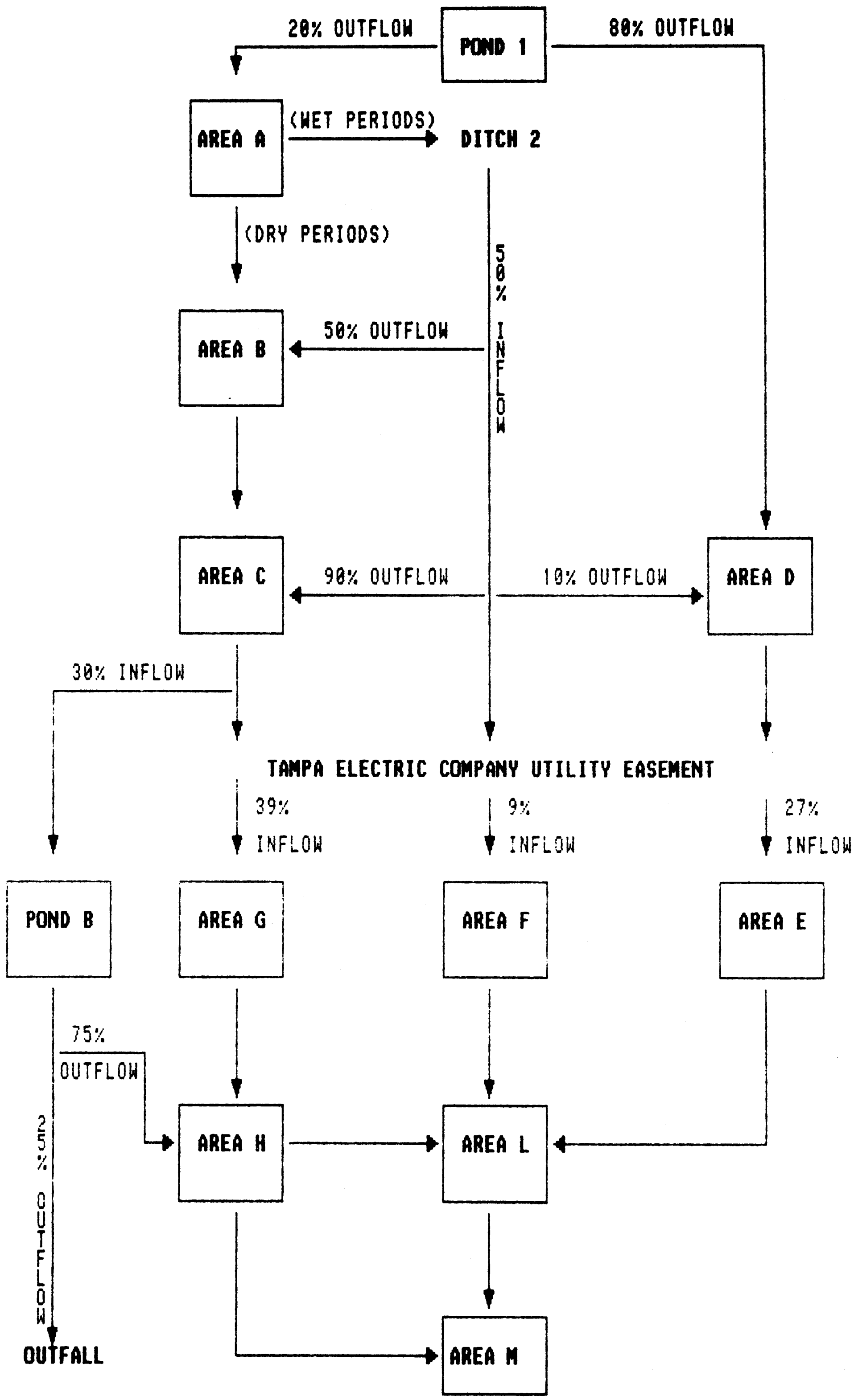
WETLAND CONSTRUCTABILITY ANALYSES

BOUNDARY CONDITIONS. Horizontal boundaries in the form of perimeter and interior ditches perform recharge functions when surface waters are present. Borrow pit ponds and cypress domes also serve as horizontal boundaries. Upper vertical boundaries were defined as the existing landscape elevations, and lower vertical boundaries were based on the presence of a contiguous 10 foot thick semiconfining clay unit which serves to separate the water table from the underlying limestone aquifer. The clay boundary was considered to be a no flow boundary to the system. Vertical leakance across this unit was estimated to be 0.18 liters per day per cubic meter (0.0013 gallons per day per cubic foot) (SWFWMD, 1984). Pond 1 was used to represent steady state recharging for the water balance model. Area A also recharges the system during periods when the unsaturated soil zone is subjected to rapid, heavy rainfall following prolonged dry periods. The water balance model took into account reversed gradient condition.

FLOW ROUTING. Flow routing (Figure 3) was based on water table contour maps compiled during the 13 month monitoring period. Two factors were utilized in determining flow routing: (1) recharging functions of surface water bodies during wet season periods, and (2) surface water to land (surface area) ratios contributing toward declining water table conditions during dry season periods.

The majority of recharge from Pond 1 was routed into Area D based on the surface area relationship between Pond 4 and Ditch 2. Outflows from Area A into Area B or into Ditch 2 were controlled by water table responses to wet and dry months. During wet periods, Ditch 2 served to intercept groundwater flows entering Area B from Area A, diverting groundwater southward as surface water through the ditch. Recharge into Ponds 3 and 4 occurred along the south section of the ditch. During dry periods, groundwater flow occurred due west from Area A into Area B. Routing followed from Area B into Area C.

Figure 3. Flow routing.



Flows were directed southward across the TECO easement into the proposed bank site areas. Inflows were directed into Areas E, F, G and Pond B based on surface area ratios. Recharge from Pond B was divided into Areas H and M based on contact distances along the respective southeast and south shorelines. Area M served as the termination point for the model.

GRID BOUNDARIES. The grid system shown in Figure 4 followed the previously described routing scheme. Groundwater ridges, depressions, and perimeter ditches along with ponds and cypress domes, were used to establish grid segment boundaries.

MODEL METHODOLOGY

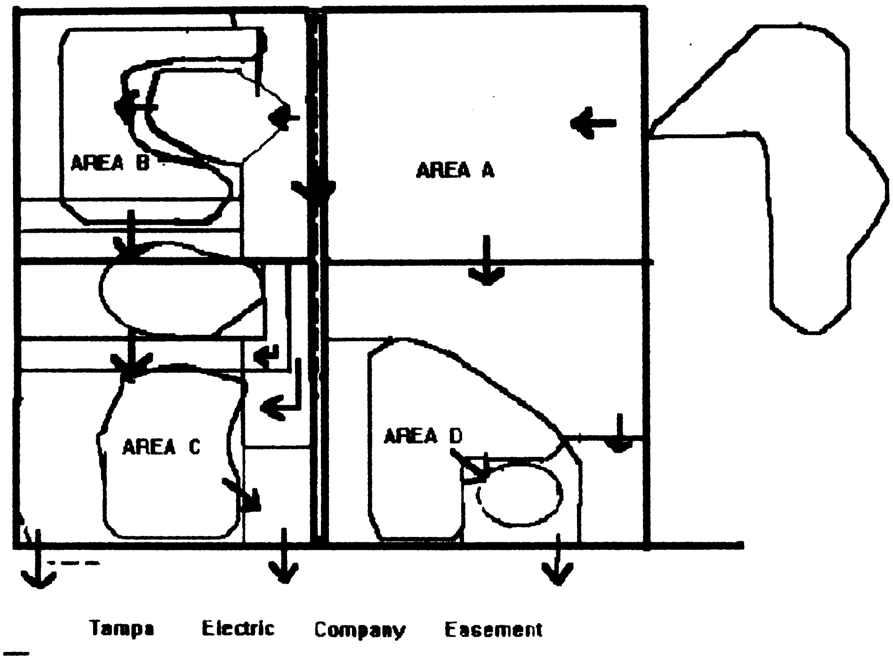
A method was needed to evaluate the proposed construction design against the accumulated hydrologic data. To accomplish this task, the model was separated into two parts. The first part involved the application of a simple water balance analyses which accounted for balancing net gains against net losses. The intent of this part of the model was to approximate the existing hydrologic conditions in the study area between February 1993 and March 1994. The period from February through March 1993 represents an abnormally wet weather pattern coincident with the Winter Storm of 1993. April through November coincided with the normal wet season. December 1993 through March 1994 coincided with typical dry season conditions.

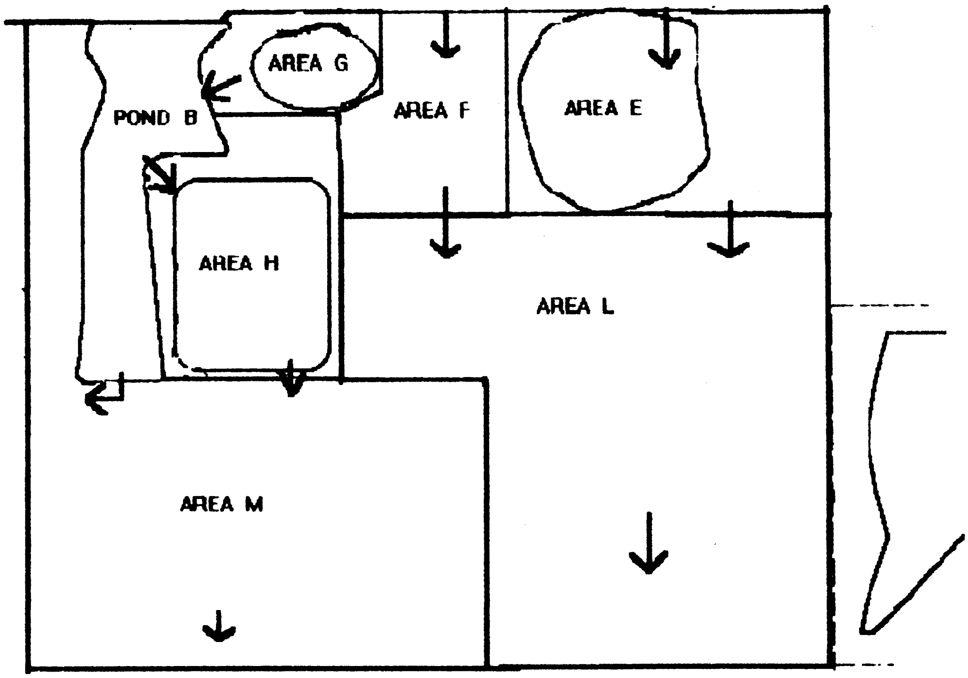
The water balance analyses relied on the following equation:

Water Balance = Net Gains - Net Losses

Net gains into the system appeared as positive values and included precipitation water table inflow, and surface water infiltration occurring across grid boundaries. Net losses from the system appeared as negative values and included evaporation, evapotranspiration, and storage in surface water bodies and cypress domes. Net balance results were used to predict and identify which grid segments were acting as storage and release components.

Figure 4. Grid boundaries.





An estimated annual evaporation value of 127 cm (50 inches) was obtained from Visher and Hughes (1975). The value was converted to 10.7 cm (0.35 feet) per month to maintain consistent units used in the model. Evaporation losses were applied toward all surface water bodies. Evapotranspiration rates were estimated to be 76.2 cm (30 inches) per year (Bloom, 1975), or 6.4 cm (0.21 feet) per month, applied toward the heavily vegetated cypress dome and wooded sections of the study area. A value of 3.0 cm (0.1 feet) per month was used to represent the less densely vegetated areas.

The unsaturated zone model was approached in two separate steps. The first step was to evaluate the hydration sources that would discharge into the proposed bank site. The inlet structure elevations proposed in the construction design were compared against the surface water elevation data collected from each station monitored within Ditch 1, Pond 3, Ditch 2, and Pond 4. Figure 7 presents the quantity of water that would have discharged through the inlet structure into the proposed bank areas (E, F, G, and Pond B) at the proposed invert elevations.

The second step of the model evaluated the existing and proposed conditions of Pond B. The pond site is an existing surface water body proposed to be improved to accommodate a functioning aquatic and herbaceous wetland system. The existing volume of water contained in the pond during hydrologic monitoring, and the volume of water that will exist in the pond after dredging and filling activities are completed were estimated for the purpose of evaluating normal and seasonal high pool water levels with respect to the proposed planting zones.

MODEL RESULTS

Figure 5 graphically represents the water balance results modeled for the area north of the TECO easement. Net gains were limited to the months of May and June for Area A and Ditch 2, and June for Area D. Gains were attributed to precipitation and Pond 1 recharge into Area A, and precipitation and groundwater inflow from Area A into Ditch 2 and Area D.

Net losses attributed to pond evaporation, evapotranspiration, and cypress dome-pond storage effects appeared consistently during the entire monitoring period within Area B. Losses were prorogated into Area C and throughout the proposed bank site.

Figure 6 graphically represents water balances occurring south of the TECO easement in the proposed bank site. Net gains were limited to the month of August for Area M. Net losses for the remaining areas were attributed to evaporation and evapotranspiration which exceeded precipitation gains.

Figure 5. Water balance
North of TECO easement

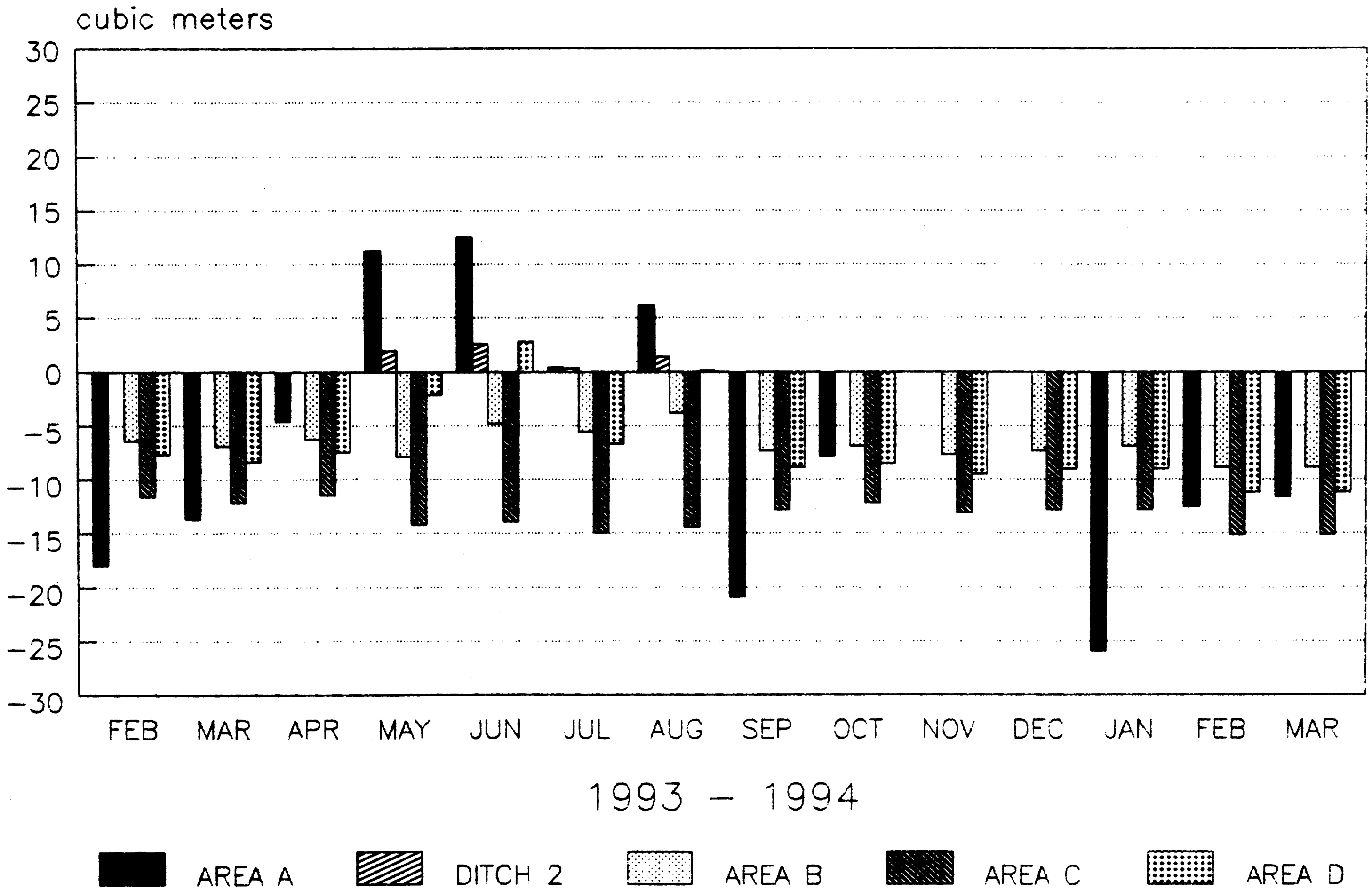


Figure 6. Water balance
Proposed bank site

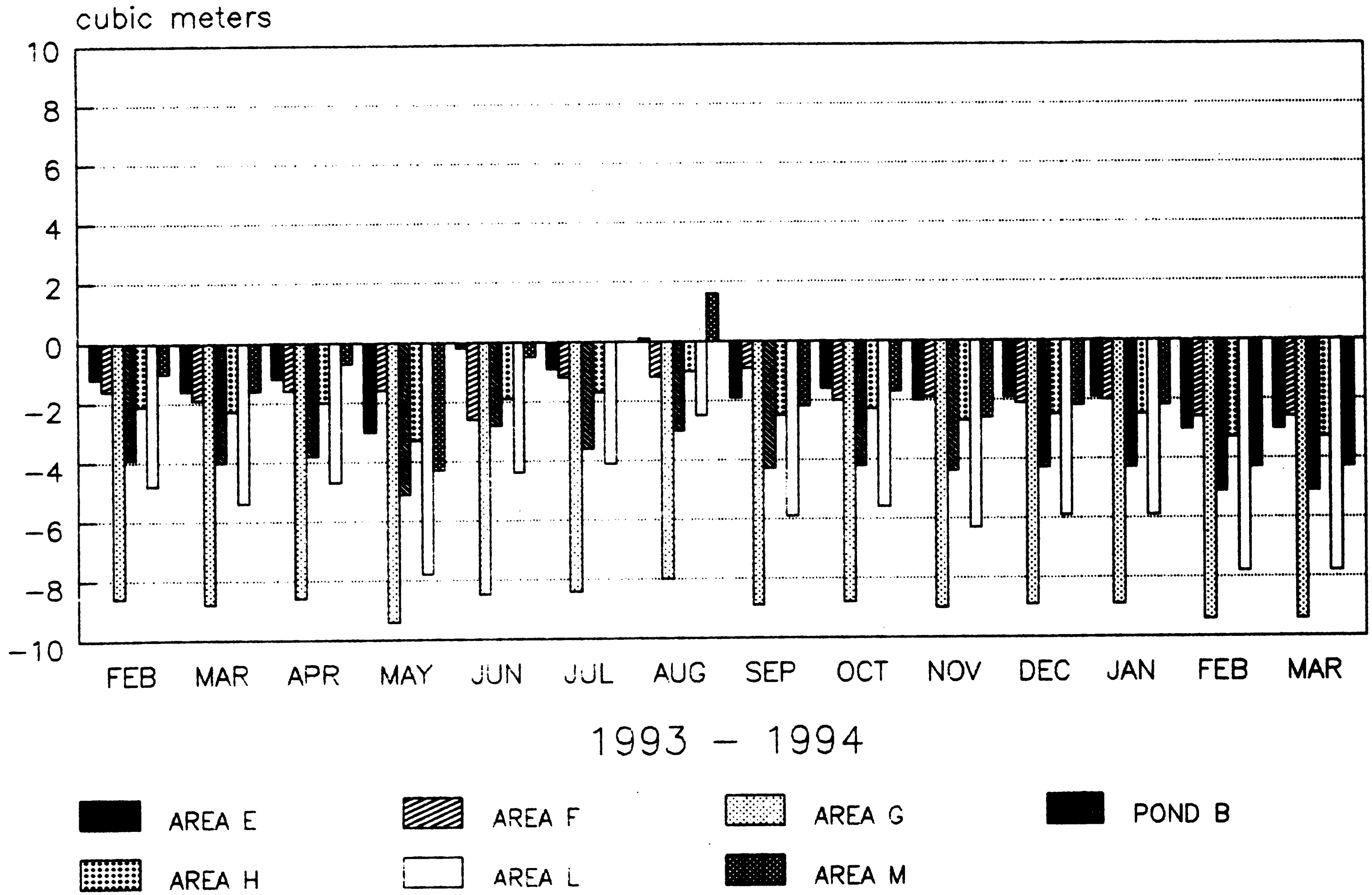
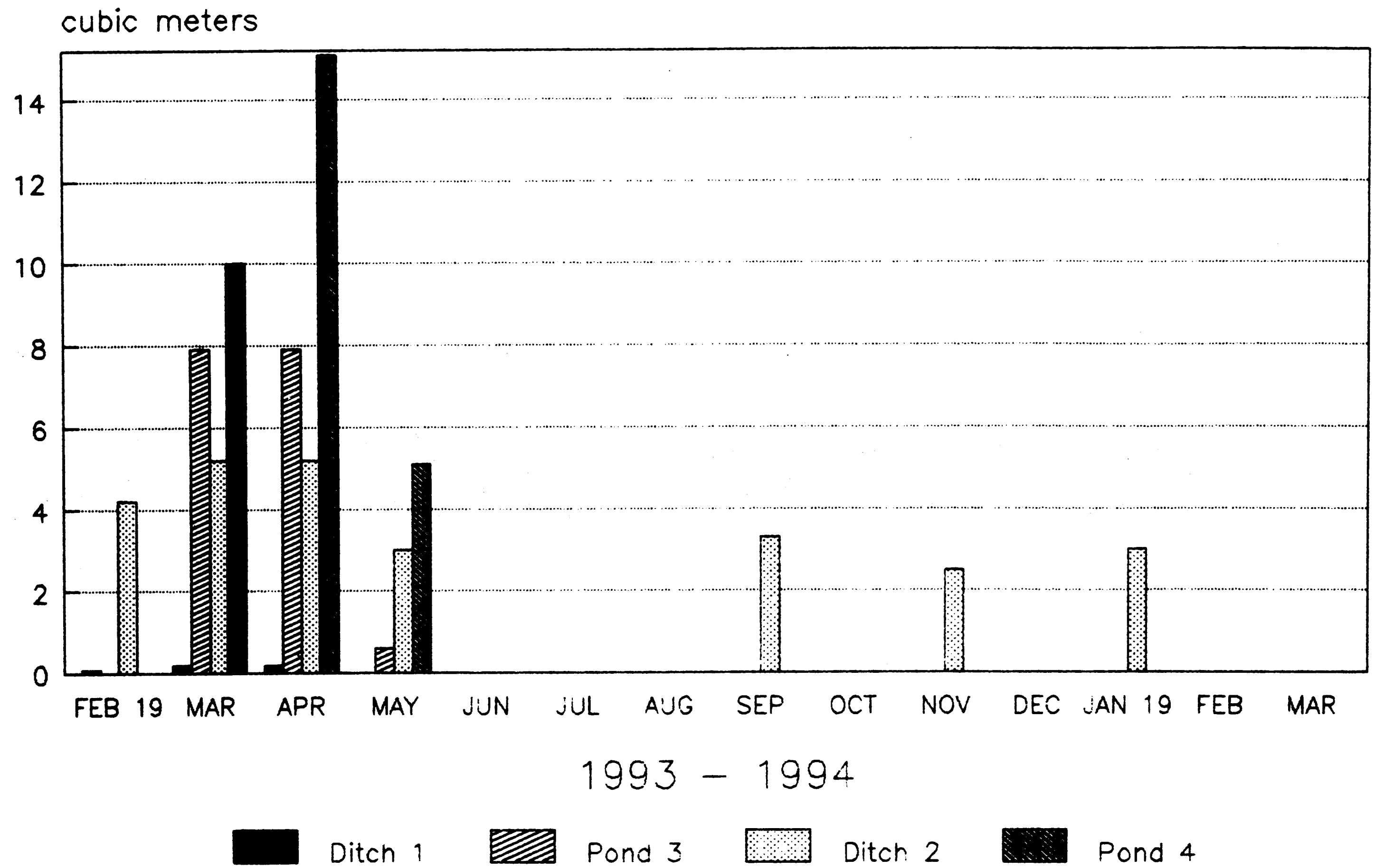
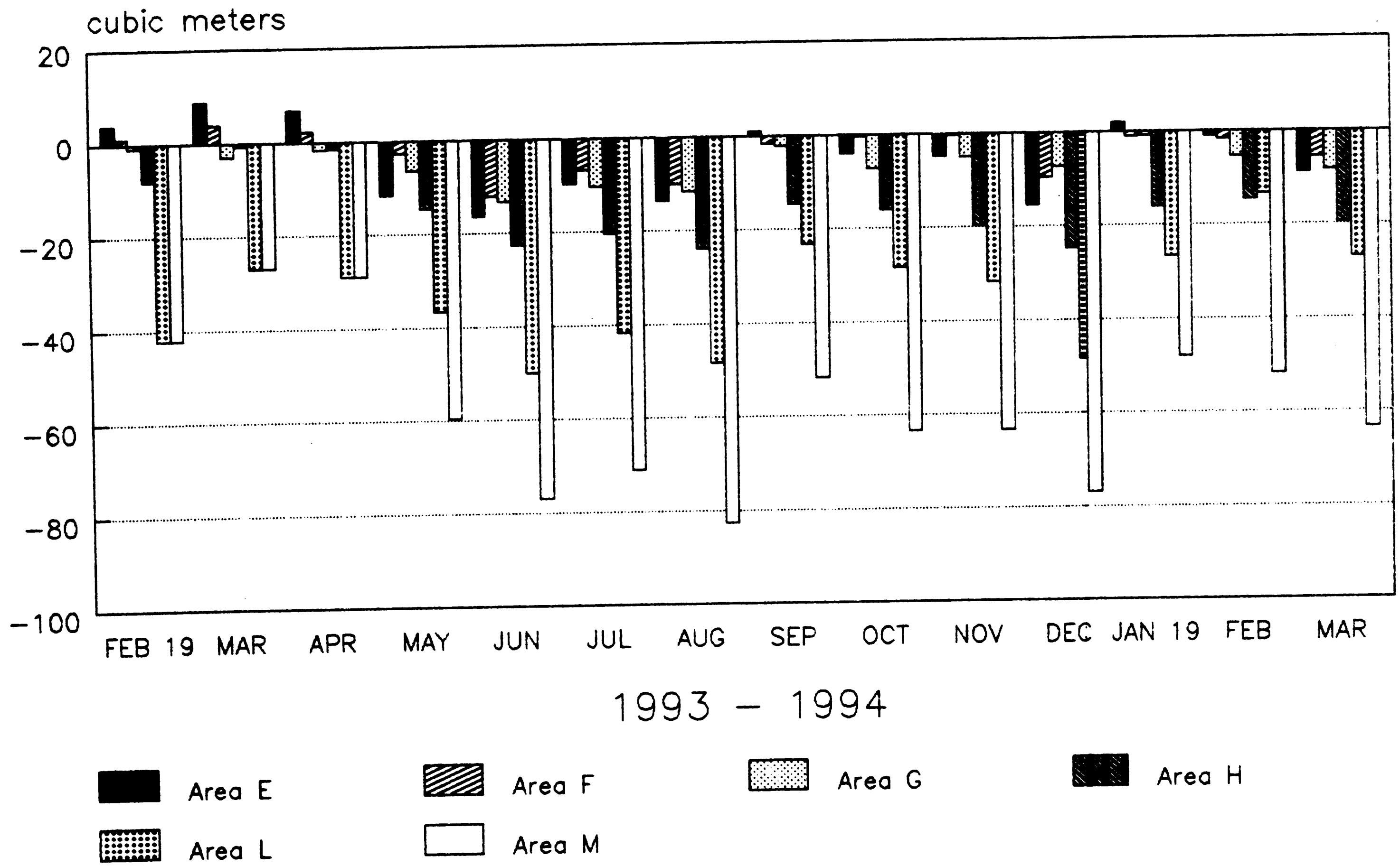


Figure 7. Unsaturated Zone Hydration Sources



North of TECO easement

Figure 8. Unsaturated Zone
Predicted pore space volume



proposed bank site

The construction design relies on fixed spillway elevations to be located at the southern ends of Ditch 1 and 2, and adjacent to the southeast corners of Ponds 3 and 4. Ditch 1 is designed to contribute surface flow into the north section of Pond B. Ditch 2 is designed to combine with surface flow from Pond 3, which will ultimately discharge into Area G. Pond 4 is designed to discharge surface flow into Area F. Figure 7 represents periods of time when spillover into these structures would occur based on the proposed design elevations. The zero line represents the proposed spillway elevation of these structures. Each bar represents the volume of water available for hydration. During the Winter Storm months of February, March, April, and May excess water volumes were predicted to occur as spillover from the combined flows out of Ditch 2 and Pond 3 into Area G, and out of Pond 4 into Area F. The volumes of water supplied to Area G are inconsequential, since plants are dormant during these months. Surface water elevations fell below the designed inverts during the critical window representing the growing season (May through November), and during the dry season period (December through March 1994), with the exception of spill occurring out of Ditch 2 during September, November, and January 1994.

Figure 8 represents the predicted pore space volume results for the proposed bank site. The zero line represents the average topographic elevation of the site. During the first quarter of 1993, flooding conditions attributed to the Winter Storm months were predicted to occur for Areas E and F. Flooding events were also predicted to occur within Area E for the months of September 1993, and January 1994. The remaining areas show significant declines in the water table which will require large volumes of water to completely fill the pore space reservoir. Model predictions suggest resulting water table declines will produce drier soil moisture conditions, thus promoting invasion of undesirable nuisance and exotic species during the growing season.

CONCLUSION

Analyses of the water balance model suggest that declining precipitation patterns are influencing surface and groundwater declines. Evaporation and evapotranspiration losses from the system exceeded the gains from precipitation, recharge, and groundwater flow. The existing cypress domes and borrow ponds located within Area B appear to be storing greater quantities of water than are being recharged back into the water table. Evaporation from surface water bodies, evapotranspiration from dense vegetation, and pond storage effects are contributing towards the observed declines in the water table south of the TECO easement, across the proposed bank site.

The unsaturated zone model indicated that spillover through the invert structures, as designed, would have occurred during the 1st quarter of 1993, coincident with the Winter Storm. Following this period, steady surface and ground water declines in elevation occurred throughout the summer and fall months. Surface water declines in elevation, which would correspondingly result in a shortfall of water supplied to the proposed project site. To accommodate these shortfalls, design modifications to the inlet structure elevations are recommended.

The pore space volume model results estimate a predicted water quantity that may be applied to the project site which would result in the creation of saturated and flooded soil conditions. Furthermore, the model may also provide an estimate of the quantity of water that would result from adjustments to the fixed invert structure elevations. These estimated quantities may be compared against the predicted pore space volume results until the hydration source and pore volume results of the model approach convergence.

The model may be manipulated using different moist and dry bulk density values suited to areas with shallow water table environments to obtain representative porosity values for predicting saturated soil capacities.

Model development and applications are governed by budget constraints, and is more suitably applied toward large capital investment type projects that warrant long term site evaluation prior to construction.

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ADVANCEMENTS IN INTEGRATED HYDROLOGIC MODELING FOR MINE RECLAMATION

Patrick Tara[1]
Mark A. Ross[2]

ABSTRACT

The Florida Institute of Phosphate Research (FIPR) funded a project to develop an integrated hydrologic model to simulate the effects of phosphated mining and improve mine reclamation. The product of the research, the FIPR Hydrologic Model (FHM), allows for more precise simulation of the interaction between surface water and groundwater processes with emphasis on the reclamation of landforms including wetlands. In Florida, with sandy soils and shallow water table aquifers, surface water bodies are effected by changes in both the surface water and ground water conditions. Therefore, properly simulation hydroperiods in wetlands or lakes requires investigation of both hydrologic systems. The FHM was originally developed with strict limitations concerning the intended application. Emerging software capabilities, recent calibration exercises, and user feedback have contributed to significant advancements in the capabilities of this developing technology. One new feature, multiple scale hydrologic systems for quantifying regional trends as well as windowing in on smaller areas to quantify local effects including wetland hydrology.

INTRODUCTION

The surface water hydrology of Florida is strongly influenced by a shallow sandy surficial aquifer such that the surface water and groundwater systems cannot be conveniently separated. Evaluating the hydrology of wetlands, both natural and reclaimed, requires that both surface water and groundwater effects be quantified together. The need for a more accurate, reliable, and standardized predictive hydrologic model to be used in reclamation design and permitting of phosphate mine sites prompted the Florida Institute of Phosphate Research (FIPR) to sponsor research to develop an integrated surface and groundwater hydrologic model (Powers, *et al.*, 1989). The model including the Geographic Information System, GIS) was designed to run on inexpensive microcomputers in an effort to facilitate

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more widespread usage and convenient digital data transfer. The role of the GIS was to perform the spatial data referencing and analysis for the model while the traditional hydrologic codes performed the calculations for time-dependent hydrologic simulation (Ross and Ross, 1989). This paper describes the FIPR Hydrologic Model (FHM) and some recent advancements that have been made in integrated hydrologic modeling.

Integrated hydrologic modeling is defined herein to mean combined hydrologic modeling of a surface water and groundwater system using comprehensive computer models, linked spatially and temporally. The FIPR Hydrologic Model, FHM, utilizes four principal components: a GIS (Tydac Technologies, Spatial Analysis System SPANS, or Environmental Systems Research Institute, Inc., ARC/Info), a surface water model (USEPA supported Hydrological Simulation Program - Fortran, HSPF, Johnson, et al., 1980, 1993), a groundwater model (McDonald and Harbaugh's MODFLOW, 1988), and an evapotranspiration (ET) code developed specifically for the intended application to Florida mine sites. The HSPF code calculates surface water runoff and rainfall losses, above water table storages, and groundwater recharge. The groundwater code calculates water budget and flow conditions for the water table aquifer, baseflow to streams and potentiometric heads below confining layers. The ET code provides continuous (daily) potential evapotranspiration losses based on daily temperature, land use (vegetation type), and available soil moisture conditions calculated by the other models. Figure 1 shows a schematic of the FHM components.

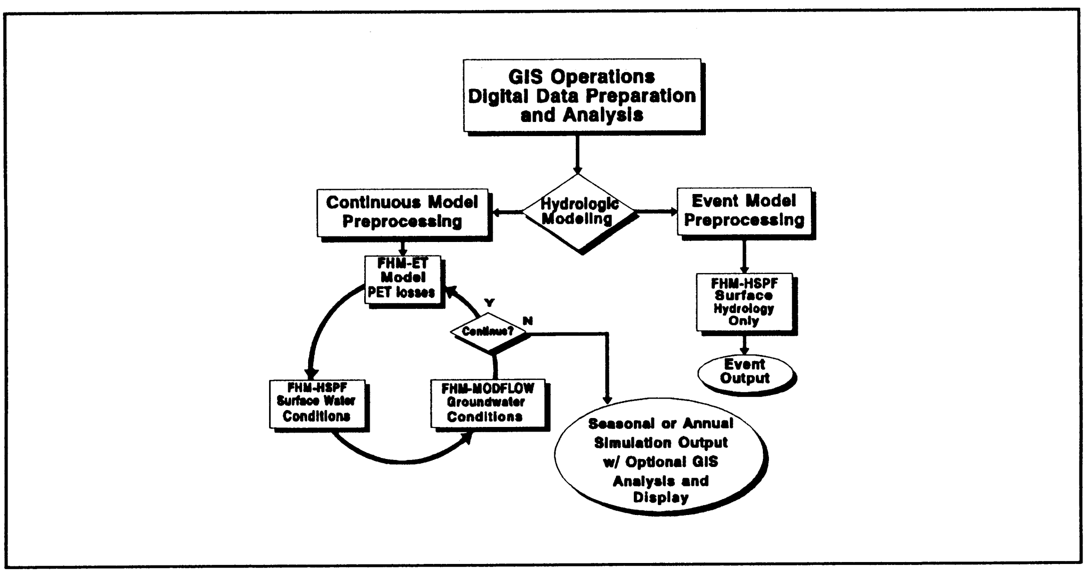

Figure 1. FHM flow - chart.

To facilitate integration between the principle modules of the model, additional data handling utility packages were developed.

INTEGRATED MODELING DISCUSSION

When the FHM was originally developed, specific guidelines which restricted the capabilities of the model were mandated. First, was the requirement that the model run on a 286 computer with 640k of RAM. Also the model was developed under the premise that all modeling would be performed on "logical reclamation units" (LRUs). Typical LRUs are small (from 0.4 km or, 100 acres to 4.0 km or 1000 acres) and have simple hydrologic characteristics (one or two) catchments). Application of the original FHM was essentially limited to the LRU concept or extremely simple natural systems. As more and more sites were modeled with the FHM and as regulatory agencies began to require a more comprehensive combined regional analysis, it was apparent that severe limitations in the model existed.

In the past three years research at USF has been supported by FIPR and others to maintain and modify the model to suit the needs of the FHM users. Adaptations of the model have occurred such that the FHM can be used for regional, impact studies. Specifically, improvements include: increasing the number of basins and subbasins the model can handle in one application to 50, increasing the number of river reaches for flow routing to 50, increasing the allowable number of grids in the groundwater model, allowing for multiple outfalls (thus multiple river basins), including all generic MODFLOW packages (e.g., wells, general head boundaries, etc.), allowing off site inflows (thus partial basins), and providing for greater flexibility in user defined and/or multiple defined site specific rainfall. No longer is the model limited to LRUs of only a few square kilometers. The FHM can and has been applied to study areas of several thousand square kilometers (see study site below, USF, 1994).

The area of interest in which research is currently directed is in the field of multi-scale modeling. This is where boundary conditions of smaller domain hydrologic models are defined by the results of larger regional scale models. Multi-scale modeling facilities simulating cumulative or larger stress effects to the regional watershed or aquifer while addressing near-field small scale effects such as evaluating the hydroperiod in an individual wetland. Maintenance of a regional scale model (at a public domain repository, e.g., DER, SWFWMD, or FIPR) will allow mine reclamation engineers and hydrologists to apply the FHM using data from the regional model to set up the smaller scale models. More importantly, the effects of mining the individual LRUs can be simulated on the regional hydrologic model and not only the LRU. The accumulation of many minor impacts at the LRU scale can now be evaluated for the effect on regional hydrology.

STUDY SITE

An example of the application of the FHM integrated model on a regional watershed is the Rattlesnake Creek study (USF, 1994). Within this basin the United States Fish and Wildlife Service (USFWS) Region 6 manages the water rights and water use on the Quivira National Wildlife Refuge (NWR). The refuge is centrally located in the state of Kansas (see Figure 2) just upstream of the confluence of the Rattlesnake Creek with the Arkansas River. The refuge has a very complex series of water control structures that regulate water levels in over 30 ponds (see Figure 3).

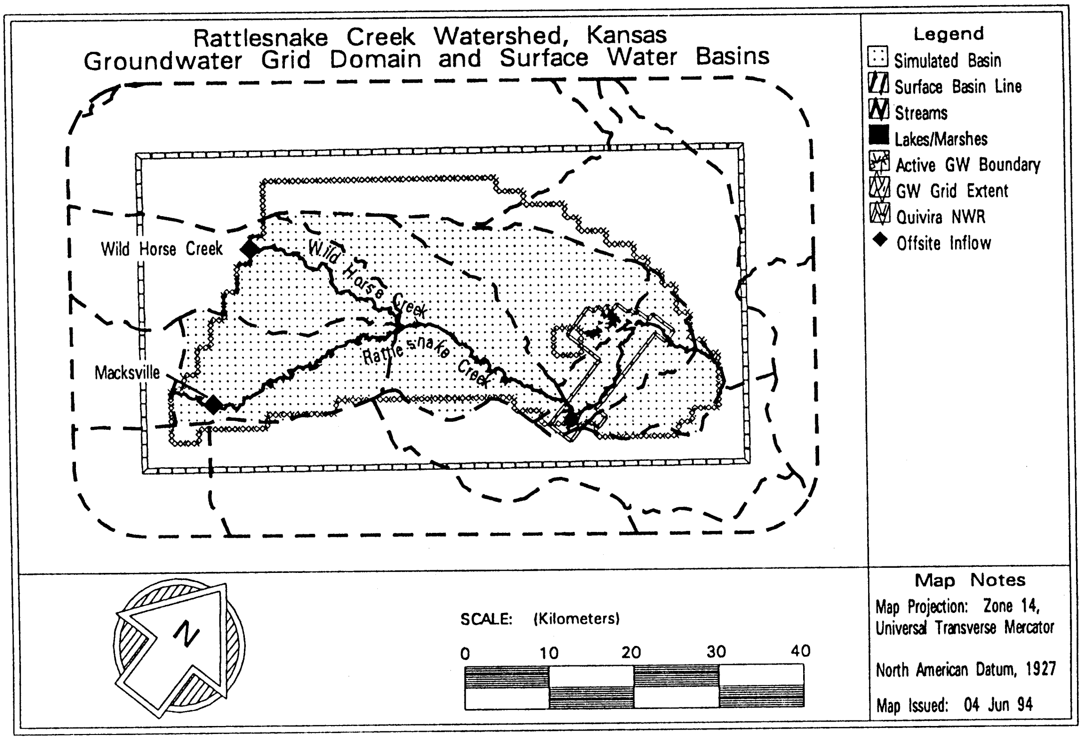

Figure 2. Rattlesnake Creek watershed, Kansas. Groundwater domain and surface water domain. Example of FHM regional application.

Rattlesnake Creek runs through the refuge boundaries and supplies water by way of diversions to the ponds. The creek drains a watershed that is approximately 1167 square miles. The flows in the creek are predominately from baseflow except during wet periods were there is a significant stormwater runoff component. The watershed land use is predominately agricultural. These farms irrigate

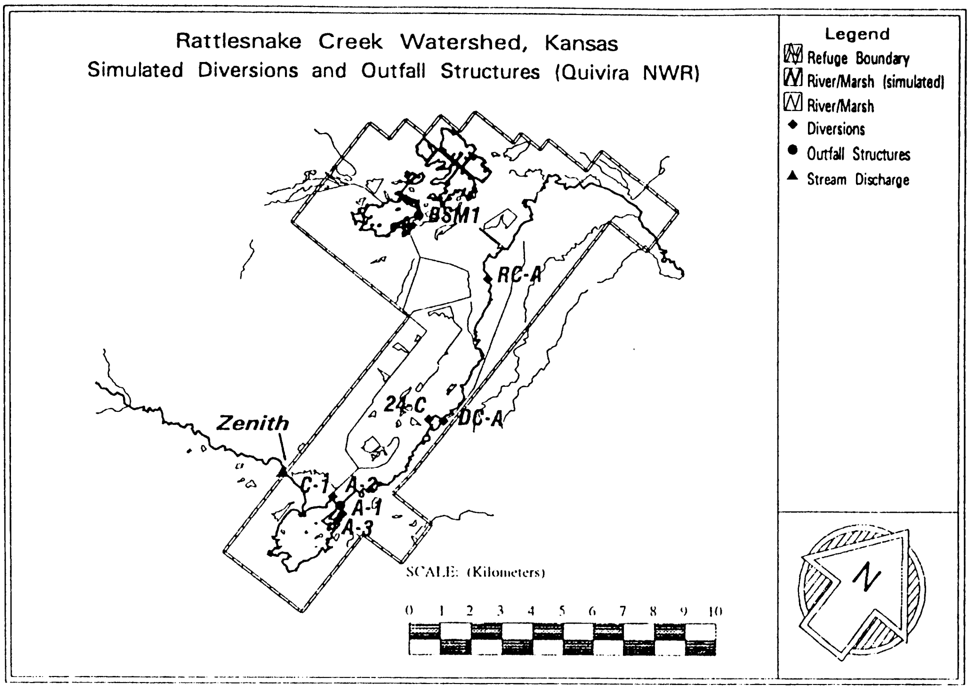

Figure 3. Quivira National Wildlife Refuge.
Example of possible near-field FHM application.

the land by pumping from the alluvial surficial aquifer. There is strong evidence that the agricultural pumping has stressed the aquifer to the point of reducing the baseflow in the Rattlesnake Creek during low flow periods leading to inadequate and poor quality water downstream in the Refuge. Since the agricultural users own the junior water rights (junior to the USFWS), the USFWS has been contesting the use based on the decline in baseflow in the Rattlesnake Creek. The FHM was applied to this watershed to help determine if the agricultural water rights were impacting the Quivira Refuge and to evaluate the magnitude and implications of stormwater runoff and basin recharge to the water budget of the Refuge.

TYPICAL FHM APPLICATION

The Quivira study is typical of FHM applications consisting of five major tasks: 1) digital data gathering, 2) GIS operations, 3) model input data processing, 4) hydrologic simulation, and 5) output post-processing. The model is capable of both event (storm discharge) hydrologic simulation and continuous (seasonal or annual) hydrologic conditions. The FHM includes a "user friendly" interface, plus specific simulation components and post-simulation output processing data presentation for management and regulatory review processes. The model also has the capability to be run in a menu-driven, but manual data definition mode without the GIS component. Optional default values are included in all of the operations of the user interface as well as checks on the acceptable range of user defined parameters. The purpose of the user interface was both to facilitate ease of use to gain widespread acceptance and, to standardize model parameter definition among users. In the mining application this minimizes subjective parameter selection so that more meaningful comparative evaluations could be made between alternative reclamation designs for regulatory convenience.

Typical model calibration requires a three step approach. First, the surface water system is calibrated to measured storm events, preferably over an extended time frame. This requires the model user to match measured stream flows to individually calibrated using available aquifer data in the same time frame as was used in the surface water calibration (recharge is estimated from the surface water calibration, parameter adjustments should be performed on the aquifer properties only). The isolated groundwater calibration helps to define the boundary conditions and aquifer parameters. The last step, calibration of the fully integrated model, is performed using the parameters from the surface water and groundwater calibration simulations. Final parameter adjustment is necessary in the integrated simulation to correct the overall water balance. In the integrated model calibration, processes with strong surface water and groundwater interdependence are compared. These include baseflow in streams, water levels in ponds and lakes, and heads in surficial wells. These steps may have to be repeated if parameters were adjusted significantly. Since in integrated modeling all components of the hydrologic cycle are explicitly included, there is much less "flexibility" in parameter selection since the overall water budget is accounted for. Once calibrated, the model can be used as a predictive tool to estimate the water budget under different circumstances both hydrologic (rainfall conditions) and land use changes (or reduced pumping stresses).

EXAMPLE OF CALIBRATED MODEL RESULTS

The integrated hydrologic model generates a seemingly unlimited quantity of output information. Built in output graphics such as hydrograph displays help significantly to interpret this data. Typical FHM output records are: subbasin flow hydrographs, stream flow hydrographs (both overland and baseflow), stream and lake/wetland stages, aquifer recharge, groundwater hydrographs, ET rates for basins and lake/wetlands, wetland inflows/outflows (both surface and ground water), soil moisture and other surface storages. During the calibration process this simulated data is compared to the measured or observed data until reasonable representation is achieved. When the user is comfortable with the comparisons between measured and simulated (under various conditions) then the model can be used as a predictive tool (at least within the range of the calibration conditions). As a predictive tool, the model can evaluate various stresses or wetland designs to estimate response to hypothetical or proposed conditions.

The aforementioned study site is an example of a calibrated regional integrated simulation. Very abbreviated specific examples of the comparison of measured and simulated data are shown in Figures 4 and 5 (USF, 1994). Figure 4 shows the comparison between measured and simulated flows at the USGS Zenith Station.

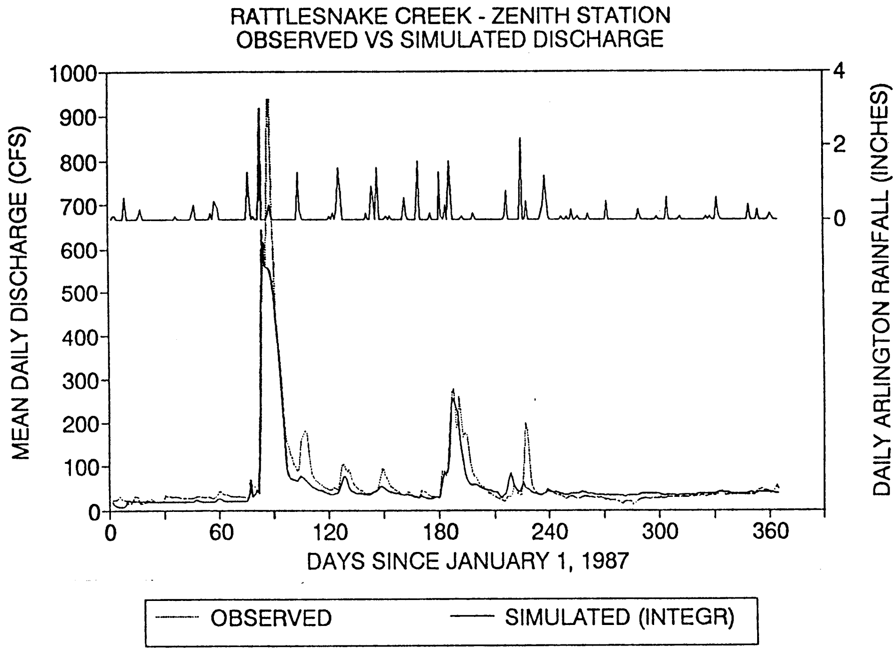

Figure 4. Example FHM application.
Comparison of measured vs. simulated stream flows.

It can be seen that the model reasonably simulates wet and dry stream flows (USF,1994). Figure 5 shows the comparison between the measured and simulated stages in one of the main marshes in the Quivira NWR. The marsh or lake receives the Rattlesnake Creek flows. Outflows from the marsh supply water to the lower Rattlesnake Creek and to the rest of the Quivira NWR. The graph and other comparisons helped support the conclusion that the model was representative of both surface and groundwater contributions to the Little Salt marsh within the Quivira NWR. Yet to be completed are the predictive and evaluative simulations that will quantify the degree of stress placed on the aquifer by the combined agricultural pumping and how much flow reduction results within the Refuge.

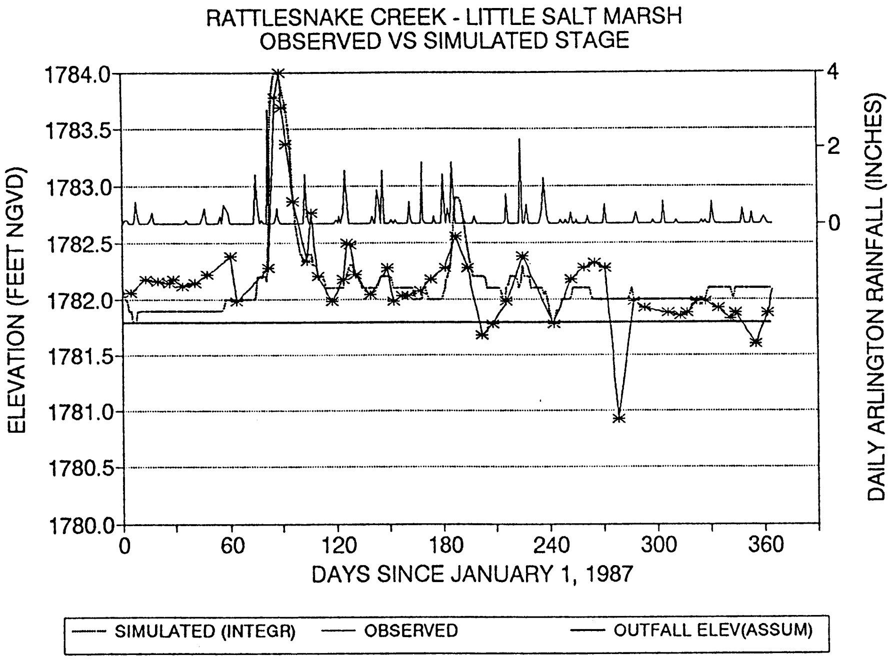

Figure 5. Example FHM application.
Comparison of measured vs. simulated lake stage.

CONCLUSION

Without a thorough study into the hydrologic characteristics of both the surface water and groundwater systems it might be, in some cases, impossible to guarantee mitigated wetlands and marshes will have an adequate water supply to maintain desired water levels. Wetlands and marshes obtain the water they consume through either predominately surface water, groundwater, or from a combination of both systems. The source of the water is often difficult to determine a priori. In Florida, with shallow sandy aquifers, the surface water budget has a dramatic effect on shallow and sometimes deep groundwater systems and vise versa. Analyzing the water budget of the systems combined is always prudent and many times necessary in order to predict the hydrologic characteristics under changing stresses and meteorologic conditions.

With the development of integrated hydrologic models such as the FHM, progress has been made in bridging two frontiers in hydrologic simulation and analysis. First, the now ubiquitous geographic information system technology has been further extended to provide spatial data handling (input, georeferencing, and analysis) for hydrologic modeling for land use management. Second, and most importantly is the integration of the surface water processes with the ground water processes on a "real time" basis. This facilitates a more comprehensive modeling evaluation of hydrologic impacts associated with land use changes than was previously cost effective. What would have taken many months of effort in terms of model parameter definition previously, can now be accomplished in several hours using digital data and the GIS.

The latest improvements to the FHM allows the integrated technology to be used on more complicated regional applications. Studying impacts of land use changes on a regional scale is important. Simply analyzing the site by site impacts within a local domain could lead to cumulative, potentially significant degradation of the regional hydrology. The multi-scale approach that is now advocated with the FHM will provide regional and local scale evaluations add to better wetland designs and better overall water management practices in general.

ACKNOWLEDGEMENTS

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RECENT DEVELOPMENTS IN WETLAND CREATION STORMWATER DETENTION AND TREATMENT DESIGNS IN NEW ENGLAND

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ABSTRACT

The primacy of protecting water quality while, at the same time, mitigating for several other wetland functions lost to development has resulted in innovative designs which combine stormwater detention and treatment with attempts to create diverse "natural" wetland systems. Several treatment designs and recently constructed projects are briefly reviewed. The Maine Turnpike Authority's Branch Brook mitigation project is presented as a case study. The required wetland compensation (Corps of Engineers permit) for 0.65 ha of freshwater wetlands filled was accomplished by creating wetlands in an abandoned gravel pit adjacent to the Turnpike. Stormwater from 2.3 lane-km is directed onto the site prior to entering Branch Brook (a municipal water supply). Groundwater monitoring and hydrologic analysis of the sloping groundwater table resulted in a terraced, two-basin design and outlet control structures equipped with gate valves to contain contaminants in the event of an accidental spill along the Turnpike. To improve habitat values, the site provides a variety of wetland habitats ranging from wooded swamp to vegetated open water which contain species with high wildlife food value. The ground surface within wooded swamp to vegetated open water which contain species with high wildlife contoured to reproduce the hummock or mounded microtopography common to natural forested wetlands. Site work was completed in the fall of 1993 and a 5-year monitoring program will be initiated in 1994.

INTRODUCTION

Due to increasing concerns and regulatory mandates to protect the quality of receiving waters, the use of nonpoint source (NPS) pollution treatment systems which combine created wetlands with other best management practices (BMPs) is becoming more common throughout New England. The intent of these systems is to enhance stormwater treatment effectiveness by combining pollutant removal mechanisms of several BMPs. Other structural BMPs can include: vegetative measures (i.e., grassed swales, filter strips), water quality inlets (e.g., oil and grit separators), infiltration systems, dry detention basins and wet detention basins with a permanent pool. Daukas *et al.* (1989) described the treatment for a southeastern Massachusetts regional mall located within the watershed of a public drinking water supply. Stormwater from the site is collected in catch basins with oil and grease traps, directed to wet detention ponds and then a series of created shallow marsh cells. Higgins et al. (1993) developed a generic treatment system for agricultural NPS control. This design includes a dry detention basin, a grassed filter strip, a constructed shallow marsh and finally a deep permanent pool stocked with bait fish and freshwater mussels. Nine systems have been constructed in northern Maine to reduce phosphorus and sediment loads from potato fields (R. Wengrzynek, pers.comm.).

In conjunction with improving the effectiveness of these combined systems for NPS treatment, there is also a growing interest in promoting other wetland functions affected adversely by development. This trend has resulted in innovative designs which combine stormwater detention and treatment with attempts to create diverse "natural" wetland systems. Ferlow (1993) described a generic stormwater treatment system or "marsh biofilter" which integrates an intermittently flooded wet meadow and scrub growth filter strip with permanent pools fringed by created shallow marsh zones. Aside from effective stormwater control and renovation, the author suggests the strong natural visual values, open-space elements, and wildlife habitat characteristics are positive environmental factors worthy of consideration for incorporation with development plans. Marsh biofilter systems have been designed and implemented for various site developments in western Connecticut (D. Felow, pers. comm.). The stormwater management system for a recently constructed regional mall in southern New Hampshire attempted to incorporate similar environmental factors within three created wetland basins totaling 2.4 ha. The largest of the three basins (1.2 ha) includes a large concrete inlet structure which serves as an energy dissipator and sediment sump and a series of berms to promote a long flow path for stormwater through a range of wetland cover types. The wetlands design includes wooded swamp, emergent marsh and aquatic bed with a permanent open water pool. However, due to greater than anticipated soil saturation, woody plantings were primarily confined to berms and side slopes (R. Prokop, pers.comm.).

CASE STUDY

This case study presents the Maine Turnpike Authority's Branch Brook mitigation project. The Authority recently received authorization to fill 0.65 ha of freshwater wetlands for the purpose of upgrading an interchange (Exit 2) located in Wells, Maine. To compensate for this unavoidable loss of wetlands, Normandeau Associates Inc., in association with Howard Needles Tammen & Bergendoff, developed a mitigation strategy involving a small restoration effort adjacent to the interchange and a larger off-site creation project. The wetland creation site, also located in the Town of Wells, was a 1.6 ha abandoned gravel mined area abutting the Turnpike (Figure 1). The site lies adjacent to Branch Brook, which supports a native brook trout (Salvelinus fontinalis) population and serves as the principal water supply for the surrounding three communities. The Kennebunkport and Wells Water District withdraws surface water through infiltration galleries along the banks of Branch Brook at the treatment plant located 2.5 km downstream of the mitigation site.

BRANCH BROOK SITE DESIGN

The design objectives for the Branch Brook mitigation project include: 1) reclaim gravel-mined lands and construct more productive wetland habitat; 2) allow for containment in the event of an accidental spill along the Turnpike; 3) alleviate existing erosion problems by providing floodwater storage and reducing peak discharge rates, and 4) enhance effectiveness of existing grassed swales in treating highway runoff by incorporating the water quality benefits of wet detention basins and created wetlands. The opportunity to meet these objectives was provided by diverting into the mitigation site stormwater runoff from an existing grassed swale draining approximately 2.3 land-km with total watershed of 5.2 ha. In order to achieve the project objectives, the mitigation site design includes a small sediment basin along the roadway embankment and two wet detention basins supporting a diverse wetland fringe, each equipped with a specialized outlet control structure. The design also provides direct access from the Turnpike in the event of an emergency.

The design of the outlet control structures within each basin incorporates several considerations. With the pool elevation controlled by the pipe exiting the catch basin, the pipe entering the catch basin remains submerged at all times (Figure 2). This allows the wetland basins to: 1) retain floatable contaminants; 2) discharge cooler waters at depth to reduce thermal impacts to the sensitive cold water fishery (Schueler 1987), and 3) discourage beaver activity by confining sounds of running water within the berm. Each inlet pipe is also fitted with an epoxy-coated wedge gate valve to contain accidental spills within the wetland basins. The outlet pipe is sized to reduce peak discharge rates of the 10, 25 and 100-year storms by approximately 90% (HNTB, unpublished data).

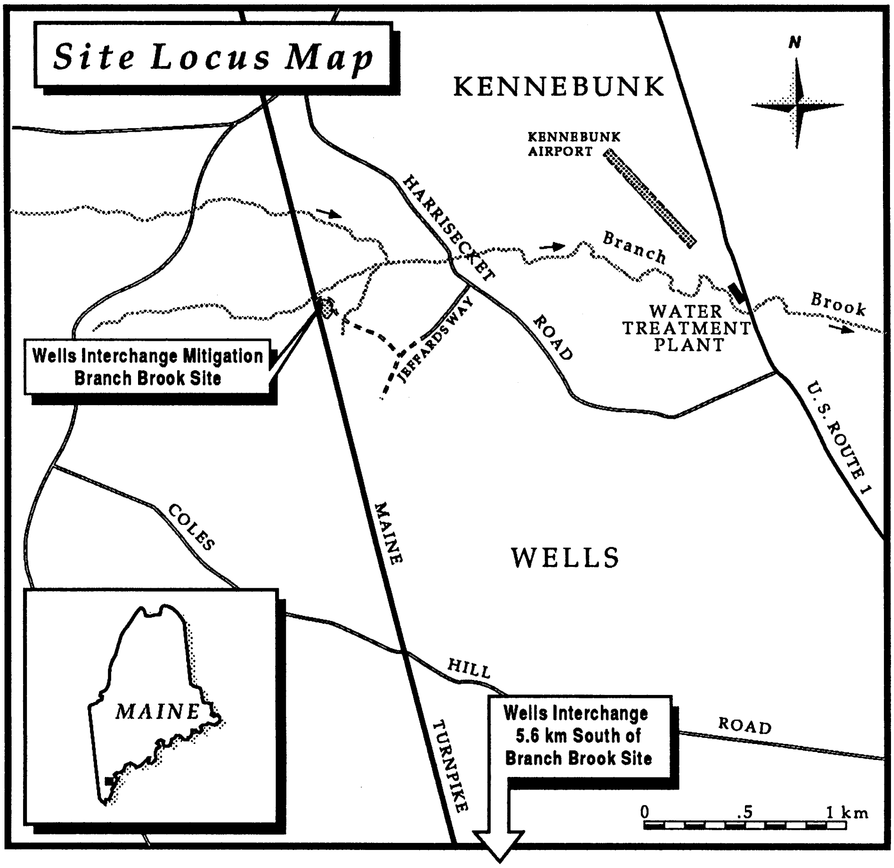

Figure 1. Location of the Branch Brook Mitigation Site.

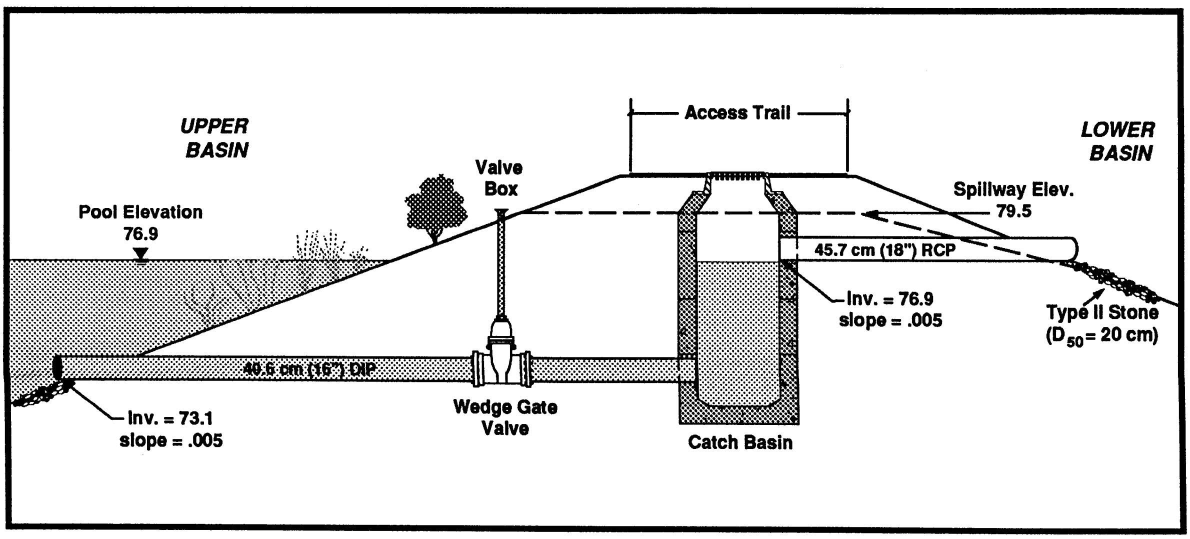

Figure 2. Generalized diagram of outlet control structure.

To ensure adequate hydrology for the wetland fringe during extended periods of limited rainfall, the basins were excavated below thegroundwater table. The permanent pool elevation and basin contouring was based on groundwater data recorded from monitoring wells during a previous growing season. In order to intercept the sloping groundwater table, a terraced, two-basin system was designed and constructed (Figure 3). During excavation of the deeper portion of each basin, marine-origin clays were encountered. This low-permeable material was incorporated through the subgrade to impede water loss from the basins. Schueler (1987) recommended wet detention ponds located within a watershed less than 8 ha incorporate a supplementary water supply and clay liner.

The basins were excavated during the fall of 1993 and backfilled with 20cm of wetland soil salvaged from the impact sites (Figures 4 and 5). This material was spread over the various wetland cover types integrated within each basin. No soil amendments were added to non-vegetated, open water portions of the basin. To improve wildlife utilization, each basin provides a range of wetland habitat types including wooded swamp, emergent marsh and aquatic bed. Each zone was planted with indigenous vegetation selected for their excellent food and cover value.

To overcome the retardation of woody plant establishment by prolonged soil saturation or inundation, the mound-and-pool microtopography common to natural forested wetlands was included within the wooded swamp zone. Typically, mounds were contoured to an elevation at or slightly above seasonal high water, while pools were graded to maintain 30 cm of standing water for extended periods into the growing season. Over 1500 containerized wetland trees and shrubs were planted during the spring of 1994. With the exception of buttonbush (Cephanlanthus occidentalis), which tolerates prolonged inundation, all 11 indigenous woody species (Figure 3) were planted on mounds. Over 3,600 bare-root plants or tubers of 7 emergent species were planted throughout the marsh communities. Three additional species were planted within the aquatic bed zone. This diversity of plant species and growth forms is further enhanced by the seed bank and propagules contained within the salvaged wetland soils.

Side slopes received 20 cm of loam and were hydroseeded with a low-maintenance roadside mixture augmented with crown-vetch (Coronilla varia) and birdsfoot-trefoil (Lotus corniculatus). Six upland tree and shrub species were planted around the basins to provide additional wildlife food and cover. As recommended by Adams et al. (1983), approximately 50% of the perimeter was left open to enhance waterfowl habitat.

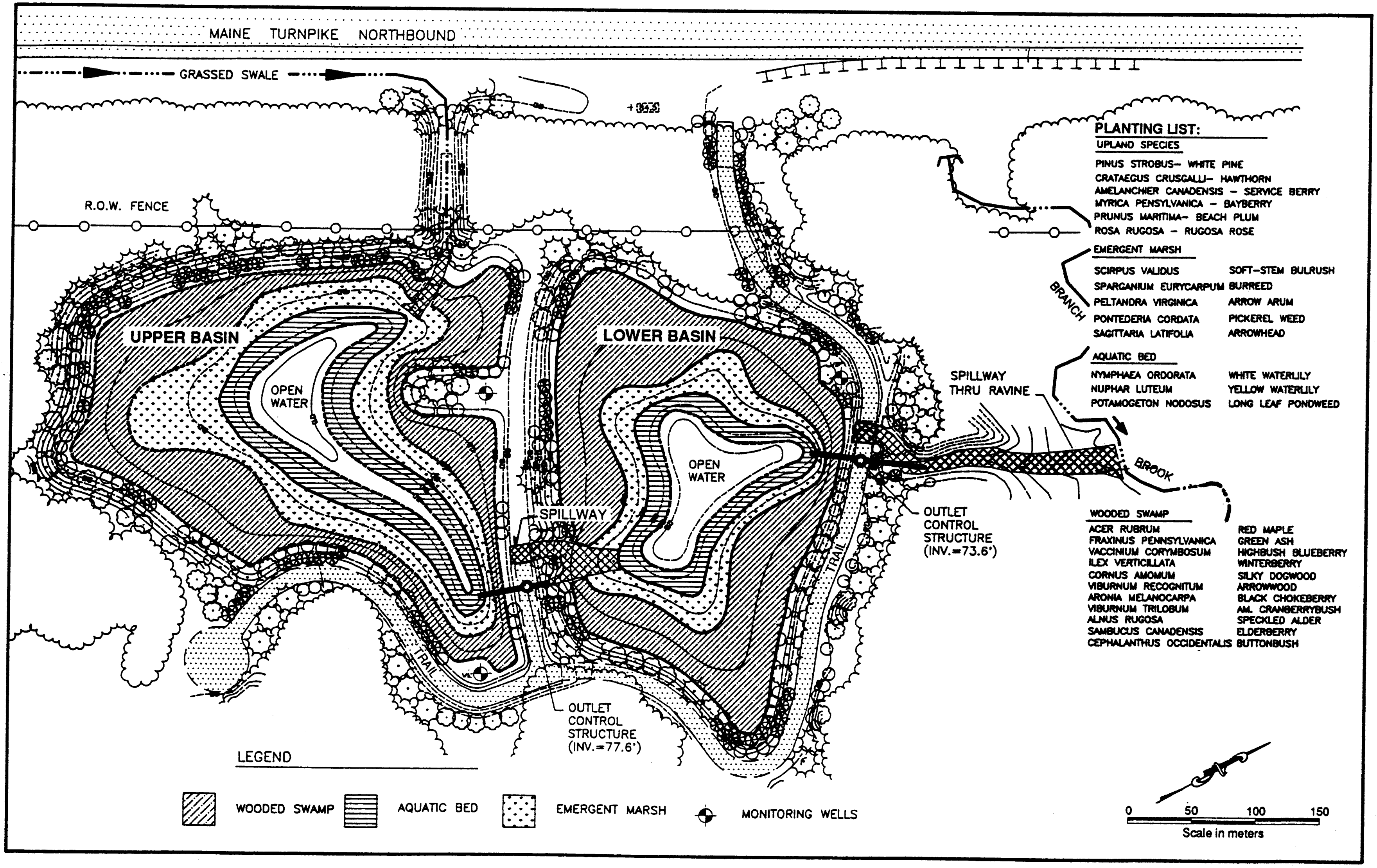

Figure 3. Conceptual design for the Branch Brook Site Mitigation Site.

Figure 4. Branch Brook Site following excavation, Spring 1994.

Figure 5. Branch Brook Site (upper basin viewing north) following excavation, Spring 1994.

The inclusion of open water areas not only improves the water quality treatment potential but greatly enhances ancillary benefits for wildlife (Knight 1993). To maintain fish populations as a food source for wildlife and to help control nuisance insects, the basins have a water depth of 1.8 m (Adams *et al.* 1982).

TREATMENT SYSTEM REMOVAL EFFICIENCY

Initial stormwater treatment at the site is performed by the existing grassed swale which conveys highway runoff along the entire drainage area (0.8 km). In fact, Burch *et al.* (1985) suggested where public water supplies are not involved, highway runoff conveyed by swales in excess of 60 m in length is not likely to have adverse effects on receiving waters. Swales employ the natural capability of vegetated surfaces to reduce velocity of runoff, enhance sedimentation, filter suspended solids and increase infiltration. To enhance pollutant removal effectiveness prior to discharge into the Branch Brook site, a stone check dam was installed within the swale and a small dry sediment basin was constructed along the roadway embankment.

As previously mentioned, the Branch Brook site design employs two wet detention basins supporting a diverse wetland fringe, each equipped with a specialized outlet control structure. An accessible sediment forebay is located at the inlet to the upper basin. The Turnpike Authority is responsible for routine site maintenance and periodic sediment removal. The U.S. EPA's Nationwide Urban Runoff Program (NURP) found detention basins with a permanent pool are among the most effective treatments for reducing pollutant loads from urban watersheds (Athayde 1983). By maintaining a permanent pool, wet ponds achieve particulate and dissolved pollutant removal through particle settling, decay processes and biological uptake (Yu 1993). The effectiveness of the treatment system is further enhanced by integrating the diverse wetland habitats. Pollutant removal mechanisms in wetlands include sedimentation, adsorption, chemical precipitation, filtration, volatilization and biological processes such as nutrient uptake. In a recent review of reported pollutant removal performance of stormwater ponds and wetlands, Schueler (1993) found the best overall performance was reported for systems which combined detention basin and wetland treatment techniques.

Although wet detention basins are generally considered an effective stormwater management technique, the degree of pollutant removal is dependent on basin size, configuration and residence time as well as individual storm characteristics. The two-basin design with a sinuous edge helps to reduce the effects of short-circuiting, where incoming runoff passes through the basin without displacing existing waters. The average permanent pool volume of the basins slightly exceeds four times the volume of runoff generated by the mean storm over the watershed area. From methodology described in Hartigan (1986), the design provides an average of two weeks of retention within each basin. Based on NURP results as presented by Shueler (1987), long-term pollutant removal efficiency for a basin of this size will exceed 60% for total phosphorus, 80% for lead and 85% for total suspended solids.

To fulfill permit requirements, Normandeau Associates Inc. will initiate a 5-year monitoring program during 1994 to document vegetation establishment, hydrologic conditions and water quality. The Branch Brook mitigation site, with its stormwater treatment and spill containment capabilities as well as habitat enhancement components, is an important contribution to the long-term protection of the public water supply and other natural resources within the watershed.

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