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Proceedings of The 13th Annual Conference on Wetlands Restoration and Creation

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Hillsborough Community College

Environmental Studies Center

May 15-16, 1986

Hillsborough Community College

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PROCEEDINGS OF THE THIRTEENTH ANNUAL CONFERENCE ON WETLANDS RESTORATION AND CREATION

May 15-16, 1986

Sponsored by
Hillsborough Community College
Environmental Studies Center

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Editor

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INTRODUCTION

The Annual Conference on Wetlands Restoration and Creation provides a forum for the nationwide 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 Thirteenth Annual Conference.

This year's conference would not have been possible without the assistance and cooperation of Mr. Roy R. Lewis, III. We are grateful for his untiring help and participation in this, as well as previous conferences. Appreciation is also extended to Charles Deusner for providing administrative support for the conference.

The following people also deserve thanks for contributing to the conference and assisting in the preparation of the proceedings for publication: Fay Crowe, Cynthia Fields, Johnnie Harcleroad, Gary Lytton, Leslie McFetridge, Angelo Tuliemeri, David Walker, and Jackie Watford.

Thanks are also extended to Richard Callahan, Colleen O'Sullivan, and Richard Paul for arranging and conducting field trips to wetland restoration/creation sites.

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

To all these people, thank you.

KEYNOTE ADDRESS

THE SAVE OUR EVERGLADES PROGRAM

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INTRODUCTION

Historically, water flowed overland and through natural streams from near Orlando through the Kissimmee River floodplain into Lake Okeechobee. During summer high water periods, the lake would overflow its southern banks into the Everglades. The water would continue its southward flow through the Everglades at a rate of about one foot per day into Florida Bay and the Ten Thousand Islands area.

South Florida, still unexplored in the early 1800s, was considered to be an uninhabitable archipelago until settlement brought efforts to change this situation.

Private and public efforts to drain the Everglades predate statehood (1845). Florida's first legislature petitioned Congress to send the Army Corps of Engineers to drain the Everglades so it could be converted to agricultural land.

The first successful effort at drainage was by Hamilton Disston, a Philadelphia industrialist. Disston bought 4,000,000 acres of state land at $.25 an acre and was promised half of all the land he could drain. He channelized the Caloosahatchee River in an attempt to drain Lake Okeechobee, and connected the lakes in the Upper kissimmee Basin. The land was then used for agricultural and urban development.

Everglades drainage by the state began in 1909. The Everglades Drainage District dug major drainage canals from Lake Okeechobee to the ocean via Miami, St. Lucie, North New River, South New River, and Hillsborough, and diked Lake Okeechobee. This continues to be the backbone of today's water management system.

Following a 1928 hurricane that washed down the muck dike surrounding the southern end of Lake Okeechobee, the Army Corps of Engineers joined Florida's drainage (flood control) efforts. Between 1930 and 1938 a dike 85 miles long and 30 feet high was built around the lake.

Additional hurricanes and flooding in 1947 prompted federal legislation authorizing the Corps of Engineers to participate with Florida in construction of the Central and Southern Florida Project. The intent of this project was to provide flood control and water supply. The overall result of the project today is the control of water in all of South Florida and the Everglades National Park

Some specific results of the central and southern Florida project are:

1. Creation of the Kissimmee Canal (C-38) which is 48 miles long, 300 feet wide, and 20 feet deep with 5 locks.

2. Lake Okeechobee is completely controlled by levees, canals, and water structures.

3. Over 600,000 acres of Everglades muck south of Lake Okeechobee is in agriculture (mostly sugar cane) and protected.

4. Over 1,000 miles of canals and levees lace South Florida providing flood control, navigation, and water supply. Almost every river and stream in southeast South Florida has been channelized.

5. Three state owned or controlled water conservation areas totalling 861,000 acres provide water supply, flood control, and recreation benefits to urban southeast Florida.

The water conservation areas (Everglades) are completely diked and controlled by a Corps of Engineers regulation schedule. Water released from the water conservation areas through four water control structures on Tamiami Trail (U.S. 41) supply all external water for the eastern portion of Everglades National Park. During periods of prolonged rainfall and high water, excess water is released from the water conservation areas into Everglades National Park regardless of the natural cycles. This action has been found to be very destructive to nesting and brooding birds and alligators.

Additional private drainage and development activities have affected the Everglades. These include:

1. The Everglades Agricultural Area has converted over 600,000 acres of Everglades to agricultural use. To protect crops, most excess water is pumped into the water conservation areas, sometimes causing water excesses in these areas.

2. Massive residential developments have been constructed immediately northwest of the park and Tamiami Trail (U.S. 41). In the 1960s Gulf American Corporation divided a 60,000 acre area in the Fakahatchee Strand and Big Cypress Swamp into 2.5 and 5 acre unimproved parcels and sold the lots in its unsuccessful Remuda Ranch venture. Gulf American merged with General Acceptance Corporation (GAC) and initiated Golden Gate Estates adjacent to and west of Remuda Ranch. Golden Gate Estates subdivided 111,000 acres into 1.25, 2.5, and 5 acre lots and sold these lots to over 50,000 individuals worldwide. Approximately 183 miles of flood control canals were dug and 813 miles of roads were built. Golden Gate Estates failed, but the effect of the canals has been drastic. Water levels were lowered over two feet and seasonal flooding greatly reduced. It is documented that the estuaries of the Ten Thousands Islands in the Everglades Park have been seriously degraded by the large influxes of fresh water from the Faka Union Canal.

3. East Everglades--In the 1960s the sawgrass marshes of the East Everglades west of Homestead were sold in small parcels. An 8.5 square mile area of Northeast Shark River Slough, the major flow-way into the eastern portion of the park, is now developed into 200-300 home sites. About 10,000 acres of the East Everglades are planted in agriculture. Another 60,000 acres are undeveloped but owned in small parcels by

about 5,000 individuals around the world.

4. Aerojet General--In the early 1960s Aerojet General purchased 70,000 acres in the lower East Everglades, and under a NASA contract developed and tested space shuttle booster rockets. In order to move rocket parts to the assembly site, a canal (C-111) was dug from Biscayne Bay. The canal interrupted water flow into the park and caused salinity and ecological changes in Florida Bay. Subsequent to deactivating the rocket plant, Aerojet General sold all but about 12,000 acres of its holdings to the state. It now leases about 5,000 acres adjacent to the park in the Taylor Slough watershed for agricultural production, creating water flow and chemical pollution conflicts with the park. Aerojet has proposed to reactivate the plant for construction of solid (no-joint) rocket motors for the space shuttle. It also proposes to swap nearly 6,000 acres of non-agricultural land to the federal government for public land in Nevada.

5. Jetport--In 1967 the Dade County Port Authority approved a plan to construct, in the Big Cypress Swamp, the world's biggest airport, with a projection of a jet being landed every thirty seconds within five miles of the park. The jetport was planned to cover 38 square miles and spawn a huge urban area. The outcries of state and national environmentalist's led to the formation of an Everglades coalition to oppose the project. The jetport died in 1970 with the signing of the Jetport Pact by Florida, the U.S. Departments of Interior and Transportation, and the Dade County Port Authority. Two runways which were constructed before the opposition organized were used to train pilots until the late 1970s and then abandoned. The jetport controversy was the major impetus for the establishment of the 574,522 acre Big Cypress National Preserve by the Department of Interior and the State of Florida in 1974.

THE SAVE OUR EVERGLADES PROGRAM

On August 9, 1983, Governor Bob Graham announced the Save Our Everglades Program. It is the goal of the program that by the year 2000 the Everglades will be more like it was in 1900 than it is today. Components of the program are:

1. Reestablishment of the Values of the Kissimmee River.

   a. Problem--Channelization by the Corps of Engineers and Florida in the 1960s converted a 98 mile long meandering river with a 1 to 2 mile wide flood plain into a 48 mile long by 300 foot wide by 20 foot deep canal with 5 navigational locks. The project directly drained 40,000 acres of marsh and led to the loss of another 100,000 acres. Water now flows into Lake Okeechobee 11 times faster than its natural flow rate. Waterfowl populations have declined by 90 percent and 6 fish species were lost from the river. Restoration will require Corps and, likely, Congressional approval. The Corps currently holds the position that restoration is not eligible for federal assistance because there is no net national economic benefit.

b. Solution--Since no major river channelized as a public works project has ever been restored, the state is developing a phased approach. Phase one will be used to design phase two, phase three, etc., until the program is complete. Ultimate plans are to partially backfill the channel and reflood the old oxbows along two-thirds of the river. Federal assistance will be sought.

c. Progress--Phase one construction is complete. The main features completed are three sheet pile weirs which cross the channel in order to divert water back into the old oxbows along a 12 mile stretch of the river. The weirs, along with the elevation in water levels in the river, have caused a reflooding of the oxbows and old floodplains for the first time since channelization.

2. Protection of Lake Okeechobee.

a. Problem--This 730 square mile lake, an integral part of the water supply system for 4 million people in southeast Florida, is in jeopardy. For over 30 years it has been the discharge point for phosphorous and nitrogen rich runoff water from the agricultural area (sugar) to the south and the dairy and cattle industries to the north. Nutrients have doubled in the last 10 years and are threatening the viability of the lake.

b. Solution--In August, 1985, Governor Graham directed the Florida Department of Environmental Regulation to do an intensive study of the lake. A technical committee of experts was formed and produced a report with numerous recommendations on how to clean up the lake. Recommendations include ceasing pumping of nutrient rich water into the lake from the agricultural area to the south and control of nutrients from the dairy and cattle farms to the north. Also recommended was diverting the major source of dairy pollution, Taylor Creek and Nubbin Slough, away from the lake.

c. Progress--Cleaning up the lake is a top state priority.

3. Restoration of the Holey Land and Rotenberger Tracts.

a. Problem--A 100 square mile area of former Everglades adjacent to the water conservation areas has been drained incidental to general drainage in the Everglades agricultural area. This land has been neglected, burned, and is overgrown with upland vegetation. The state owns 75 percent of the land, but the other 25 percent is divided into hundreds of small parcels. The Seminole Indian Tribe owns 3800 acres of the area.

b. Solution--The state is in the process of acquiring all privately owned land in the area. Discussions have begun with the Seminoles, and a state plan has been developed for restoration of natural water levels on this land.

c. Progress--Construction of dikes along the eastern portion is underway. The 35,300 acre eastern tract (Holey Land) is planned for completion in 1988.

4. Management of deer in the Everglades.

a. Problem--In the summer of 1982, a herd of about 6,000 deer suffered high mortality due to extremely high water (2-3 feet deep) in the water conservation areas. During high water, food supplies are reduced and the deer starve. About half of the herd was lost and the public became alarmed. Management practices are required which will help deer populations survive high water periods.

b. Solution--The Governor asked the Florida Game and Fresh Water Commission to manage the deer herd at a (lower) level that can withstand high water. He also directed that water management practices be improved for the benefit of wildlife.

c. Progress--Since 1982 the deer herd has been maintained at about 2500 to 3000 with no water related mortalities.

5. Incorporation of Environmental Improvements in Converting Alligator Alley to Interstate 75.

a. Problem--Alligator Alley traverses the Everglades causing over-drainage in some parts of Water Conservation Area 3 and impoundment in other parts. It also poses a serious threat to the endangered Florida panther when crossing in the Big Cypress Swamp and Fakahatchee Strand in Collier County. Four panthers have been killed on the Alley since 1983.

b. Solution--Plans for I-75 include three additional bridges and numerous culverts, water spreader systems, and plugs in roadside canals. These should alleviate hydrological problems and recreate a natural water flow through the Everglades. Thirty-six panther and animal underpasses and ten foot roadside fences will be constructed in the Big Cypress swamp and Fakahatchee Strand. Over $12 million worth of animal protection measures will be installed with the state paying $10.5 million of the total. The project offers a unique opportunity to acquire a 128,000 acre addition to the Big Cypress National Preserve at half the cost of the land. Severance damage payments to adjacent property owners will effectively reduce the value of the property by half. Federal legislation is necessary to expand the Preserve. The proposed addition to the preserve is an integral part of the Big Cypress hydrological system that supplies 50 percent of Everglades National Park's external water through overland flow. It is also the habitat of the panther and several other endangered species.

c. Progress--In January, 1986, federal legislation adding 128,000 acres to the Big Cypress National Preserve was introduced by Senator Lawton Chiles (S.2029) and U.S. Representative Tom Lewis (HR.4090). The State of Florida has set aside $22.5 million in order to meet its 20 percent share of the purchase and to make other purchases in the Everglades region.

6. Restoration of the Everglades National Park.

a. Problem--Bird populations in the park have steadily declined to only about 10 percent of the 1934 population existing in 1983. Fish and crustacean populations have declined. Salinity changes have occurred in the estuaries, and exotic species have invaded. These problems are a result of hydrological alterations caused by activities outside the park. The Golden Gate Estates Canal System, the Central and Southern Florida Project, development, agricultural practices, and the Aerojet Canal (C-111) are major causes of these problems.

b. Solution--A water flow which duplicates the original natural amounts and timing is needed. This can be achieved by acquiring large buffer tracts around the park, restoring natural flows in the East Everglades and Golden Gate Estates, and improving the functioning of the Central and South Florida Project (the public water management system).

c. Progress--Since 1983 the Corps of Engineers has breached a levee, allowing water to flow more naturally from the water conservation areas into the Big Cypress National Preserve and, subsequently, overland into the park. The Corps also plugged a canal adjacent to the park in order to force water from the canal into the marshes of Shark River Slough. The South Florida Water Management has redesigned the water delivery plan for the park so that water is released into the park from the water conservation areas in proportion to rainfall. Public Law 98-181 of December, 1983, provides for experimental water deliveries to the park over private land in the northeast Shark River Slough of the East Everglades. This program effectively doubles the area over which water flows into the eastern portion of the park.

The state has purchased 55,000 acres in Shark River Slough and Taylor Slough which flow into the park and plans to acquire over 70,000 additional acres in Shark River Slough. The state has also attempted to purchase most of the remaining 13,000 acres of Aerojet property in the East Everglades. The state and Corps have plans to correct hydrological problems caused by the Aerojet Canal (C-111). The state plans to purchase 86,000 acres in Golden Gate Estates and the Fakahatchee Strand and restore the natural hydrology on 30,000 acres which drain into the Ten Thousand Islands area of the park. Since 1984, conditions in the park have improved--increased ibis, woodstork, and heron feeding; increased numbers of snook in Florida Bay; and expansion of marine grass beds in Whitewater and Hell's Bays.

7. Protection of the Florida Panther from Extinction.

   a. Problem--Less than 50 Florida panthers exist, all in the Fakahatchee Strand, Big Cypress Swamp, and Everglades National Park. Habitat loss and highway mortality are the major threats to the panther with twelve of twenty known deaths caused by automobiles, and continued habitat loss a cause for additional concern.

   b. Solution--Acquisition of habitat, highway improvements, and wildlife regulations are crucial to the survival of the Florida panther. Scientific research and captive breeding offer hope for rebuilding its population. The state plans to purchase 86,000 acres of panther habitat in the Fakahatchee Strand and Golden Gate Estates; the U.S. Fish and Wildlife Service plans to purchase a 30,000 acre national wildlife refuge in the Fakahatchee Strand; and federal legislation (S.2029 and HR.4090) proposes the purchase of 134,000 acres as an addition to the Big Cypress National Preserve. State and federal environmental regulations offer some protection to panther habitat. However, these regulations are not totally effective in protecting wildlife. The Florida Game and Fresh Water Fish Commission has an extensive radio tracking program for panthers to determine proper locations for the panther and animal underpasses planned for I-75. The regulation of deer and wild hog hunting by the Commission is also important to maintaining an adequate food supply for the panther.

c. Progress--Since 1983 the state has purchased 9,755 acres in the Fakahatchee Strand. The Department of Interior has acquired over 32,000 acres in the Big Cypress National Preserve, and about 4,000 acres of private land remain to be acquired. The U.S. Fish and Wildlife Service has secured $6.4 million for purchase of the 30,000 acre $17 million refuge. Over the past three years, the Florida Game and Fresh Water Fish Commission has spent $250,000 annually on panther research, and the National Park Service has budgeted $400,000 over the next three years for panther research. The U.S. Fish and Wildlife Service, National Park Service, Florida Department of Natural Resources, and Game and Fresh Water Fish Commission have formally joined forces in developing a panther recovery plan. Panther warning signs, lowered speed zones, and motorist alert strips are located on Alligator Alley, State Road 29, and Tamiami Trial (U.S. 41).

The Florida Game and Fresh Water Fish Commission is negotiating a contract to captively breed panthers on a 7,000 acre natural site in northeast Florida. Captively bred offspring will be raised and then released in the wild.

CONCLUSIONS

Florida has purchased 77,387 acres of land in the Everglades system since 1983 (under the Save Our Everglades program) and the federal government has purchased 32,209 acres. Florida plans to purchase 297,806 acres in this region and proposes that the federal government purchase 212,450 acres. The protection afforded by these extensive land purchases, combined with the restoration of damaged systems and further improvements to the public water management system in South Florida, will improve and protect the integrity of Everglades National Park and the entire Kissimmee River-Lake Okeechobee-Everglades Ecological System.

Achievement of this goal requires the long-term commitment of the Everglades Coalition, public officials, and the general public of Florida.

CLONAL PROPAGATION OF *POTAMOGETON PECTINATUS* IN AXENIC CULTURE

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ABSTRACT

Explants of Sago pondweed (*Potamogeton pectinatus*) taken from the terminal buds of dormant turions and the tips of rhizomes were used to establish axenic cultures. Various combinations of surface sterilants, fungicides, and antibiotics were required to disinfest the explants of microflora. The most successful treatment was a sequential exposure of explants to 5 percent Captan for 24 hours, 10 percent Clorox for 5 minutes, and 10 percent Kanamycin for 2 hours. Cleaned explants were cultured on Murashige's Minimal Organic Medium supplemented with 10 percent sucrose and serial dilutions of kinetin and indole-3-acetic acid. The tissues showed typical dose-response behavior to hormonal treatments. Increased kinetin concentrations to 2 mg/l stimulated shoot formation. Increases in indole-3-acetic acid concentration led consistently to greater root growth throughout the range tested. After six weeks in culture, new plants were obtained by subdivision of the rhizomes at a rate of 10 plants per explant. The plants produced are currently being used in revegetation projects and for testing the effects of various environmental parameters on plant mortality, growth rates, and biomass production.

INTRODUCTION

The ecological significance of submerged aquatic angiosperms is widely recognized (Thayer et al. 1975, Cattaneo et al. 1980). Communities of submerged aquatic vegetation (SAV) provide food and add structural complexity to shallow coastal ecosystems, thus creating habitats capable of supporting abundant and diverse animal populations (Thayer et al. 1975). SAV is also important for nutrient cycling (Kenworthy et al. 1982) and exerts marked influence on sedimentological processes through the stabilization of sub-tidal soils and the dissipation of tidal- and wind-generated wave energy (Ward et al. 1984).

Potamogeton pectinatus (Sago Pondweed) is reported to have worldwide distribution in freshwater ponds and streams and brackish coastal waters with salinities of 0 to 12 ppt. While common in the United States and Canada, it has been observed in similar habitats in Russia, India, South Africa, Venezuela, Hungary, Pakistan, and East Germany. In parallel with other Maryland SAV, *P. pectinatus* populations have undergone a general decline according to annual surveys conducted by the U.S. Fish and Wildlife Service (Stevenson et al.

1978). The ecological impact of this decline is difficult to assess, but it seems likely that their loss has already had a profound effect on ecosystem composition. P. pectinatus is one of the more important waterfowl plant foods, providing numerous seeds and tubers rich in carbohydrates and abundant forage in the form of leaves and rhizomes (Martin et al. 1939). The plant provides protective habitat for fish, oysters, crabs, and benthic creatures in shallow shoal areas (Fassett 1960). Furthermore, P. pectinatus with its long, narrow vertical leaves serves as an excellent sediment trap (Butcher 1933). The importance of P. pectinatus to the Chesapeake Bay ecosystem has prompted my laboratory to select it as the top priority for initial efforts at in vitro SAV propagation.

In vitro systems of plant cultivation offer a highly efficient mechanism for the propagation of SAV. In addition, these techniques provide the opportunity to conduct acute and chronic toxicity tests for various types of environmental stresses. A major obstacle for applying in vitro techniques to SAV is the great difficulty in obtaining axenic cultures. This paper reports on the relative effectiveness of various disinfestation procedures used to obtain axenic cultures of P. pectinatus.

MATERIALS AND METHODS

Stock plants of Potamogeton pectinatus were collected from brackish intertidal ponds (8 ppt) or fresh water impoundments (Wildlife Nurseries, Oshkosh, Wisconsin). The plants were washed in running tap water and various explants such as the leaves, stem sections, rhizome segments, and terminal turion buds were treated in the conventional manner (Vasil 1984) with serial dilutions of sodium hypochlorite (obtained from commercial bleach) in an effort to establish an effective sterilization procedure. These treatments failed to eradicate resident fungal and bacterial contaminants at doses non-lethal to plant tissues.

Fungal contaminants were tested for sensitivity to three common broad spectrum fungicides: Daconil (tetrachloroisophthalonitrile); Captan [n-(trichloromethylthio)-4-cyclohexene-1, 2-dicarboximide]; and Banrot [15% 5-ethoxy-3-trichloromethyl-1, 2, 4-thiadiazole and 25% dimethyl 4, -4'-o-phenylene bis, (3-thioallophanate)]. These compounds can be obtained from common agricultural chemical sources. Contaminated explants were soaked in 5 percent aqueous solutions of these fungicides and then reinoculated on fresh medium. Treatments were evaluated on their ability to control fungi without causing severe tissue damage.

Bacterial contaminants were tested for sensitivity to 16 antibiotics: penicillin, streptomycin, erythromycin, chloramphenicol, novobiocin, tetracycline, kanamycin, neomycin, nitrofurantoin, sulfadiazine, sulfathiazole, sulfisoxazole, polymixin B, oxytetracycline, chlortetracycline, and bacitracin. All antibiotics were purchased from

Difco Laboratories, Detroit, Michigan. The bacteria were isolated from several cultures, grown in nutrient broth and plated on nutrient agar. Filter paper discs impregnated with antibiotics were placed on the agar surface. These cultures were incubated for 72 hours at 30°C at which time antibiotic sensitivity was determined.

Sterilized explants were cultured on solid (0.6% agar) and liquid Murashige's (Murashige 1978) minimal organic medium supplemented with 10 percent sucrose and the hormones kinetin and indole-3-acetic acid at concentrations of 0 to 2 mg/l. The pH of all media was adjusted to 5.6 with KOH. Media were autoclaved for 20 minutes at 121°C and 18 psi. Cultures were maintained in growth chambers at 27°C under continuous illumination with cool white fluorescent lights at 150 uE/m2s.

RESULTS

Over the entire range of Clorox concentrations (0-10%) and exposure times (1-10 min.), including those lethal to plant tissues, 95 percent of the cultures were contaminated with bacteria and/or fungi. Another problem was that all green explants exhibited chlorine phytotoxicity at low concentration and short exposures. Explant source was thus restricted to the protected terminal bud of dormant turions which could withstand the longer exposures and high concentrations needed for adequate surface sterilization. Most surface bacteria and fungi could be effectively removed without the loss of tissue viability by a 5 minute exposure to a 10 percent Clorox solution containing 0.01 percent Triton as a wetting agent. Excellent control of fungal contaminants without apparent phytotoxicity was achieved with a 24 hour exposure of the tubers to a 5 percent solution of Captan. Daconil and Banrot were less effective than Captan for controlling fungal growth and seemed to promote tissue blackening.

Bacteria proved much more difficult to remove from the cultures. Although sterilization with sodium hypochlorite was effective in removing surface bacteria, the treatment did not remove a slow growing bacterium which seemed to reside inside the plant tissue. Bacteria were isolated from the cut edge of explants which had been previously exposed to the Clorox and Captan pretreatments. Bacterial sensitivity was evaluated by the standard Kirby-Bauer methods. Table 1 shows the relative effectiveness of different antibiotics for restricting growth of the contaminant as judged by the largest zones of inhibition. Kanamycin, tetracycline, and streptomycin were the most effective but the latter two seemed to inhibit subsequent growth of the explant. It was then found that a 2 hour soak in a 10 percent kanamycin solution following surface sterilization reduced contamination to an acceptable 20 percent level with no apparent tissue damage. All subsequent work used to following sequence of explant treatments: Captan (24 hr.), Clorox (5 min.), and kanamycin (2 hr.).

Once sterilized, the tissues showed typical dose-response behavior to hormonal treatments. Increased kinetin concentrations stimulated

Table 1. Effects of antibiotics for controlling bacterial contaminants as judged by the size of the zone inhibition.

Antibiotic	Zone of Inhibition (mm)	Antibiotic	Zone of Inhibition (mm)
Penecillin	-	Bacitracin	-
Nitrofurantoin	5	Streptomycin	10
Sulfadiazine	-	Erythromycin	-
Sulfathiazole	-	Chloramphenicol	3
Sulfisoxazole	-	Novobiocin	2
Polymixin B	-	Tetracycline	14
Oxytetracycline	12	Kanamycin	14
Chlorotetracycline	10	Neomycin	-

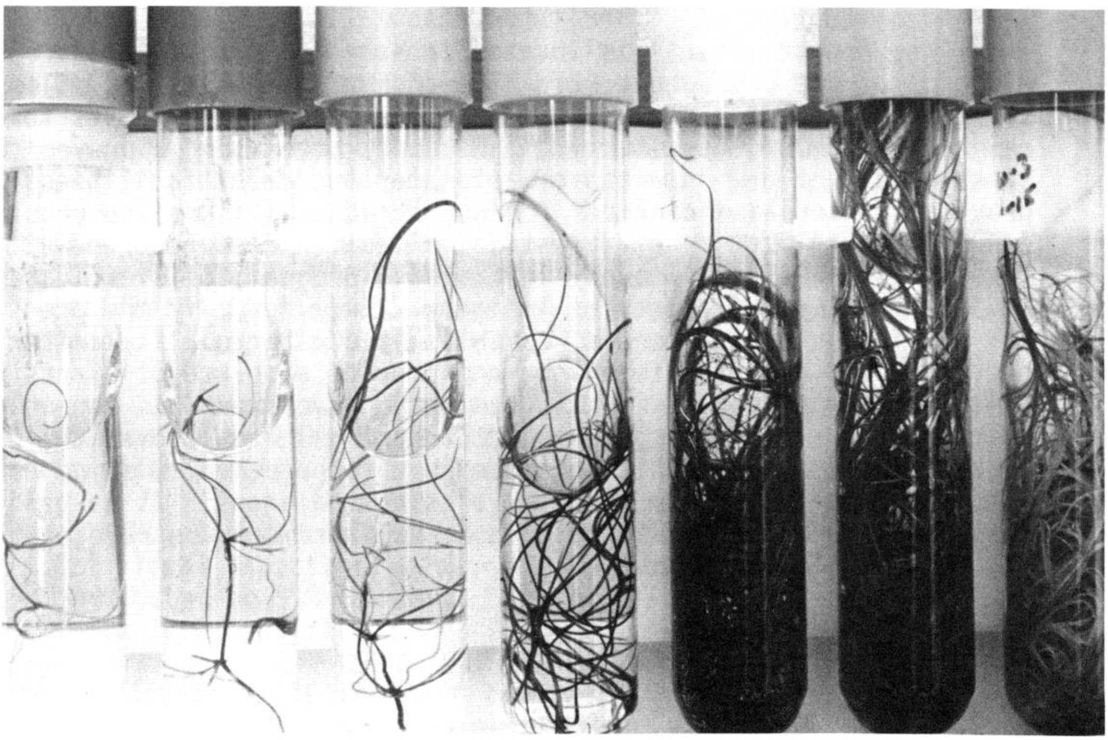
Table 2. Effects of kinetin on P. pectinatus in cultures. Evaluations are derived from visual observations of cultures, with + being no growth and ++++ being equivalent to a full tube after six weeks of growth.

Concentration mg/L	Root Formation	Shoot Formation	Biomass
0.0	+	+	+
0.3	++	++	++
0.5	+++	+++	++++
1.0	++	++++	++++
2.0	++	++++	++++

Table 3. Effects of IAA on P. pectinatus in cultures. Evaluations were derived from visual observations of cultures.

Concentration mg/L	Root Formation	Shoot Formation	Biomass
0.0	+	+	+
0.3	++	+	+
0.5	++	+	+
1.0	+++	+	++
2.0	++++	+	++

Figure 1. Six week old cultures of P. pectinatus containing: (L to R) 1 mg/L kinetin and 1 mg/L kinetin and IAA.



shoot formation; however, root formation was inhibited with concentrations above 0.5 mg/l. (Table 2). Optimal indole-3-acetic acid concentrations (Table 3) were not found as increases in IAA concentration led consistently to greater root growth throughout the range tested. Indole-3-acetic acid did not affect shoot formation. An example of axenic plants after 6 weeks in culture is shown in Figure 1.

DISCUSSION

Standard procedures used for the surface disinfestation of plant material (Thorpe 1981) were insufficient for obtaining tissue free of microorganisms. It is reasonable to attribute this difficulty to the diversity of micro-epiphytes common to submersed spermatophytes (Marlin 1980), the presence of spore-forming cellulolytic bacteria frequently found on field-collected P. pectinatus (Robb et al. 1979), and the lack of a well-developed protective cuticle (Martin et al. 1970).

Combinations of the fungicides, antibiotics, and surface sterilants, which are necessary for obtaining axenic cultures of P. pectinatus, are also effective with other SAV species (Ailstock unpublished). Once established, these cultures are easily maintained using standard in vitro procedures. Given the value of clonal axenic culture systems, these efforts are likely to provide a better understanding of SAV biology and the factors which affect their survival. Current efforts are involved with efforts to manipulate the organism through its entire life cycle in vitro.

Anne Arundel County is located on Maryland's western shore at the midpoint of the Chesapeake Bay. The county, which has 468 miles of shoreline, has taken a leading role in developing strategies for revitalization of the estuary. The county government approved the construction of new innovative wastewater treatment facilities, provided financial incentives for non-structural shoreline erosion, and encouraged utilization of industrial sites for resource renewal. Moreover, in 1985, the county initiated a program to investigate the environmental requirements of indigenous SAV, identify the pressures on SAV within county watersheds, establish the water quality criteria necessary for SAV proliferation, and provide a source of plants for SAV revegetation projects. Finally the state government has recently enacted the Critical Areas legislation as well as approved the Chesapeake Bay Initiatives which are designed to preserve existing natural resources and hasten the recovery of stressed areas. It is believed that the combination of these efforts will promote the revegetation of the Bay with SAV species.

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VEGETATIVE STABILIZATION OF DREDGED MATERIAL IN MODERATE TO HIGH WAVE-ENERGY ENVIRONMENTS FOR CREATED WETLANDS

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ABSTRACT

The U. S. Army Engineer Waterways Experiment Station (WES) has assisted three Corps of Engineers districts during the last 11 years in efforts to vegetatively stabilize dredged material and to create wetlands in moderate to high wave-energy climates in Galveston Bay, Mobile Bay, Mississippi Sound, and Southwest Pass on the lower Mississippi River. Shore stabilization has been successfully accomplished in several areas by using relatively low-cost structures and materials to protect plantings of smooth cordgrass (Spartina alterniflora). Vegetative stabilization of dredged material with the marsh grass leads to beneficial use of the disposal area by holding the material in place and by providing marsh habitat. These benefits make dredged material disposal more acceptable to environmental regulatory agencies and concerned citizens. In some areas, conventional use of bare-rooted single-stemmed sprigs of smooth cordgrass proved unsuccessful because of wave washout As a result, WES tested an array of new techniques to achieve marsh creation. Techniques included using various breakwaters to dampen wave energies as well as stabilizing plant stems. To date, successful techniques include planting behind a breakwater of large sandbags; planting behind tire breakwaters; using plants wrapped in long burlap rolls; and sprigging plants into a woven mat and then laying and anchoring the mat on the substrate. Costs of these four new techniques are only a fraction of the cost of using rip-rap for stabilization, and in addition, they can provide valuable marsh habitat not normally able to establish in high wave-energy climates.

INTRODUCTION

The U. S. Army Engineer Waterways Experiment Station (WES) has assisted various Corp of Engineers (CE) districts in stabilizing dredged material and creating wetlands in various environments over the last 11 years (Environmental Laboratory, 1978). This combination of stabilizing dredged material and creating wetlands makes dredged material disposal more environmentally acceptable to regulatory agencies and concerned citizens.

Some of these efforts focused on the feasibility of developing marsh on dredged material exposed to wave energies previously considered too high for artificial marsh establishment. One study site was located northeast of Galveston on Bolivar Peninsula adjacent to Galveston Bay (Figure 1). At this site, saltmarsh consisting of smooth cordgrass (Spartina alterniflora) and saltmeadow cordgrass (Spartina patens) was successfully developed in 1975 to 1977 by transplanting sprigs (root-bearing stems) landward of a sandbag breakwater made from 0.5- by 1.4- by 2.9-m nylon coated bags (Allen et al. 1978). The developed marsh is the only marsh on the southeast side of Galveston Bay, partly because of a long 32-km northwest wind fetch that produces large waves in the winter. The sandbag breakwater provided enough initial protection of the transplants for marsh establishment, and the marsh is still functioning well (Newling & Landin 1985). However, the sandbag breakwater was considered by some to be too expensive, and it tended to sink where filter cloth was not placed underneath the bags. Parts of the breakwater required restoration and more frequent maintenance which led to increased costs.

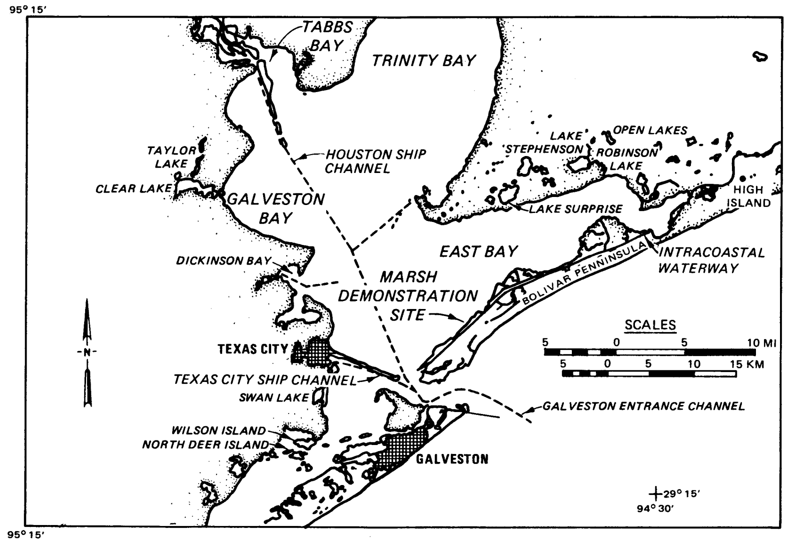

Figure 1. Marsh demonstration site at Bolivar Peninsula, Galveston Bay, Texas.

From 1981 to present, the WES has assisted the Mobile, Galveston, and New Orleans districts in stabilizing dredged material with marsh grass in areas exposed to moderate to high wave energies. The techniques involved less expensive and more expedient efforts than at Galveston planting behind the sandbag breakwater. One of these areas was Wilson Gaillard Island (hereafter called Gaillard Island) in Mobile Bay (Figure 2). Marsh was successfully established on the northwest side by use of a floating tire breakwater (FTB) (Allen & Webb 1983). The FTB provided enough wave protection for marsh establishment behind it. Later, less expensive and more attractive techniques were developed that focused on stabilizing plant stems without breakwater protection. Ten new techniques and two conventional planting

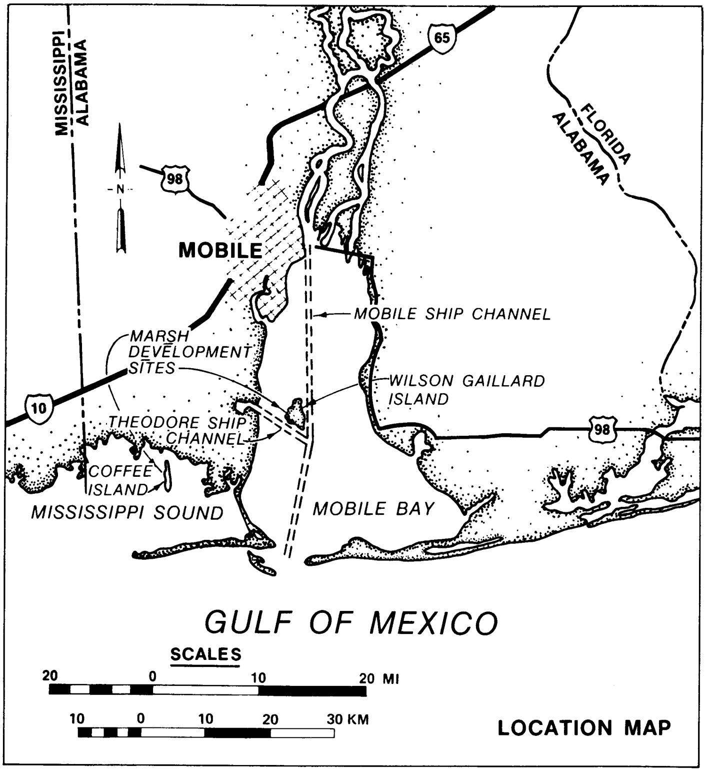

Figure 2. Gaillard Island, Mobile Bay, Alabama, and Coffee Island, Mississippi Sound, Alabama, marsh development sites.

techniques were tested at Gaillard Island and exposed to a maximum 11.2-km fetch from the north (Allen, Webb, & Shirley 1984). The conventional single-stem planting techniques proved unsuccessful at the sites tested at least three to four times previously and proved unsuccessful again. However, three techniques using plant rolls, erosion control mats (trade name Paratex*), and burlap bundles, demonstrated enough potential survival at Gaillard Island (Figure 3) (Allen, Webb, & Shirley 1984) that they were tested in demonstration plots at Bolivar Peninsula in Galveston Bay and at the Southwest Pass of the lower Mississippi River (Figure 4). The plant roll's potential usefulness also was demonstrated in a nonexperimental way along a 0.5-km front at Coffee Island in Mississippi Sound. Results of these three demonstrations are the main subject of this paper.

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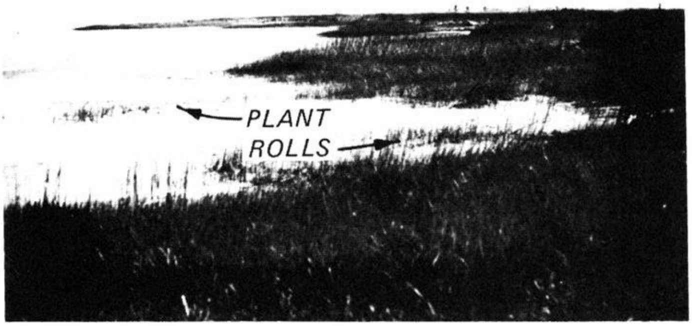

Figure 3. Successfully established smooth cordgrass marsh at Gaillard Island showing plant rolls extending out into the water.

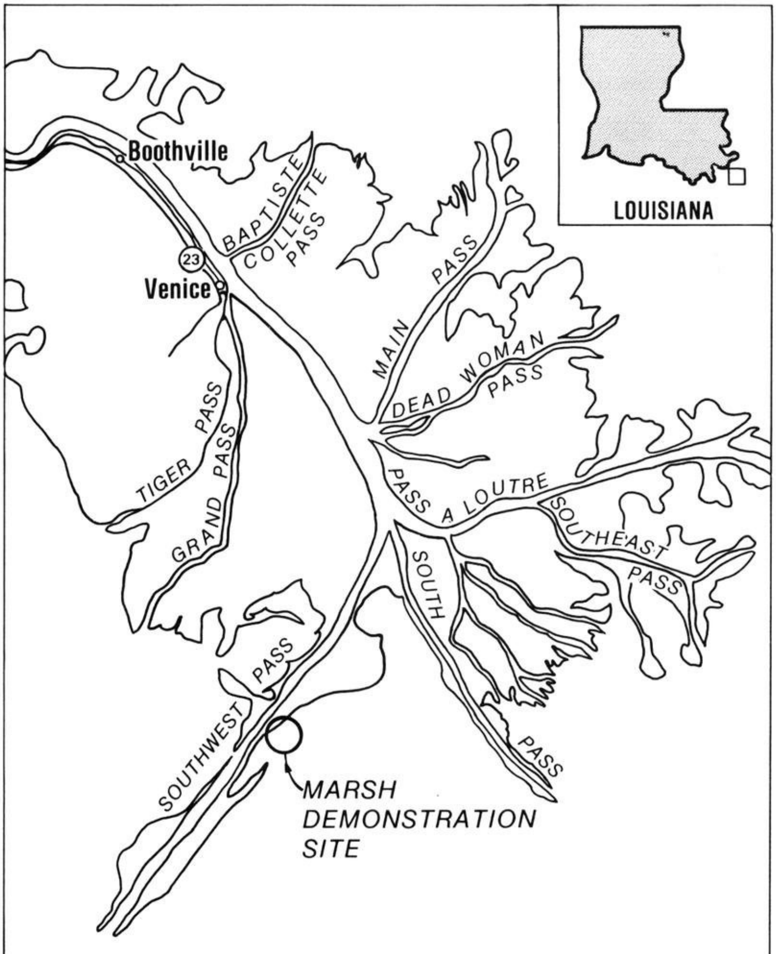

Figure 4. Marsh demonstration site at Southwest Pass, lower Mississippi River, Louisiana.

DEMONSTRATION SITES

The demonstration site at Coffee Island (Figure 2) is located in Mississippi Sound about 6 km south of Bayou La Batre, Alabama. The site was formed from dredged material consisting largely of clay that was deposited in 1981 adjacent to the east side of Coffee Island, a natural island. The dredged material formed an eroding face because of exposure to storms originating from the southeast with fetches of 8 to 16 km. Stabilization with smooth cordgrass was undertaken to halt the erosion. A natural smooth cordgrass marsh existed adjacent to the site in a wave-protected cove of the original island.

The demonstration site at Bolivar Peninsula (Figure 1) is about 1 km west of the 1975 site described earlier and is exposed to a 32-km fetch from the north and northwest. It was formed from fine, sandy material dredged from the Gulf Intracoastal Waterway, which lies immediately south of the site.

The demonstration site at Southwest Pass, the main outlet of the Mississippi River, is located on the east bank of the Pass (Figure 4) about 14 km southwest of the Head of Passes. It was formed from about 11,000 cu m of medium- to course-textured sandy dredged material and is exposed to unlimited fetch from the southeast and southwest. A stand of smooth cordgrass and glasswort (*Salicornia* spp.) lies adjacent to the dredged material site, but is behind a natural sand-spit that provides wave protection.

MATERIALS AND METHODS

Coffee Island Site

A mixture of single-stemmed transplants and plant rolls were dug from a nearby smooth cordgrass marsh and transplanted at the site (Figure 2) in June, 1985. Plant rolls were placed end to end and seaward of single-stemmed transplants over a linear distance of about 0.5 km to cover an area 5 to 10 m in width landward of mean low water. Transplants or the plant clumps within the plant rolls were placed on 0.5-m centers at an elevation corresponding to the elevation of the natural marsh in the area.

Bolivar Peninsula Site

In August, 1984, transplants of smooth cordgrass were dug from the 1975 site and planted at the new site 1 km to the west. Transplants were placed landward of two tire-breakwater systems used for wave protection while others were placed in unprotected plots (Figure 5). The transplants were planted in an elevation zone corresponding to the older marsh east of the site.

Prior to the demonstration, physical 1/4th-scale models of several

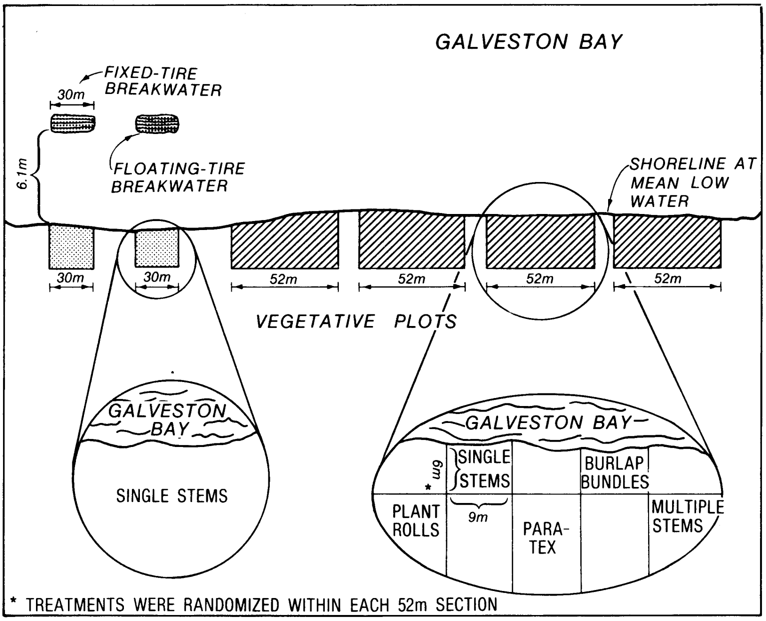

Figure 5. Site layout at Bolivar Peninsula.

tire breakwater configurations were laboratory tested in a wave tank at WES. The breakwaters chosen for the field demonstration as a result of these tests consisted of a three-tier FTB and a fixed tire-pole breakwater. These breakwaters reduced wave energies by 80 and 90 percent, respectively, in the wave tank (Markle & Cialone, in press).

A 30.5-m front of each breakwater type (Figures 6 & 7) was constructed and placed at the site 6 m seaward of two 6- by 30.5-m plots (Figure 5). Single-stemmed transplants were initially used behind each breakwater with 1056 plants placed on 0.5-m centers. About one year later in July, 1985, plant rolls with single stems planted between them were used, all on 0.5-m centers. Eight plant rolls were placed landward of each end and the middle portions of each breakwater with rows of single stems among them. After replanting, each breakwater site once again had 1056 planting locations consisting of single-stemmed transplants or plant clumps. This was done as a remedial effort explained in the results.

Four 6- by 9-m replicate demonstration plots of five treatments described below were laid out without wave protection to test their relative success. Each plot had 280 plant locations consisting of either single sprigs or plant clumps (3-4 stems per clump) placed on 0.5-m centers. Randomized within each unprotected replicate or planting area (block) were the following treatments:

Treatment 1. Bare-root single-stemmed sprigs of smooth cordgrass (with no other treatment) were planted conventionally with a spade to serve as a control.

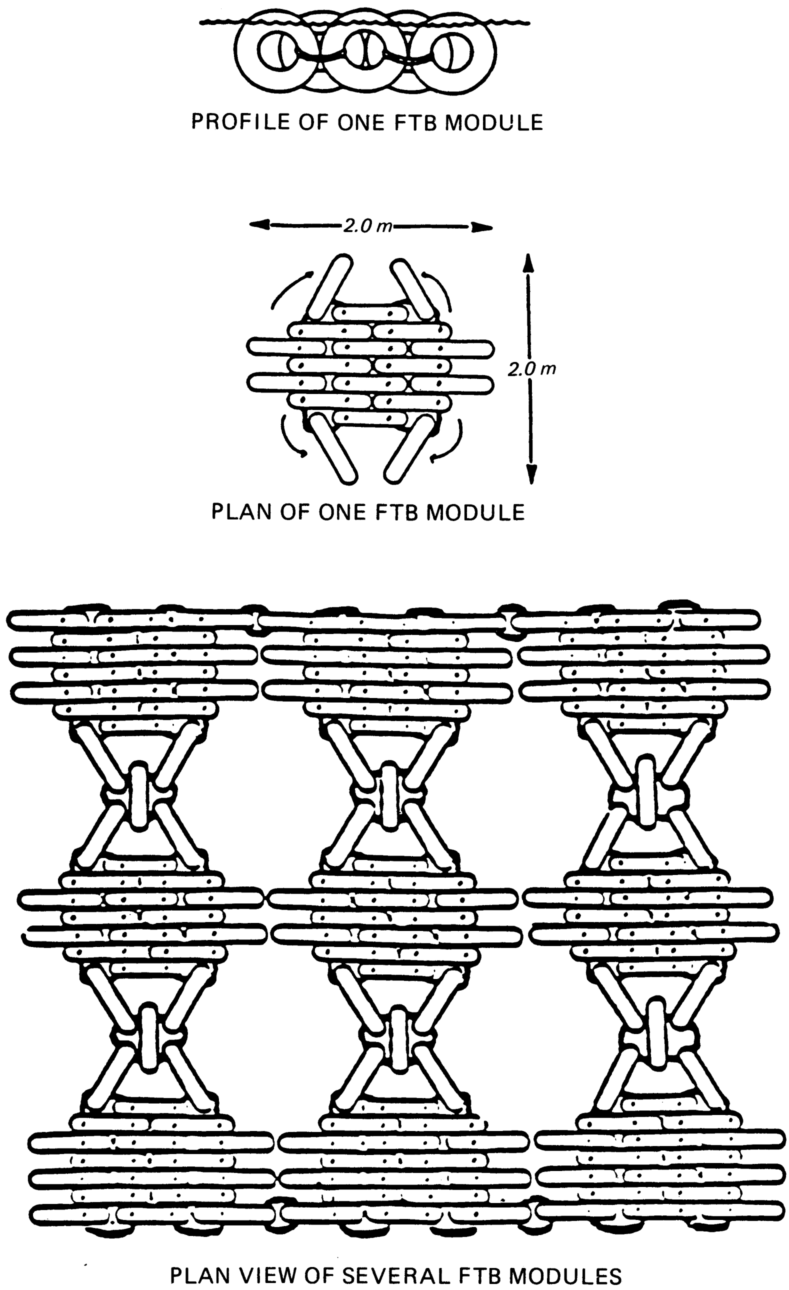

Figure 6. Schematic of three-tier floating tire breakwater (FTB) consisting of 18-tire modules.

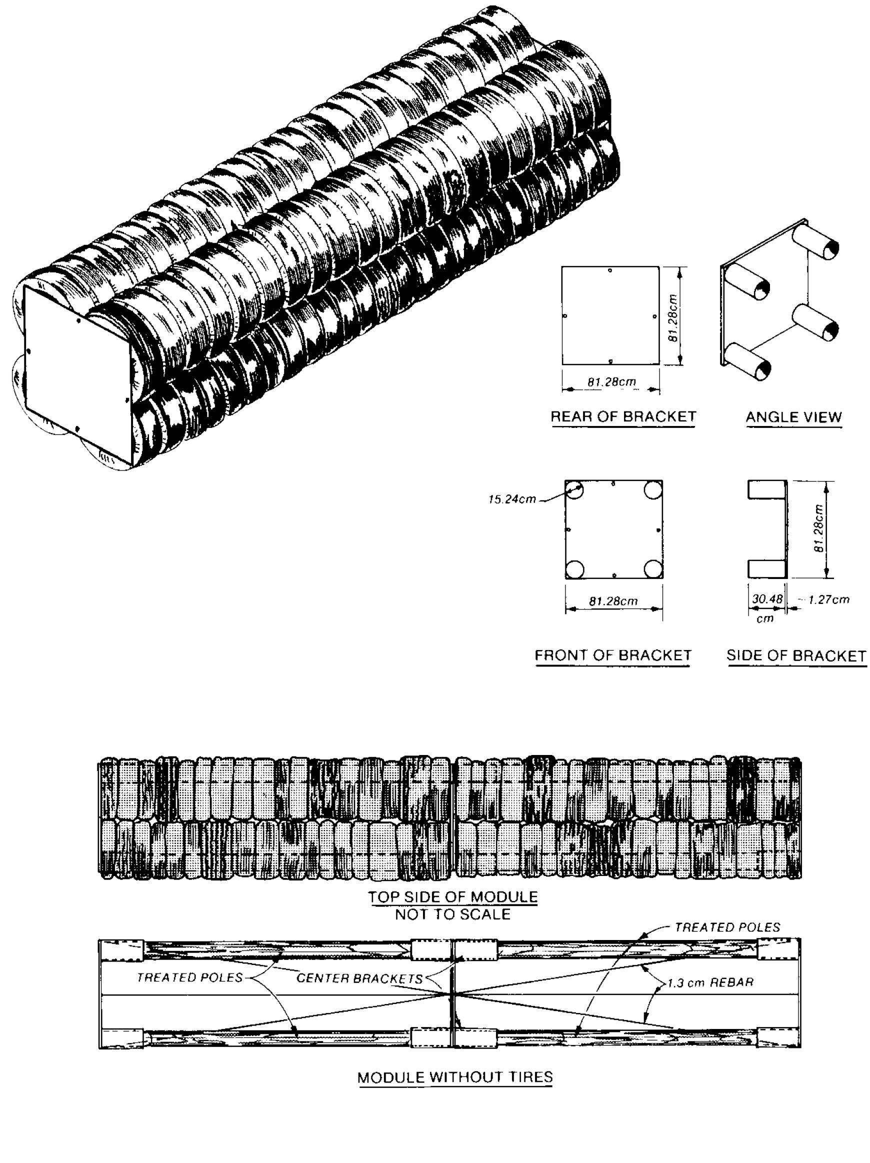

Figure 7. Schematic of fixed tire-pole breakwater.

Treatment 2. Bare-root multi-stemmed plants consisting of three or more large stems were planted like those in Treatment 1.

Treatment 3. Roots and lower stems of multi-stemmed plants were wrapped with a burlap square (46 by 46 cm) and fastened with hog-rings to form a burlap bundle (Allen, Webb, & Shirley 1984), which was buried with a spade.

Treatment 4. A plant roll was constructed by laying a 3.7-m length of 0.9-m-wide burlap on the ground. Sandy soil was placed on the strip of burlap and six clumps of plants were spaced at 0.5-m intervals on the burlap. Then, the sides of the burlap were brought together around the plants and fastened with hog-rings. This created a 3-m-long roll of plants and soil (Figure 8). The plant rolls were placed parallel to the shoreline and buried in the plots by the use of a jet pump (Allen, Webb, & Shirley 1984).

Figure 8. Plant rolls constructed on site ready for installation.

Treatment 5. A biodegradable fabric mat, trade-name Paratex, consisting of 0.1 kg/m^2 natural fibers was laid like carpet on the shore. Then, single-stemmed transplants were inserted into slits cut through the material. The edges of the mat were nailed between 5- by 15-cm boards that were then placed on their edge and buried in the sediment (Allen, Webb, & Shirley 1984).

Southwest Pass

Smooth cordgrass sprigs were transplanted to unprotected and protected plots in mid-May, 1985, at Southwest Pass in the same site layout used at Bolivar Peninsula (Figure 5) with a few modifications. The fixed tire-pole breakwater had additional vertical timber piles placed every 6 m and a 1.3-cm rebar was added to stabilize the breakwater. Behind the FTB and the fixed breakwater, both plant rolls and single-stemmed sprigs were used in a 50-50 percent mixture of 528 plants or plant clumps each. About two months later, it was necessary to replant behind each breakwater as a remedial effort. This time, only single-stemmed sprigs were used because of time and money limitations. Each breakwater site received stems in 1056 planting locations on 0.5-m centers.

The unprotected plots were the same as at Bolivar Peninsula except that the Paratex mats were covered with 2.5- by 10-cm woven wire to stabilize the mat and the plant rolls were placed with the long axis perpendicular to the shoreline. As at Bolivar Peninsula, transplants were dug from a nearby site protected from waves and were planted in an elevation zone corresponding to the natural marsh.

Monitoring at all of the above sites was started immediately after installation and continued at various intervals. Monitoring at Coffee Island and Bolivar Peninsula continued for almost two years while at Southwest Pass, it continued for only six months. At Coffee Island, only qualitative monitoring was performed by comparison of photographs taken several months apart. At Bolivar Peninsula and Southwest Pass, quantitative data were taken for each plot, and photographs were periodically taken to observe changes over time. Prior to plants coalescing, plant counts were made; and after coalescence, percent cover of plots was visually estimated.

Cost estimates were derived from the work done at Gaillard Island (Allen & Webb 1983; Allen, Webb, & Shirley 1984) and the 1985 work at Bolivar Peninsula and Southwest Pass. Cost records for Bolivar Peninsula and Southwest Pass were kept on materials and time (manhours) required to build the breakwaters and plant the marsh.

RESULTS

Coffee Island

The demonstrational planting at Coffee Island gave very noteworthy findings, although from a nonexperimental perspective. Periodic inspection revealed that the plant rolls placed end-to-end and seaward of single-stemmed transplants satisfactorily stabilized the eroding dredged material face. This is evident from comparisons of a photo made just 2-1/2 months after planting (Figure 9) to one made 1-1/2 years later (Figure 10). Upon inspection of the site at the time of the latter photo, the marsh fringe showed signs of accreting sediment and protecting the island from further erosion.

Breakwaters. The FTB was in such shallow water that it immediately became bottom seated due to sediment build-up within the tires, and it subsided somewhat. The fixed tire-pole breakwater also

Figure 9. Coffee Island marsh development site 2-1/2 months after planting, showing plant rolls seaward of what were originally single-stemmed transplants.

Figure 10. Coffee Island marsh development site 1-1/2 years after planting with smooth cordgrass.

subsided, and both breakwaters tended to cause an accretion of sediment landward of them. By October 30, 1984, two months after planting, most of the single-stemmed sprigs transplanted behind the breakwaters were covered with 25 to 30 cm of sediment. Of 1056 plants sprigged, only 63 were found behind the FTB while only 152 were found behind the fixed breakwater. Little change occurred from October 30, 1984, to July 30, 1985, with only 96 and 130 plants found behind the FTB and fixed breakwater, respectively.

Observations on August 7, 1985, indicated that both breakwaters were battered and had subsided since the 1984 observations, but were still effectively breaking waves. It appeared that the sediment accretion process had reached equilibrium; that is, the likelihood of any additional sediment accretion was remote. The fixed breakwater was partially damaged; one 6-m tire-pole section had broken loose from the breakwater, and the tires were scattered. Because the sediment build-up covered the plants behind the breakwaters and because the breakwaters were still breaking waves, the areas behind each breakwater were replanted on August 7, 1985, to bring the total plant-location count to 1056 plants or plant clumps.

A site inspection was conducted again on November 6, 1985, and plant counts were made. Of the 1056 plants or plant clump locations, 311 (29%) remained behind the FTB and 445 (42%) remained behind the fixed breakwater (Figure 11). It was anticipated that, if these plants remained in place over the winter of 1985, the marsh would probably become well-established during the next growing season.

Figure 11. Smooth cordgrass behind fixed tire-pole breakwater at Bolivar Peninsula site.

These plants survived the 1985 winter and spread in the spring of 1986. Another site inspection was conducted on June 10, 1986. Behind the FTB, smooth cordgrass plant cover was estimated to vary between 70 percent in the eastern two-thirds portion of the plot to 40 percent in the western third of the area. Behind the fixed breakwater, marsh extended across most of the protected 30.5-m area with about 70 percent cover in the stand.

Unprotected treatments. Observations on June 10, 1986, almost two years after planting, revealed some promising results. Of the four replications of five planting treatments, Treatment 5, the Paratex mat, clearly showed the most potential. Two of the four replicated plots receiving the mat had an estimated plant cover exceeding 70 percent (Figure 12). One of the four replicated plots receiving Treatment 2 (the multi-stemmed plants) also had an estimated 70 percent plant cover. Treatments 1 and 4 had previously washed out and treatment 3 had negligible plant cover (less than 5%). Erosion had occurred landward of the plots containing the Paratex mats. These plots appeared as islands about 6 to 9 m from the shore at high tide. Earlier observations on July 30 and August 7, 1985, indicated that scouring was occurring between plots and may have contributed to some plots being washed out.

Figure 12. Smooth cordgrass in fabric mat at Bolivar Peninsula 15 months after planting.

Southwest Pass

Breakwaters. Observations were made at the conclusion of planting on May 19, 1985, and it was noticed that sediment accumulation was occurring rapidly behind each breakwater. By July 24th, an estimated 0.6 meters of land had accreted in depth behind the breakwaters while the shoreline had advanced 6 m seaward to the breakwaters. In contrast, the unprotected area outside the influence of the breakwaters was eroding. The accreted sediment covered many of the plants behind each breakwater. Of the 1056 original plants or plant clumps behind each, only 18 and 66 remained for the fixed breakwater and the FTB areas, respectively.

Visual inspection of the breakwaters on July 24, 1985, and the May, 1985 data showed that the FTB was more effective in damping waves and protecting plants than the fixed breakwater. This is partly because the fixed breakwater sustained some damage. Part of the upper tier of tires, two tire-pole sections, broke loose from the brackets and anchors holding them together. The FTB also was more effective because it did not cause quite as much sediment build-up and smothering of transplants as the fixed breakwater. On July 24-25, 1985, the fixed breakwater damage was partially repaired by cabling the loose ends of the broken sections to the intact portions of the breakwater.

The areas behind the breakwaters were replanted on July 22-24, 1985, because of the plant-smothering effect of the sediment build-up behind the breakwaters. It was assumed that most of the accretion that was going to occur had already occurred. Single-stemmed plants were transplanted behind each breakwater since the breakwaters were still effectively breaking waves despite the damage to the fixed breakwater. The same number of planting locations, 1056 per breakwater area, was used. It was anticipated that with the wave protection offered, single-stemmed plants could become established. This later proved not to be the case because of an unusual succession of hurricanes.

Hurricanes Danny and Elena passed near the project site on August 15 and September 2, 1985, respectively. A site inspection was conducted on September 19. The fixed breakwater sustained major damage with several sections washed ashore and the resulting lack of protection led to transplant washout behind it. Surprisingly, the FTB remained mostly intact although visibly battered. Because of these storms, additional sediment was deposited behind the FTB and no plants could be found, probably because of smothering.

A third hurricane, Juan, hit the Louisiana coast near the site on October 31, 1985. If any plants were to survive behind the FTB as a result of growing through the deposited sediment, this hurricane precluded that possibility. The FTB's anchor straps were broken by the hurricane, and it was washed ashore and partially buried with more sediment.

Unprotected treatments. Observations on May 19, 1985, immediately after planting, showed that 88 to 96 percent of the plants in the single- and multi-stemmed and the burlap-bundle treatments had already washed out. All of the plots containing the plant rolls and Paratex mats were still intact and contained all of the 280 plants or plant clumps.

The site was inspected again on July 22-24, 1985, two months after planting The unprotected plots outside the influence of the breakwaters were eroding while sediment was accumulating behind the breakwaters. The only treatments with remains of plants included the Paratex mat and plant-roll treatments. The plants that were left in the mat (two plots with 2 and 7% survival) appeared to be severely abraded by the sand and waves. The plants in the Paratex-mat treatment had an average of 2 percent survival; in two plots, the mats were in place, but no plants were found. In the plant-roll treatment, there was one washout; in two plots, the rolls were in place with 23 and 31 percent survival, but plant tops were severely abraded; and in the fourth plot, there was 50 percent survival. Average survival in the plant-roll treatment was 26 percent.

Costs

Costs of new planting techniques with plants behind breakwaters when applicable are given below (Table 1).

Table 1. Costs of Planting Treatments*

Treatment	Cost per Plant	Cost/linear Meter (20-m deep)
Single-stemmed plants	$ 0.15	$ 12.00
Multiple-stemmed plants	0.25	16.00
Burlap bundle	0.34	27.00
Plant roll	0.60	48.00
Paratex mat	1.58	126.00
FTB with planted sprigs	1.58	126.00
Tire/pole breakwater with planted sprigs	1.95	154.00

*Costs are based on an hourly rate of $6.00 plus $.10/plant for digging, gathering, and transporting. Cost of materials are included; other direct and indirect costs are not included. Costs per linear meter also assume that plants are placed on 0.5-m centers and are planted in a swatch 20-m wide.

DISCUSSION AND CONCLUSIONS

The results illustrate that marsh grass can become established in areas of moderate wave energies where fetches do not exceed 32 km and where breakwaters or new planting techniques, such as the ones discussed in this paper, are appropriately used. It was evident that both breakwaters and the Paratex mat were successful techniques for establishing marsh at the Bolivar Peninsula site and that the plant roll with single sprigs landward of it was successfully used at Coffee

Island. It should be noted, however, that successful marsh establishment did not occur behind the breakwater areas until replanting and after sediment accretion was thought to have ceased or slowed dramatically.

It was anticipated that the plant-roll treatment would have been successful at Bolivar Peninsula because of its success at Coffee Island and at Gaillard Island. There are two possible explanations for the failure at Bolivar Peninsula. First, plant rolls were placed in relatively small plots instead of extending across the whole site, which made the plots more vulnerable to scour from the sides. At Coffee Island, plant rolls were installed across the entire planting site, which may have prevented scour among plants and provided stability to the plants landward of the plant rolls. Second, the plant rolls were smaller in diameter (10-15 cm) than those used at Gaillard and Coffee Islands (15-25 cm), possibly causing them to wash out much easier.

The site at Southwest Pass represented a worst-case situation where high wave energies prevail because of unlimited fetches from the south. The plants without protection either washed out almost immediately or were abraded to the extent that chance of successful establishment was unlikely. It is noteworthy, however, that two unprotected plots still contained plant rolls after the first two hurricanes.

Despite the occurrence of three hurricanes less than two months apart after planting, some planting and plant-protection treatments showed potential even though no long-term plant establishment was accomplished. It was not until Hurricanes Danny and Elena hit that severe damage resulted to the fixed breakwater; the FTB was still intact and functional after the second hurricane, Elena. Additionally, there were still a few plants in plant rolls in unprotected plots after these two hurricanes, even though other unprotected treatment-plots were missing.

This leads to the conjecture that had such severe storms not occurred in such close succession and if plant rolls instead of single stems had been placed behind the breakwaters after sediment accretion had ceased, plants may have become established. Certainly, the single-stemmed transplants and plant rolls placed behind the breakwaters at Bolivar Peninsula were successfully established when replanted after the apparent cessation of sediment accretion. Because plants were placed prior to completion of the sedimentation process and because hurricanes destroyed the integrity of the breakwaters, the plants really never had a good chance to develop. In a normal year at Southwest Pass and if plants had more time to develop behind breakwaters without the hurricane conditions experienced in 1985, they could probably become established given occasional severe conditions. However, for marsh to remain in the area over a long period, plants likely would continue to need wave protection.

Costs of treatments discussed in this paper are very reasonable for the combined benefits of stabilization and wetland habitat creation. They are but a fraction of the costs of traditional structural means of stabilization, such as riprapped revetments (Allen & Webb 1983).

ACKNOWLEDGEMENTS

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METHODOLOGY FOR RESTORING IMPOUNDED COASTAL WETLANDS

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ABSTRACT

Coastal wetlands have undergone major changes due in part to the creation of coastal impoundments. For various reasons--including coastal development, farming, and waterfowl hunting--areas which were once thriving salt marsh have been impounded by roads and dikes. This has resulted in an increase in fresh water concurrent with a loss in salt marsh vegetation and replacement by freshwater and brackish water species.

This paper describes the methodology used to restore such impoundments to their original salt marsh state using examples from the southeastern United States. Methods include:

1. Detailed studies of local hydraulics resulting in the production of a numerical flow model.

2. Detailed wetlands transects establishing local elevations (relative to mean sea level) for optimal growth of important species.

Field studies included a survey of tidal creek and channel cross-sections, measurement of current velocities and tidal elevations at various stations, water quality measurements, and surveys across impounded and natural wetlands to determine species zonation, substrate and species elevation, and sediment type (by coring). The resulting numerical flow model was combined with these data to produce a management plan for improvement of wetlands and application to mitigation for developers.

INTRODUCTION

The impoundment of coastal waters in the United States has resulted in the loss or alteration of large areas of wetlands and has created a controversy. The controversy centers on the following questions:

1. Does the impoundment of wetlands result in decline of productivity in these or nearby wetlands?

2. Are aquaculture and waterfowl hunting adequate reasons for creating impoundments from wetlands?

3. Should existing impoundments be maintained or repaired, or should they be allowed to return to natural marsh?

4. What happens to impoundments when tidal flushing is restored?

The state of South Carolina is currently being used as a testing ground to help answer these questions. As shown in Figure 1, the state currently has some of the most extensive coastal wetlands in the United States, including over 70,000 acres of impoundments (Tiner 1977). Most of the impoundments which occupy the coastline (Fig. 2) are a result of rice culture which took place in the 18th and early 19th centuries (reviewed by DeVoe 1982). The ending of the civil war and other factors halted rice culture, but impoundments soon became popular as natural duck hunting areas. Management of these impoundments became important for ongoing use in duck hunting operations which continue today (Fig. 3). Recent controversies arose when landowners attempted to reimpound wetlands for use in waterfowl hunting or aquaculture. State and federal agencies opposed this practice and generally denied permit applications to reimpound wetlands. Lawsuits were filed from landowners who have "king's grants" over their wetlands or who have had waterfowl hunting operations in the past. To attempt to solve the problems and answer some of the controversial questions, South Carolina Sea Grant recently completed a coastal wetland impoundment project, the results of which will be released soon. The project addresses the productivity of impoundments versus natural wetlands, and it provides needed information on which to base future management decisions.

Most recently, coastal developers have added to the controversy by wanting to use costal impoundments on their property for purposes other than duck hunting and aquaculture. They want them to look aesthetically pleasing to property owners. They want them managed as golf course ponds or other architectural uses. Concurrent with these uses is a fortunate realization by property owners that vegetated coastal wetlands are attractive and interesting, and that living near a salt marsh has benefits similar to living near the ocean. The results of these views are that developers frequently desire impoundments to be restored to natural salt marsh as opposed to less productive and less visually pleasing cattail impoundments. If done correctly, restoration provides improved views for the developer and enhanced productivity for the local environment. It also provides the developer with mitigation for necessary, water-related alterations to other wetlands.

The restoration of tidal flushing to impoundments creates problems, however. Workers have seen problems with acid sulfate soils, called "cat clays" by the Dutch, in many areas of the world (Hart 1959; Dost 1973; Moorman 1973; Saenger et al. 1983). Toxic runoff, fertilizer inefficiency, hyperacidity, high aluminum concentration, and generally low productivity are associated with flushing these soils (Saenger, et al. 1983). In South Carolina, Czyscinski (1975) studied cat clays and found similar problems due to the oxidation of iron sulfides to pyrite, as summarized in the following reaction:

$$FeS_2 + O_2 \xrightarrow{drying} KFe_3(SO_4)_2(OH)_6(\text{Jarosite}) \xrightarrow{wetting}$$

$$K^+ + 2SO_4 = + 3Fe(OH)_3 + 3H^+$$

Czyscinski determined that marsh muds growing Spartina alterniflora, Juncus roemerianus, and ecologically similar species which had sulfur contents greater than 0.75 percent were very likely to result in cat-clay formation upon drying and reemersion (Fig. 4). The primary methods he found of avoiding this problem where to prevent drying for over four months and provide adequate tidal flushing following restoration.

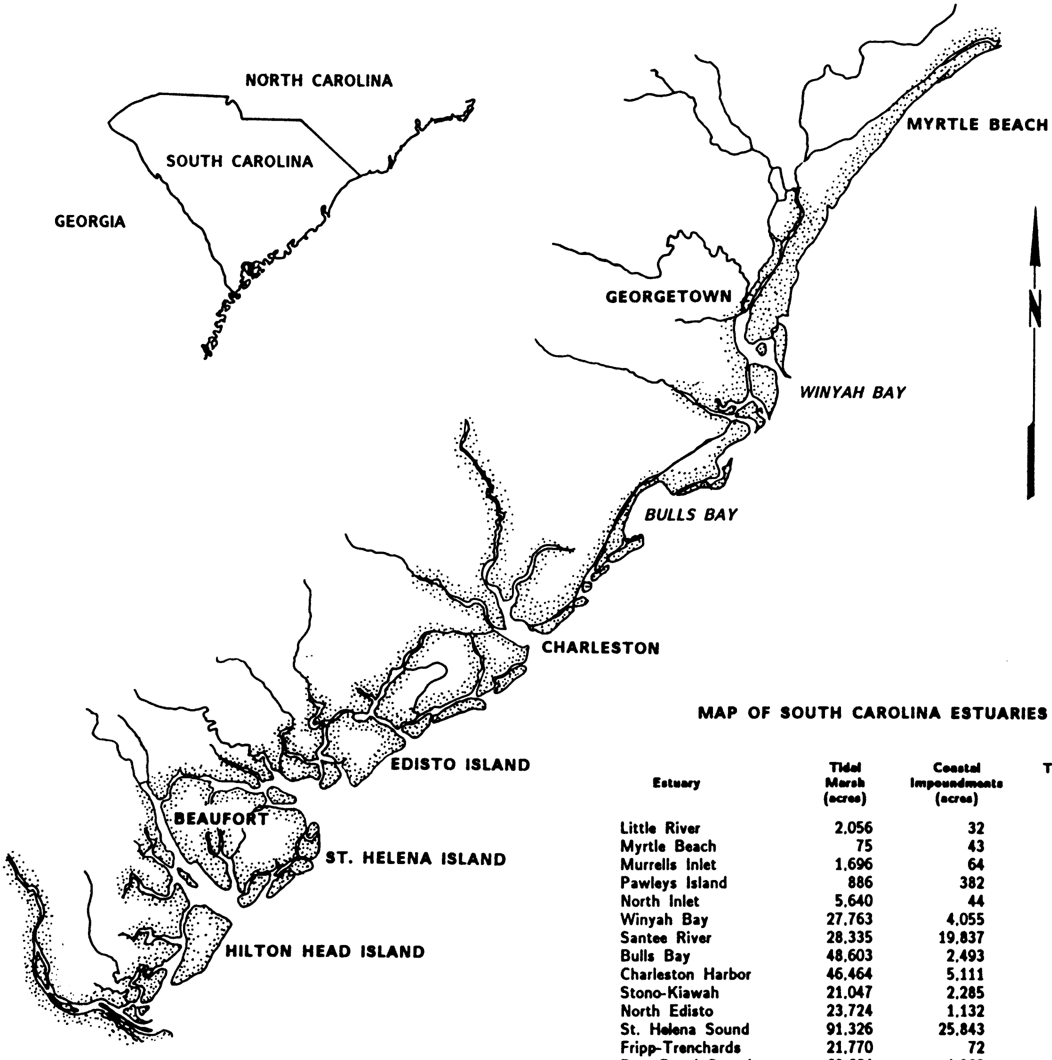
Two case studies were used to determine whether other similar problems arise when tidal flushing is restored to impoundments. The first was an area that was impounded, restored, impounded again, and restored to tidal flushing again--all within a ten-year period. The vegetation was typical for the area except for larger diversity because of elevation changes resulting from excessive human activity. The other case is of an old impoundment on which the dikes deteriorated and allowed flushing. Vegetation returned to normal, indicating that problems in these impoundment were uncommon in natural situations.

METHODS

Understanding the nature of the soils, vegetation, and water is critical to proper restoration. Using methodology developed for sea level rise studies along the eastern U.S. coast (Kana et al. 1986a,b), plant elevations can be established, and a predictive model can be produced (Baca et al. 1986). A particular marsh species grows at different elevations in different locations, depending upon tidal range and other factors. Numerous examples are available of planted vegetation not succeeding because of elevation being in error by as little as a few centimeters (Figs. 5 & 6).

Using standard survey methods (rod and level), transects (less than 1,000 ft.) are run across a functional marsh in the immediate vicinity of the area to be restored. The beginning, center, and ending of vegetation zones are tied to elevation. If reliable benchmarks are available, the elevation can be based on mean sea level datum (such as 1929 National Geodetic Vertical Datum). Otherwise, elevations can be surveyed at a precise tidal period, such as slack low tide. The restoration site must be surveyed at the appropriate time within a few days.

Using elevations, distance, and vegetation, the modal elevation and areal coverage of each species are determined (Table 1). A composite transect can thus be drawn (Fig. 7) which shows the expected vegetation, tidal flat, and open water in a "typical" area. The vegetation and appearance of a restoration site can then be predicted with a high degree of accuracy. Modifications to the restoration site can then be made to achieve a certain productivity and appearance.



MAP OF SOUTH CAROLINA ESTUARIES

Estuary	Tidal Marsh (acres)	Coastal Impoundments (acres)	Total Coastal Marsh (acres)
Little River	2,056	32	2,088
Myrtle Beach	75	43	118
Murrells Inlet	1,696	64	1,760
Pawleys Island	886	382	1,268
North Inlet	5,640	44	5,688
Winyah Bay	27,763	4,055	31,823
Santee River	28,335	19,837	48,172
Bulls Bay	48,603	2,493	51,096
Charleston Harbor	46,464	5,111	51,575
Stono-Kiawah	21,047	2,285	23,332
North Edisto	23,724	1,132	24,856
St. Helena Sound	91,326	25,843	117,169
Fripp-Trenchards	21,770	72	21,842
Port Royal Sound	69,624	1,329	70,953
Calibogue Sound	16,483	113	16,596
New-Wright	20,846	1,688	22,534
Savannah	7,551	4,321	11,972
Total	**433,994**	**70,451**	**504,445**

Figure 1. Summary of wetlands along the South Carolina coast.

Figure 2. Impoundments being managed for various uses along the coast of South Carolina.

Figure 3. Impoundment being managed for duck hunting. Water is kept brackish (<15 ppt) which stimulates the growth of *Scirpus* spp., *Eleocharis* sp., and *Ruppia maritima*.

Figure 4. Beginning formation of hard, acidic "cat clays" during drying of a coastal impoundment.

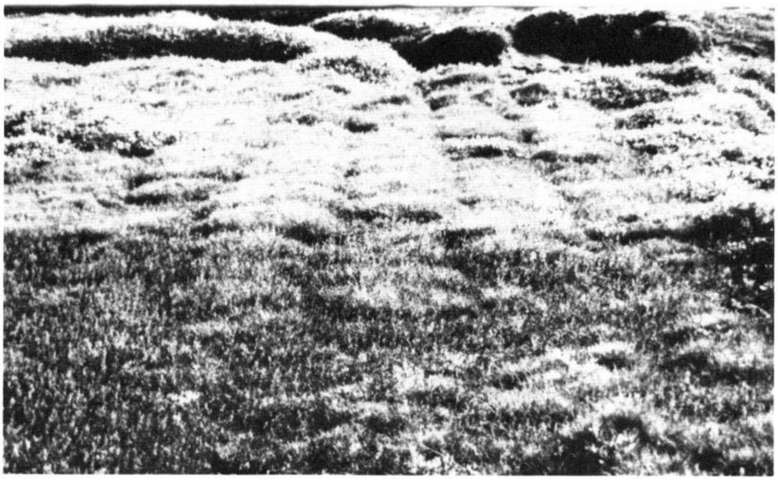


Figure 5. Successful planting of marsh species as a result of proper elevation selection.

Figure 6. Marsh in same area which has not spread six years after planting because of elevation being 5 cm too low.

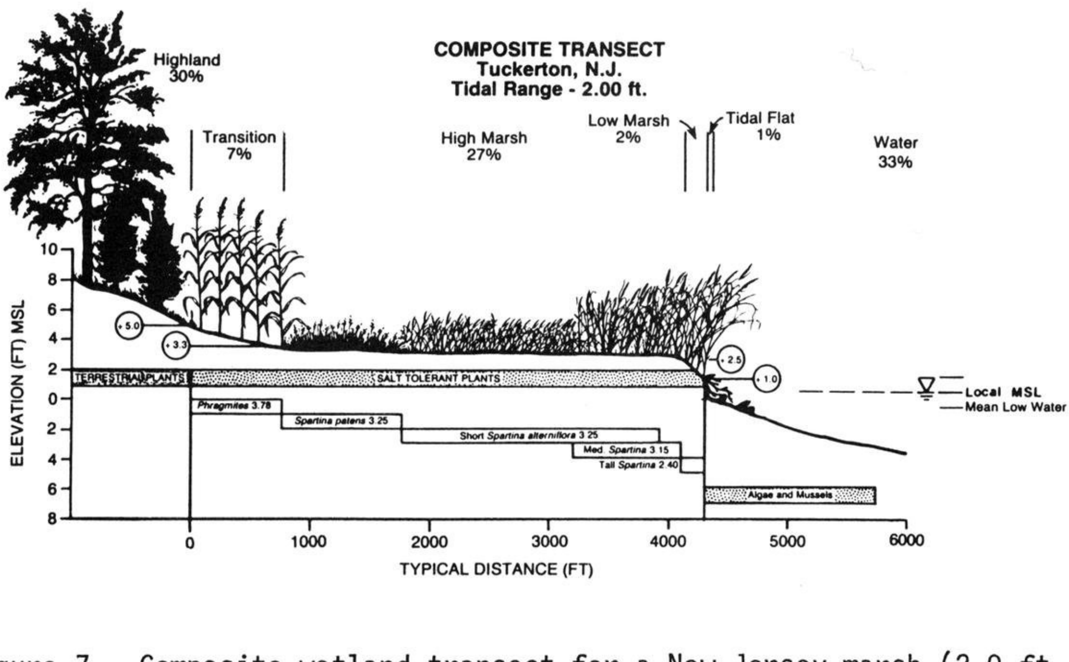


Figure 7. Composite wetland transect for a New Jersey marsh (2.0-ft. tide range), illustrating the approximate % occurrence and modal elevation for key indicator species or subenvironments based on surveyed transects.

Table 1. Sample computation of modal elevation for various marsh species from a New Jersey site (tide range = 2.0 ft. MSL).

Species	Modal Elevation (Ft. MSL)	Standard Deviation	Number Observed >1%	Percentage Occurrence Composite
Spartina patens	3.04	0.36	8	23
Short S. alterniflora	2.98	0.27	7	49
Medium S. alterniflora	2.99	0.37	5	20
Tall S. alterniflora	2.40	0.18	3	4
Iva fructescens	2.75	0.31	2	2
Panicum spp.	4.30	0.51	3	3
Salicornia spp.	2.85	0.23	2	2
Limonium carolinianum	2.83	0.12	2	3
Pluchea purpurescens	--	--	0	<1
Phragmites communis	3.78	0.23	6	17
Ruppia maritima	1.82	0.25	2	2
Distichlis spicata	3.09	0.38	4	11
Juncus gerardi	--	--	0	<1

Once a particular elevation and design are decided upon, the next step is a hydraulic analysis of local waters. This should include current velocity measurements, channel cross-sections, and tide ranges taken at stations along connecting channels or waters in the vicinity of the restoration site (Fig. 8). Sediment cores for grain size and pollutant analysis, and water quality analysis should be conducted in area and impoundment waters.

These data are then used to develop a hydraulic model of flushing potential in adjacent waters. Details are in Siah (1986) and are based on the finite-element method. Flushing (as discharge and velocity) is computed for open channel and various control structures to determine the most efficient method of restoring tidal flow to the impoundment. Salinity can be used as a measure of flushing and water quality, and the distribution within an impoundment can also be determined with various control structures (Fig. 9).

CONCLUSIONS

Obtaining local, site-specific data relative to elevation is most important for successful restoration. In impoundment restoration, we found that vegetation and hydraulic analyses, culminating in a hydraulic flow model, can aid in the design of wetlands and can insure their productivity and utility. We suggest that elevation and hydraulic data be an integral part of any similar restoration projects.

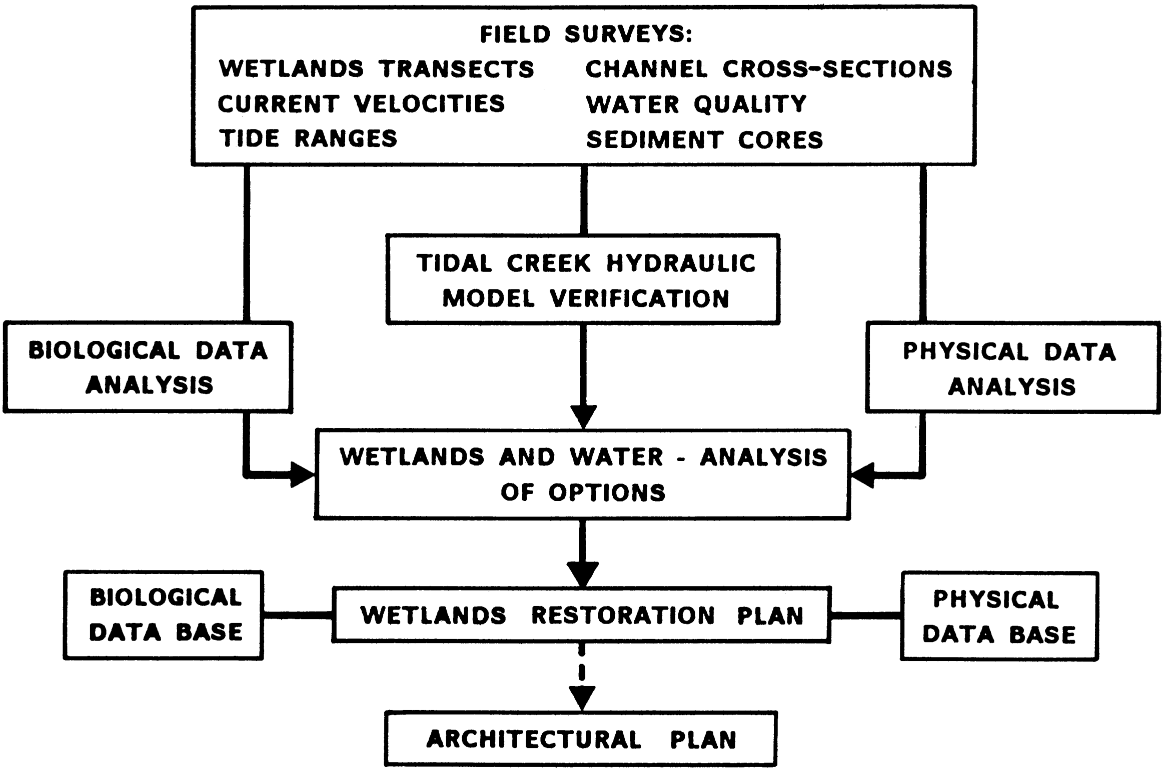


Figure 8. Flow diagram of the procedures for obtaining vegetation and hydraulic information for restoration.

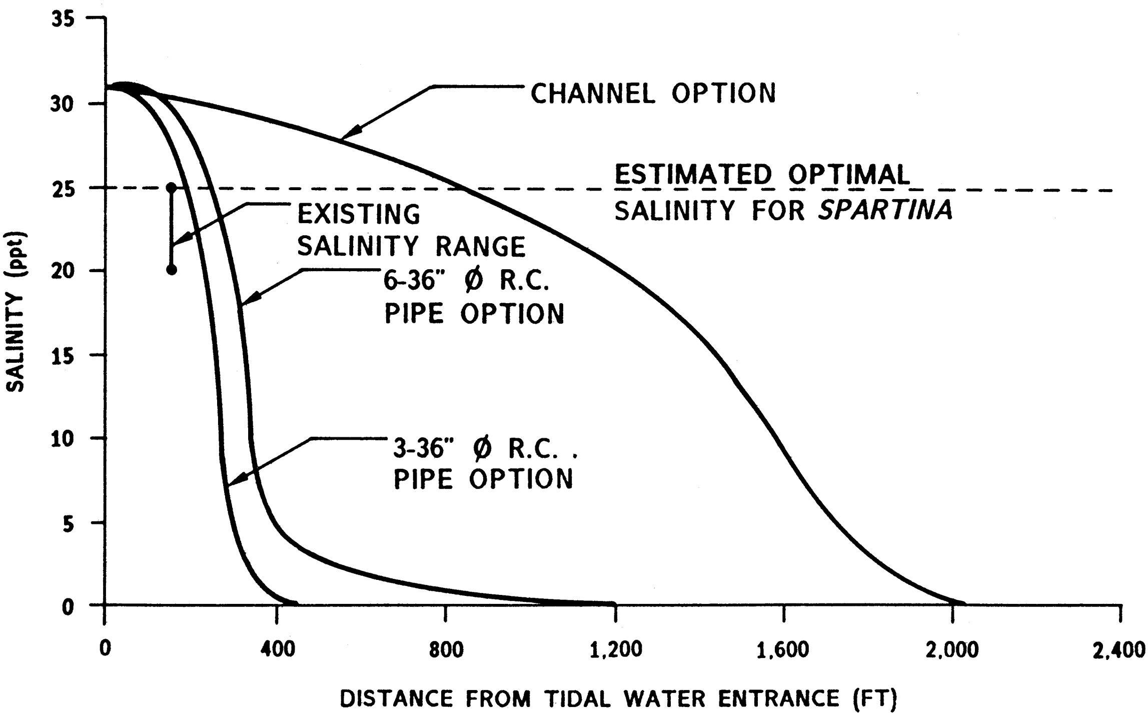


Figure 9. Sample computation of salinity distribution in a restoration area based on the hydraulic model.

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THE ECOLOGICAL IMPACT OF A TERRAFIX CROSSING UPON A FRESHWATER STREAM

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ABSTRACT

Roads constructed for patrol and maintenance purposes are located within Florida Power and Light Company transmission line corridors. These roads often transverse riparian wetland systems where either bridges or culverts are utilized at crossings. In an effort to explore viable alternatives to these traditional crossings, a Terrafix system was installed in the Myakka-Rotunda right of way at Ainger Creek, Sarasota County. Terrafix consists of laying interlocking concrete blocks over a three dimensional geotextile fabric. The purpose of this study is to measure the impact of the Terrafix crossing upon water quality, flow, and wetland plant communities associated with the stream. The period of this study was 17 months, beginning in June of 1984 and continuing through November of 1985. Results indicate a minimal impact of the crossing upon the vegetation and hydrological regime of Ainger Creek.

INTRODUCTION

The Florida Power and Light Company (FP&L) has demonstrated a concern regarding the possible harmful effects upon wetland systems resulting from powerline corridor construction and maintenance. In an effort to assess the significance of these activities and to explore less harmful alternatives, FP&L instituted a number of research projects directed toward assessing the ecological impact of powerline corridor construction and maintenance upon wetland systems. FP&L has also initiated a number of experimental alternatives to present methods.

One of these projects was a Terrafix crossing at Ainger Creek in Sarasota County. It was hoped that using Terrafix rather than culverts would allow a natural flow of water across the corridor. The following is an impact assessment of the crossing upon riparian wetlands along the Myakka-Rotunda corridor at Ainger Creek.

SITE LOCATION AND DESCRIPTION

The site is located within the FP&L Myakka-Rotunda 115 transmission line at the south fork of Ainger Creek in Sarasota County (Fig. 1). The south fork of Ainger Creek meanders through a slash pine palmetto community which was heavily grazed throughout the period of this study. Grazing was more extensive upstream than downstream and caused a skewing of vegetation data. Historically, Ainger Creek has been dredged for agricultural purposes. It is not certain when dredging was done, but it is estimated by tree and shrub size that dredging upstream of the crossing occurred within the past 5 to 7 years and downstream within the past 10 to 12 years.

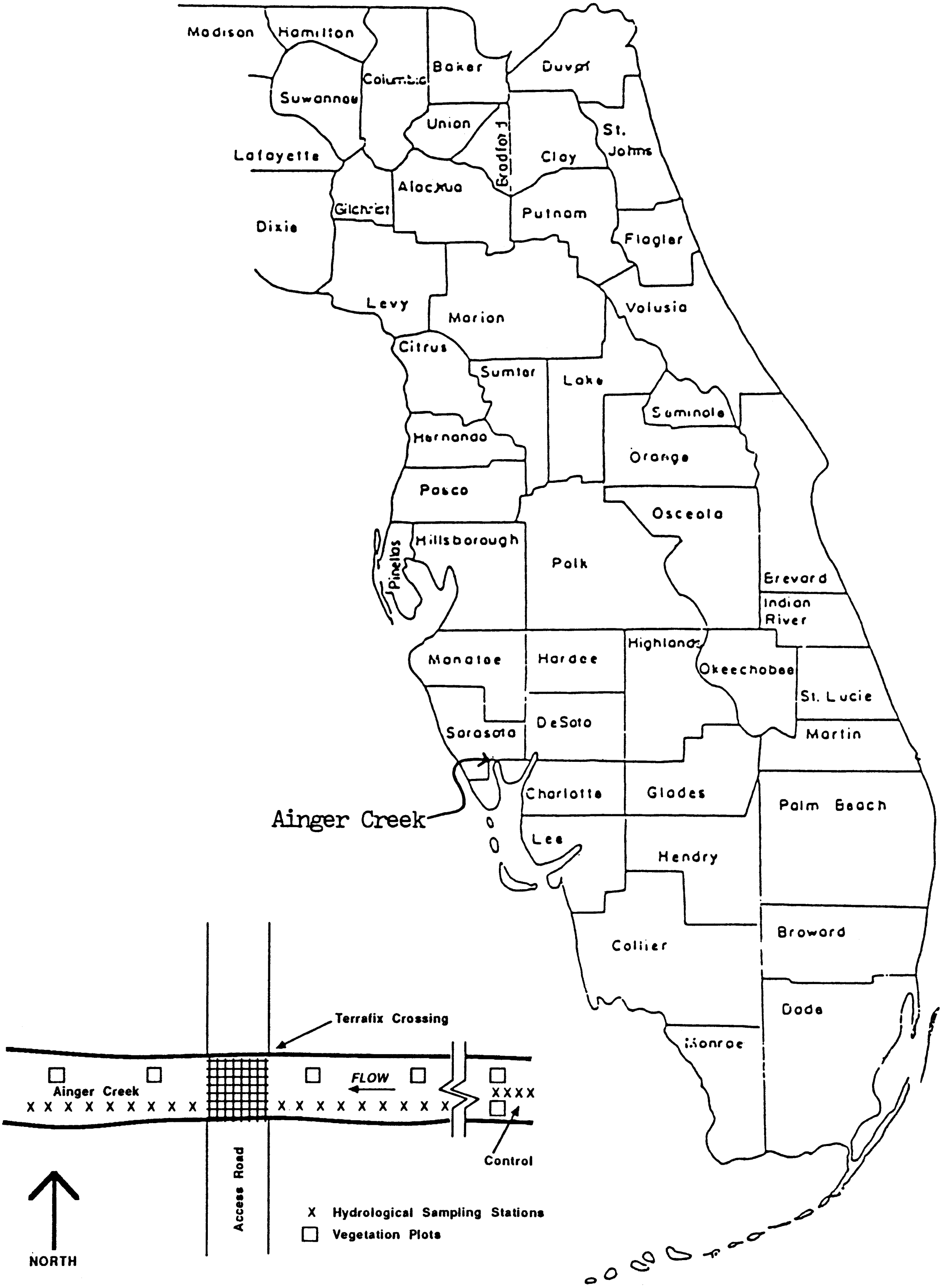
METHODS

In June of 1984, a total of 18 hydrological sampling stations were established at 25 meter intervals. Nine stations were located upstream of the crossing and nine downstream. Four one-meter-square vegetation plots (Daubenmire 1986) were randomly located along the transect--two upstream and two downstream. Four sampling stations and two one-meter-square vegetation plots were established 300 meters upstream of the crossing to function as a control.

The following physical, chemical, and biological parameters were measured:

Hydrology	Water Quality	Vegetation
Flow	Temperature	Density
Depth	pH	Relative density
	Dissolved oxygen	Dominance
	Conductivity	Relative dominance
	Turbidity	Frequency
		Relative frequency

Figure 1


Madison
Hamilton
Baker
Suwannee
Union
Lafayette
Clay
St. Johns
Alachua
Putnam
Dixie
Flagler
Levy
Marion
Volusia
Citrus
Sumter
Lake
Seminole
Hernando
Orange
Pasco
Osceola
Pinellas
Hillsborough
Polk
Brevard
Indian River
Manatee
Hardee
Highlands
Okeechobee
St. Lucie
Sarasota
DeSoto
Martin
Charlotte
Glades
Palm Beach
Ainger Creek
Lee
Hendry
Broward
Collier
Dade
Terrafix Crossing
Ainger Creek
FLOW
Control
Access Road
NORTH
X Hydrological Sampling Stations
Vegetation Plots

Data were analyzed by using the following formulae (Cox 1979):

$$\text{density} = \frac{\text{number of individuals}}{\text{area samples}}$$

$$\text{relative density} = \frac{\text{density for a species}}{\text{total density for all species}} \times 100$$

$$\text{dominance} = \frac{\text{total of basal area of areal coverage value}}{\text{area samples}}$$

$$\text{relative dominance} = \frac{\text{dominance for a species}}{\text{total dominance for all species}} \times 100$$

$$\text{frequency} = \frac{\text{number of plots in which species occurs}}{\text{total number of plots sampled}}$$

$$\text{relative frequency} = \frac{\text{frequency value for a species}}{\text{total of frequency values for all species}} \times 100$$

Pre-construction data were collected in June, July, and August of 1984. Construction began on August 21 and the during construction data were collected August 22 and 23. Additional construction data were collected on October 8 during grouting of portions of the Terrafix which was deflected during testing in August. Post-construction hydrology and water quality data were collected between June, 1984, and November, 1985, with vegetation data being collected in August, 1984, and April and September of 1985.

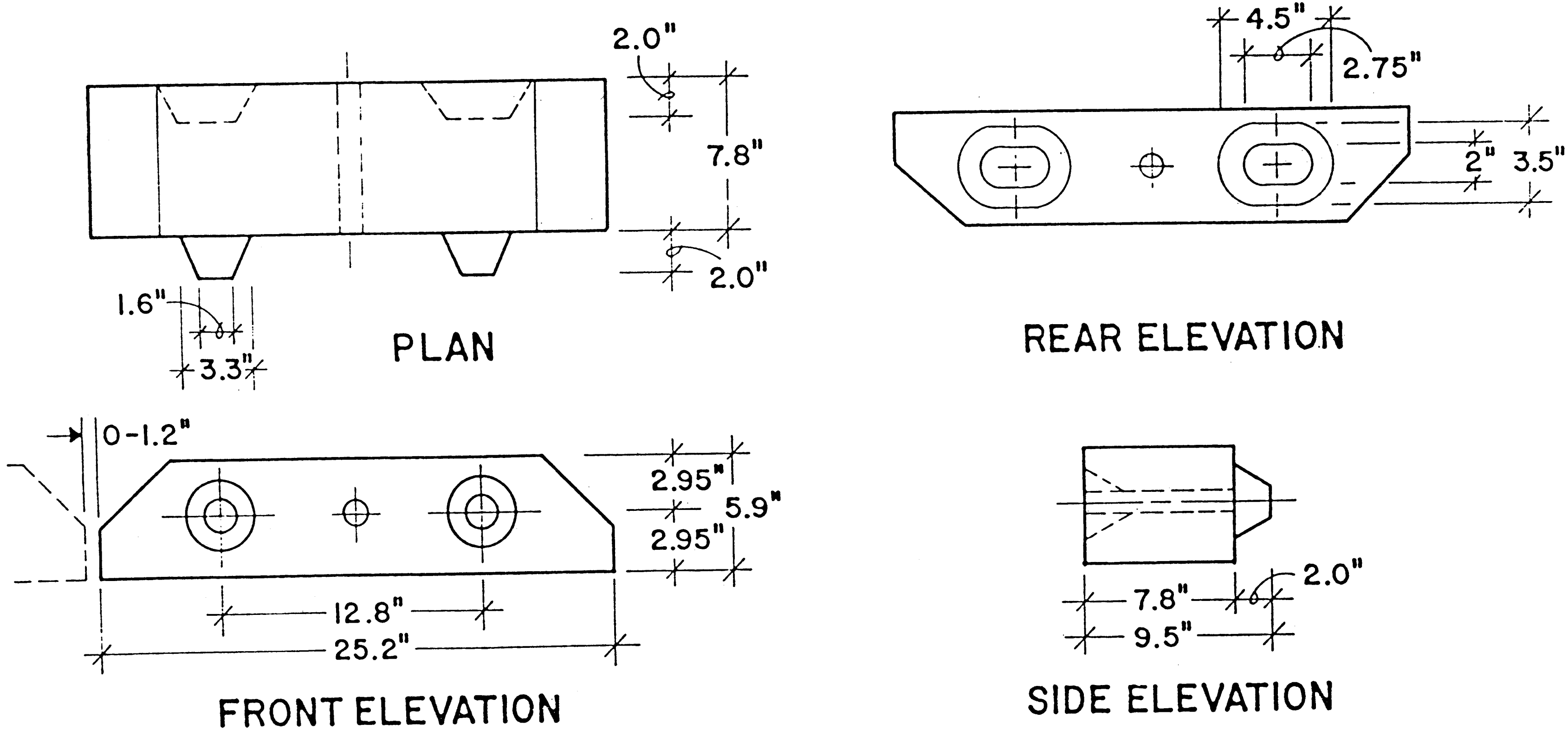
CONSTRUCTION

Erosion Masters of Miami, Florida, was awarded a contract from FP&L to construct the Ainger Creek crossing. Construction began August 21, 1984, and was completed on August 27, 1984. The site was graded by a bulldozer with enough of the stream bed being removed to assure the crest of the Terrafix would not be above the natural elevation of the stream bed. This is essential to maintain the natural rate of water flow. The geotextile fabric was then laid and the excess was trimmed. Next, the Type T60 concrete Terrafix blocks (Fig. 2) were installed by hand and anchored at both ends and at the edges into a 3 foot deep ditch with 5/16 inch Duravet polyester cable threaded through each block (Fig. 3). Upon completion of the block installation, the ditch was filled.

A loaded dump truck weighing approximately 15 tons was used to test the crossing on August 31, 1984. The truck crossed the site 10 times resulting in a deflection of the Terrafix blocks in an area of about 30 feet on both the north and south sides of the crossing. Concerns arose regarding the possible damage to truck tires as a result of the deflection. After thirty days of evaluation, it was decided that the deflection portion of the crossing would have to be grouted to stabilize the blocks. On October 8, 9, and 10 of 1984, the crossing was grouted. Holes were drilled through the concrete block and grout

Figure 2

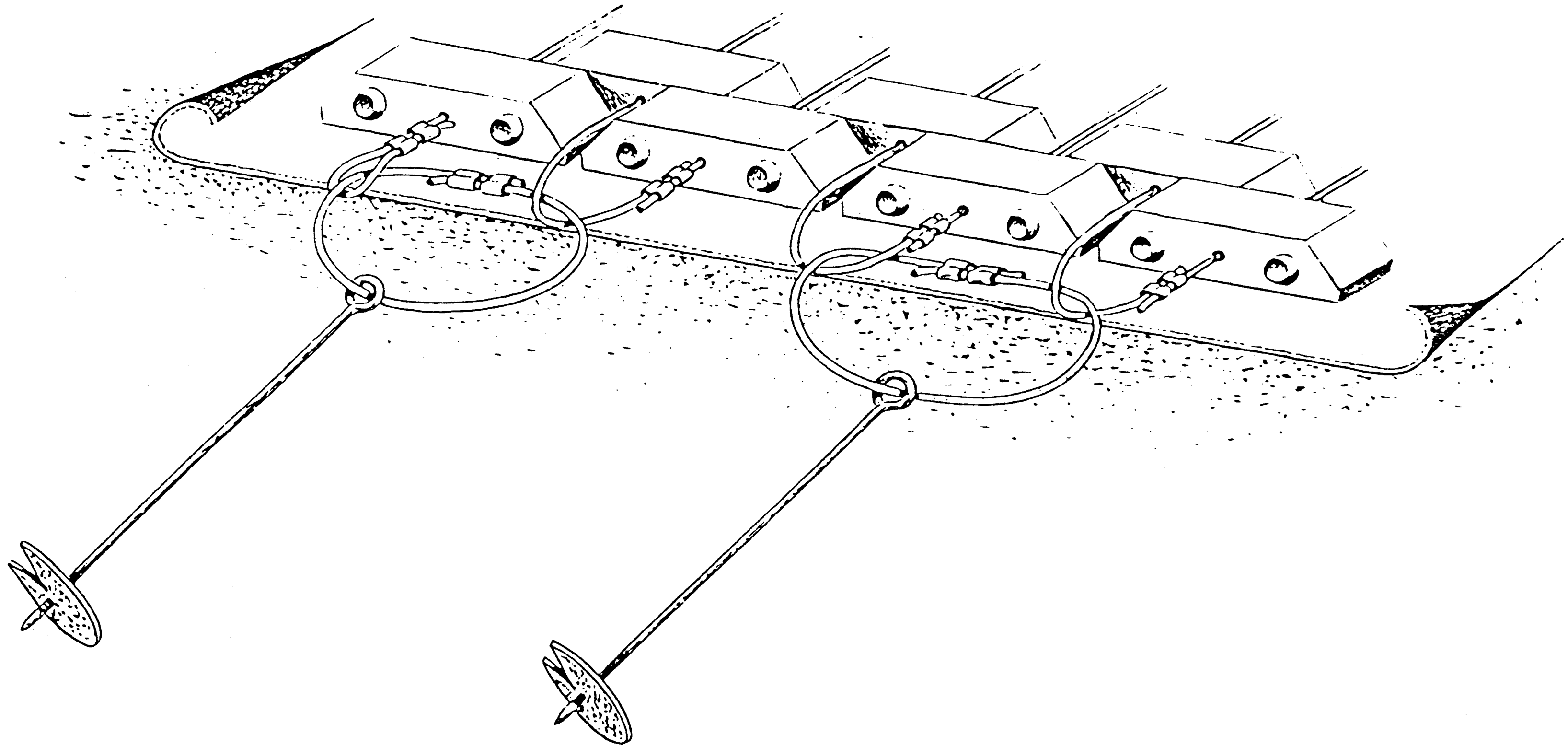
INTERLOCKING CONCRETE BLOCK
TYPE T 60



Source: Erosion Masters, Miami, Florida

Figure 3

THE TERRAFIX SYSTEM



Source: Erosion Masters, Miami, Florida

pumped 4 to 6 feet below the ground surface until the deflection was corrected. In subsequent projects where Terrafix was used on FP&L sites, 4 to 6 inches of rock was used as a base and placed between two layers of the geotextile fabric sewn together to create a pillow effect. The Terrafix blocks were then installed on the upper layer of fabric.

RESULTS

Past dredging of Ainger Creek resulted in a more gradual decrease of elevation profile downstream than upstream. As water levels began to drop in December of 1983, water was impounded upstream at stations 3, 4, 6, and 8. This was a function of high relative elevations at stations 2 and 7 and not a result of the crossing elevation (Fig. 4). By February 28, 1985, there was no water flow at the site and water levels had dropped below the surface of the stream bed by mid-March of 1985. Surface water was again present in the stream and flowing by early June of 1985.

Post-construction flow data indicated no substantial changes from pre-construction findings (Fig. 5). However, inflated data were collected due to a 1.7 inch rainfall event which occurred during construction. The higher mean rate of flow downstream was undoubtedly a result of a gradual drop in elevations between stations 2 and 9. In contrast, variable elevations upstream tended to decrease the mean flow rate. A comparatively lower mean flow rate was noted downstream after the 1.7 inch rain. This lower rate was due to higher flow rates at stations 2, 5, 7, and 9 upstream. An examination of Figure 4 indicates extreme decreases in elevations at these stations resulting in higher flow rates during high water levels. Flow data revealed no significant impact of the crossing at Ainger Creek.

As with water flow, greater depth readings were recorded during the 1.7 inch storm event at the time of construction. Lower preconstruction depth findings were due to a drier than normal wet season in 1984. Also, pre-construction water depth profiles indicate no impact as a result of the crossing (Fig. 6).

Water Quality

Preconstruction temperatures reflect higher averages because data were collected in June, July, and August of 1984 while post-construction data were collected through the entire wet season of 1985 (Fig 7). As one would expect, yearly averages were lower compared to a three month period during the summer months. Slightly lower temperatures were recorded downstream where a complete canopy with relatively mature vegetation was present. However, upstream temperatures reflected a more open situation with little or no shade. Upstream and downstream data indicated no significant impact upon temperature.

Figure 4

CROSSING AND STREAM BED ELEVATIONS

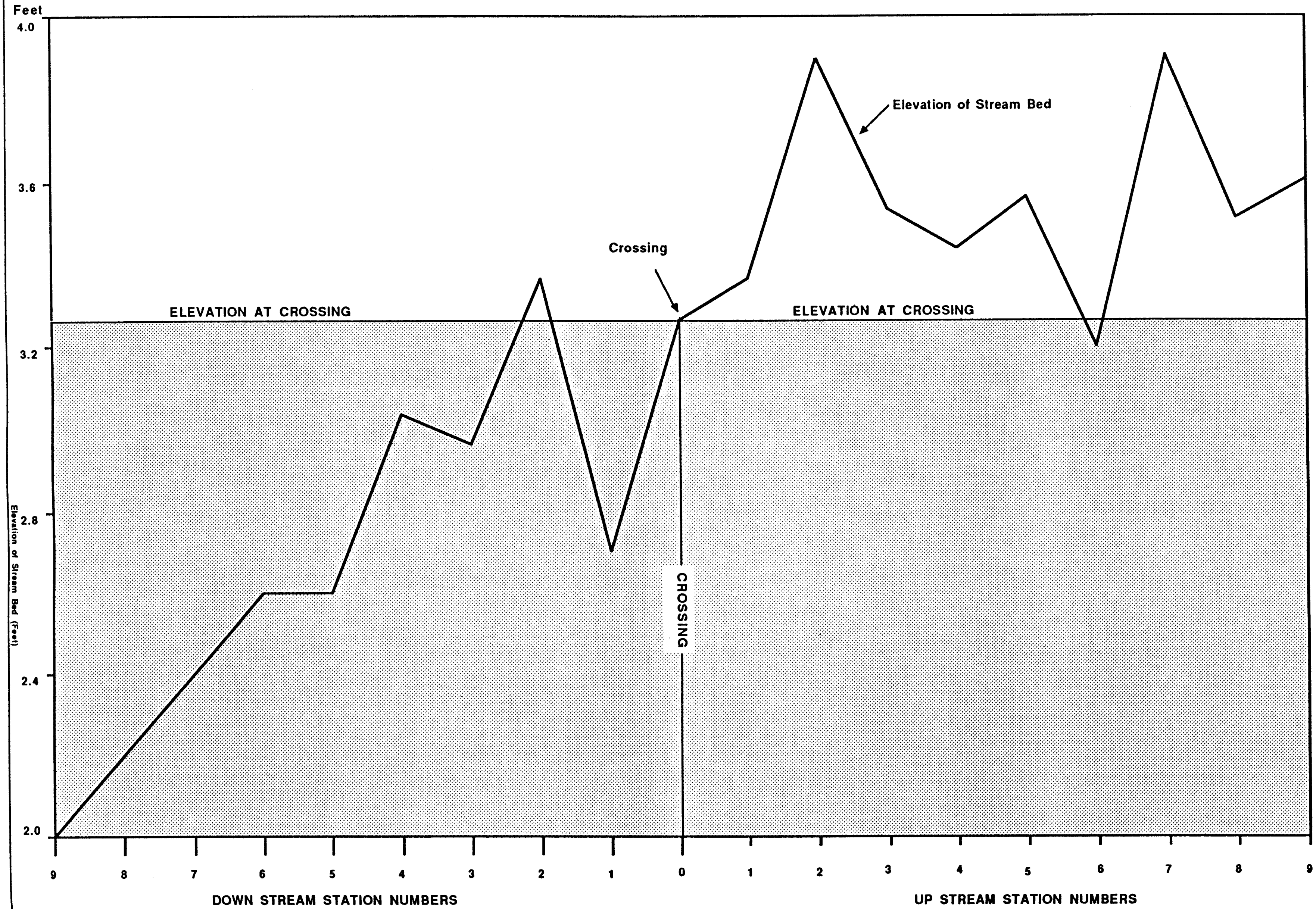
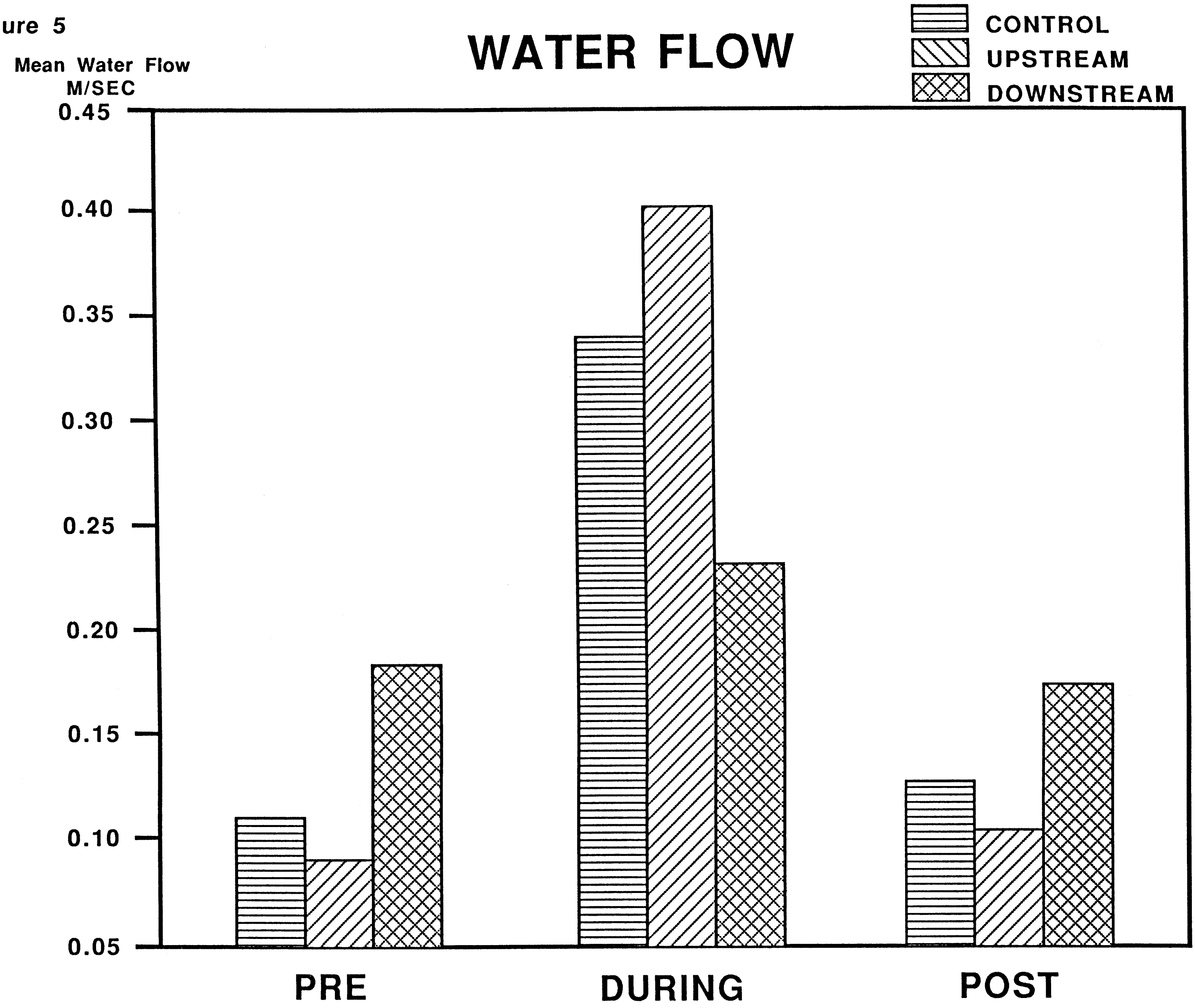


Figure 5


WATER FLOW
Mean Water Flow
M/SEC
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
PRE
DURING
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CONTROL
UPSTREAM
DOWNSTREAM

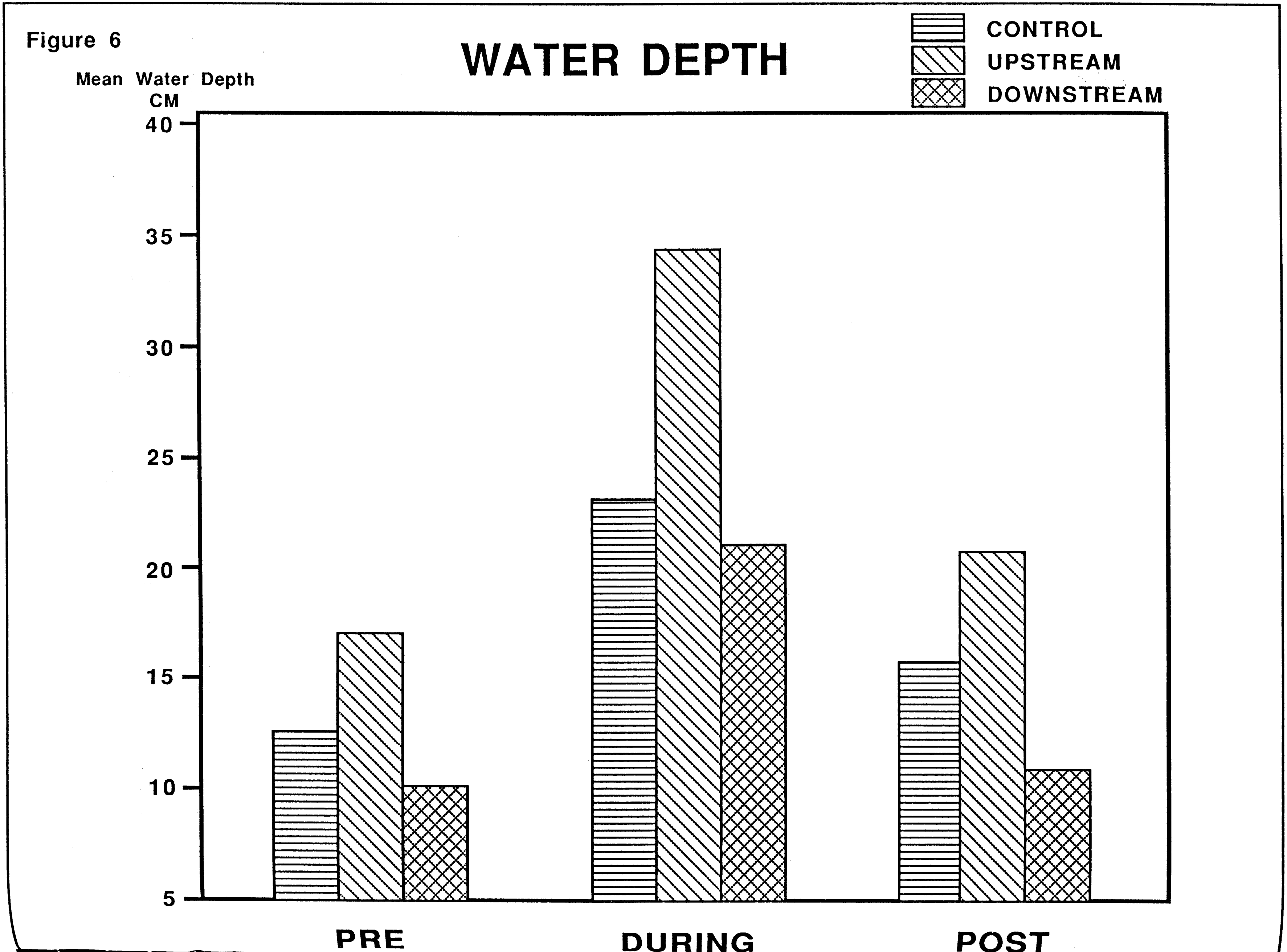

Figure 6
WATER DEPTH
Mean Water Depth
CM
CONTROL
UPSTREAM
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40
35
30
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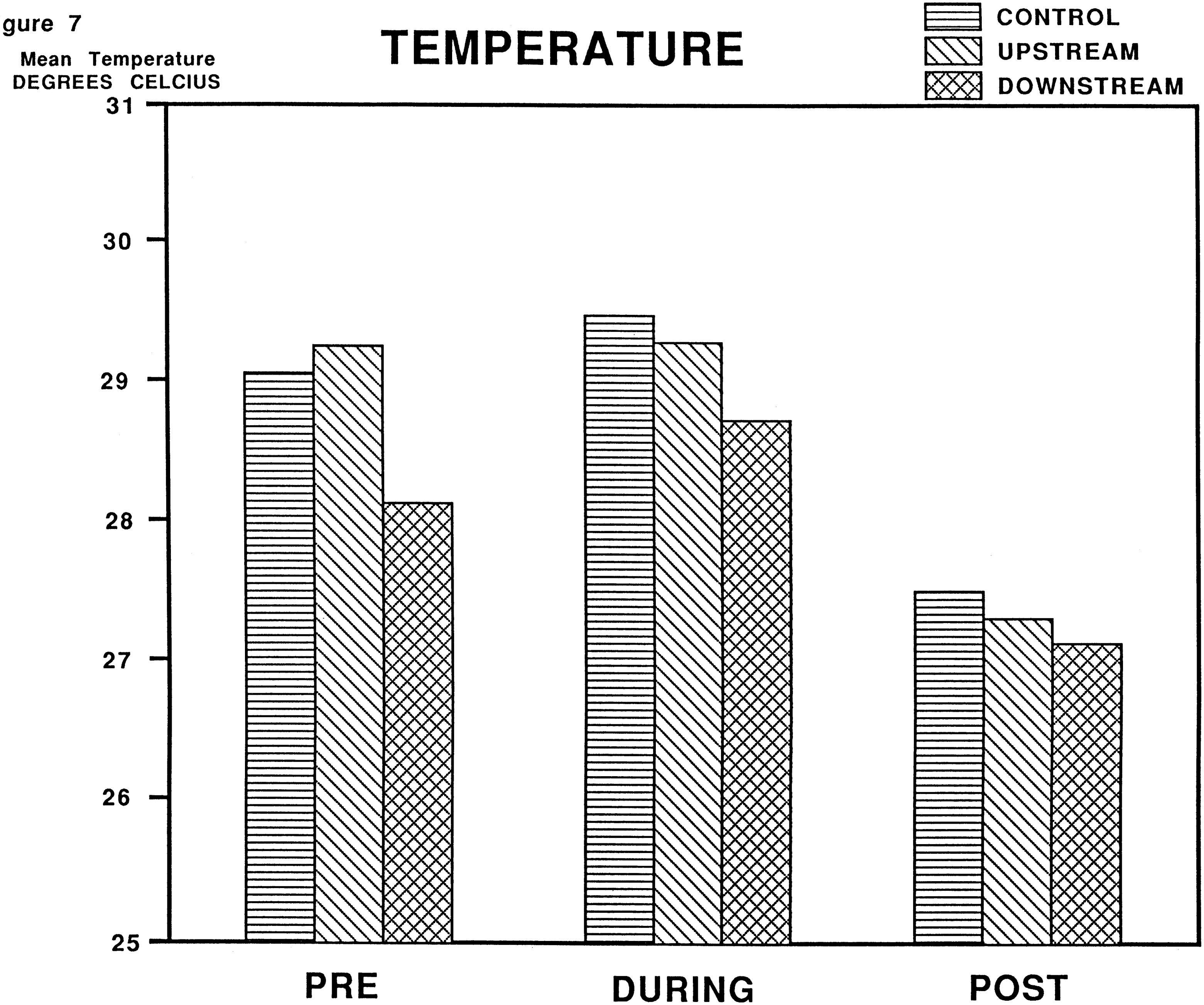
Figure 7


TEMPERATURE
CONTROL
UPSTREAM
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DEGREES CELCIUS
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29
28
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25
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The pH values at the site have been influenced by dredging which created an effluent stream where the bed of the stream after dredging was below the water table. Water seepage through limestone substrate into the stream probably resulted in a more alkaline pH than would normally be expected. This is especially evident during low water periods when seepage into the stream is at its peak. Pre-construction pH data support the condition as data were collected while water levels were abnormally low. This explanation is conjecture and not within the research parameters established for this study. Although pH values varied between pre- and post-construction conditions, there was no significant difference between upstream and downstream data indicating no impact upon pH as a result of the crossing (Fig. 8).

A significant correlation between depth and dissolved oxygen is seen with the pre and during construction data collected while water levels were low (Fig. 9). However, dissolved oxygen values collected throughout the wet season of 1985 were higher because data were collected over a longer period during higher flow rates. The upstream and downstream dissolved oxygen values before and during construction reflect differences due to higher water depths upstream. No significant impact upon dissolved oxygen was evident as a result of the crossing.

Conductivity values were higher, as would be expected, after the 1.7 inch rainfall event during initial construction and lower values were recorded with decreased flow rates before construction (Fig. 10). As with dissolved oxygen, post-construction conductivity values were higher than pre-construction because sampling of post-construction data was done throughout the wet season of 1985. Conductivity data collected upstream and downstream of the crossing reveals no significant impact.

Turbidity values were highest downstream during construction (Fig. 11), then dropped to below 3.5 nephelometric turbidity units (NTU) the following day. The grouting operation resulted in temporary turbidity values in excess of 100 NTU. The use of bales of hay and geotextile fabric to contain turbid water met with limited success. The bales of hay washed downstream and the fabric was not permeable enough to allow the passage of water and resulted in damming water upstream at the crossing. Turbidity control measures would have been more effective had the storm not occurred during construction. Although turbidity data were high, as expected, during construction, it was a short term impact and not considered significant. The crossing has had no long term impact upon turbidity.

Control data for hydrology and water quality parameters did not vary significantly between upstream and downstream values. Pre-, during, and post-construction control data fell within the range expected.

Vegetation data were collected before construction in August of 1984 and after construction in April and September of 1985. Once the

Figure 8

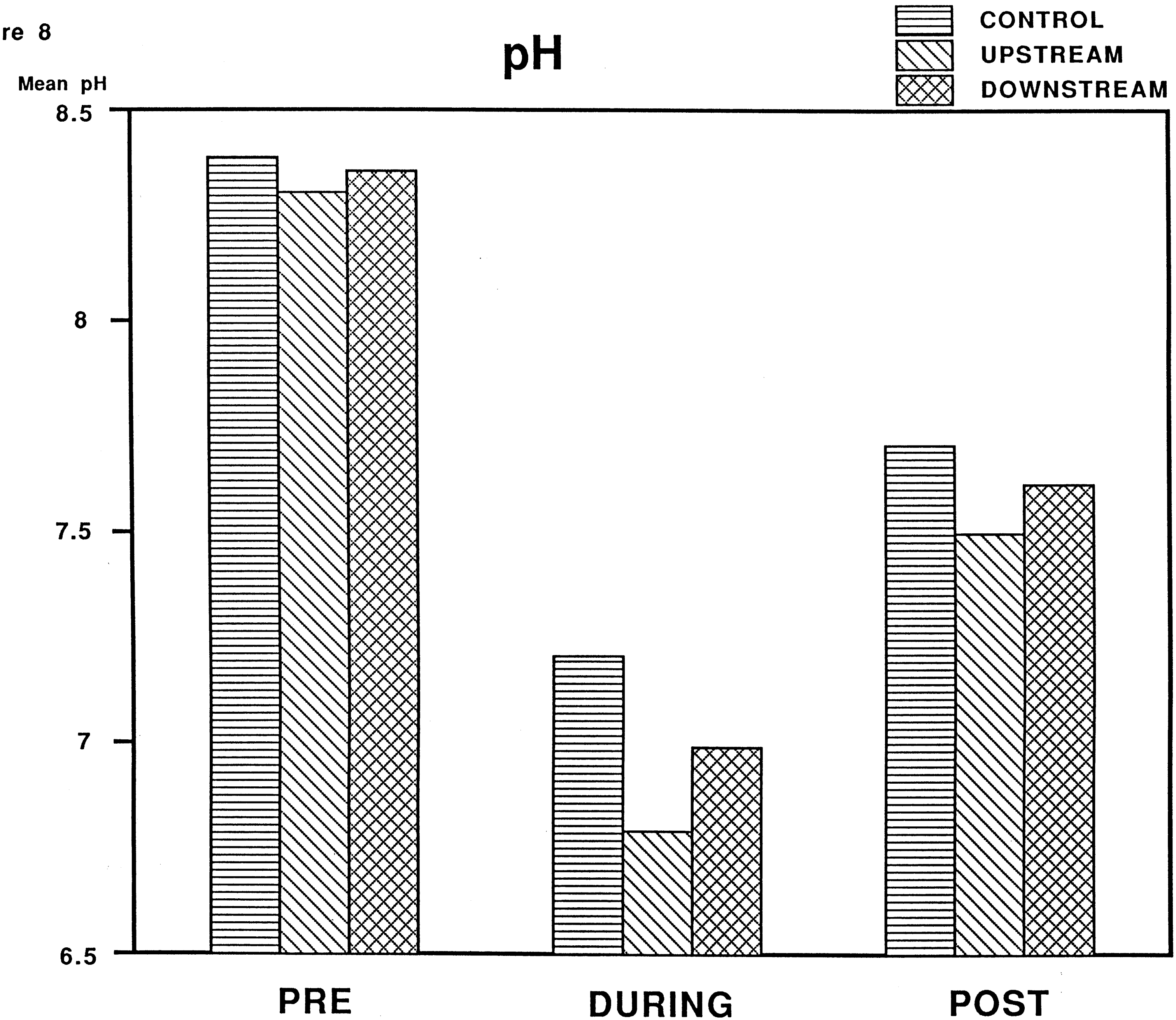
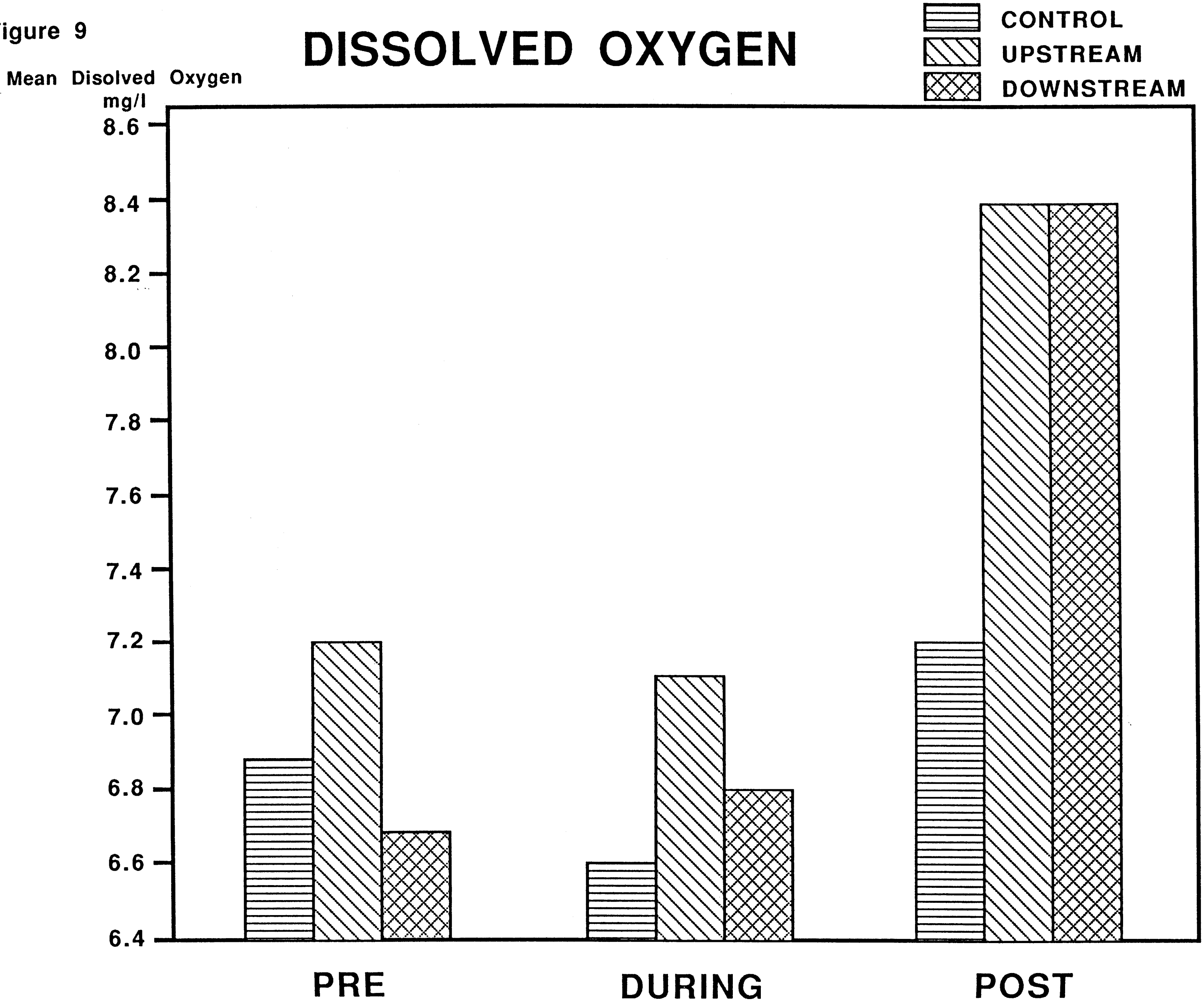

pH
CONTROL
UPSTREAM
DOWNSTREAM
Mean pH
8.5
8
7.5
7
6.5
PRE
DURING
POST

Figure 9



DISSOLVED OXYGEN
CONTROL
UPSTREAM
DOWNSTREAM
Mean Disolved Oxygen mg/l
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
PRE
DURING
POST

Figure 10

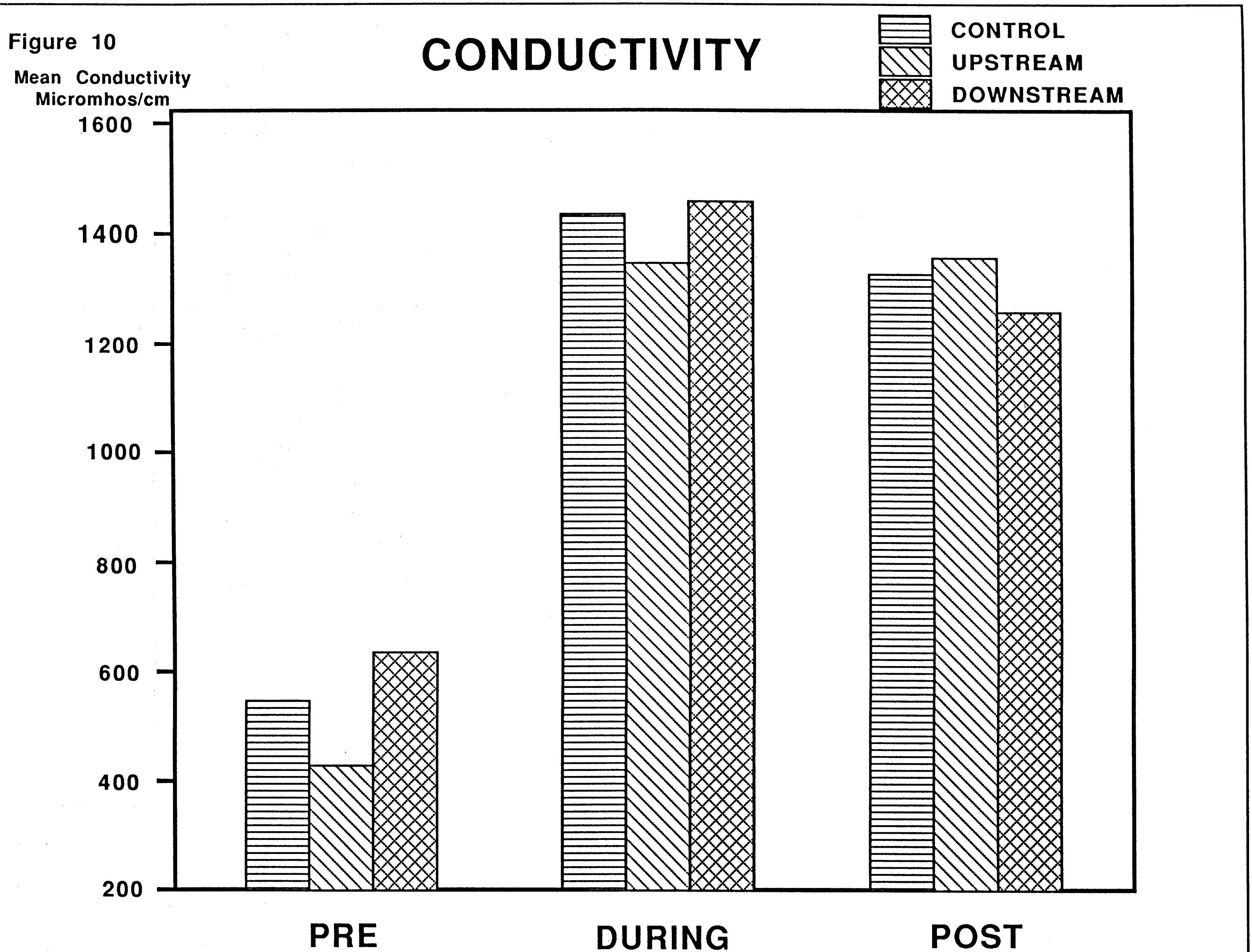
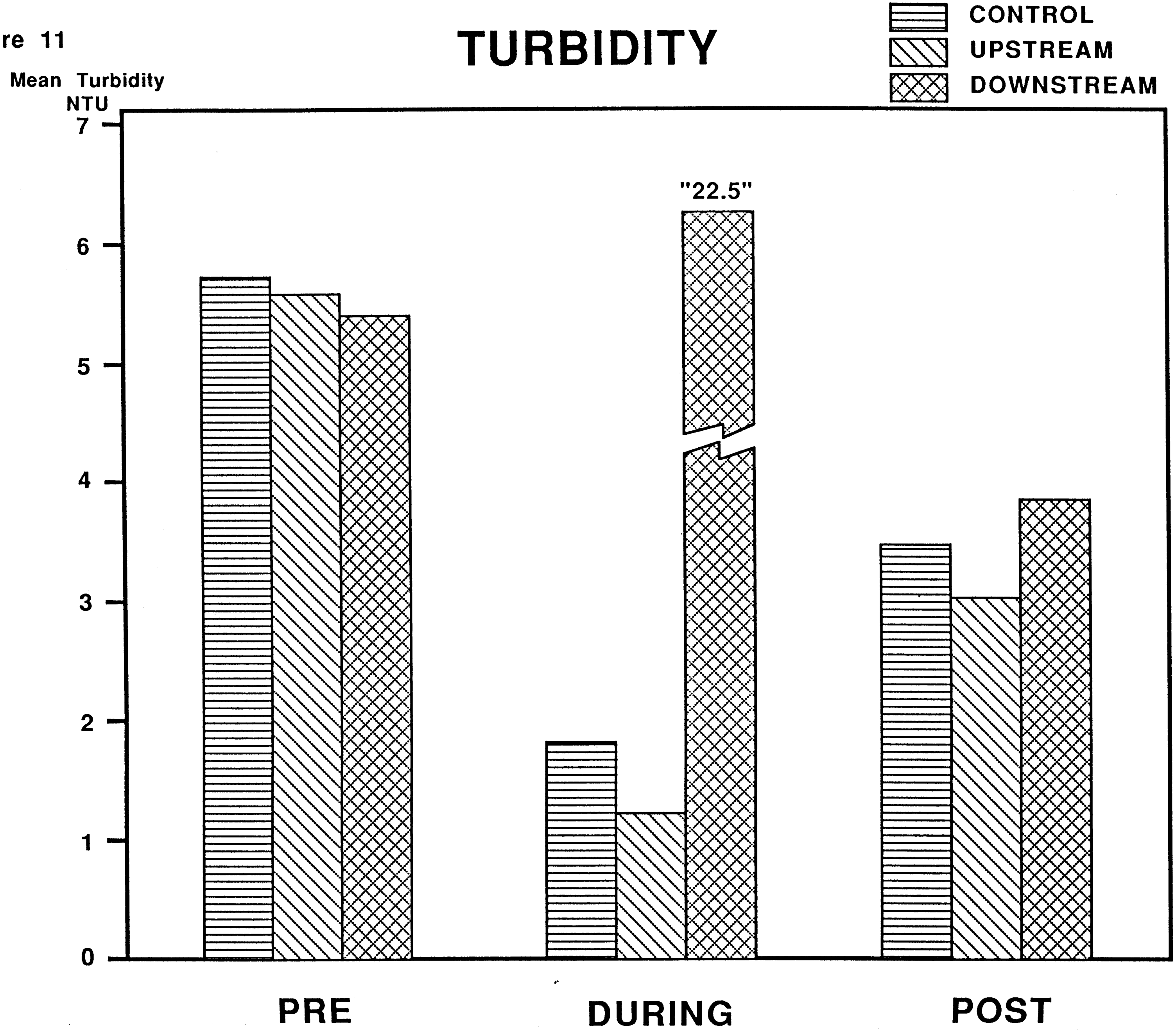

CONDUCTIVITY
Mean Conductivity
Micromhos/cm
CONTROL
UPSTREAM
DOWNSTREAM
1600
1400
1200
1000
800
600
400
200
PRE
DURING
POST

Figure 11


TURBIDITY
CONTROL
UPSTREAM
DOWNSTREAM
Mean Turbidity
NTU
7
6
5
4
3
2
1
0
"22.5"
PRE
DURING
POST

six 1-meter-square plots were established, individual species were identified, counted, and measured. All herbaceous and shrub species were measured within 5 centimeters of ground surface while *Pinus elliottii* and *Sabal palmetto* were measured at diameter at breast height (dbh).

Interpretation of vegetation values was complicated because the site was grazed throughout the study period. As water levels began to recede below the stream bed in the spring of 1985, cattle used the upstream portion of the site more intensely than downstream. However, by the third sampling replicate in September of 1985, water levels returned to normal seasonal highs and vegetation had recovered and equalled or exceeded pre-construction values (Table 1).

DISCUSSION

The Terrafix crossing at Ainger Creek has had minimal impact upon hydrology and water quality. Because grazing influenced data collected most noticeably during the post-construction phase of this project, values are not indicative of the impacts of the crossing alone. However, since hydrology and water quality remain essentially unaffected and vegetation recovery was evident by the third replicate in September of 1985, data suggest it is unlikely that the crossing adversely impacted vegetation either upstream or downstream.

The initial cost of a Terrafix system exceeds substantially that of bridges or culverts. However, the long term maintenance cost is held to a minimum making the Terrafix system economically viable.

RECOMMENDATIONS

In circumstances where the Terrafix system is deemed appropriate, the following recommendations should be considered:

1. The Terrafix blocks should be installed on top of 4 to 6 inches of rock placed between two layers of the geotextile fabric.

2. To further minimize the ecological impacts of future Terrafix crossings, runoff from the site after construction must have approximately the same rate of flow, volume, timing, and quality as runoff which would have occurred following the same rainfall under pre-construction conditions (Comer & Hubbell 1982).

ACKNOWLEDGEMENTS

Appreciation is expressed to the following for their assistance in the completion of this study: Bob Kessler, Peter Quincy, Phil Simpson and Don Wisdom.

Table 1. Vegetation Analysis, Ainger Creek.

	Total Density	Total Dominance	Total Frequency
Pre-Construction August 1984			
Downstream	37.5	240	8.5
Upstream	66.0	38	7.5
Control	57.5	32	8.0
Post-Construction April 1985			
Downstream	19.0	248	8.5
Upstream	17.5	15.6	7.0
Control	17	23	6.0
Post-Construction September 1985			
Downstream	42.1	251	8.0
Upstream	78.5	40	7.0
Control	60.0	32	8.0

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A REVIEW OF WETLAND RESTORATION, ENHANCEMENT, AND CREATION PRACTICES IN THE LOUISIANA COASTAL ZONE

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ABSTRACT

The Coastal Management Division is a permit granting authority with the responsibility of administering the Louisiana Coastal Resources Program. In a regulatory context, wetland restoration, enhancement, and creation activities can be categorized as (1) Best Practical Techniques, (2) Restoration Activities, and (3) Preservation, Enhancement and Creation Projects. "Best Practical Technique Activities" are those which result in benefits to the wetland system but are a by-product of a permitted development project, e.g., spoil island construction during channel dredging. "Restoration Activities" are those in which an area is returned to near pre-project condition after an activity has been conducted and/or abandoned, e.g., lowering the elevation of a development site to encourage marsh vegetation reestablishment. "Preservation, Enhancement and Creation Projects" are those activities designed to primarily benefit wetlands, e.g., the installation of water control structures to regulate water levels within an impounded wetland. Areas under marsh management have a potential for revegetation and enhanced productivity. Other currently employed or potential techniques for promoting wetland resources in Louisiana include vegetational plantings, marsh and beach renourishment, backfilling of canals and pipelines, road degradation, waste pit restoration, sediment and freshwater diversion, and shoreline stabilization. The benefits and limitations of these practices are discussed as well as the role of these practices in regulatory strategies.

INTRODUCTION

Louisiana's coastal zone is currently experiencing various problems due to man-made and natural causes. Approximately 3 million of Louisiana's 5.0 million acres of wetlands are in the coastal zone. This area is composed of approximately 24 percent fresh and intermediate wetlands, 48 percent brackish marsh, and 14 percent saline marsh. Due to a combination of man-made and natural causes, Louisiana is experiencing a land loss rate of 31,250 acres per year (Wicker et al. 1980, 1981). Therefore, approximately 0.6 percent of Louisiana's coastal zone is lost annually.

Natural causes of land loss include subsidence, apparent sea level rise, saltwater intrusion, storm surges, wave energy, and root damage from over grazing by fur bearers (Boesch et al. 1983). Man-made causes of coastal erosion include leveeing and channelization of the Mississippi River, navigation channels, access roads, drainage projects, and other dredge and fill projects. The leveeing and channelization of the Mississippi River has deprived the wetlands in the Deltaic Plain Region of much of the sediment necessary to counter subsidence (Boesch et al. 1983). This practice has also reduced freshwater input into wetland areas. The multitude of navigation canals and oil and gas access canals in coastal Louisiana has disrupted and usurped the natural dendritic drainage patterns within the wetlands. These canals have provided an avenue for saltwater to move into the fresher parts of those wetlands thus killing vegetation adapted to freshwater conditions. Spoil banks from these access channels, roads, as well as levees, have blocked the natural sheet flow of water over the wetlands causing impoundment of water and reduced input of nutrients to the system (Craig et al. 1979; Scaife et al. 1983). Other wetland areas in coastal Louisiana have been impacted by dredge and fill projects such as marinas and other waterfront developments.

Coastal wetlands provide many benefits in addition to those derived from the development of coastal areas. Wetlands act as storm buffers, pollution filters and provide habitat for fish and wildlife. The policies of the Louisiana Coastal Resources Program (LCRP) enable the state to protect, develop, restore, and enhance the resources of the coastal zone (La. R.S. 49:213.2(1). The goals of the Louisiana Coastal Resources Program are to encourage multiple uses with renewable resource management (Section 213.2(3); to develop a Coastal Resource Program based on the resources, the environment and the needs to the people (Section 213.1(5); to enhance the recreational opportunities in the coastal zone (Section 213.2(6); and to provide the expertise to determine the future course of development and conservation in the coastal zone (Section 213.2(7) (Louisiana Coastal Resources Program, Final Environmental Impact Statement, 1980).

STATEMENT

One way in which the Coastal Management Division (CMD) strives to achieve the goals of the LCRP is through the regulatory program, particularly the Coastal Use Permitting System. There are three ways that restoration, enhancement and creation can play a role in this program. The first is through the use of Best Practical Techniques, whereby an activity may be permitted and conducted in a manner such that the primary objective is achieved while, at the same time, wetlands are benefitted. The second is through Restoration Activities, which are conducted in an effort to reverse or diminish the adverse impacts resulting from a permitted activity. The third is through Preservation, Enhancement and Creation Activities, which are those designed expressly to benefit wetland resources.

BEST PRACTICAL TECHNIQUES

Best Practical Techniques are incorporated into and are an integral part of the primary activity. These are intended to reduce overall impacts thus making the activity in better conformance with the Coastal Use Guidelines (Table 1). One such technique is to place spoil during canal dredging in such a manner so as to create spoil areas which, upon compaction of sediments, form wetlands. This wetland creation activity can take the form of either spoil islands or shoreline extensions. Vegetation is usually allowed to establish by invasion; however, vegetational plantings are preferred. Another Best Practical Technique is to construct water control structures such as fixed crest weirs or culverts at intersections of canals and existing waterways. This is done to maintain the existing hydrology. The placement of dredge spoil across a natural, typically shallow, waterway can completely block the flow of water. This situation can result in loss of large areas of wetlands to open water through the impoundment of water by the spoil bank, and in addition, limit the ingress and egress of aquatic organisms. Creating a gap in the spoil bank at a canal and natural waterway crossing may improve this situation. However, there is a potential for excessive drainage of the wetland area caused by the presence of a deeper, wider canal. This increases the potential for accelerated erosion caused by increased volumes of tidal water. Fixed crest weirs or culverts properly set in the gap at stream crossings allow for moderated water movement while preventing excess drainage of water from the wetlands into the canal. The discharge of liquid spoil from the hydrologic dredging of canals and channels onto broken wetlands is another acceptable technique provided that it is done in a manner so as not to smother healthy productive marsh or live waterbottoms (LCRP, FEIS 1980).

Table 1. LCRP Coastal Use Guidelines Relevant to Best Practical Technique Practices.

Guideline 2.0: Guidelines for Levees

2.2 Avoid the segmentation of wetlands.
2.6 Use Best Practical Techniques to minimize disruption of existing hydrologic patterns.

Guideline 3.0: Linear Facilities

3.4 Pipelines should be installed through the "push ditch" method and the ditch backfilled.

3.9 Use best practical techniques to minimize disruption of natural hydrologic and sediment transport patterns, water quality, or wetlands.

3.10 Use best practical techniques to prevent bank erosion, and saltwater intrusion.

3.11 All canals which connect more saline areas to freshwater areas shall be plugged at waterway crossings.

3.13 All pipelines should be constructed in accordance with State and Federal Regulations.

3.15 Best practical techniques should be used for site restoration and revegetation.

3.16 Confined and dead end canals shall be avoided. Canals shall be designed using best practical techniques to avoid water stagnation.

Guideline 4.0: <u>Dredged Spoil Deposition</u>

4.1 Spoil should be deposited using best practical techniques to avoid water movement disruption.

4.6 Spoil disposal areas should be constructed using best practical techniques to retain spoil, reduce turbidity, and reduce shoreline erosion.

Guideline 5.0: <u>Shoreline Modifications</u>

5.2 Use best practical techniques to minimize adverse environmental impacts.

5.4 Use best practical techniques to avoid the introduction of pollutants into coastal waters.

5.5 Piers and docks should be constructed using best practical techniques to avoid obstruction of water circulation.

Guideline 6.0: <u>Surface Alterations</u>

6.4 Drainage and fill projects shall be constructed using best practical techniques to reduce environmental impacts.

6.11 Surface mining and shell dredging shall be done using the best practical techniques to reduce adverse impacts.

6.13 Use best practical techniques to prevent the release of pollutants or toxic substances.

Guideline 7.0: <u>Hydrologic and Sediment Transport Modifications</u>

7.7 Water control structures shall be designed using best practical techniques to prevent "cut arounds," permit tidal exchange, and minimize obstruction to aquatic organism migrations.

Guideline 8.0: <u>Disposal of Wastes</u>

8.1 Best practical techniques should be used to minimize the impacts of waste storage, treatment, and disposal facilities.

8.4 Waste facilities shall be constructed using best practical techniques to prevent leaching.

Guideline 9.0: Alteration of Waters Draining into Coastal Waters

9.3 Runoff and erosion from agricultural lands shall be minimized using best practical techniques.

Guideline 10.0: Oil, Gas, and Other Mineral Activities

10.1 Geophysical surveying shall use best practical techniques to minimize damage to the environment.
10.4 Mineral exploration and production facilities shall be constructed to maintain natural water flow and to avoid erosion.
10.5 Access routes shall be designed to avoid adverse impacts to critical ecological areas.
10.6 Drilling and production sites shall be constructed and operated using best practical techniques to prevent the release of pollutants.
10.9 All drilling and production equipment shall be constructed using best practical techniques to withstand adverse conditions.
10.10 Mineral facilities shall be constructed using best practical techniques to minimize adverse environmental impacts.

RESTORATION ACTIVITIES

Restoration activities take place after the initial impacts have occurred. If the activity is ongoing, the area may be restored to the degree allowable and still conduct the activity. For those activities that are completed or abandoned, restoration is conducted to the maximum degree practical. The degree of restorability is taken into consideration during the evaluation of the Coastal Use Permit application, federal consistency, and violation review (Table 2).

Oil and gas board roads have a significantly higher potential for successful restoration than that of oil and gas access canals. Access roads are constructed by dredging alternating (staggered) borrow areas and subsequently depositing spoil between the borrow areas to form a road dump. Culverts are placed in the road at all waterways and at regular intervals to help preserve the existing hydrology. Upon abandonment of the site, boards are removed and the dredging process is reversed. The road dump thereby becomes fully degraded and much of the borrow areas are refilled. Past practices of abandoning board roads without restoration has resulted in habitat (typically shrub/scrub in nature) which is far less productive than that of a restored road which will revert to wetlands.

Another restoration technique is the backfilling of pipeline trenches created by the push ditch installation method. Upon completion and testing of the pipeline, the spoil stockpiled on the edge of the trench is deposited into the trench. In some instances a double ditching technique is used in which the top layer of marsh material is placed on one side of the trench while the deeper sediments are placed on the other. The top sediments are deposited last when backfilling, thus allowing plant propagules to sprout for faster revegetation of the corridor. The success of backfilling may be limited by the nature of the soils. Highly organic soils, when exposed to air, shrink due to oxidation. This limits the amount of material available for backfilling. The intersections of pipelines and waterways are often reinforced by bulkheads, earthen plugs, or rip-rap dams in combination with shoreline stabilization materials.

Backfilling on a larger scale is sometimes used to restore canals. After backfilling, canals are dammed with an earthen or shell plug. Backfilled canals which have soil elevations and soil types which make them suitable for revegetation are generally quickly invaded by plants from surrounding areas. To partially restore dead end access canals in areas not practical or suitable for backfilling, the spoil banks are cut to help reestablish existing hydrology and a dam or water control structure is placed at the canal entrance. This reduces the forces of erosion within the closed canal and helps to reduce the tidal prism which contributes to erosion in other areas. The plugged canals typically become shallower by siltation and detrital deposition from the surrounding wetlands. These shallower water bottoms are more productive and their waters are less prone to oxygen depletion.

The restoration of abandoned oil and gas waste pits is of increasing importance due to new Louisiana Department of Natural Resources, Office of Conservation and the U.S. Environmental Protection Agency regulations which require pit closures within the next three years. These closures require special restoration efforts due to the potential for pit residue contamination.

Leveed areas may be restored by the placement of gaps to return the area to its former hydrologic condition. Filled areas may be restored by degrading the filled area to wetland elevation. Solid waste disposal sites should be restored by the placement of an earthen cover over the fill according to the Louisiana Department of Environmental Quality regulations.

Table 2. LCRP Coastal Use Guidelines Relevant to Restoration Activities.

Guideline 3.0: <u>Linear Facilities</u>

3.8 Linear facilities which traverse beaches, tidal passes, or other natural shorelines shall be restored.

3.11 All canals which connect more saline areas to freshwater areas shall be plugged at waterway crossings.

3.14 Areas shall be backfilled or otherwise restored to preexisting conditions.

3.15 Best practical techniques should be used for site restoration and revegetation.

Guideline 5.0: Shoreline Modifications

5.7 Neglected shoreline modification structures shall be removed at owner's expense when appropriate.

Guideline 6.0: Surface Alterations

6.6 Areas shall be returned to pre-project conditions after termination of use.

Guideline 10.0: Oil, Gas, and Other Mineral Activities

10.13 Mineral sites shall be restored to original condition upon termination of use.

ENHANCEMENT, CREATION, AND PRESERVATION ACTIVITIES

Enhancement, creation, and preservation activities are done to increase the productivity of wetland resources, to reduce saltwater intrusion, and to control erosion. These projects are often desired by landowners to improve the quality of their land and to prevent the loss of surface and mineral rights to the state should the land erode to open water. These activities are subject to both coastal use and U.S. Army Corps of Engineers permitting (Table 3). They are often encouraged by CMD provided their implementation does not benefit a particular resource at the undue expense of other wetland resources. They may be conducted as compensation for impacts derived from activities conducted offsite for which restoration may not be possible. The compensating activities are considered only after a full review of the project for which compensation is sought. It is not until after compliance with the Coastal Use Guidelines has been determined and the project is determined to be consistent with the Louisiana Coastal Resources Program that the "mitigation" (or offsite enhancement) project is given consideration as compensation for unavoidable adverse impacts. Projects of this nature can be restoration projects for activities conducted prior to the Louisiana Coastal Resources Program. Also considered in this category are marsh creation projects similar to the spoil island creation and shoreline deposition mentioned previously in the Best Practical Techniques section. Although disturbed areas naturally revegetate quickly in Louisiana, in some mitigation projects vegetational plantings are recommended to insure success. Other enhancement, creation, and preservation activities include the stabilization of shorelines by structural and nonstructural means. Vegetational plantings have been found to be a successful method of controlling erosion in Louisiana as demonstrated by the U.S. Department of Agriculture Soil Conservation Service experimental planting along Lake Calcasieu and in other pilot projects in the coastal zone. This agency, aided with CMD funds in conjunction with the

Lafourche-Terrebonne Soil and Water Conservation District is developing a plant materials lab in Golden Meadow, Louisiana, to select and propagate wetland vegetation most suited for Louisiana. Shell, rip-rap, and matting material is frequently used to stabilize shorelines in preservation and restoration projects. Sediment may be diverted by angling cuts off river passes through spoil banks and natural levees. In this manner, new wetland has been created through the process of deltaic splay formation.

Perhaps the most prevalent wetland enhancement creation and preservation activities are those that involve marsh management plans. These plans often contain many of the preservation and restoration activities previously mentioned. However, in management plans, these activities are unified into one cohesive plan for their implementation, continued operation, and maintenance. Typically, these plans include the control of water levels in semi-impounded areas or "treatment units." Each treatment unit is generally bounded by levees, spoil banks, or natural water blocking features.

Water levels in marsh management areas are regulated by water control structures. Structure design is dictated by the intensity of management and the objectives of the marsh management plan. Passive management can be achieved by the installation of a fixed crest low level dam structure of which the wakefield design is the most common weir type currently used in Louisiana. The weir height is generally set at 15 cm (6.0") below marsh level. One linear foot (30 cm) of weir crest is necessary to regulate approximately 70 acres (28.3 hectares) of wetlands. These weirs act to dampen tidal action and erosional forces. They reduce waterflow which results in greater water clarity which in turn provides for greater submerged aquatic plant production, especially in shallow water. They also protect wetlands from excessive drainage during times of drought, which over prolonged periods can cause shrinkage of the overlaying layer of soil by the oxidation of organic matter and can make the marsh more susceptible to harmful burns (peat burns).

In areas where active marsh management is necessary, structures are implemented which allow for the manipulation of water levels. There are numerous structures of this type which characteristically include one or more flap gates and a variable crest weir element and/or screw gate. During the first three to five years of management, these structures are operated to help establish vegetation within the management area by a controlled lowering of water levels in the spring or summer months with the aid of tides and winds. Seeds germinate more readily under these drier conditions. Also, dried shallow waterbottoms consolidate the soils which reduces turbidity after reflooding. In the late summer and fall, water levels in the management areas are allowed to rise to marsh level. This increases the desirability of the area for use by waterfowl and furbearers. This "draw down" procedure is repeated until desired water to marsh ratio is achieved which may take from three to five years. Thereafter, water control structure operation is modified to simulate a more passive type of management except during times of excessive saltwater intrusion. At these times structures are operated to prevent the impact of highly saline water during the duration of the event. Also during the second phase, more allowances are made for ingress and egress of aquatic organisms.

The success of the above techniques are greatly influenced by a number of variables such as sediment types, erosional forces, salinity regimes, and vegetation types. The U.S.D.A. Soil Conservation Service in cooperation with CMD is developing an inventory and assessment of specified restoration, preservation, and creation techniques for discrete areas of Louisiana's coastal zone. Areas suitable for restoration work in each coastal parish are to be identified and evaluated by this method so that consideration will be given to these areas when offsite restoration projects are recommended for the purpose of offsetting the environmental impacts of a proposed project.

Table 3. LCRP Coastal Use Guidelines Relevant to Enhancement, Creation, and Preservation Activities.

Guideline 4.0: Dredged Spoil Deposition

4.2 Spoil shall be used to improve productivity or create new habitat or deposit spoil in upland habitats.

Guideline 7.0: Hydrologic and Sediment Transport Modifications

7.1 Freshwater diversion methods are encouraged.
7.2 Sediment deposition systems may be used to offset land loss.
7.4 Diversion of freshwater through siphons, etc., to offset saltwater intrusion and to introduce nutrients into wetlands is encouraged.
7.5 Water management plans shall result in an overall benefit to the productivity of the area.
7.7 Water control structures shall be designed using best practical techniques to prevent "cut arounds," permit tidal exchange, and minimize obstruction to aquatic organism migrations.
7.8 Impoundments shall not be constructed in brackish and saline areas.

CONCLUSIONS

The Louisiana Coastal Zone presently has a severe land loss problem (31,250 acres lost annually) which threatens the future existence of many coastal resources. The coastal erosion problem is a result of complex natural and man-made factors. The state has established the Coastal Resources Program which, with other state and federal programs, strives to minimize the man-made impacts to the coastal zone.

Many of the practices described in this discussion may appear to be meager in light of the tremendous decline in productivity and wetland loss that Louisiana is facing. It is our desire to improve on the existing technology for reducing the adverse impacts associated with development projects as well as increasing success of restoration and preservation projects. It is also the intent of the Louisiana Coastal Management Division to develop a strong program for the evaluation of the effectiveness of various Best Practical Technique, Restoration and Enhancement, Creation and Preservation practices. It is our job as regulators to convince operators to incorporate impact avoidance and compensation measures into their activities in the early stages of project design, and to encourage landowners to pursue restoration, preservation, and enhancement projects in order to reduce the erosion and wetland deterioration problems that currently exist in Louisiana.

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BENEFICIAL USES OF DREDGED MATERIALS AT BARREN ISLAND, DORCHESTER COUNTY, MARYLAND

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ABSTRACT

In 1984, the Corps of Engineers dredged the Federal channel from the Chesapeake Bay to Honga River, Dorchester County, Maryland. Approximately 38,226 cubic meters (m^3) of dredged material was deposited on the northeast eroding edge of the original wildlife habitat island established in 1981 creating a protective edge of approximately 5.2 hectares (ha). North of the habitat island, approximately 76,452 m^3 of material was deposited creating a 4.7 ha island to act as additional protection for the exposed north and northeast side of the new protective edge. Fish and wildlife habitats were developed by controlling the direction of the discharge pipe to provide designed dredged material elevations and configurations and by conducting post-disposal landscaping. Eight months following dredging, approximately 1.6 ha of *Spartina alterniflora* derived by seeding, 3.0 ha of unvegetated bird habitat, and 0.2 ha of artificially placed sand and shell were added to the existing habitat island created in 1981. The project costs were approximately 30 percent less than the traditional confined dredged material placement option.

INTRODUCTION

The Corps of Engineers has legislative authority to maintain navigation in approximately 90 channels within the Baltimore District's Civil Works boundaries. This authority, along with a favorable evaluation of project benefits, resulted in the maintenance dredging of the Honga River, Dorchester County, Maryland.

The Tar Bay/Barren Island Gap section of the Honga River channel has a historical dredging frequency of three years with the most current maintenance dredging having occurred in November, 1984, through January, 1985. The Tar Bay/ Barren Island Gap channel is a vital link to the productive shellfish and fishery areas of the Chesapeake Bay.

The commonly occurring problem with any dredging program is the location of an environmentally, engineering, and economically acceptable dredged material placement (DMP) site. This is particularly true for this project since upland disposal, the preferred method of disposal by environmental review agencies, would require approximately 14 hectares (ha). To be economically feasible, the site had to be located within 3.2 kilometers (km) of the dredging area. Overboard disposal options for this project are limited due to the abundance of oyster bars, crabbing bottom and submerged aquatic vegetation. More importantly, any disposal option selected had to be acceptable to the environmental review agencies.

In 1981 the Honga River Federal channel was dredged. The dredged materials were used to develop a wildlife habitat island just southeast of the northernmost end of Barren Island. The entire dredged material island was stabilized vegetatively except for the northeast side where seeding was unsuccessful due to the mobile sandy sediments. By 1984 the unvegetated northeast side of the new island had eroded in a southwest direction by as much as 130 feet.

Maintenance dredging of the Federal channel was again necessary in 1984. The dredged material disposal option selected by the Corps of Engineers was to protect the eroding northeast side of the previous dredged material island by disposal of approximately 38,226 cubic meters (m^3) of dredged material along this side, creating a new protective edge of 5.2 ha. Just north of this protective edge, a 4.7 ha barrier island was developed with approximately 76,452 m^3 of dredged materials. The purpose of this project was to stabilize the northeast side of the original island by creating various wildlife habitats and provide an environmentally acceptable disposal area.

SITE DESCRIPTION

The Honga River maintenance dredging project is located on the eastern shore of Maryland in Dorchester County, approximately 32.1 km southwest of Cambridge (Fig. 1). The Federal project includes the Barren Island Gap, Tar Bay and Honga River sections, and is a vital commercial and recreational waterway separating the mainland from Hooper and Barren Islands.

The authorized dredging area is 18.2 meters (m) wide, 3,657 m long and 2.1 m deep with 0.6 m as an over-dredge area. The dredging resulted in approximately 114,678 m^3 of predominately fine-grained sediments hydraulically pumped and deposited in the DMP site.

The DMP site was located in a shallow water area off the northeast corner of the original dredged material island at Barren Island (Fig. 2). Predredging depths of the DMP site ranged from mean low water (MLW) to 1.2 m MLW. Field inspections in the summer of 1983 and 1984 documented the presence of *Ruppia maritima* along the southern, western, and eastern perimeter of the existing dredge material island. Literature reviews documented *Ruppia* populations at varying densities at a number of different sampling stations in the Honga River from 1971-1981 (Stevenson & Confer, 1978).

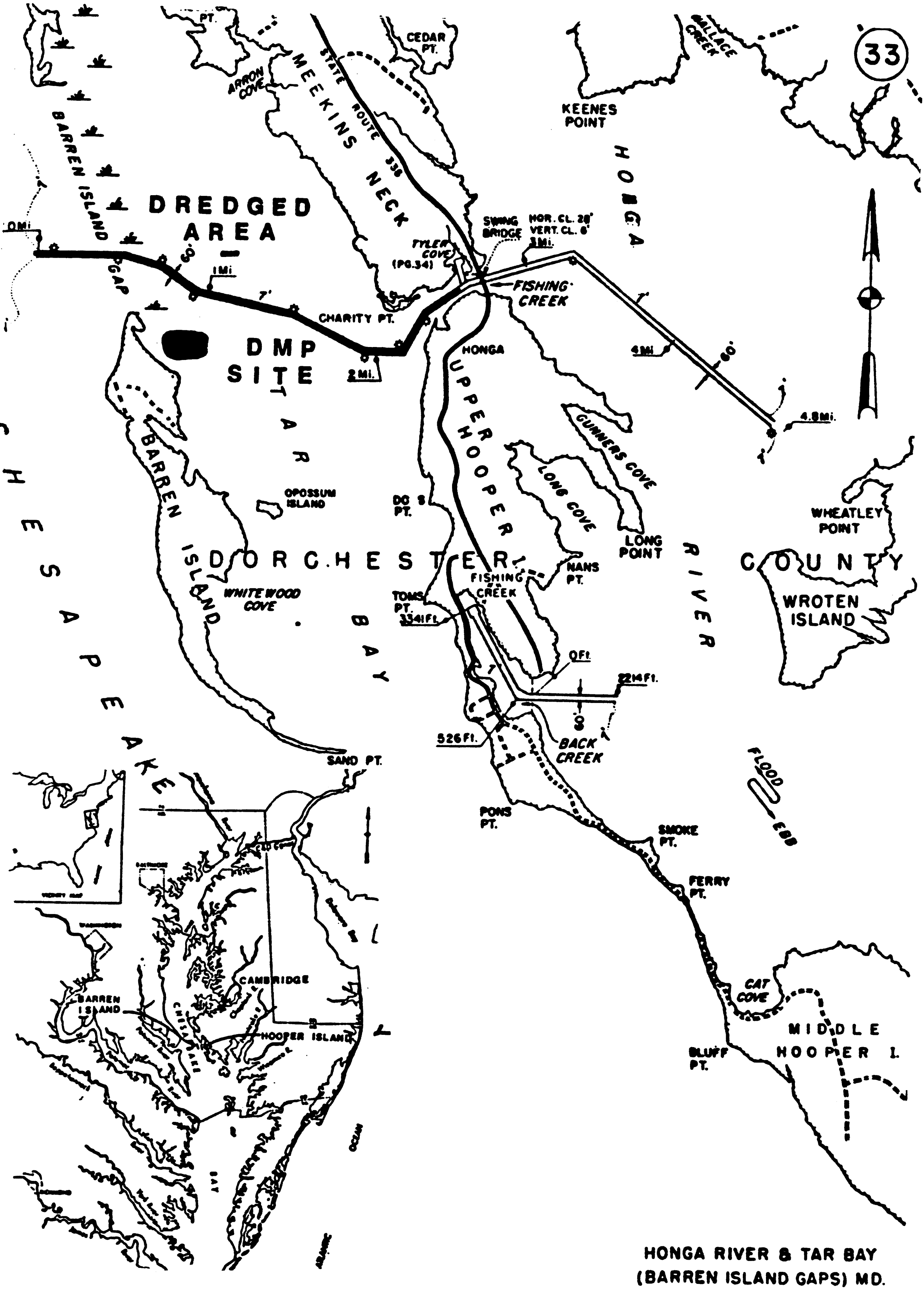
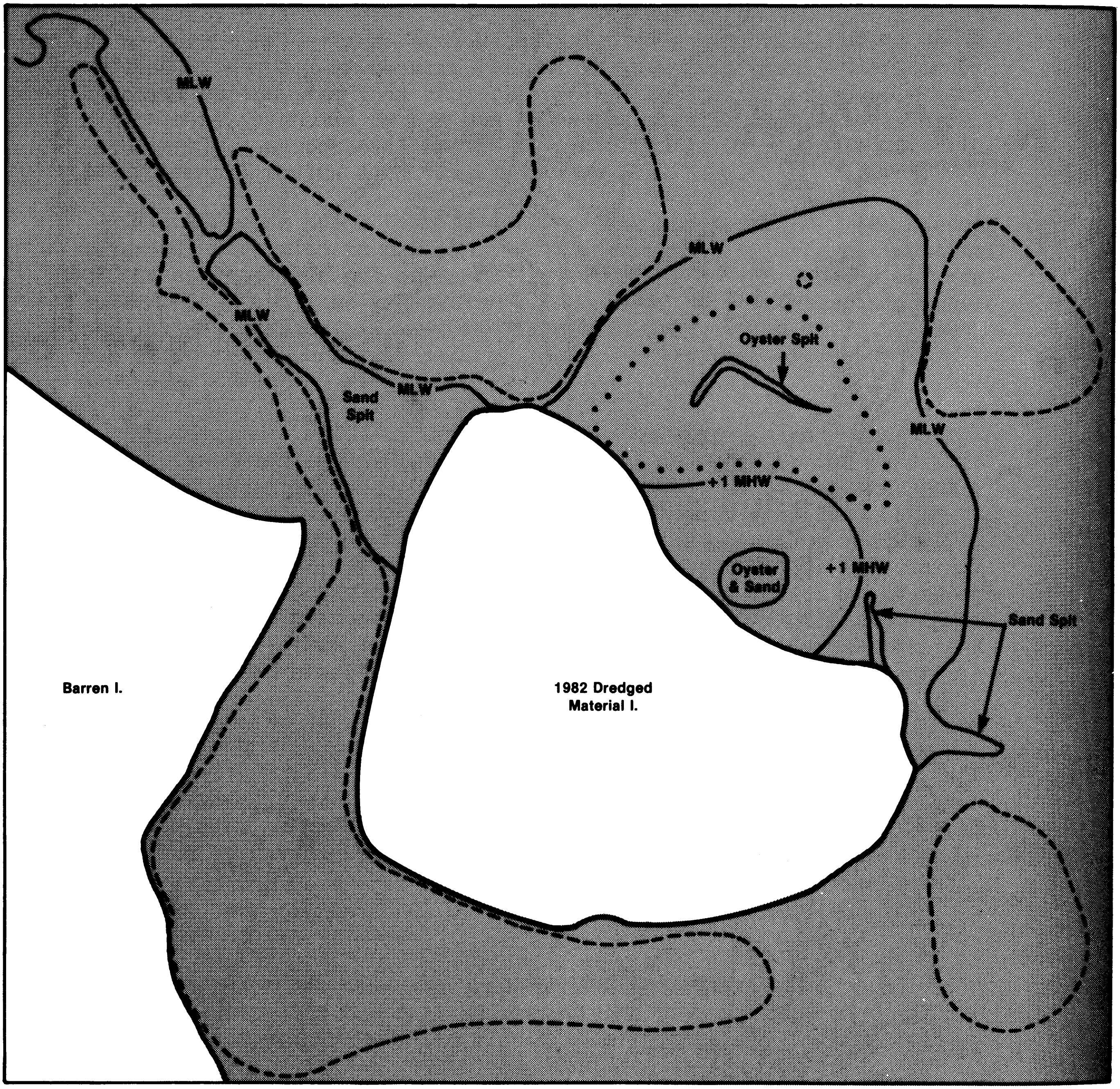


Figure 1. The dredging and DMP site location map.



Legend

- Outfall Location
- --- Volunteer Widgeongrass Bed
- •••• Cordgrass Seedlings Developing

Scale: 1 cm = 24m
MLW = 0.0m
MHW = 0.4m

Figure 2. Barren Island Dredged Material Island: 1985

(Source: Environmental Concern, Inc.).

The Tar Bay section of the Honga River is a valuable oyster producing area. Two oyster bars, Tar Bay 36.4 ha and White Wood 8.1 ha are located in the vicinity of the project area. The Tar Bay oyster bar is located approximately 1,524 m and White Wood bar is approximately 3.657 m from the DMP site (Maryland Department of Tidewater Fisheries, 1961).

The cove area at the northeast corner of Barren Island has a moderate erosion rate ranging from 1.2-2.4 m per year (Maryland Coastal Zone Administration, 1975). The sand bar north of the cove is a documented accretion area and is vegetated with *Spartina alterniflora* along the mean high water (MHW) line. South of the cove and to the interior of the main island, the elevation increases with the predominate vegetation being loblolly pine.

METHODS

The channel was dredged using a 31.4 centimeter (cm) hydraulic dredge with a 1000 horsepower (H.P.) pump. The dredged material was pumped through a pipeline and discharged directly into the shallow water DMP site through the opened end of the discharge pipe. In September, 1984, grade stakes were installed indicating three dredge discharge locations.

Environmental Concern, Inc. (EC Inc.), under contract to the Corps of Engineers, established three discharge pipe locations prior to initiation of the dredging. Elevation stakes were placed at the discharge locations to indicate the limits of the desired elevations of fill material during dredging. The elevation stakes were guides used by the COE and EC Inc. inspectors to indicate the elevation of the fill material during the dredging operation.

The dredging contractor was required to discharge the material at the designated outfall locations until the elevation reached 0.9 m (MLW) at the outfall located on the existing island and 0.6 m (MLW) at the proposed buffer island. If the elevation of the dredged material reached the desired elevation, the dredging contractor was required to relocate the discharge pipe to another designated location.

The dredging contract was awarded to Barnaget Bay Dredging Company of Harvey Cedars, New Jersey. The dredging was initiated on November 1, 1984, and completed on January 19, 1985. Consolidation of the dredged material occurred through the winter and spring of 1985.

In January, 1985, approximately 6.4 ha were documented by aerial photographs between MLW to 0.7 m (MLW). In April, 1985, thirteen 0.4 ha plots were staked in preparation for seeding. Consequently, approximately 1.2 ha of intertidal area were lost due to erosion or consolidation during this 4-month period (Garbisch 1985).

The seeding of the DMP site with *S. alterniflora* was conducted on

April 29-May 3, 1985, by EC Inc. Approximately 5.3 ha were seeded with the all terrain vehicle (ATV). Seeding was accomplished by surface broadcasting a seed-cat litter (drying agent) mix and cultivating the substrate and seed using the ATV with a spiked drag at low tide. An average of 111 seeds/m^2 were used for the seeding. The S. alterniflora seeded area was fertilized on June 25, July 10, July 22, and August 5, 1985. A 10-10-10 granular fertilizer was used at a rate of 110 kg/ha.

RESULTS

Approximately 114,678 m^3 of dredged material was deposited at three designated discharge locations. Based on aerial photographs taken at low tide in June, 1985, a total of 55.2 ha of new dredge material area was created, of which 3.8 ha exists between MLW and 0.7 m MLW. The oyster shell and sand least tern nesting area is 0.2 ha.

The following data indicates the loss of area from MLW to 0.7 m MHW during the period of January 9-June 17, 1985.

January 9, 1985	6.4 ha
April 29, 1985	5.3 ha
June 17, 1985	3.8 ha

Comparing the sequence of aerial photos, the newly created northern barrier island has either eroded or consolidated. The remains of buffer island has merged with the new protective edge of the 1982 dredge material island.

Approximately 5.2 ha was seeded, with 3.8 ha at acceptable elevations to support Spartina alterniflora. As a result, approximately 1.6 ha of cordgrass was established on the northwest side of the island created to protect the eroding edge of the island created in 1982 (Table 1).

In conjunction with the dredge material disposal operation and the resulting reduction in water depths around the perimeter of the island favorable shallow water habitat was created for introduction of submerged aquatic vegetation. Consequently, 2.8 ha of Ruppia maritima naturally volunteered the shallow water areas surrounding the 1982 and 1985 dredged material islands (Fig. 2).

The maximum elevation outfall located on the 1982 dredge material island was 1.2 m MLW (Earhart & Garbisch 1982). This was designed to create least tern habitat composed of sand and shell, and unvegetated area composed of silt and fine sand for ground nesting shore birds. In 1985, the maximum elevation of the outfall was 0.9 m (MLW) with approximately 3 ha of unvegetated habitat established from 0.3 m MLW to 1.2 m MLW and 0.2 ha of shell and sand artificially established for least tern nesting habitat.

Table 1. Hectares of habitat created at Barren Island, Dorchester County, Maryland.

	FY 82 (hectares)	FY 85 (hectares)	TOTAL (hectares)
Ponds	4.1	0.0	4.1
Ditch & tidal flats (MLW) to lower boundary of *S. alterniflora*	2.4	0.0	2.4
S. alterniflora (0.2-0.5 m MLW)	6.5	1.6	8.1
S. patens (0.4-0.7 m MLW)	2.4	0.0	2.4
Unvegetated Bird Nesting	1.9	3.0	4.9
Sand/Shell Area Least Tern Nesting	0.2	0.2	0.4
*Total	17.5	4.8	22.3

*Includes area exposed at MLW only. Does not include shallow water habitat created below MLW.

DISCUSSION

Innovative uses of dredged material are becoming a necessity in order to meet more demanding engineering, environmental, and economic standards for dredged material disposal. Federal channels that were authorized for commercial watermen's access to productive fishing areas may transect valuable environmental resource areas and may result in conflicting ideas on potential beneficial uses and the impacts of the resources.

This is the case with the Honga River Federal maintenance dredging project. The Honga River channel is an important channel for the commercial watermen operating in the Hooper Island area. This section of the channel is in the vicinity of the productive adult oyster, seed oyster, crab, and fishery resources.

The most current dredging necessitated an acceptable dredged material disposal plan to accommodate approximately 114,678 m^3 of fine-grained sediments. The most environmentally acceptable DMP plan, a contained upland site, would require approximately 14.1 ha located within 3.2 km of the dredged area. Unfortunately, an upland DMP site that met the above criteria was not available.

Most of the environmental concerns were examined and verified as having no significant impact on the environment as a result of the 1982 dredging (Earhart & Garbisch, 1983). The main environmental consideration was to insure that the habitat development design of the DMP site would adequately mitigate the loss of the shallow water habitat. Actual habitat resulting after the first year was approximately 8 ha of wetland, submerged aquatic grasses, shallow water, and unvegetated bird nesting areas.

The main engineering factor of concern to the COE was stabilization of the DMP site. Numerous reports exist on using transplanting techniques to vegetatively stabilize dredge material (Garbisch, 1977; Knutson et al., 1981). However, the largest known dredged material stabilization using seed stock of S. alterniflora prior to the Barren Island work was a 2.4 ha project. The most critical concern of this work compared to the 1982 work was the seeding of cordgrass in a more exposed area.

Extension of dredged material placement some 1500 feet north of the 1982 dredged material island put these materials in an exposed location. Wave scouring of surface silt layers and of sand led to erosion with loss of intertidal area, seedlings, and seed. Some loss of intertidal area may also have resulted from sediment consolidation of the low elevation barrier island. The buffer island, although largely gone, continues to provide the designed buffer of the new protective edge of the 1982 dredged material island through wave dampening from shoaling. The 1.6 acre area where stable cordgrass seedlings are developing is in the best location for protection of this new protective edge and least tern nesting area.

The most critical factor to insure success of seeding is to control elevations during the disposal operation. Once the disposal operation was completed, equipment access and ability to work on soft sediments precluded extensive earthwork operations prior to seeding.

The success of the project was based on careful inspection of the disposal operation insuring proper elevations of the dredged material, accurate predictions of the final slopes of the dredge material and the physical characteristics of the DMP site. These considerations must be evaluated several months prior to the actual seeding. Also, several months of consolidation of the dredged material prior to seeding is recommended to insure seeding at the proper elevations required for S. alterniflora. In fact, differences of tenths of a meter in elevation may alter species of wetland plants that inhabit an area.

Finally, from an economical viewpoint, the habitat development as a disposal option was cost effective in many ways. The traditionally and environmentally preferred mode of disposal would have been to use a contained DMP site. Approximately 14 ha would have been required to contain the resulting dredged material.

Comparing similar types of DMP sites constructed on past jobs and their respective costs, an estimated DMP site cost for 14 ha DMP would be approximately $250,000 which includes sediment control measures required for contained DMP sites. The habitat development site costs for the habitat development disposal option including inspection of the disposal operation by EC Inc. was approximately $67,867.

There are several individual items in the overall cost of the habitat development disposal option which merit some discussion. There are substantial cost savings involved by seeding an area compared to transplanting. Seeding and fertilization costs were approximately $3,317/ha in 1982 and $5,451 in 1985 compared to approximately $25,604/ha transplanting costs of the *S. patens* utilized in 1982.** Consequently, a requirement to use *S. alterniflora* transplants would have been cost prohibitive as a disposal option at the Honga River.

Also, besides being cheaper, a more uniform cover is obtained by seeding in lieu of sprigging at the usual 0.6 m grid. Optimal transplanting time is in June. Consequently, seeding in late April and early May allows for growth of the plant to compare in size with peat pots that would normally be transplanted in June. As a result, the stabilization benefits of seeding are comparable to transplanting.

Another economic benefit obtained by using habitat development as the disposal option occurred in the actual dredging costs. Unit costs for dredging are usually lower for overboard disposal compared to costs associated with a contained DMP. In the case of the Honga River, the cost for dredging 135,831 m^3 in 1982 and 114,678 m^3 at $1.91/$m^3$ in 1985. In the fall of 1982, the COE dredged approximately 99,385 m^3 at the eastern section of the Honga River utilizing a contained DMP site at a cost of $2.17/$m^3$. The unit costs referenced above do not include DMP site construction or mobilization and demobilization costs.

CONCLUSIONS

With increasing difficulty experienced by the COE and local sponsors in acquiring DMP sites, the time has arrived to critically evaluate innovative and productive uses of dredged material in lieu of relying on traditional DMP sites. Many hectares of valuable upland wildlife habitat have been lost due to the traditional "hands off" policies of utilizing aquatic resources as DMP sites.

Overboard disposal can be a viable alternative provided the disposal operations are critically evaluated by personnel from environmental, engineering, and economic perspectives. Environmentally, the 1982 and 1985 Barren Island habitat development project created 22.3 ha of diversified biological habitat. Additionally, it shoaled

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**1982 seeding and transplanting costs were erroneously reported in Earhart and Garbisch 1983.

approximately 36 ha of shallow water habitat and allowed extensive volunteering of this area by Ruppia maritima. Of even more importance, specific habitat was created for least terns which have been reported as a declining species in the Chesapeake Bay.

This work documented that dredged material can be stabilized in an open-water DMP site by seeding techniques. The benefits of stabilized dredged material with seeding techniques are even more economically beneficial when large areas of dredged material require stabilization.

The important engineering consideration of selecting a site of suitable wave energies to accommodate seed germination and seedling development is of utmost importance. This work illustrates that moderate exposure or extended wind fetches can preclude desired seeding success of Spartina alterniflora.

Another important economic benefit of the habitat development disposal option resulted in costs that were approximately 30 percent cheaper than a contained DMP site. Also, seeding techniques are not only engineeringly preferred over transplanting, they are more economical while providing similar stabilizing benefits.

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MECHANICAL HARVESTING OF SEAGRASSES FOR MITIGATION PROJECTS

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ABSTRACT

This paper presents a discussion of the development of a mechanical harvesting technique for salvaging seagrasses scheduled to be destroyed by a beach renourishment project in Dade County, Florida. Salvaged seagrass material was incorporated into the Port of Miami Seagrass Restoration Project, a large scale mitigation program. More than 168,000 15-cm plugs of Thalassia and Syringodium were harvested in a 53-day period.

INTRODUCTION

During the latter part of the 1970s, the Seaport Department of Dade County, Florida, began planning for major expansion of its facilities at the Port of Miami. Key features of the expansion included deepening of the access channel, dredging of a turning basin, and filling and expansion of Lummus Island, an island created by the deposition of material dredged during the construction of the main entrance channel to the Port and lying adjacent to the Port of Miami.

The need for extensive dredging and filling mandated that the Port apply for a number of environmental permits, including a U.S. Army Corps of Engineers (USACE) standard dredge and fill permit.

In order to expedite the permitting process, the Seaport worked closely with environmental groups, regulatory agencies, and the public. Since dredging and filling activities were expected to result in the elimination of approximately 33 ha (81 acres) of seagrass beds, it was agreed that mitigation for the unavoidable environmental impacts of the project would be effected through a seagrass revegetation program. The term mitigation in this paper refers to restoration of public resources that are impacted by the development of a project.

A standard USACE dredge and fill permit was issued to the Port of Miami in October of 1980. That permit required the Seaport to plant 102 ha (251 acres) of Biscayne Bay bottom with seagrasses. This requirement included mitigation not only for the 33 ha (81 acres) of seagrasses that would be directly impacted, but also 69 ha (170 acres) of unvegetated bottom considered by the National Marine Fisheries Service (NMFS) as potential seagrass habitat.

The planting techniques to be used in the execution of the mitigation program were ones that had been used in various small scale seagrass restoration programs conducted by Thorhaug and Hixon (1975), Thorhaug and Austin (1976), and Thorhaug (1983).

Planting was initiated in December of 1981, and by early fall of 1984, approximately 24 ha (60 acres) of bay bottom were planted with seagrass units on 0.9 m (3 foot) centers. The types of planting units used in the program through the end of the 1984 planting season included *Halodule* and *Syringodium* shoots with rhizomes, *Thalassia* shoots, *Thalassia* seedlings, and a limited number of *Syringodium* plugs.

Results of the first two phases of the program (Phase I and IIa) are reported in various documents including Gaby and Langley (1985) and Gaby et al. (1986). Virtually all of the planting carried out during the Seaport's mitigation program was by Applied Marine Ecological Services.

By the end of 1984 planting season, the Seaport's program was to involve the identification of areas to be used as recipient sites and a planting and monitoring program that would be continued until the Port's mitigation obligations were satisfied. The planting techniques and species to be used in the execution of the remainder of the program were to be based on the results of earlier portions of the program analyzed through a detailed monitoring program carried out under my direction.

Need to Salvage Large Quantities of Seagrasses in a Short Period of Time

For more than a decade, efforts had been directed toward gaining approval for a major beach renourishment project on Key Biscayne in Dade County. The project was quite controversial, from the standpoint both of potential environmental impacts and economics. Nonetheless, permits were issued in 1984 for the renourishment of approximately 3.9 km (2.4 miles) of Atlantic shoreline. Despite the fact that as much as 10.5 ha (26 acres) of prime seagrasses were to be destroyed in the execution of the beach fill, the environmental permits did not require seagrass revegetation.

In October of 1984, Mr. Eric Hughes, Life Scientist with United States Environmental Protection Agency, requested that the Port consider salvaging the seagrasses that were to be buried by the Key Biscayne project and incorporating them into the revegetation program. Mr. Hughes indicated that the federal resource agencies were interested in salvaging as much of the seagrass resource as possible.

In ensuing discussions, it became apparent that if the Seaport were to carry out a major salvage effort, significant changes were needed in the mitigation program. According to the schedule for the Key Biscayne project as outlined by the USACE in the fall of 1984, by mid-July of 1985 a dredge was to be positioned offshore of Key Biscayne to begin beach renourishment. The Corps of Engineers anticipated that beach filling would be completed by fall of 1985. In the spring of 1985, I and other representatives of the Port of Miami met with the Interagency Coordinating Council, a group representing all of the federal agencies that had reviewed the Seaport's dredge and fill permit application. It was decided that the Seaport would explore the feasibility of salvaging the seagrasses and the regulatory agencies would begin considering ways to allow the Seaport to use the salvage operation in partial fulfillment of the Port's mitigation requirements. In attempting to undertake a major seagrass salvage operation, the Seaport had to address two key questions:

1. How could large quantities of seagrasses be harvested in a timely and cost-effective way?

2. Could nearly 80 ha (200 acres) of suitable Bay bottom be identified to serve as recipient sites?

Conventional Techniques for Seagrass Harvesting

Seagrass harvesting generally involves manual techniques, including non-destructive procedures such as harvesting rhizomes that are not attached to the substrate, and procedures such as the use of high pressure water pumps to remove the sediment overlying the rhizomes so that the rhizomes and shoots can be harvested. The latter technique is potentially damaging to donor beds.

The typical manner of harvesting seagrass plugs is manually through the use of post-hole diggers. Since the goal of the potential salvage operation was to maximize the amount of seagrass to be transplanted, it was decided that sods would be harvested and then cut into plugs. The size of the plug to be used for the program was ultimately based on regulatory, biological, and practical considerations.

The Seaport's objective was to transplant as many as one-half million seagrass plugs, and therefore manual means of harvesting were judged to be physically and logistically impractical early in the feasibility study. Development of a mechanical harvesting technique was sought under my direction. Since any seagrasses not harvested by the Seaport would be destroyed by beach renourishment, damage to donor beds was not of primary concern in project planning. A mechanical harvesting technique was sought, however, that would minimize wastage of resources while maximizing harvesting rates. It was hoped that the harvesting techniques developed for this project would be usable for the salvaging of seagrasses for other beach renourishment projects.

Requirements for Mechanical Seagrass Harvesting Equipment

At Key Biscayne, the toe of fill was to be up to 60 m (200 feet) waterward of the crest of the dune line, necessitating harvesting in waters ranging between 0.6 and 2.1 m (2 and 7 feet) depending on slope and tide stage.

The basic requirements of a mechanical harvester for seagrasses included:

1. Ability to work in depths between 0.6 and 1.7 m (2 and 5.5 feet), assuming deeper areas would be harvested at low tides;

2. Stability in light to moderate wave action;

3. Capacity to dig deep enough to get beneath the rhizome mass (approximately 30 cm below the surface of the substrate);

4. Ability to harvest seagrasses with rhizomes intact;

5. Ability to be moved easily from collecting site to collecting site; and

6. Ability to harvest Thalassia, Syringodium, and mixtures of the two.

There were other important practical considerations, including the capacity of the device, whether or not the device could be left in the water or on the shoreline at the harvest area when not in use, additional or auxiliary equipment needed at the site, etc.

MATERIALS AND METHODS

Various options were considered in looking for a suitable mechanical harvesting device; it was hoped that some type of farm implement might be suitable, but no such device was found. Potential mechanical harvesting techniques considered included use of a dragline either to harvest the seagrasses and bring them to shore or to undercut the beds with a bucket that had the rear portion removed and have the material gathered by hand or through the use of some other mechanical device. Discussions with dragline operators convinced us that a dragline would not be satisfactory as a harvesting and collecting apparatus, since dragline operators indicated that they did not have sufficient control over the dragline to ensure that they were undercutting the rhizome mass. Furthermore, it was determined in field trials that seagrass sods would not float, so the idea of undercutting them with an open end dragline bucket was abandoned. A backhoe on a barge was considered and rejected because of the need to have a boat available to reposition it. Fabrication of a custom harvesting device was considered and judged to be infeasible because of costs and the amount of time available. Ultimately, two types of equipment were field tested.

The first type of mechanical equipment tested was a crane with a clamshell bucket. It was hoped that the crane, working from shore, could scoop up sods, which could, in turn, be deposited on the beach to be cut into plugs. Obviously, this technique would be somewhat restrictive, since a 45.7 m (150-foot) boom would be too short to harvest near the seaward side of the fill area and at high tide the equipment might not have sufficient operating room on the beach waterward of the dune. In field trials, a crane was found to be unacceptable for harvesting because of difficulty in controlling the depth of the cut. Only a small portion of each bucketful had rhizomes attached to the shoots.

The second type of mechanical harvesting equipment tried was a vessel known as a Water Witch. This boat is usually used for clearing debris out of harbors and is fitted with a hydraulic lifting arm on the front. The arm was fitted with a "face shovel," a 1.9 cu m (2.5 cu yd.) digging apparatus. Field trials with the Water Witch were successful.

A procedure for harvesting seagrass was developed. The shovel was propelled by the vessel's engine and dug into the substrate deep enough to get below the rhizomes of the seagrasses. The hydraulic arm then lifted the sod. The boat was then positioned so the sod could be deposited on stationary or floating tables near shore where it was cut into plugs and packaged in polyethylene bags for shipment to the planting site with both sediment and rhizome mass intact. A hole was put into each bag to allow gas and water exchange once the plugs were dropped into the water at the planting site. Plugs were placed into polyethylene baskets for shipment to the planting sites. Approximately 20 15-cm (six-inch) plugs could be produced per shovelful.

The Search for Planting Sites

In experiments carried out in 1984, Gaby and Langley (manuscript in preparation) determined that sidescan sonar could be used effectively to map seagrass beds in shallow, turbid waters. This technique was applied to the search for large suitable sites for seagrass planting. While previous site searches performed by the Dade County Department of Environmental Resources Management and the Phase I planting contractor relied heavily on "spot diving" and the use of aerials, the sidescan sonar technique using the 100 or 500 kHz bands could search an area up to 300 meters in width in the shallow water of Biscayne Bay at a speed over 2 knots. Unlike aerial photo and spot diving surveys, side scan sonar is not limited by turbid water.

Additionally, a Trisponder (a microwave-based navigation device) allows any transect to be relocated ±1 meter. Coupled with knowledge of the bay and some ground truthing, it was thus feasible to identify recipient sites rapidly.

RESULTS

More than 165,000 15-cm (six-inch) seagrass plugs were harvested in a 53-day period. The majority of these were plugs of *Thalassia* or *Thalassia* mixed with *Syringodium*.

Final survival results are not available at this time, but monitoring data have been collected. Additional monitoring data will be collected in July and August of 1986. We are relatively confident that the plugs used as planting units will have a relatively high survival rate. Plugs transplanted in May appeared healthy at the end of August. A tropical storm came through the Miami area in late August and an inspection of the plantings after the passage of the storm indicated that the plugs, no doubt owing to the large rhizome mass buried beneath the sediment, appeared unaffected.

DISCUSSION

It is very difficult to analyzer per-acre costs for mechanical harvesting since dollars expended on the Key Biscayne salvage operation included development of procedures, site searches, and many costs related to mobilizing for a massive harvesting effort in a very short time.

There are avenues that can be pursued to increase cost effectiveness greatly:

1. The size of plugs could be increased to reduce handling time and number of personnel involved in packaging.

2. Plans exist to modify the lifting arm of the Water Witch to allow it to harvest in deeper water and increase shovel capacity.

3. Much of the handling of sods was done by inmate labor because of the need for a large work force. I believe that contract labor could be given suitable financial incentives to motivate increased output.

4. Increased unit size will reduce wastage incurred in cutting.

5. Packaging could be performed on a barge to reduce need for the Water Witch to move in close to the shore to deliver each sod.

While there was some wastage of materials in the digging of the seagrass sods, there was relatively little damage to grass beds caused by the Water Witch. Some minor propeller damage resulted to beds when the Water Witch worked at very low tides, and some scouring was done by the bow of the boat as it was beached from time to time to allow the operator to take breaks. The walls of the cuts made by the face shovel were relatively straight and very little damage occurred adjacent to the cut. This was observed early in the field trials, and was confirmed by a field inspection carried out by Mr. Eric Hughes, USEPA, after the harvesting operation terminated. The cuts made by the face shovel in Thalassia beds were usually down to a depth of 30 cm (1 foot) below the sediment surface, but sediment moved into these spaces soon after the cuts were made.

To my knowledge, the amount of material collected at Key Biscayne through the mechanical harvesting procedure represents the most seagrass harvested during any seagrass transplanting program. Certainly, no other program has produced as many seagrass plugs per unit time.

Mechanical harvesting offers the opportunity to salvage large amounts of seagrasses in a short period of time, preventing the loss of a resource that would otherwise be destroyed.

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WATER BUDGET MODEL OF A FLORIDA GULF COAST FLATWOOD/WETLANDS MOSAIC

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ABSTRACT

This paper presents a water budget model derived from a one-year assessment of the hydrologic parameters of the 142.5-square kilometer (55-square mile) Ringling-MacArthur Tract in Sarasota County, Florida. The water budget model was developed as an analytical tool for assessment of hydroperiod modifications.

The study area consists of a mosaic community of numerous wetlands, pine flatwoods, and dry prairies. Approximately 10 percent of the area is utilized for range and up to 40 percent can be classified as wetland. The site hydroperiod consists of a June through October wet season in which water levels are at or near the ground surface throughout the site. During the November through May dry season, the water table drops 0.9 to 1.2 meters (3 to 4 feet) with most wetlands becoming dry.

Field installations consisted of in-situ lysimeters, in-stream trapezoidal flumes, recording and nonrecording rain gauges, and meteorological stations. Lysimeters were installed in three distinct habitats: wetland, pine flatwood, and dry prairie. In addition to the controlled lysimeters, five discharge measurement stations and a National Weather Service Class A pan evaporation station were monitored. The field data was utilized to develop baseline estimates of evapotranspiration, rainfall/runoff relationships, infiltration rates, and soil storativity.

Office analysis consisted of water budget model conceptualization, data base development, and model calibration/verification. The calibrated model is being utilized to prepare water withdrawal alternatives that capitalize on the increased rainfall capture associated with depressed water tables. In addition, the data is being applied to develop alternatives that preserve the basic hydroperiod of critical wetland systems.

INTRODUCTION

The purpose of the Ringling-MacArthur Tract (RMT) hydrologic investigation was the development of a water budget model for estimation of RMT surface water supply capabilities. The investigation centered on quantification of the hydrologic parameters of rainfall, evapotranspiration, evaporation, soil infiltration capabilities, soil storativity, surficial aquifer water flux, and surface runoff. Site specific data were collected from April 1985 through December 1985. In addition, long-term data from the USGS, Southwest Florida Water Management District, and National Weather Service was utilized.

STUDY SITE

The RMT is an approximately 142.5-square kilometer (55-square mile) tract of land located in eastern Sarasota County, immediately east of the Myakka River, and southeast of Myakka River State Park (Fig. 1). Hydrologically, the site is a typical southern Gulf Coast wetland/upland mosaic with overall basin slopes of less than 0.2 meters/kilometer (1 foot per mile). The site rises from a low elevation of approximately 1.5 meters (5 feet) mean sea level (msl) in the southwestern corner near the Myakka River to elevations approaching 10.7 meters (35 feet) msl in the north central and northeastern portions. From the central portions of the site to the eastern boundary the land surface is characterized by a relatively level plateau with elevations ranging from 9.1 to 10.7 meters (30 to 35 feet) msl. The eastern third of the plateau within the RMT boundaries is bisected by the southwestern tending Deer Prairie Slough.

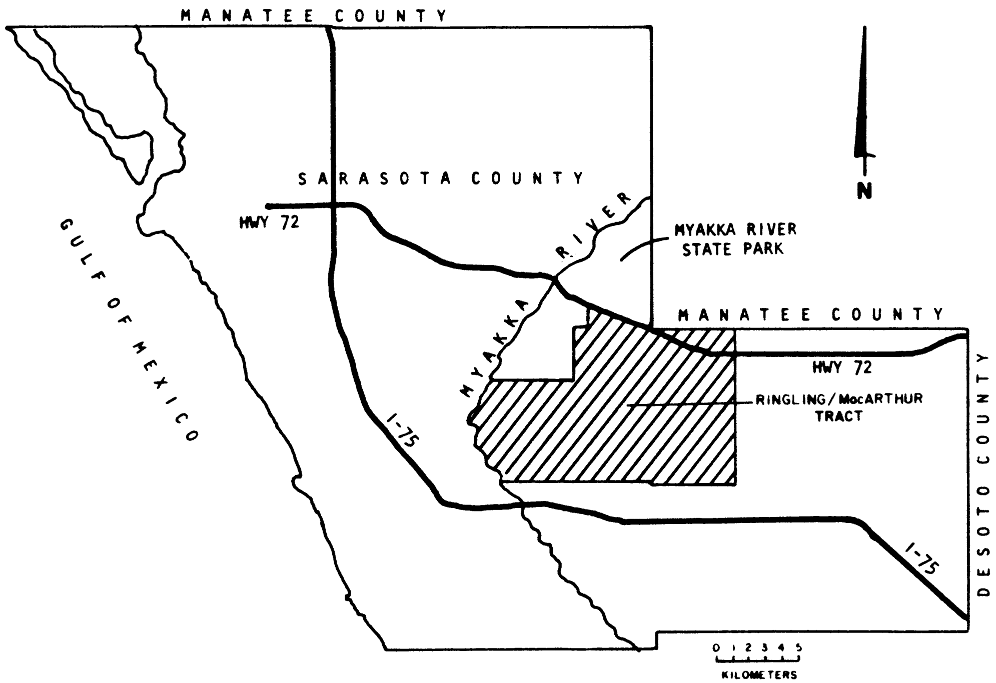

Figure 1. Site vicinity.

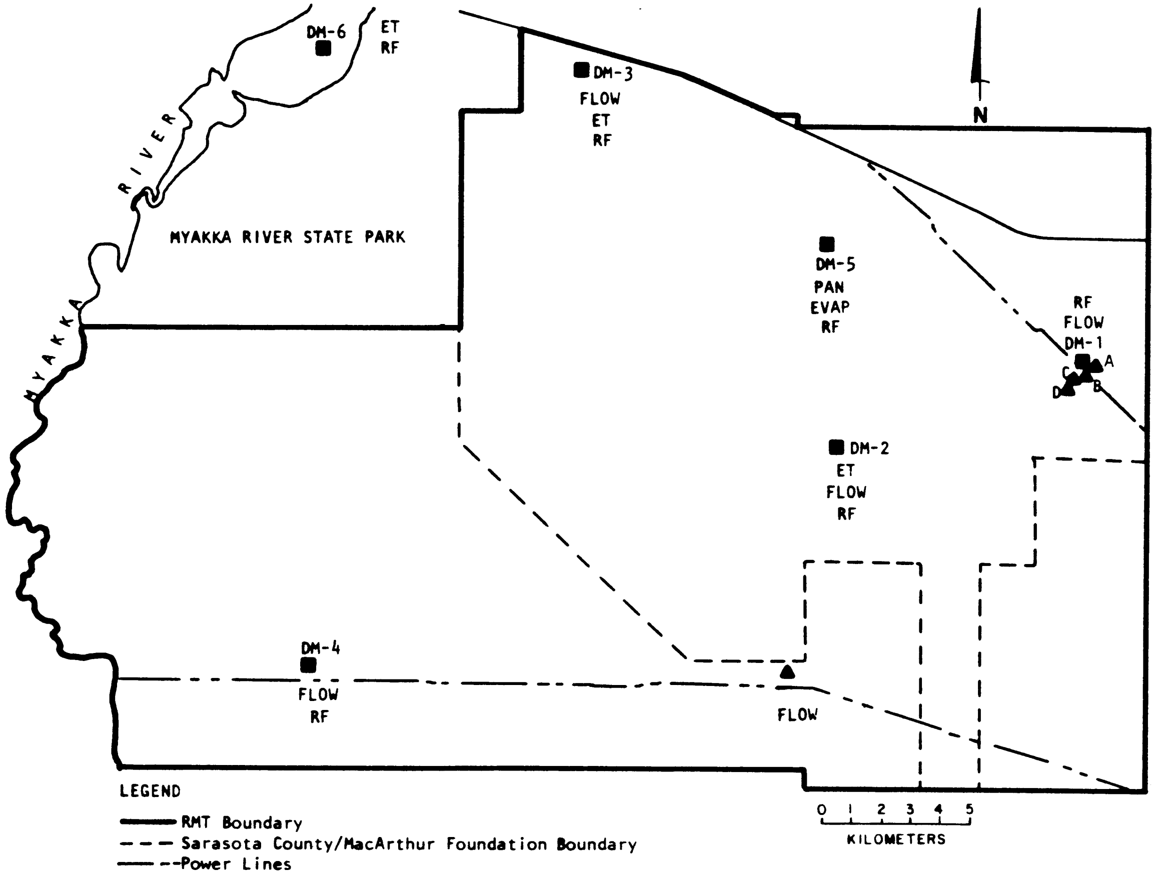

Figure 2. Location map of water monitoring station.

HYDROLOGIC PARAMETER QUANTIFICATION

Rainfall

The onsite rainfall data shows a typical distribution of rainfall corresponding to the wet and dry seasons of southwest Florida. However, the first five months of site-specific measurements experienced rainfall totals well below normal. Significant rainfall amounts did occur during the months of June and July. Most of the rainfall, however, occurred as isolated thunderstorms over limited portions of the 142.5-square kilometer (55-square mile) site. Rainfall returned to normal, as defined by the long-term averages at Myakka River State Park, during August. From mid-August until the end of October, monthly rainfall totals in excess of 15.2 centimeters (6 inches) were recorded throughout the site. From October to the end of the recording period in December, monthly rainfall totals decreased as expected.

Evapotranspiration

Evapotranspiration (ET) was measured using three non-weighing lysimeters. The data was correlated with pan evaporation data from an on-site pan evaporation station.

As defined by the National Handbook of Recommended Methods for Water Data Acquisition (1982), a lysimeter is an instrument consisting of a block of soil usually planted with some vegetation and enclosed in a container which isolates it hydrologically from its surrounding. In addition, the block of soil should contain provision for drainage of the soil water. Designs of the upland and wetland lysimeters are shown in Figures 3 and 4, respectively. Locations for the lysimeters are shown in Figure 2.

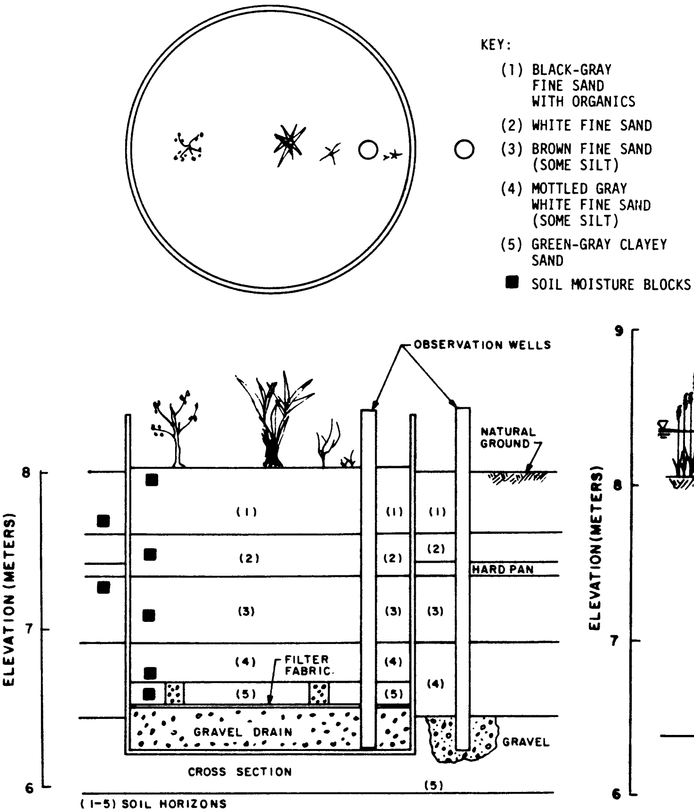

Figure 3. DM 3 dry prairie Evapotranspirometer schematic

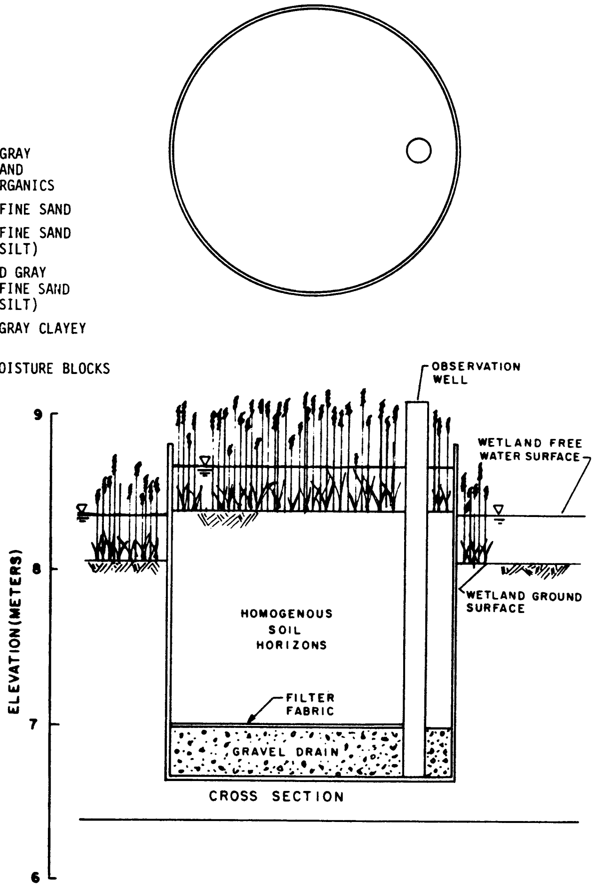

Figure 4. DM 2 wetland Evapotranspirometer installation schematic

If properly constructed, located, and operated, lysimeters provide the most accurate information on actual or potential ET and are the only means to calibrate other methods of measuring or estimating ET

(Gangopadhyaya and others 1966; Harrold, 1966; Tanner, 1967; Blad & Rosenberg, 1975).

The lysimeter approach was chosen for monitoring and determining ET based on its credibility from the scientific community, practical construction and installation requirements, maintenance issues, and costs. The ultimate goal of the ET investigation was development of empirical ET relationships between individual macroscale vegetative communities and National Weather Service pan evaporation data.

Results of the analysis indicate ET is strongly correlated with vegetative community, depth to water table, and season. For the wetland, which never experienced unsaturated conditions, ET ranged from over 120 percent of pan evaporation in September to approximately 80 percent of pan evaporation in November. For the uplands, the relationship was different in that ET was never more than 80 percent of pan evaporation; it decreased fairly gradually as the water table declined (see Fig. 5), and didn't appear to be as strongly correlated with season.

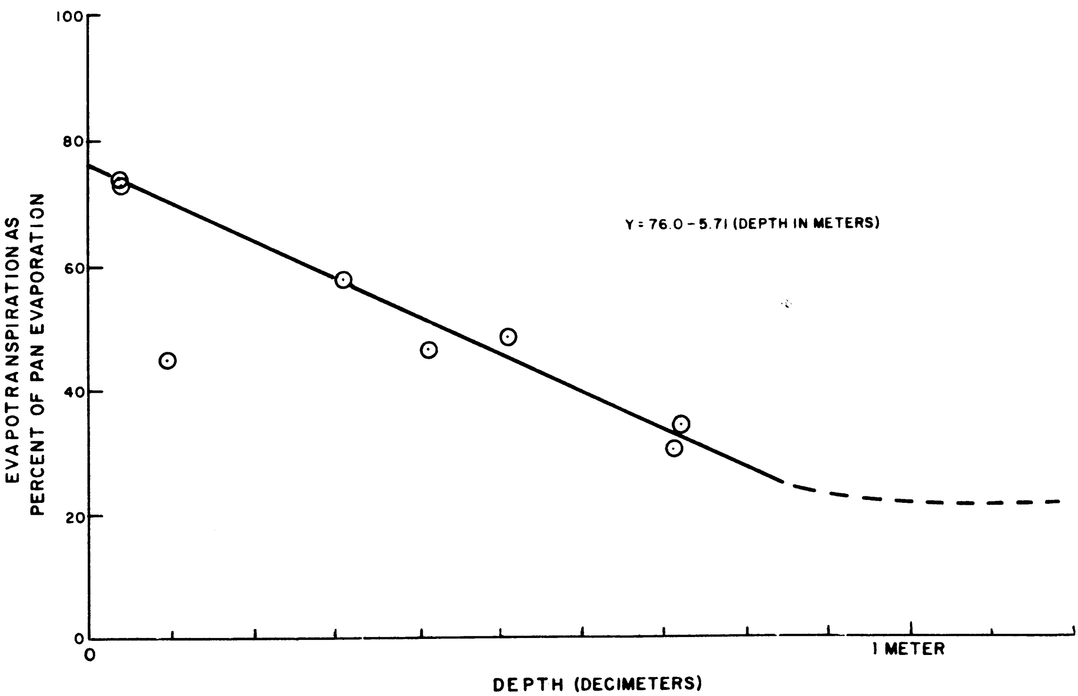

Figure 5. Evapotranspiration versus depth relationship upland.

Runoff Quantification

Four stream locations (see Fig. 2) were chosen in order to quantify runoff characteristics of the RMT. The stations ranged in drainage area from approximately 5.2 square kilometers (2 square miles) up to 31.1 square kilometers (12 square miles). In addition, long-term discharge data were available from the Myakka River near the site at the Highway 72 Myakka River crossing. Further, three years of discharge data were available at a USGS gaging station just downstream of the site on Deer Prairie Slough with a drainage area of approximately 91 square kilometers (35 square miles).

The rainfall/runoff values were compared against the Soil Conservation Service empirical rainfall/runoff relationship represented by the runoff curve number (CN) method. CN values calibrated against actual rainfall/runoff volumes provide reasonable approximations of the runoff hydrograph shapes and peaks. CN was found to be strongly correlated with depth to water table but largely independent of antecedent rainfall. Heavy antecedent rainfall under low water table conditions had virtually no effect on the CN. However, calculated CN values varied significantly with the water table. On the average, across the flatwoods/wetlands mosaic, CN varied from 0 (no runoff) when the water table was below the stream inverts to a high of 85 when the water table reached the ground surface.

Storativity

Storativity values were obtained based on pump test data from 20 well clusters installed on the site during the study to investigate the ground water hydraulic properties. In addition, storativity information was obtained based on water level fluctuations and known input-output quantities from the three lysimeters. Storativity was found to range from 3 percent to approximately 10 percent. An average over the site of 5 percent was utilized.

Surficial Aquifer Leakance

Surficial aquifer leakance was obtained based on five secondary aquifer pump tests conducted to estimate the hydraulic parameters of the secondary aquifer across the site. This data was converted into average leakance values in the water budget analysis. Under normal conditions in which the secondary and surficial aquifer potentiometric surfaces are approximately equivalent, leakance was taken as zero. Under potential maximum pumping conditions in which the Haythorne aquifer potentiometric head may be reduced as much as 12.2 meters (40 feet), the leakance was taken as .051 cm/day.

WATER BUDGET ANALYSIS

General

The water budget analysis consisted of: (1) development of a mass balance model and (2) utilization of that model for the assessment of temporal modifications to the ground water regime under various withdrawal scenarios. The steps involved in the analysis consisted of the following:

1. Model conceptualization

2. Data base development

3. Model calibration/verification

4 Analysis of site water balance

5. Analysis of various withdrawal scenarios

Model Conceptualization

The controlling equations for the mass balance analysis are:

Q(i)	= f [y(i), eta(i), r(i) a(i)]	Equation 1
eta(i)	= f[et(i), et(i-1)]	Equation 2
et(i)	= f[pc(i), y(i)]	Equation 3
y(i)	= f[s, y(i-1), r(i), eta(i)]	Equation 4
a(i)	= f[y(i), z(i)]	Equation 5

where:

Q(i)	= runoff in centimeters for month i
y(i)	= water table depth below the surface in meters at end of month i
et(i)	= evapotranspiration rate (centimeters/month) at end of month i
eta(i)	= average evapotranspiration (centimeters/month) for month i
s	= storativity (meters of available storage)/depth in meters
pc(i)	= pan evaporation in centimeters
r(i)	= rainfall for month i in centimeters
a(i)	= water table aquifer leakage in centimeters for month i
z(i)	= secondary aquifer potentiometric head for month i.

The independent variables in the above equations are rainfall, pan evaporation, and storativity. The equations as presented cannot be solved as there are six variables and five relationships. Equation 5 cannot be practically solved analytically given the complexities of the aquifer water fluxes. The solution was accomplished by taking the z(i) variable as a constant independent parameter derived from the various aquifer pumping and non-pumping scenarios.

The data bases available for calibration and verification of a mass balance model and subsequent analysis are:

1. 40 years of rainfall data at Myakka River State Park (1944 - 1985),

2. 4 years of continuous water level measurements at SWFWMD Wells ROMP19ES and ROMP19WS,

3. Evapotranspiration data at the Dames & Moore lysimeters,

4. On-site pan evaporation data,

5. 4 months of continuous RMT site runoff data,

6. Regional runoff data (1936 - 1985) on the Myakka River at the USGS Highway 72 gage, and

7. Storativity data from Dames & Moore pump tests and the lysimeters.

Calibration/Verification

Calibration. The model was calibrated against the average of measured water depth data from SWFWMD Wells ROMP19ES and ROMP19WS. The results of the calibration are shown in Figure 6. The predicted water levels are in reasonable agreement with the average of the water levels measured at the two ROMP wells. In particular, the trends of water level variation are in close agreement except for the winter of 1982. The predicted and measured water table depths are within 30.5 centimeters (1 foot) for 70 percent of the 52 months of measured water level data. The remaining 30 percent of the months were within 45.7 centimeters (1.5 feet) except for 2 months when the difference exceeded 61 centimeters (2 feet). Although large variances do occur, they are not perpetuated from year to year. As shown for 1982 and 1985, large variations are factored out during each wet season and reasonable correlation is recovered.

It is likely that the primary forcing function behind the variation in predicted and measured water depth is the variability of recharge/discharge between the surficial and secondary aquifers. This variation is best seen in the drought period of 1984-1985 in which the measured water levels are considerably lower than the predicted water levels. It is possible that this difference represents water loss from the surficial aquifer into the secondary aquifer during the later part of the 1984 wet season. The general close agreement of the model with measured data (except during extreme drought) indicates that the water budget can be estimated with appropriate accuracy under non-artesian aquifer pumpage conditions without inclusion of recharge/discharge between the aquifers unless the artesian aquifer potentiometric head is slowed dramatically by pumpage.

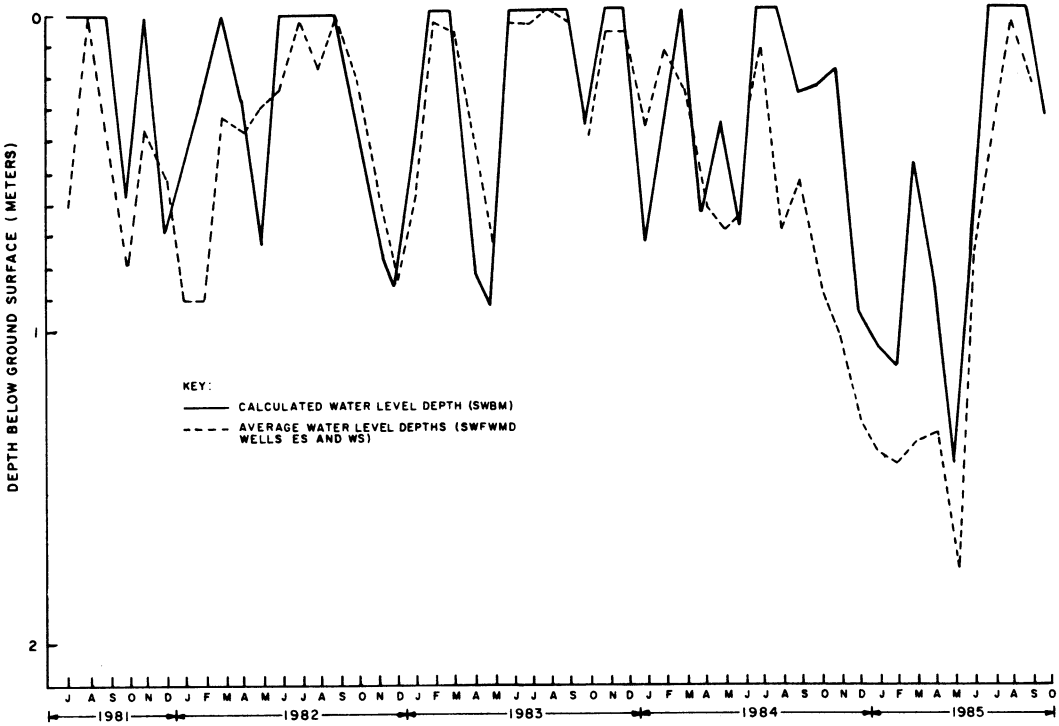

Figure 6. Site water budget model calibration (SWBM)

Model verification. Following calibration, the model's predictive capability was verified by comparison of predicted RMT site runoff with measured Myakka River basin unit runoff. The results of the comparison are shown in Figure 7.

The comparison between predicted and measured values is generally good except for periodic wet season months in which predicted values significantly exceed the measured values. The exceptionally high predicted runoff, relative to measured, is most pronounced in the years following 1964 in which there were eight monthly occurrences. The variation between the predicted and measured data is lessened considerably when the comparison is on a quarterly basis. This is explained by the fact that peak monthly rainfall in the Myakka Basin may be measured as runoff over a period of perhaps several months whereas monthly rainfall peaks on the RMT will be reflected as runoff more rapidly.

Overall agreement between predicted and measured is best for the first 20 years of the period of record (1945-1965). Following 1965 several months of intense rainfall produced yearly predicted runoff totals that are in excess by up to 20 percent of measured values. For the overall period of record the predicted runoff is 39.6 centimeters (15.6 inches). This represents a difference of approximately 8 percent over the measured Myakka River runoff of 36.6 centimeters (14.4 inches).

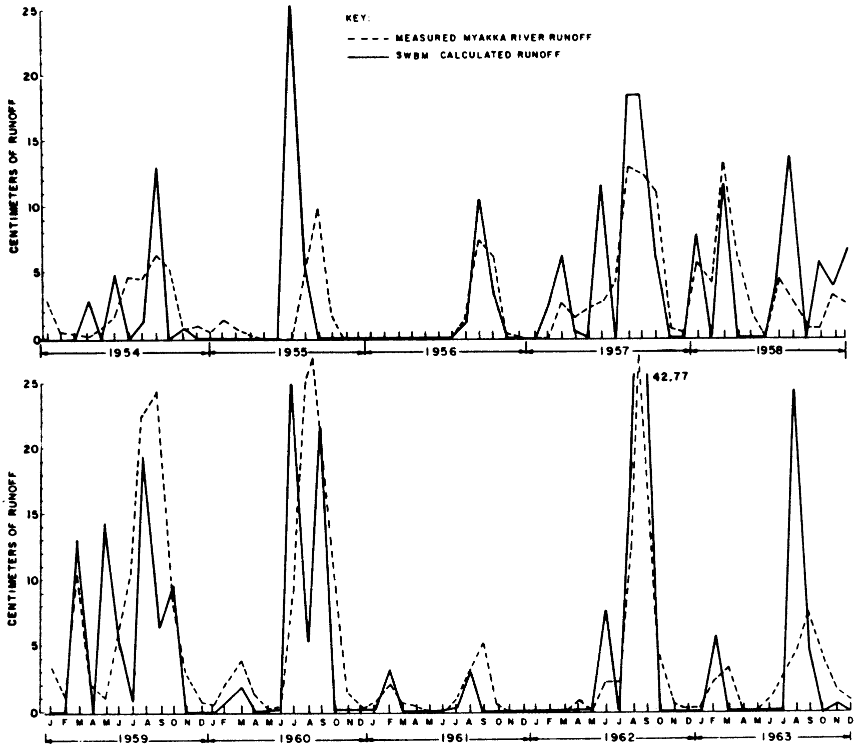

Figure 7. Site Water Budget Model Verification

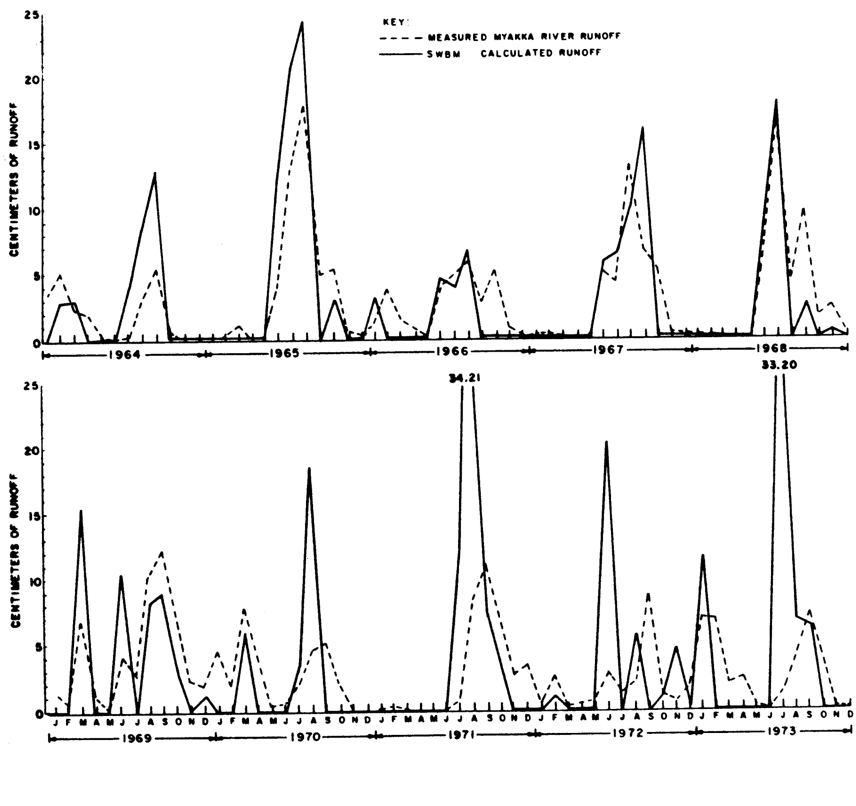

Figure 7. Site water budget model verification.

The difference between predicted and measured values may be a function of one or more of the following factors:

1. Aquifer recharge which is not accounted for in the model.

2. Actual higher unit runoff within the RMT than in the basin as a whole due to differences in Myakka system storage.

3. Erroneous estimation of ET.

4. Unrepresentative rainfall from Myakka River State Park.

5. Errors in storativity.

CONCLUSIONS

The Site Water Budget Model (SWBM) calibrated with hydrologic parameter values specific to a Gulf Coast flatwoods/wetlands mosaic is a tool for inexpensively screening temporal macro-scale variations in water table and runoff. In addition, SWBM is an effective screening tool for assessment of temporal changes in water table and runoff under water withdrawal scenarios. Finally, the SWBM can be utilized to estimate potential water crop variability over large, poorly-gaged drainage basins.

The results generated with the SWBM assessments must be used with some caution. The model predictions are limited in that: (1) the model itself utilizes a relatively simple water budget approach that does not attempt to define micro-scale variability, (2) the model may overestimate the volume of runoff for very high rainfall months, especially following a drought period, and (3) the model assumes a constant recharge rate from the surficial aquifer to the secondary.

Inaccuracies in water table prediction were most pronounced during extreme drought conditions. This is likely the result of the unmodeled increase in surficial to secondary recharge associated with depression of the artesian potentiometric surface by over 20 feet. The absence of a function for relating recharge to head differential is a weakness that will be corrected in future model applications.

Inaccuracies in runoff estimation are most pronounced during extreme wet months. This is likely the result of the absence of a mechanism for incorporating surface storage. The low gradients common along the Gulf Coast coupled with the vegetation and ill-defined drainage channels produce high surface retention capabilities.

The ill-defined nature of surface retention and storage is likely the single greatest uncertainty in any attempt to estimate water budgets for a Gulf Coast mosaic. It is also, perhaps, the most difficult parameter to either measure or extrapolate to other basins.

Despite its potential limitations, the SWBM is effective for macro-scale temporal modeling and feasibility grade planning of ground and surface water withdrawal.

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IDENTIFICATION OF SITES AND APPLICATION
OF A MITIGATION PROGRAM ALONG THE TEXAS COAST

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ABSTRACT

Field surveys were conducted during February, May, and October, 1985, to identify at least 120 potential mitigation sites along the Texas coast. These surveys were commissioned by the Texas General Land Office, which has the responsibility for managing submerged lands within the state.

Mitigation sites were selected in areas of ecological similarity on the basis of improving seagrass beds, emergent marshes, rookery areas, and oyster reefs. For each site, a narrative for implementing the recommended mitigation option was presented with supplementary maps and color photographs.

One of the sites is presently being used to mitigate for seagrass impacted by energy development operations. Department of the Army, Corps of Engineers permits were issued to oil and gas exploration applicants which approved maintenance dredging within an existing channel; dredging of a new channel, slip, and basin; and drilling of exploratory oil wells. These activities occurred in the Laguna Madre in an area of Resource Category 2 seagrass meadows.

The permit holders agreed to implement a prescribed mitigation plan which included creation of seagrass habitat at a depth conducive to growth of shoalgrass (Halodule wrightii). After excavating a slightly emergent tidal flat with a hydraulic dredge in the late summer, shoalgrass was transplanted on approximate 0.91-m (3-ft.) centers during early April of the following year. Delay in the transplanting effort should assure a greater success rate since planting would take place after site stabilization and during the spring growth surge.

INTRODUCTION

The Texas coastal zone encompasses 1611 square km (622 sq. mi.) of coastal marsh, 5400 square km (2100 sq. mi.) of bays and estuaries, and 552 square km (213 sq. mi.) of wildlife refuges within its 25.4 million acres (Texas A & M University 1972). Of this total acreage, approximately 16 percent is owned by the state. The majority (80%) is under private ownership with the remaining 4 percent equally divided between federal and local governments.

Few areas of the coastal zone are totally free from the development pressures of urbanization, commercialization, and/or industrialization. Urban and commercial developments result in permanent losses of coastal habitats, while industrial developments (e.g., oil and gas production activities) can have permanent or, at best, long-term impacts. Such loss of habitat displaces or decreases productivity of resident populations in the bays and surrounding areas.

The fish and wildlife of the Texas coastal zone are important natural resources for aesthetic, ecological, commercial, and recreational purposes Any loss of habitat that decreases wildlife numbers can have global, as well as local, implications. For example, 78 percent of the world population of redhead ducks (Aythya americana) is reported to winter in the Laguna Madre (Shew et al., 1981). This study was initiated to identify areas where improvements to existing habitat could help minimize impacts to wildlife and fisheries from development activities in state-controlled areas of the coastal zone. The objectives of the study were: (1) to identify ten sites totalling at least one hundred acres in each of twelve ecological areas of the Texas coast; and (2) to identify and describe measures to improve the wildlife or fisheries habitats in each of these areas. This report addresses potential sites in the four ecological areas of the lower coast in general, and more specifically, details one of the sites that was used to mitigate for energy development impacts to seagrass meadows.

METHODS

Field surveys were conducted in each of the twelve ecological areas of the Texas coast. The field survey for the lower texas coast (Areas 1-4) was conducted during February, 1985. Surveys of the middle coast (Areas 5-8) and upper coast (Areas 9-12) were conducted in May and October, 1985, respectively. Prior to initiating field surveys, U.S. Geological Survey 7.5 minute quadrangle maps were obtained from the Texas General Land Office (TGLO). These maps had been revised to show coastal areas under TGLO jurisdiction and included biological assemblages as identified by the University of Texas Bureau of Economic Geology. National Wetlands Inventory maps on the same scale as the TGLO maps were obtained form the U.S. Fish and Wildlife Service (USFWS) in Albuquerque, New Mexico. Potential mitigation sites were located on these maps and were later visited in the field. Contacts were also made with various agency (i.e., USFWS, Padre Island National Seashore, and Texas Parks and Wildlife Department) and organization (i.e., Audubon Society) representatives prior to and after the surveys to identify sites and/or acceptable mitigation measures. Local fishermen were also contacted during the field investigations to obtain input specific to their locale.

Various criteria or guidelines were followed during selection of potential mitigation sites. The primary factor was to identify as many sites as possible within the jurisdiction of the TGLO (i.e., submerged coastal land up to mean high water). This includes all of the bay area proper and the offshore waters to the three marine leagues state limit; however, no sites were selected in the Gulf of Mexico waters. Other criteria which were considered in selecting possible mitigation sites were based upon: (1) maximizing habitat diversity, both locally and regionally; (2) increasing habitat which was historically abundant in the area but had been particularly degraded by man's activities; (3) maximizing habitat for particularly important or sensitive species and for those species experiencing population decline in an area; and (4) maximizing the probability of mitigation success. With regard to the last criterion, depth of water in the vicinity of a site was a major factor in selection of sites and/or for mitigation that could feasibly be proposed. Water depths at some sites were so shallow that boat approach was nearly impossible, therefore, lack of accessibility would make any future mitigation measures cost prohibitive.

The proposed sites do not represent the only available sites where improvements were needed or were possible. While attempts were made to survey as much of an area as possible, time restraints and logistic problems prevented total coverage of all potential sites and did not allow an intensive survey at any one site. It should also be noted that site visits were made at various times of the year which may not be representative of conditions during other seasons; therefore, detailed surveys of each site should be conducted prior to work initiation to confirm the recommended procedures and to properly plan for the needed improvements. This will ensure a greater level of success for any improvements which are undertaken.

It should be pointed out that the proposed mitigation/improvement programs will not provide immediate relief from impacts experienced in an area. Success of any program will depend on numerous factors and results may not be realized for several years, a period wherein communities become established through annual growth. Conversely, development projects will have immediate and long-term impacts unless properly planned, and the lag time between the impact and the recovery of the system can be lengthy. It is therefore critical to recognize that the best possible mitigation is one that minimizes impacts at the initiation of development activities.

DESCRIPTION OF THE STUDY REGION

The lower Texas coast differs in terms of climate, physiography, and ecology from the central and upper coastal regions. Unlike others, this region is characterized by a lack of freshwater runoff. Combined with low annual precipitation and high evapotranspiration rates, this results in generally hypersaline conditions in the bays. Wind is a major driving mechanism for circulation in the bays and also plays a significant part in the transport of barrier island sediments into the bays. Such transport has resulted in shoaling of many portions of the bays and in creation of extensive tidal flats that are covered with water only under certain meteorological conditions.

Biologically, the area is characterized as having few resident species, but often with large populations (Shew et al., 1981). Lack of freshwater input results in relatively clear water in the lower Laguna Madre which enhances extensive growth of seagrasses on the bay bottom. These seagrasses form the basis of a food chain which supports large wintering colonies of birds and an important recreational finfishery.

In spite of the regional similarities, local conditions are sufficiently different to recognize four ecological zones (i.e., Study Areas 1, 2, 3, and 4) along the lower Texas coast. These differences are particularly noticeable between the lower and upper Laguna Madre and the Corpus Christi Bay complex.

Study Area 1

Study Area 1 encompasses that portion of the Laguna Madre from the Rio Grande River to near the Land Cut north of Port Mansfield. Within this area are the only major sources of freshwater inflow along the lower Texas coast. These include the Rio Grande River and the Arroyo Colorado. The area is relatively undeveloped except for the southern extreme, where Port Isabel and South Padre Island developments are impacting barrier island and bayside habitats. Dredging of the Brownsville Ship Channel to provide Gulf of Mexico access has resulted in creation of extensive disposal areas along the channel. Dredged material disposal impacted both Vadia Ancha and Bahia Grande aquatic nursery grounds (Breuer, 1972).

Despite generally hypersaline conditions in the area, the oyster *Crassostrea virginica* exists in harvestable numbers in South Bay. Live oysters were also observed during the field survey outside of South Bay in the Port Isabel area. Seagrasses are common in this area and include shoalgrass, widgeon grass (*Ruppia maritima*), manatee grass (*Cymodocea filiformis*), and turtle grass (*Thalassia testudinum*). Emergent vegetation is comprised primarily of succulent halophytes including saltwort (*Batis maritima*), glasswort (*Salicornia bigelovii* and *S. virginica*), and sea blite (*Suaeda conferta* and *S. linearis*). The mouth of the Arroyo Colorado is reported to be an active site of *Spartina alterniflora* growth (Shew et al., 1981; R. Perez, U.S. Fish and Wildlife Service, Corpus Christi, Texas, 1985, personal communication), but shallow water prevented a survey of the area to determine the existence of this community. The upper marsh is dominated by a herbaceous community consisting of sea-oxeye daisy (*Borrichia frutescens*), shoregrass (*Monanthochloe littoralis*), and saltwort. Sacahuista (*Spartina spartinae*) is dominant in the high marsh and the black mangrove (*Avicennia germinans*) is locally abundant in the South Bay area. Shew et al. (1981) report the latter species to be spreading throughout the area, however, recent freezes had seriously affected many plants in the area.

Disposal of dredged material in shallow water has resulted in creating a long string of islands along the Gulf Intracoastal Waterway

(GIWW). These islands are in various stages of vegetative recovery, ranging from bare to 100 percent coverage. Some of the islands of the mainland side of the GIWW are connected to the mainland during low water periods because of natural shoaling and the creation of disposal banks from channels cut from the GIWW. This connection has allowed predators to invade the islands and reduce their value as rookeries. Green Island, due to management by the Audubon Society, has the most diverse vegetation of all islands in the area, supporting more than 150 species of plant life (W. Fluman, Audubon Society Warden, Arroyo City, 1985, personal communication). It is one of the few islands in the entire Laguna Madre complex where a large tree and shrub community exists. This island and the Laguna Atascosa National Wildlife Refuge provide important bird and mammal habitat in Area 1.

Study Area 2

Study Area 2 extends from near the Land Cut on the south to its opening into the upper Laguna Madre, a distance of approximately 65 km (40 mi.) north of Port Mansfield. The area is bounded by the Padre Island National Seashore on the east and the King Ranch on the west. Port Mansfield provides the only urban development near the area, although numerous fishing shacks are found along the GIWW.

The bay deepens north of the Port Mansfield Channel, reaching 2.5-m (8-ft.) depths in some portions of the bay proper. This natural depth has resulted in less dredging of the GIWW between the Port Mansfield Channel and the Land Cut. As a result, fewer islands are found in this area of the Laguna Madre than in other areas of the region.

The Land Cut is the predominant geographic feature of Area 2. In this area, beginning approximately 29 km (18 mi.) north of the Port Mansfield Channel, wind-transported sands from Padre Island filled the estuary and created broad expanses (tens of square kilometers) of mud and sand tidal flats. This portion of the Laguna Madre has been filled for the past 175 years (Shew et al., 1981) and represents the greatest development of tidal flats along the entire western side of Padre Island. Tidal flats in the area are irregularly covered with water during storm surge periods or certain meteorological events. The flats tend to be largely unvegetated with the exception of the eastern side of the GIWW where dredged material disposal has created sufficient elevation for establishment of vegetation. Vegetation types are similar to those in Area 1 except on the tidal flats where algal mats provide the dominant vegetation during flood periods (Brown et al. 1977). Numerous blind channels (some extending for several kilometers into the flats) have been cut from the GIWW for oil and gas development purposes.

Study Area 3

Study Area 3 extends from the northern boundary of the Land Cut to Corpus Christi Bay on the north. Similar to Area 2, urban development is minimal and concentrated at the extreme northern end. The bay shallows in this area and numerous disposal islands have been created along the GIWW and channels dredged for oil and gas activities. Fishing shacks are found on a large proportion of these islands.

As in the lower Laguna Madre, major intertidal areas consist of sand and mud tidal flats along the western Padre Island shoreline. Most of these flats are contained within the Padre Island National Seashore where emergent marsh areas are generally lacking. Seagrasses in the area are dominated by shoalgrass (Shew et al., 1981), although Research Planning Institute (1982) reports the presence of five species of seagrass in this area.

The Texas Parks and Wildlife Department created an artificial reef in the area on State Tract 186 behind a line of dredged material disposal islands. This reef was created through transplantation of live oysters to the site. While the reef has been somewhat successful in attracting fish, it has not been successful in terms of increased oyster production, probably because of high salinity conditions in the bay (R. Harrington, Texas Parks and Wildlife Department, Flour Bluff, 1985, personal communication).

Study Area 4

Study Area 4 consists of the Corpus Christi Bay complex, a heavily populated area of the south Texas coastal region ringed by urban development. Shipping, refineries, oil and gas production, and commercial fishing are major industries affecting the area.

Extensive dredge and fill have occurred in the Corpus Christi Bay area, with much of the dredged material being used to fill and elevate lands for expansion of industrial facilities. A few islands have been created along the Corpus Christi Ship Channel, and one of these, Pelican Island, is an important pelican rookery. Additional disposal islands have been created in the Ingleside and Aransas Pass areas from channel dredging. Except for Shamrock Island, which is privately owned, the lower portion of the bay has few islands.

Seagrasses are less common than in the Laguna Madre because of bay depths. Existing beds are primarily distributed along the inshore side of Mustang Island and the northeastern shore of Corpus Christi Bay. Dominant species include shoalgrass and widgeon grass (Matlock & Weaver, 1979).

Emergent tidal marshes are fairly common in the Corpus Christi Bay area. Spartina alterniflora is dominant in the low marsh zone, with higher marsh zones including Batis maritima, Salicornia begelovii, Distichlis spicata, Borrichia frutescens, Monanthochloe littoralis, and Suaeda sp. (Brown et al., 1976). Benton (1977) also recognized the presence of black mangrove, mesquite (Prosopis glandulosa), salt-marsh bullrush (Scirpus maritimus), and tule (Typha domingensis), among others.

Corpus Christi Bay supported extensive oyster reefs until disease caused massive mortalities during the 1950s (Texas Parks and Wildlife Department, 1975). Existing reefs include Rincon Point Reef and Indian Point Reef. Major fish and invertebrate nursery areas are located in the area west of Harbor Island, Ingleside Cove (especially important for red drum), and shallow grass flats along the bay side of Mustang Island.

MITIGATION OBJECTIVES

Study Area 1

From an ecological perspective, the major importance of the lower Laguna Madre includes its recreational fishery and the large number of resident and migratory birds supported by the area. Important areas include South Bay as a fish and invertebrate nursery, and many of the islands that run along the GIWW north to Port Mansfield. These islands are used extensively by birds and other wildlife.

The wintering bird population feeds on shallow tidal flats in the bay. Fish and invertebrates, which provide food for many of the bird species, depend on detrital input from seagrass systems as a primary organic source. These seagrass beds are particularly vulnerable to damage from channel dredging and marina development. The mitigation sites selected in this area emphasize seagrass and/or rookery enhancement at seven of the ten proposed sits. The remaining proposals include development of an artificial reef to enhance fisheries and planting of emergent vegetation for waterfowl habitat at two sites.

Study Area 2

Recreational fishing is an important resource in Area 2, a region of active oil and gas exploration. One drilling rig was working in the bay during the period of field survey; this activity necessitated dredging of a channel and creation of a disposal area. Several other islands had been created from dredging related to previous drilling operations. In the Land Cut area, numerous blind channels were cut through wind-tidal flats for the purpose of servicing oil and gas wells. Vegetation on the islands and along the channels was generally sparse. Conversations with local fisherman indicated that fishing was very poor within channels that support little or no submerged vegetation.

Proposed mitigation in Area 2 was designed to increase fishery production, increase the diversity of vegetation on tidal flats (particularly around blind canals), and improve habitats for fish and bird use. This will be accomplished primarily through selective dredged material disposal, planting of seagrass and marsh vegetation, and creation of an artificial reef. Seven potential seagrass sites and one site each for emerged vegetation, reef construction, and rookery enhancement were proposed for this area.

Study Area 3

The upper portion of Study Area 3 has been impacted form urban developments at Flour Bluff and Padre Island, and from oil and gas development in the bay. Dredging activities for the latter activity, in addition to GIWW requirements, have created numerous channels and disposal islands throughout the area. The lower portion of Area 3 is protected from extensive shoreline development by ranches on the west side of the bay and Padre Island National Seashore to the east.

Study Area 3 is characterized by extensive tidal flats and shallow water habitat, but few intertidal marshes. Despite large numbers of disposal islands in the area, most are not suitable as bird rookeries because of accessibility to predators. Also restricting rookery potential are the fishing shacks constructed on most of these islands. In some cases, fishing shack developments have taken the form of small communities.

Objectives for enhancing wildlife habitat in Study Area 3 include: (1) improve rookery status of North Bird Island, South Bird Island, and Pita Island; (2) improve an existing intertidal area on the bay's west side through programs to revegetate portions of the area, increase circulation and flushing of an existing lagoon, and transplant of seagrass; (3) improve fishery habitat by creating an artificial reef and planting seagrass; and (4) improve existing fish and wildlife habitat on existing dredged material disposal areas. One artificial reef, two seagrass, three rookery enhancement, and four emergent vegetation sites were proposed in this area.

Study Area 4

Study Area 4 is the most heavily developed area of the south Texas coast. Extensive filling of wetland areas in the Corpus Christi/ Aransas Pass/Port Aransas areas has resulted in the loss or current decline of extensive wetland habitat. Existing and proposed developments along Mustang and Padre Islands are threatening more intertidal habitat in this area. Major objectives of the program in this area are twofold: (1) enhance productivity of certain unique systems in the area and identify those which should be protected as wildlife preserves; and (2) initiate recovery projects at sites impacted in the past and currently in a state of low or declining productivity. One rookery enhancement, two reefs, three seagrass, and six emergent vegetation sites are proposed for Area 4.

IMPLEMENTATION OF THE MITIGATION PROGRAM

The following narrative was extracted from an original report presented to TGLO. Site 2-SG-1 was selected during the field survey as the first potential seagrass site in Area 2. It was subsequently selected by the TGLO as a site to mitigate for past oil and gas drilling activities near Redfish Bay. This section describes the site as it existed at the time of survey and details activities to conduct the mitigation program.

Suggested Mitigation Program

Site 2-SG-1 is approximately 21 km (13 mi.) north of the Port Mansfield Ship Channel and approximately 3 km (2 mi.) east of the GIWW. Specifically, it is located on the South of Potrero Lopeno NW Quadrangle Map 105 and extends over State Tracts 394 and 393. Upward to 50 acres of potential seagrass habitat are available for mitigation in this general area.

Signs of previous oil and gas activity were obvious at the time of the field survey in the area. Several blind channels and a dredged material disposal site were found in the area. Extensive unvegetated tidal flats and sparsely vegetated dunes were also present. Vegetation on the dunes included Uniola paniculata, Spartina spartinae, and some groundcover species (e.g., Ipomoea spp. and Batis maritima). A scattering of Salicornia spp. was present on the tidal flats and some algal growth was evident during April, 1986, when mitigation work was initiated at the site. No submerged vegetation was noted in the channels; however, a thick layer of fine sediment had accumulated on their bottoms.

Few birds were observed at this site. This occurrence is in contrast to a small island approximately one mile to the south, where blue herons and white pelicans were observed in sizable numbers. That low profile island had dense vegetative cover (U. paniculata, among others). Pelicans were observed on mud flats associated with the island.

The primary mitigation activity proposed for this site entailed excavating some of the tidal flat to a depth conducive for the transplantation of seagrass. It was suggested that material generated through excavation could be used to create a variety of habitats and topography in the tidal flat area or could be piped to the existing disposal site.

Additional options for the area included the planting of appropriate vegetation (i.e., grasses, shrubs, groundcover) on the dune area. Such would help stabilize the dunes and maintain this habitat in the area. Other suggested measures included the maintenance of habitat for gulls, terns, and skimmers (i.e., shallow, unvegetated beach front) and the planting of black mangrove along the channel fringes to serve as a source of detrital material and also to stabilize the banks.

It was estimated that the probability for success of mitigation at this site was good to excellent. This was based on the fact that access to the site was good and that abundant seagrass was growing nearby. To optimize the probability for success, it was suggested that dredging should be completed during the fall or winter before planting to allow the site to stabilize. Seagrass transplanting was recommended to occur during the spring.

Seagrass Transplanting at Site 2-SG-1

Prior to creation of seagrass habitat at Site 2-SG-1, two field surveys were performed. The first survey was conducted to determine if suitable substratum for seagrass growth would be exposed after excavation to that depth prescribed in the permits. Sediment cores were taken at six stations randomly sited within the project area to determine if anoxic conditions existed at the prescribed depth. The cores were also analyzed for sand-silt content. The second survey was necessary to determine if the depth of excavation would coincide with water depth at a nearby meadow of lush shoalgrass which was to be used as a borrow site for transplant material. During the second trip, tide gauges were also emplaced by the survey crew at critical locations adjacent to the project area. These gauges served as points of reference for the dredge operator during excavation of the site.

Dredging operations. A small hydraulic dredge capable of operating in water depths of about 0.65 m (28 in.) was necessary for this project. The 0.91 m (36 in.) cutterhead was swung back and forth during coverage of a 25-m (80-ft.) dredging swath. The forward cut was held above the desired depth of excavation in order for the return cut (i.e., at the prescribed depth) to remove any sediment that sluffed during the first swing. This technique resulted in a very consistent bottom relative to depth (±1 in.) and to overlying unconsolidated sediments (∿2 in. and patchily distributed). After completion of dredging, personnel from the involved regulatory agencies visited the site and accepted it without reservation. At that time (late June), a decision to postpone transplanting efforts until the following April was unanimously reached. Such a delay would allow the site to stabilize and mellow, shoalgrass would be entering a renewed growth period, and ambient water conditions (i.e., temperature and salinity) would be more conducive to transplant survival and growth.

Transplanting efforts. Recommendations offered by Fonseca (1986) were implemented during transplanting of the shoalgrass during early April, 1986. Three to five shoots of new growth per rhizome were observed in the borrow stock which indicated that the shoalgrass was transplanted at a very appropriate time in relation to growth stage.

Planting units were randomly checked to determine the number of apical meristems contained within each unit; 50 typical planting units yielded an average of 4.5 apical meristems per unit. At the beginning of each planting day, a new donor site was designated to minimize impact on the existing seagrass meadow. All transplant material used in the project had apical meristem counts within the range of the originally observed material.

Planting units were anchored to the bottom with 6 x 1 x 6, 12 gauge wire staples. The transplants were put upright in the sediment surface and then pressed slightly into the sediment so that the top of the U-shaped pin was a few millimeters into the bottom. Approximately 16,500 planting units were planted within the dimensions of the mitigation site. Calculations indicate that 3.326 acres of seagrass were transplanted on 0.9-m (2.96-ft.) centers within the site. These numbers show excellent agreement with the mitigation requirement of 3.3 acres to be transplanted on 0.91-m (3-ft.) centers. Exact placement of the planting units was not considered to be critical if an appropriate number of planting units were transplanted within the prescribed dimensions of the mitigation site (Fonseca, 1986).

Monitoring program. The proposed monitoring program will document survival and coverage of the transplanted shoalgrass after 3-month, 6-month, and 12-month intervals. Randomly selected planting rows will be examined for percent survival and transect counts of surviving transplants within the full length of six rows (i.e., approximately five percent of the total number) will be run during the first two monitoring efforts. A survey of planting units for area coverage will be incorporated with this activity. Thirty randomly selected planting units will be measured for the area of the bottom they cover. A 0.5 by 0.5-m grid with 5 x 5 cm squares will be placed over the selected transplant and the number of squares filled with seagrass will be counted. The number of units planted at time 0, the survival percentage, and the average area coverage per transplant will give an estimate of the actual area of grassbed that has been generated. At the end of the monitoring program, growth and coverage models from other systems will be used in interpretation of these data in an evaluation of this seagrass habitat mitigation project.

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WETLAND BENEFICIAL USE APPLICATIONS OF DREDGED MATERIAL DISPOSAL SITES

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ABSTRACT

The U.S. Army Corps of Engineers over the past 15 years has built over 3300 ha of wetlands, and over the past 100 years over 2000 islands in U. S. waterways from dredged material or direct construction. These sites have been built for a variety of reasons, including accidental construction, research, special requests from local sponsors, and mitigation. Case studies on six of these sites are presented, and include Bolivar Peninsula, Texas; Buttermilk Sound, Georgia; Gaillard Island, Alabama; Miller Sands, Oregon; Pointe Mouillee, Michigan; and Salt Pond #3, California. Technical information is available from Waterways Experiment Station which identifies principal applications and outlines techniques for project planning design, construction, and management to achieve success in wetlands development, including a state-of-the-science engineer manual on beneficial uses of dredged material.

INTRODUCTION

The U.S. Army Corps of Engineers (CE) continues to make a vigorous effort to determine the environmental impacts of dredged material disposal, to develop alternatives to increase the beneficial use of dredged material, and to reduce the adverse effects of both land and water disposal. An attractive alternative is the consideration of dredged material as a manageable, beneficial resource. Dredged material disposal provides opportunities for a number of environmental, economic, and aesthetic beneficial uses. These include wetland, aquatic, upland, and island habitat development for fish and wildlife; shoreline stabilization and erosion control; beach nourishment; and aquaculture. These uses can be incorporated into marine, coastal, lake, and riverine plans for disposal sites.

Over 1300 cases of beneficial uses of disposal sites have been documented in North America alone, including construction of over 8500 ha of wetlands and over 2000 islands in navigable waterways. Over 3300 ha of fresh, brackish, and salt marshes have been created through operation and maintenance dredging and other direct construction means. Another 5248 ha have been constructed as mitigation in regulatory permitting activities, which may or may not have involved dredging. An estimated additional 9062 ha of wetlands are already planned or proposed, primarily utilizing dredged material. This is a low-estimate, based on information from New Orleans CE District that they have the potential to create up to 15,000 ha of additional marsh over the next 50 years. Wetland activity is shown by CE Division in Table 1.

Table 1. Wetlands built or planned by the CE or required for permits or mitigation (in hectares)[1].

Division[2]	Constructed by CE		Permitting or Mitigation[3]		Proposed or Planned[4]	
	Coastal	Fresh	Coastal	Fresh	Coastal	Fresh
Lower Miss. Valley	1103	10	0	1538	8580	0
Missouri River	0	0	0	110	0	4
New England	0	0	12	18	0	24
North Atlantic	51	0	180	0	71	0
North Central	0	1882	0	148	0	22
North Pacific	24	4	25	0	31	0
Ohio River	0	0	0	61	0	3
South Atlantic	142	20	102	2024	34	4
South Pacific	45	0	982	0	2	0
Southwestern	26	0	49	0	287	0
Totals	1391	1916	1350	3899	9005	57
	(3307)		(5249)		(9062)	

[1]Ha include some Jacksonville District wetlands built as a result of phosphate mining and dredging, as well as 1620+ ha of greentree reservoir wetlands built in the Lower Mississippi Valley and Missouri River Divisions.

[2]Huntsville and Pacific Ocean Divisions have no constructed wetland areas.

[3]Ha built as a requirement for permits or for mitigation, and are incomplete because some Districts did not have complete information for all years.

[4]When canvassed in 1983 and 1985, some Districts did not have firm information on proposed or planned wetland construction in their areas, and New Orleans District said they could over the next 50 years create up to 15,000 ha of additional marsh.

Although there are exceptions, most of these manmade wetlands have been successful. In addition to the economic benefits derived, the created wetlands that have been monitored after construction and compared to nearby reference natural marshes have shown such important qualities as vigorous plant growth and reproduction, prime wildlife and fish habitats, erosion control, site stabilization, high recreational benefits (consumptive and non-consumptive), and improved aesthetic values. More hectares of coastal wetlands than fresh water wetlands have been built by the CE, with 79 percent of the coastal wetlands constructed on the Gulf of Mexico, and 98 percent of the fresh water marshes constructed in the Great Lakes Region. Hectares required as mitigation are more evenly distributed throughout the U.S., and more fresh water wetland sites have been built for mitigation than have coastal sites.

There has been almost no management of CE wetland sites once they are completed. In fact, a number of older successful wetlands resulted from placement of dredged material for reasons other than resource development, and were "accidental" marshes. That is seldom the case now, as wetland development is included in dredging plans in most CE Districts.

WETLAND SUCCESSION ON CE SITES

Most of the intertidal coastal wetlands that have been built have taken three to five years to fully develop as a viable marsh habitat. Growth of vegetation has generally been vigorous and become dense by the second or third years. Transition of dredged material soil to natural marsh conditions is still taking place on CE-monitored sites, but only a trained observer could identify the difference.

Fresh water marshes have developed more rapidly than salt marsh sites. Conditions are generally more favorable for rapid growth, and if soil or dredged material was placed at the correct elevation, plant establishment will generally result without planting. For example, once dredged material was placed at the correct intertidal elevation (fresh water, tidal) at a CE site at Windmill Point, Virginia, emergent marsh plants colonized naturally and completely covered the site in two years. Planted freshwater sites will develop vegetative cover within the same growing season in most cases. If a site is allowed to fill with sediment naturally rather than from soil or dredged material placement, such as the marsh at Pointe Mouillee, Michigan, a number of years may be required before emergent plants become permanently established.

Although few sites of freshwater wooded wetlands have been constructed, in general, mature freshwater wooded bottomlands will take up to 50+ years to develop from bare soil, following through these documented stages: 0-3 years--woody seedling and herbaceous ground cover; 4-10 years--larger woody plants, primarily *Salix*, *Populus*, *Platanus*, *Fraxinus*, and *Acer*; 11-30 years--mature trees of the above species, and small hardwood trees of *Quercus*, *Carya*, *Ulmus*, and others; 31-500+ years--mature bottomland hardwood forest. In lower, swampy areas of primarily standing water, stands of *Taxodium distichum* and *Nyssa aquatica* may take up to 200+ years to reach a climax swamp forest condition from bare soil to timber harvest.

WETLAND MITIGATION OR CONDITIONED PERMITTING SITES

Marshes have been successfully built and established as mitigation requirements in New England, Galveston, Mobile, Detroit, New York, Sacramento, Jacksonville, Philadelphia, and Baltimore and other Districts. A number of CE Districts have specifications for marsh development included in project plans to mitigate wetland losses. These wetlands have been built before or during project work by permit applicants. There are a number of CE projects which are expected to require development, purchase, and/or management as mitigation, such as the Tennessee-Tombigbee Waterway in Mississippi and Alabama, and Venice Cut and Donlin Island in the San Joaquin River in California. Another example is the greentree reservoirs built by Vicksburg District in the Mississippi River Delta, which have been constructed and managed cooperatively, and are considered very successful. Their wetland, wildlife, and recreation al values are quite high. Marshes built of dredged material at Gaillard and Coffee Islands in Lower Mobile Bay and Mississippi Sound were constructed partly as mitigation requirements Both of these sites are vegetating rapidly and vegetation is spreading to nearby areas.

WETLANDS IN CIVIL WORKS PROJECTS

Most of the wetlands built by the CE have been part of Civil Works projects. Six of these projects are presented as case studies in the following section.

Bolivar Peninsula, Texas

This site, located east of Galveston, Texas, consisted of 8 ha of hydraulically placed sandy dredged material in its first phase of development. In January, 1976, the site was graded and fenced, and a sandbag dike was constructed to protect the lower intertidal zone from wave action and wind fetch. Intertidal plantings demonstrated that both *Spartina alterniflora* and *S. patens* could be successfully established on sandy dredged material in the Galveston Bay area. The development and vigor of the plant community has continued to improve since its construction and first planting in 1976. It withstood direct hits from hurricanes in 1983 and 1986 with no visible impacts. The *S. alterniflora* has spread throughout the intertidal zone, and dense stands of *S. patens* remain. Plant growth and production parameters at the site (stem height and aboveground biomass) equal or exceed those of the three reference areas. Root biomass is less than that of plants growing on the natural reference area.

The site has been heavily colonized by invertebrates such as fiddler crabs and receives much use by small fish during high tide. Oysters have densely colonized the sandbag dike area (Fig. 1). Moderate to heavy wildlife use occurs, primarily by seabirds, wading

Figure 1. The salt marsh at the original Bolivar Peninsula site, 8 years after planting, showing colonization of systems in the intertidal zone.

birds, clapper rails, and nighthawks, and mammal use is increasing.

At the Galveston District's request, one of the two deposits of sandy dredged material on either side of the original Bolivar Peninsula site was planted with *S. alterniflora* using a variety of erosion-control materials and designs. It is being monitored on a bimonthly basis and is being compared both the older original Bolivar Peninsula site and to the new but unplanted dredged material deposit of the same-age.

In addition, in January 1986, the District made an experimental deposit of sandy dredged material on a part of the original site so that the effects of deposition of various depths of material upon an existing marsh can be evaluated. This marsh smothering study will be compared to a site in East Matagorda Bay, Texas, where silty dredged material will be deposited on an existing marsh in August, 1986.

Buttermilk Sound, Georgia

This wetland site is a 2-ha intertidal marsh created during 1975-76 by plantings of several species in the intertidal zone on a deposit of sandy, infertile, hydraulically pumped dredged material. Success of the plants was related to tidal inundation and the type of propagule used. Sprigs were more successful than seeds, and *S. alterniflora* was the most successful species planted.

This site has been very successful since its establishment; since 1979 it has been visually indistinguishable from three natural reference marshes. Although tidal scouring initially washed out lower plantings and eroded the lower one-third of the intertidal zone, the site quickly stabilized with remaining plants. It has attained a contour similar to that of the natural marshes and its plant community occupies the same area in the intertidal zone. The plants have trapped large amounts of fine material, which has resulted in a thick layer of silt covering the original sandy substrate. S. alterniflora dominates the entire lower two-thirds of the site (Fig. 2). Stands of S. cynosuroides and S. patens remain in the upper elevations where they were planted. S. patens has invaded and now dominates the high elevations on the site where it had not been planted. Acnida cannabina, an invading species, occurs throughout the site.

Figure 2. The salt marsh at the Buttermilk Sound site, 6 years after planting.

The Buttermilk Sound site differs from its reference marshes by possessing greater plant diversity at lower elevations. This is probably due to planting species in zones lower than they would naturally colonize. Aboveground biomass is similar to the reference marshes, but belowground biomass is less. Wildlife use of the site is more diverse and greater than that of the reference marshes. This is probably the result of the greater habitat diversity found on the Buttermilk Sound island site.

Gaillard Island, Alabama

The site was built in 1981 by the Mobile District with the construction of a 450-ha enclosed three-side, diked containment island in Lower Mobile Bay. It is scheduled to be filled with dredged material over the next 50-80 years.

Immediate dike erosion and subsidence problems made stabilization imperative; part of that stabilization effort was the development of salt marsh vegetation on two sides of the island behind temporary breakwaters. The marsh is growing and spreading over a large part of the planted area, primarily on the northwest dike (Fig. 3a). Different areas of the containment dike have been planted each year since 1982, and a variety of erosion control methods have been tested. The most successful of these have been applied to additional sites in the Mississippi Sound and at Bolivar Peninsula. These include erosion control matting and plant rolls.

From the time of its construction, this island has received heavy use by nesting and loafing seabirds, especially laughing gulls, black skimmers, and seven species of terns. In 1983, brown pelicans began nesting on the island, a first nesting record for this species in Alabama in this century. In 1985, 133 successful brown pelican nests were recorded (Fig. 3b). In addition, several hundred nonbreeding American white pelicans and brown pelicans live year round on the island, feeding around its weir and inside the containment area. Since 1984, an estimated 16,000 seabirds have nested on the island each year.

Although S. alterniflora was the only species planted on Gaillard Island, S. patens, Scirpus robustus, Sc. americanus, Typha latifolia, and several other high marsh species have colonized swales which have formed landward of the original marsh. Muskrats colonized the island in 1985, and have already established territories in these swales. Recreational and commercial fishermen use the containment area, and have reported large, sustained catches of blue crabs, brown shrimp, founders, redfish, mullet, and other species.

Miller Sands, Oregon

Miller Sands Island, a 100+ ha long-term disposal site for the Portland District, is a horseshoe shaped island in the fresh water intertidal region of the Columbia River (Fig. 4). Dredged material is placed hydraulically on the island annually, and was placed in the intertidal zone during 1975. The intertidal area was graded and planted with eight marsh species. Large-scale plantings of Deschampsia caespitosa and Carex obnupta were generally successful, especially at middle and higher elevations in the intertidal zone. Upland plantings of Ammophila arenaria were established in 1977 on the sand spit surrounding the marsh to retard sand erosion, and are well established. A. arenaria now grows over large areas of the entire sand spit, which has been enlarged due to increased dredging of Mt. St. Helen's ash and

Figure 3. (a) The salt marsh at Gaillard Island at 4 years after planting. (b) The brown pelican colony on Gailllard Island.

Figure 4. The fresh water intertidal marsh at Miller Sands, where large areas of natural marsh have colonized around the original planted area.

debris in the Columbia River. These plantings are helping to stabilize the dredged material.

The marsh site has progressed through successional changes and is completely vegetated and withstanding grazing pressures of furbearers on the island. The marsh has expanded from the original planted area to cover much larger intertidal areas surrounding the island. A considerable amount of invasion by other wetland plants has also occurred. The originally planted marsh now has more mud flat area than in early years due to buildup from trapped sediments and the natural hydrology of the island aquatic areas.

Considerable wildlife use of Miller Sands occurs, and includes use by the 33 pairs of bald eagles nesting in that reach of the Columbia River, nutria and muskrats, Columbia white-tailed deer, large numbers of Canada geese and other waterfowl, a nesting colony of western gulls, numerous species of nesting songbirds, and thousands of migrating shorebirds. Wildlife use of the island site is much greater than any of the natural reference areas to which it was compared, and the marsh and other plantings compare favorable for aboveground biomass and species composition.

Pointe Mouillee, Michigan

Pointe Mouillee is a 1840-ha freshwater marsh created by constructing a large diked disposal island about 0.8 km off the Michigan shore in Lake Erie. The site provides a diversity of habitat because it contained emergent and submergent marsh plants plus numerous areas of periodically inundated high marsh. The island, which protects a marsh that had been eroding at a rapid rate due to wave action and wind fetch, was designed to allow the marsh to re-form naturally. This is being done through water manipulation and use of gated culverts to encourage sediment-load drop inside the marsh site. Predominant marsh species colonizing both the marsh site and wetland areas inside the containment island itself are *Typha latifolia*, *Carex* spp., *Phragmites australis*, *Scirpus fluvitialis*, *Scirpus validus*, *Populus deltoides*, and *Salix* spp. (Fig. 5).

Since completion of the island, the site has received much waterbird use by great blue herons, black-crowned night herons, and great egrets, and is a major stopover for migrating shorebirds and waterfowl. Whit-tailed deer have been observed on parts of the site, and small mammals live throughout the site in spite of its urban location and almost constant presence of fishermen. These recreationalists use the entire water portions of the complex, both inside and outside the culvert areas and in Lake Erie around the riprapped island dike. Hunting is seasonally regulated, but fishing is year round and includes ice fishing.

Development of this site is being monitored in a cooperative effort between the Detroit District, WES, and the Michigan Department

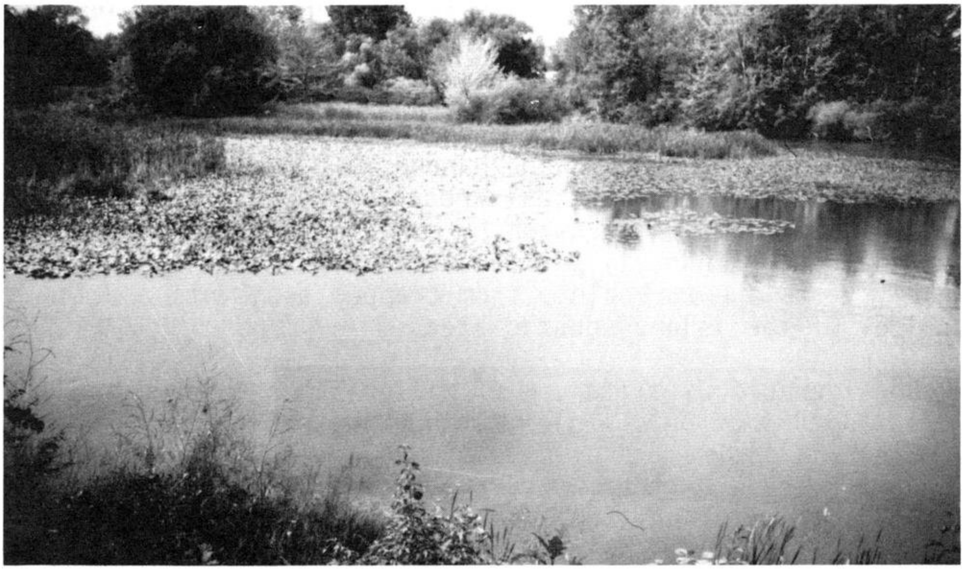

Figure 5. The fresh water marsh at Pointe Mouillee in western Lake Erie, where marsh is being allowed to colonize naturally behind the containment dikes.

of Natural Resources (MDNR). The entire site is under close supervision by the MDNR. Access is limited to foot traffic and small fishing boats and the site is designated as a Wildlife Management Area for the state of Michigan.

Salt Pond #3, California

This wetland site was established on a portion of a 40-ha salt water evaporation pond in south San Francisco Bay that was partially filled in 1974 with hydraulically dredged clay material. Plantings of *Spartina foliosa* and *Salicornia pacifica* were established during 1976-77. *S. foliosa* sprigging was successful in the lower two-thirds of the intertidal zone. Planting in the upper one-third was not necessary because this area was rapidly invaded and dominated by naturally occurring *Salicornia* spp. (Fig. 6).

The plantings have not only maintained themselves, but have spread into adjacent previously unvegetated areas. Production is somewhat less than in the natural reference areas due, perhaps, to the slow growth characteristics of *S. foliosa* which has resulted in a slower succession rate on the site. Visually, the lower tidal zone dominated by *S. foliosa* appears equivalent to the natural marshes.

Wildlife use of the salt pond is extensive in the intertidal zone, primarily by shorebirds and seabirds. However, songbirds and raptors are frequently observed in the high marsh area as well.

Figure 6. The salt marsh at Salt Pone #3 in south San Francisco Bay, where the original 3-ha plantings now cover the entire 40-ha site.

MONITORING INFORMATION AND ENGINEER MANUAL

The above described case studies have been monitored, along with a number of other CE-built wetlands, since 1974. Technical information is available on CE-built wetlands in Landin (1985), Landin (1986), Landin et al. (1986), Newling and Landin (1985), and numerous other WES Technical Reports. An engineer manual, "Beneficial Uses of Dredged Material," which gives comprehensive information on biological and engineering techniques, planning, monitoring, legal aspects, chemical and physical dredged material properties, transport of dredged material properties, transport of dredged material, and plant species and their propagation and use, will be released by the Office, Chief of Engineers in Fall, 1986 (OCE 1986).

CONCLUSIONS

Not only have CE-built wetlands proved in most cases to be highly productive marshes and welcome additions to the wetlands of the U. S., but these wetlands have generally been received favorably by both the public and by resource agencies. As more information is obtained which will aid in development of wetland sites from dredged material or from mitigation, more such sites will be routinely incorporated into operations and maintenance work and into permitting requirements. The use of dredged material substrates for development of wetlands is considered by the CE to be highly beneficial to the wetlands resource, as well as an economic application of dredged material.

ACKNOWLEDGEMENTS

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A PILOT PROGRAM FOR PRIVATE LANDS WETLAND RESTORATION IN MINNESOTA

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ABSTRACT

In an effort to test techniques for restoring drained prairie wetlands to existing waterfowl production habitat, the U. S. Fish and Wildlife Service leased land containing drained wetlands from farmers in three western Minnesota counties inn 1984 and 1985. With financial assistance from Ducks Unlimited, the Minnesota Waterfowl Association, and local sportsmen's groups, 280 wetlands were restored on 90 participating farms. Drained wetlands (591 hectares; 1,460 acres) were restored and 1,498 hectares (3,700 acres) of associated uplands were seeded to cover for ground nesting birds and soil erosion control. Landowners participating in the ten-year program are paid annually by the Fish and Wildlife Service an amount equal to cash rent, $158 per hectare ($64 per acre), for the use of their land which was enrolled in the program.

Through this pilot effort, it is apparent that many farmers were willing to lease out marginal lands for conservation purposes for ten-year periods at rates equal to cash rent. Restored wetlands quickly revert to a natural state and provide wildlife habitat and all other benefits which wetlands provide.

INTRODUCTION

Wetlands serve many valuable functions to mankind wherever they occur (Brun et al., 1981; Doyle, 1974; U.S. Dept. Transportation, 1983; Winter & Carr, 1980). These values, however, usually accrue to society in general and not directly to property owners who hold title to wetlands (Leitch & Danielson 1979). Wetland losses to agricultural drainage on the glaciated prairies of the north central states have severely reduced waterfowl production habitat. Despite efforts begun in the late 1950s with extensive land acquisition programs to preserve wetlands by state and federal wildlife agencies, wetland drainage continues, leaving only remnant portions of many wetland communities.

Owners of wetlands in the northern prairie states as well as other parts of the country readily convert their wetlands to other uses for immediate, often short-term, personal economic gain. Of 87 million hectares (215 million acres) of wetlands in the United States at the time of the country's settlement, no more than 40 million hectares (99 million acres) remained by the mid-1970s, a loss of 54 percent (Tiner, 1984). Wetlands in the United States continue to be drained at an annual rate of about 185,400 hectares (458,000 acres). Tiner also reports that 87 percent of these losses are for agricultural development.

Agricultural drainage has been a major factor of wetland losses and continues to be the greatest threat to the inland wetlands that remain. Many states and the federal government, particularly the wildlife agencies, are engaged in wetland preservation, primarily for wildlife management purposes. Since 1972, the U.S. Department of AGriculture has also been engaged in wetland preservation through the Water Bank Program.

Most drained wetlands can be restored by removing tile drains or plugging open ditch drains which carry water from the basin. The key to wetland restoration lies with the needs and desires of those who own former wetlands. These owners are often the same individuals who drained their wetlands. The work reported here deals with efforts by the Fish and Wildlife Service to address the needs and desires of landowners to develop and assess a strategy for restoring drained wetlands.

METHODS

The Fish and Wildlife Service developed a program to pay landowners for the use of drained wetlands so they might be restored. Certain drained wetlands in Otter Tail, Grant and Douglas Counties of west central Minnesota were selected for restoration. Payment schedules were established and contract terms were drawn up to enroll privately owned wetlands and adjacent uplands in a ten-year wetland restoration program. This effort is part of the agency's Mid-Continent Waterfowl Management Project, a pilot program to develop techniques for increasing duck reproduction.

Drained wetlands selected for inclusion in the program were ranked on their proximity to existing wetlands; the type, size and shape of wetlands expected after restoration; the present use of the drained wetlands and adjacent uplands; the relative difficulty of restoring the drained wetlands; and the current owner's willingness to cooperate in the program. Drained wetlands close to existing wetland communities of small, irregular shapes which were being farmed and would be relatively easy to restore were rated highest for inclusion in the program if the landowner was willing to participate.

A goal of 810 hectares (2,000 acres) of wetlands was established for restoration in this initial trial. In addition, 1,620 hectares (4,000 acres) of adjacent uplands were targeted for inclusion in the program to provide nesting cover for ducks and other wildlife and soil erosion control.

Qualifying landowners were contacted, and boundaries acceptable to participating landowners and the Fish and Wildlife Service were drawn. Each property was appraised according to its agricultural value.

Offers made to landowners were based on this appraisal. If all terms were accepted by the landowner, he or she was enrolled in the program by signing a ten-year lease for use of the land.

Ditch plugs or tile blocks were designed and installed to provide an optimum water depth in the reestablished wetland. An agreement was also developed with participating farms to establish nesting cover on adjacent uplands. Participants were offered three options for upland cover in their wetland restoration contracts: non-use grass, delayed harvest of alfalfa, and no-till small grain. In each case the participant remained a partner in the management of the tract by performing all work necessary to establish and maintain the nesting cover on the upland acres.

RESULTS

During the initial trial period for the wetland restoration effort, 90 landowners enrolled in the program. Restoration of wetlands was completed on 591 hectares (1,460 acres) by bringing water levels to desired depths using earthen dams and water control appurtenances, while 1,498 hectares (3,700 acres) of adjacent uplands were developed for nesting cover. Average costs of leasing land in the three counties, paid by the Fish and Wildlife Service, was $158 per hectare ($64 per acre) per year. Development costs for ditch plugs and cover establishment were paid for by grants from Ducks Unlimited, the Minnesota Department of Natural Resources, the Minnesota Waterfowl Association, and the Fergus Falls Fish and Game Club. Budgets were established for one-time development costs--$200,000--and land lease payments--$300,000 per year for ten years.

While no quantitative data are yet available on wildlife use and duck production on the restored wetlands, early indications are that the areas are at least as good as naturally occurring wetlands. Hydrophytes invaded the newly reclaimed wetlands immediately after reflooding. Waterfowl were also observed on these wetlands. Because this pilot project was directed at privately owned land that had been converted to agricultural use, waterfowl production on the tracts prior to restoration was low or nonexistent. Other wetland values apparently have been fully restored also.

CONCLUSIONS

Landowner interest in the program was high. Many landowners want to retire marginally producing lands, such as poorly drained wetlands, into this long-term, income-producing program. When the initial budget for the pilot program was expended, there remained a backlog of landowners who had expressed an interest in the program. A larger scale retirement program for certain drained wetlands and surrounding uplands might very well be met favorably by Minnesota farmers. The same might be said of farmers in many other parts of the United States, particularly since passage of the conservation provisions of the Food Security Act of 1985.

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OBSERVATIONS CONCERNING THE ESTABLISHMENT OF MARSH VEGETATION (PRINCIPALLY SPARTINA ALTERNIFLORA) BY USE OF THE PLANT ROLL TECHNIQUE

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ABSTRACT

From May 21-28, 1985, a total of 666 marsh plants consisting of *Spartina alterniflora*, *Spartina patens*, and *Distichlis spicata* were transplanted at two sites along the Intracoastal Waterway as part of a pilot shoreline stabilization project in Palm Coast, Florida. The Intracoastal Waterway in this area exhibits characteristics of a moderate wave energy environment. Three methodologies were tried, bare root seedlings, plants plugs and plant rolls. The bare root seedlings washed out over a two week period. Plant rolls provided the best overall stabilizing method for plant growth, followed by plant plugs, providing proper substrate was available. Total mortality for the entire group of plantings was 33 percent over a five month period. Plant mortality was impacted by higher than normal tides caused by two hurricanes during the study as well as scouring effects from flotsam, poor substrate for plant stabilization and lack of stability of the Intracoastal Waterway shoreline from channel maintenance operations.

INTRODUCTION

Coastal erosion due to storm events is most noticeable on beach and dune areas, but it can occur within the Intracoastal Waterway (ICWW). At Palm Coast in Flagler County (Fig. 1), the ICWW was originally created by dredging through upland areas to connect the Matanzas River to the Halifax River (Elliot, 1915). The resulting steep banks have continued to be unstable, a problem which is aggravated due to boat traffic, periodic maintenance dredging and storm events.

In November, 1984, a major storm event which lasted 36 hours brought 50 mph winds and 10 foot waves to the coastline (Craddock 1985). This storm caused extensive erosion damage along the ICWW at Palm Coast. Numerous large trees and portions of a jogging path fell into the ICWW in the vicinity of the study site. In order to determine

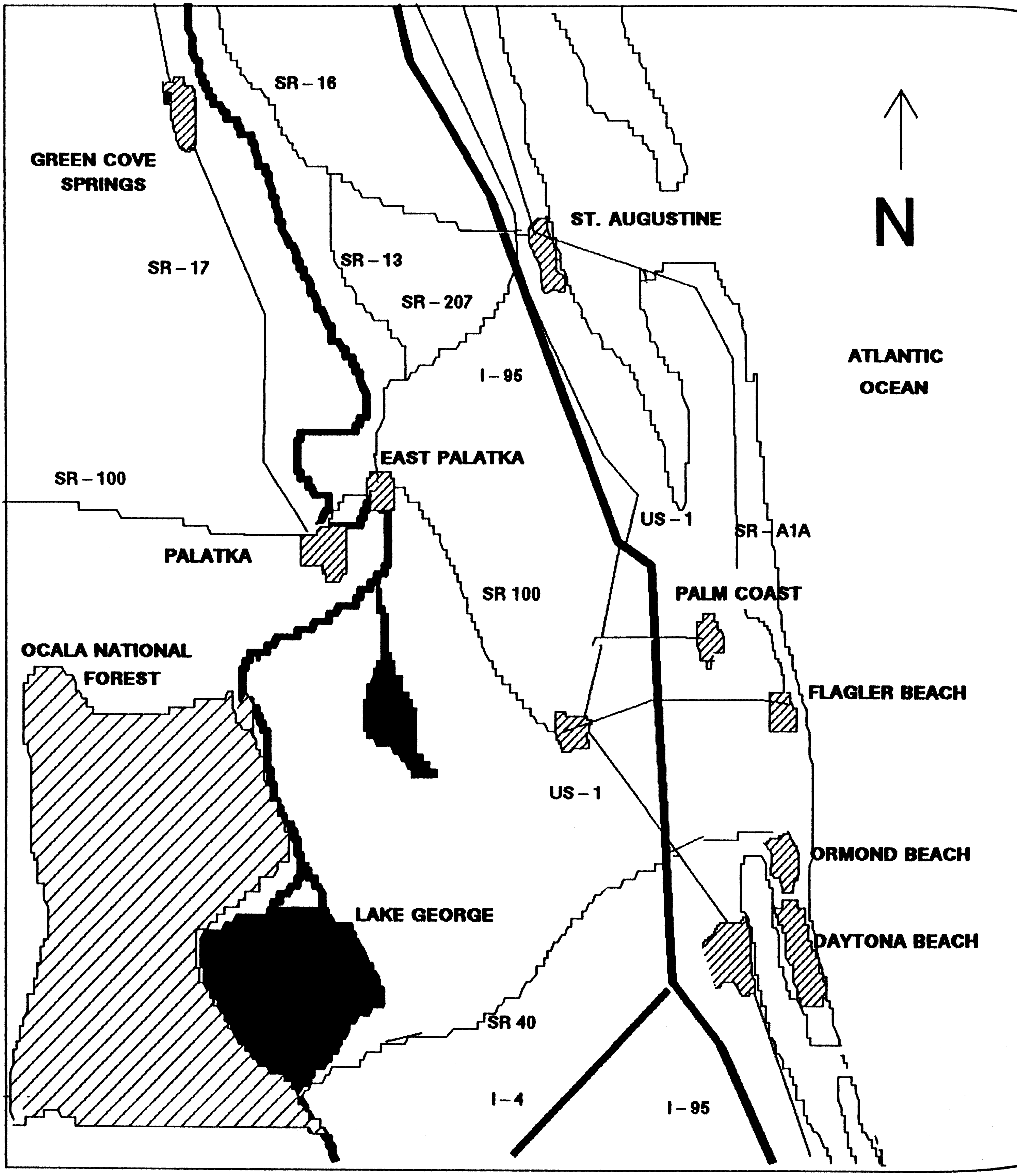

Figure 1. Location map.

whether future erosion could be minimized by using salt marsh plants as a natural wave barrier, it was decided that a small test planting should be done. The project was done on a minimum budget and was not originally designed as a scientific research project. Nevertheless, the authors feel that the results are of sufficient interest to merit reporting the project in its entirety.

There have been many investigations which have indicated that eroding shorelines can be stabilized with marsh plantings (Gosselin, Odum & Pope, 1974; Graig & Day, 1977; Knutson, Ford & Inskeep, 1981; Phillips & Eastman, 1959; Sharp & Vadin, 1970; Garbisch, Woller & McCallum, 1975; Knutson, 1976; Newcombe et al., 1979; Dodd & Webb, 1975 & 1976). Smooth Cordgrass (Spartina alterniflora) can be established on shorelines where natural processes have failed to adequately establish plant cover (Woodhouse, Seneca & Broom 1974 & 1976). In the vicinity of the study site, Spartina alterniflora has only gained a foothold in small patchy areas. It is suspected that colonization is inhibited by the relatively large waves caused by frequent power boat traffic. Waves in excess of three feet high are common; therefore, the shoreline was regarded as a moderate wave energy environment. Washout of bare root seedlings has been a problem in moderate wave energy environments, so the "plant roll" technique developed by Webb, Allen and Shirley (1982) was used in this study, along with bare roots and plugs for comparison.

METHODS

Two different planting techniques were used: plant plugs and plant rolls. Plant plugs have been used previously (Eleuterius, 1981), and were only used in this project in areas where poor substrate (coquina rock and shell) prevented the installation of plant rolls. The plant roll method has only recently been developed (Allen et al. 1984) and has been reported to be very successful in moderate to high wave energy environments. The plant rolls were constructed by digging a trench 20 cm wide and 20 cm deep, then lining it will 90 cm wide burlap. Soil was then placed in the trench on the burlap and plants were installed at 40 cm intervals. The sides of the burlap were then brought together and stitched, allowing only the stem and leaf blades to protrude. The resulting burlap sausage was then covered with soil to the existing grade.

Two sites (Fig. 2) which had experienced severe erosion were chosen for the study. At Site A, several large trees were in danger of falling into the ICWW and the project provided an opportunity to prevent their total loss. Shading effects, which are known to inhibit growth rates (Beamon, 1983), could also be observed. Site B was free from overhanging limbs, which provided maximum sunlight, but zones of poor quality substrate (coquina rock/shell) were present. Apparently in a previous emergency effort to halt erosion, coquina rock and shell were dumped over the bank. Digging was very difficult in those areas.

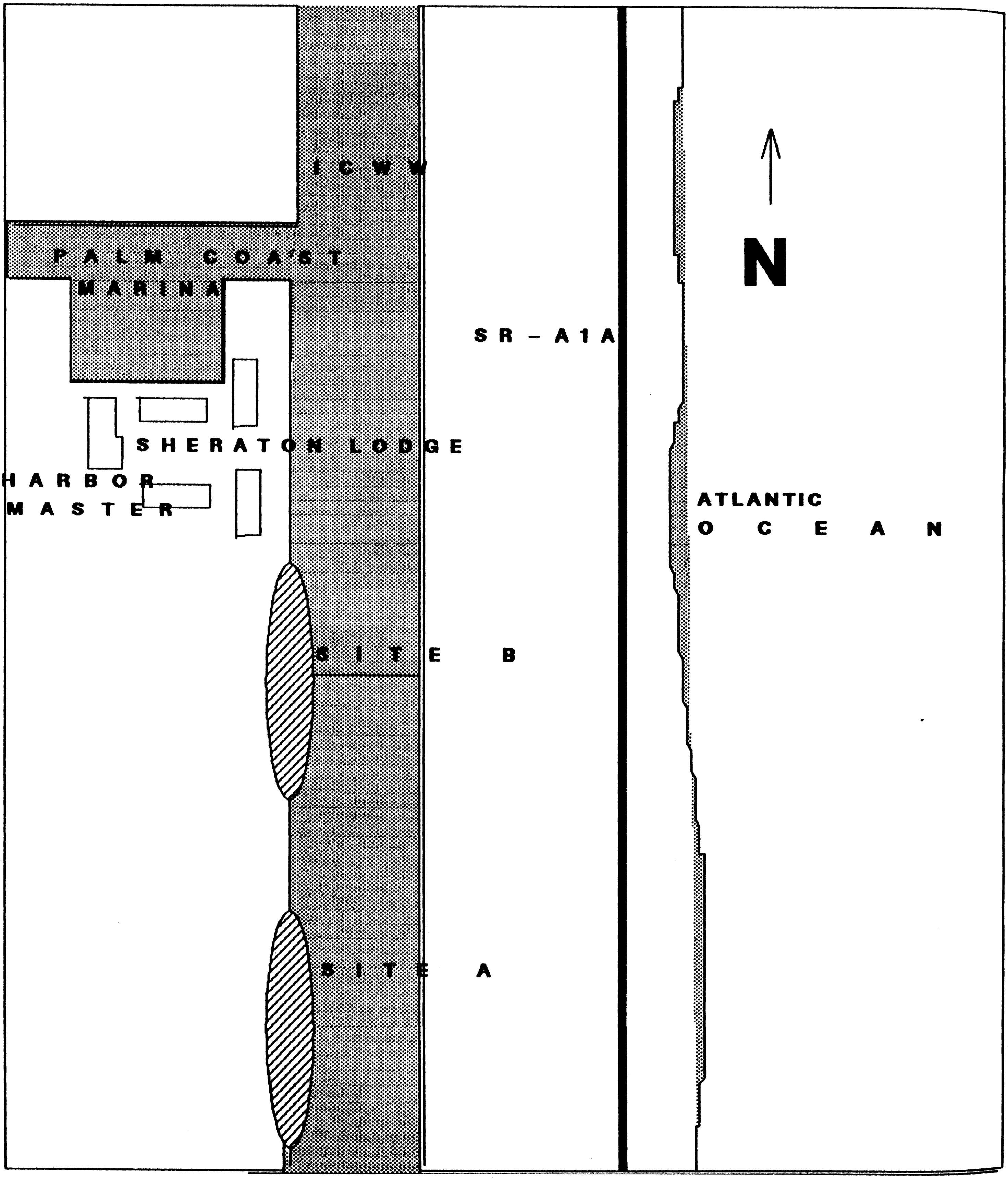

Figure 2. Study sites on intracoastal waterway.

Plants were installed 40 cm on center in rows, 40 cm apart within six zones (Fig. 3 & Fig. 4) identified as A through F. Rows are numbered consecutively outward from shore beginning with the highest elevations planted. Rows A1, B1, and C1 consisted of *Spartina patens*. Rows A2, B2, and C2 consisted of *Distichlis spicata*. All other rows were *Spartina alterniflora*. Plugs were used in Rows A1, A6, D3, E3, and F3. All other rows were plant rolls.

Spartina alterniflora was installed in the upper third of the tidal range. Naturally occurring beds of *Spartina alterniflora* adjacent to the study sites ranged from MLW to MHW. *Distichlis spicata* was installed at MHW, and *Spartina patens* was installed above MHW.

All plants were field collected, since field collected plants have been reported as having higher success rates than nursery grown plants (Woodhouse, Seneca & Broome, 1976). *Spartina alterniflora* and *Spartina patens* ranged in height from 40 to 60 cm, and *Distichlis spicata* was 20 to 50 cm high.

Monitoring was infrequent due to limited funds. The number of surviving plants was counted in June, July, September, and finally in December of 1985. No control group was provided, and no statistical analysis was done.

RESULTS AND DISCUSSION

Table 1 summarizes the plant losses by row during the monitoring period. Zone C was heavily shaded, and shows high losses. Plants in Zone C and the shaded part of Zone B appeared to have less robust growth than those in other areas. Rows D3, E3, and F3 were plugs, and showed high losses. Observation revealed that wave action washed the roots loose. None of the plants in rolls were lost due to wave action.

The major cause of plant mortality appeared to be due to the scouring effect of flotsam, which included Cabbage Palm trunks, driftwood, bottles, and a significant number of discarded tires. As a result, plant loss did not appear as a random phenomenon, but rather as the loss of entire patches 1 to 2 m long. Often the piece of flotsam causing the plant loss would be found nearby.

In September, 1985, two hurricanes delivered abnormally high amounts of rainfall to the Palm Coast area. Tidal recording data from Palm Coast Marina indicated that tides were approximately 12 inches above normal during the months of September and October. In addition, ITTCDC salinity data (not available for publication) showed that the salinity during this period had been reduced from a normal range of 15 to 30 ppt to approximately 5 ppt. During this time, the inundation period on the plants was greatly increased. Many plants in the lower rows were completely covered with water for a six-week period. Visual observation showed tissue damage which may have been due to osmotic stress. Evidence of stress was more apparent in the shorter plants

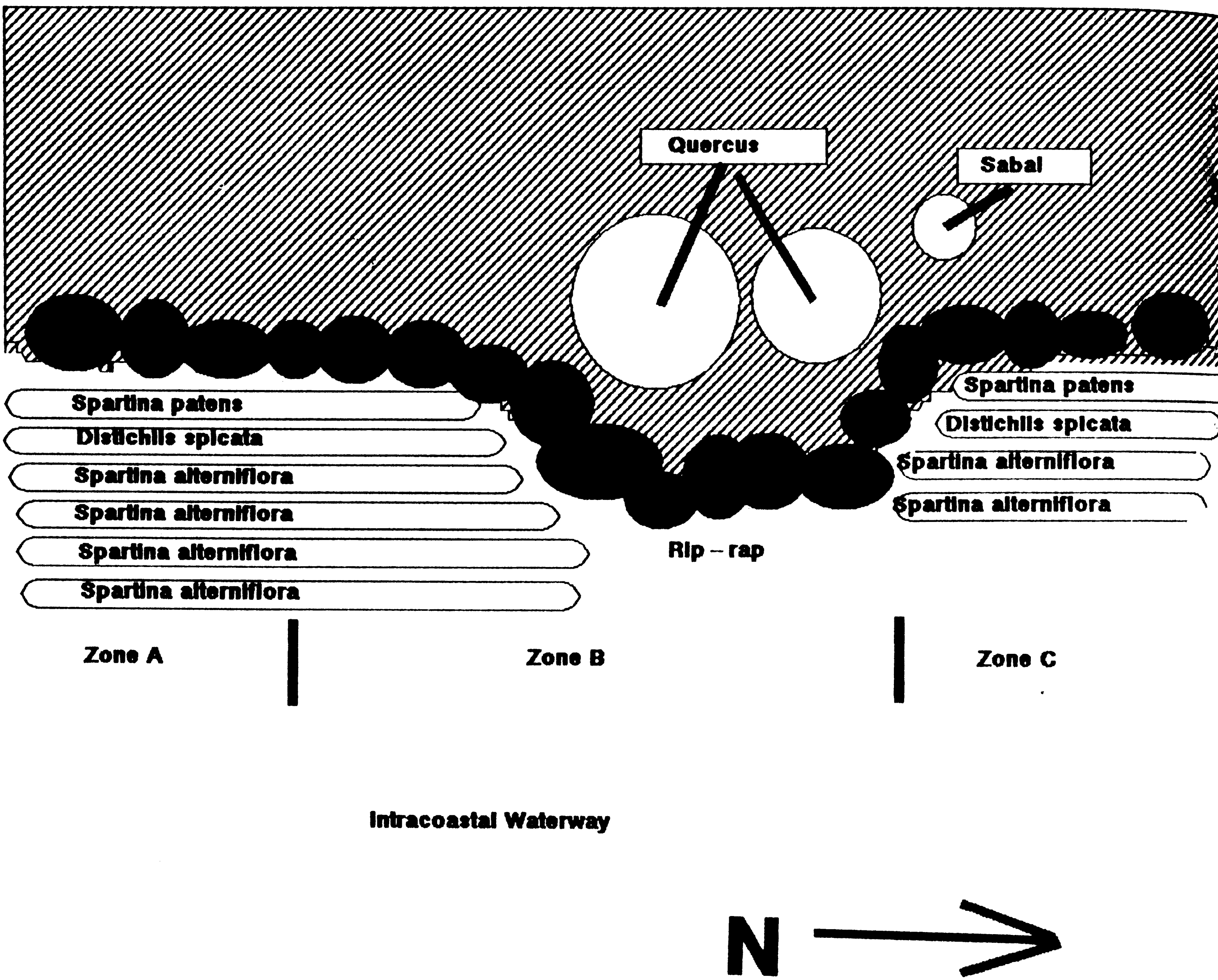

Figure 3. Site A.

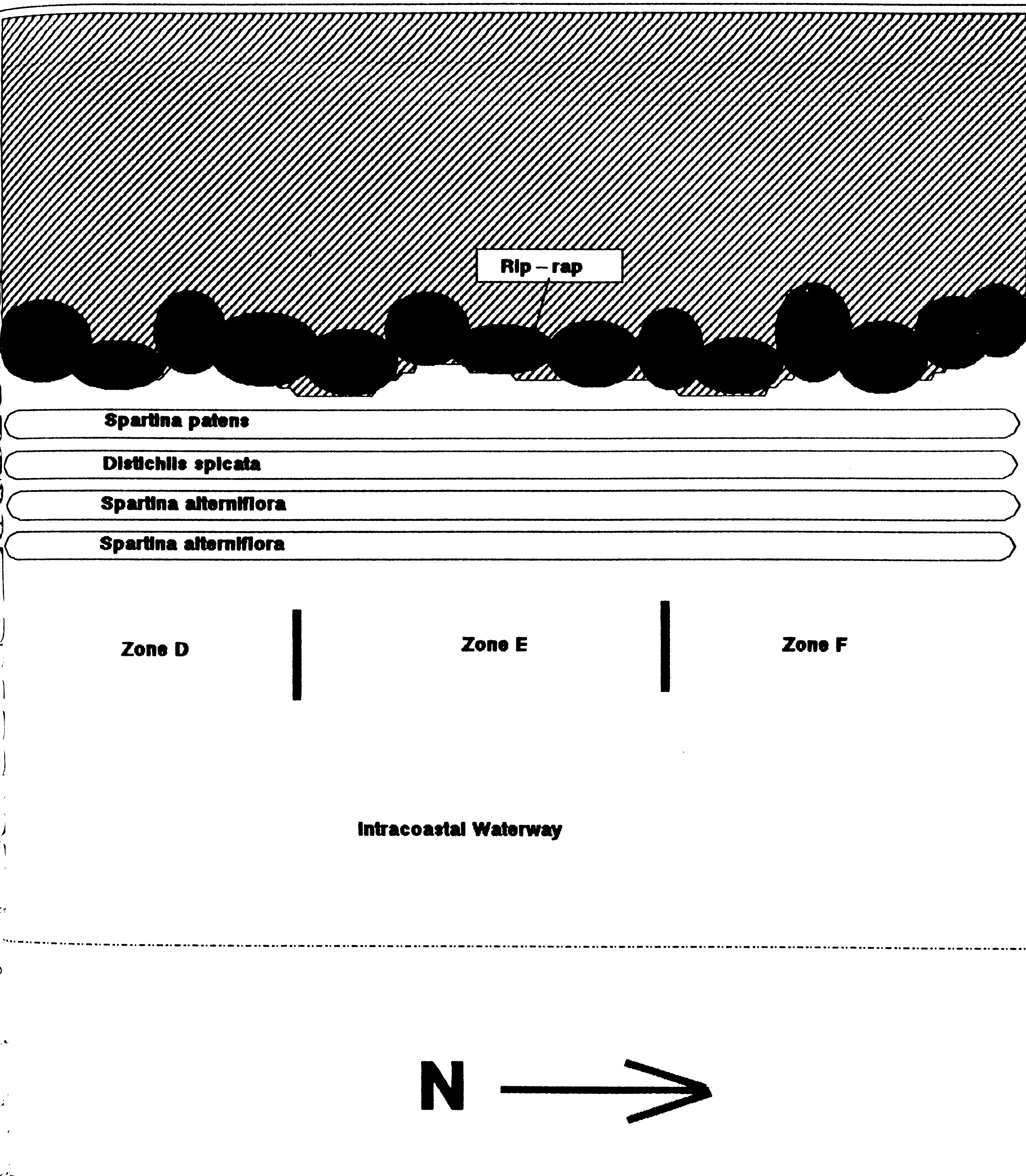

Figure 4. Site B.

Table 1. Mortality Results.

Row	Total Planted As of 6-14-85	Cumulative Loss by Row As of 6-14-85	Cumulative Loss by Row As of 7-27-85	Cumulative Loss by Row As of 9-05-85	Cumulative Loss by Row As of 10-25-85	Percent Loss As of 10-25-85
A1	22	0	2	4	4	18
A2	20	0	0	0	3	15
A3	20	0	0	2	3	15
A4	20	0	1	2	9	45
A5	20	1	1	1	3	15
A6	20	3	4	5	6	30
B1	24	1	1	2	2	8
B2	24	0	0	0	6	25
B3	24	0	0	1	2	8
B4	22	3	3	3	8	36
B5	28	5	5	5	11	39
B6	24	3	4	6	14	58
C1	10	0	0	0	5	50
C2	10	0	0	0	7	70
C3	10	0	0	1	3	30
C4	10	0	1	2	4	40
D1	5	0	0	0	0	0
D2	37	1	2	4	14	38
D3	37	15	16	16	16	43
E1	53	0	1	3	8	15
E2	53	0	0	0	5	9
E3	53	15	16	18	19	36
F1	40	0	1	2	7	18
F2	40	1	1	3	26	65
F3	40	3	7	16	35	88
TOTAL	666	51	66	96	220	33

A1, B1, C1	_Spartina patens_	A1, A6	Plugs
A2, B2, C2	_Distichlis spicata_	D3, E3, F3	Plugs
All Others	_Spartina alterniflora_	All Others	Plant Rolls

which were inundated more frequently. By the end of October, most of the shorter plants appeared to have died, particularly in the lower rows. Eleuterius and Cauldwell (1981) observed that plants located in the lower two-thirds of the tidal zone appear to die back initially, but subsequently reestablish in the spring. This same sequence of events may occur here also.

CONCLUSION

The use of plant rolls in a moderate wave energy environment provides a viable alternative to the use of bare root or plug planting techniques. None of the plants were observed to have been lost due to wave action, except those that were planted in plugs.

The major losses appeared to be due to large pieces of flotsam from the ICWW. Methodologies need to be developed to protect newly planted areas from the scouring effects caused by flotsam. Such techniques must be aesthetically compatible with land development planning guidelines, yet low enough in cost to facilitate installation.

If no protection can be provided, then regularly maintenance of the planted areas is advisable, particularly after storm events or periods of prolonged rainfall.

Significant mortality appeared to be due to excessive tidal inundation and lowered salinities during September and October. This may be an annual phenomenon and should be addressed in future projects in this area. It is recommended that plant height not be less than 60 cm, and plants be installed only in the upper 10 percent of the tidal range.

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MOSQUITO CONTROL PROJECT IN UPPER TAMPA BAY PARK HILLSBOROUGH COUNTY, FLORIDA

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INTRODUCTION

Hillsborough County Mosquito and Aquatic Weed Control constructed a minnow reservoir in December of 1984 within a saltmarsh area of Upper Tampa Bay Park for the biological control of mosquitoes. Three months later, five shallow ditches (30" deep) were excavated with a rotary ditcher scattering the spoil over the saltmarsh, which connected the low grassy mosquito producing depressions to the minnow reservoir. The minnow reservoir, 75' in diameter, 3' deep, maintains permanent water and supports several species of top feeding minnows that are predacious to mosquito larvae.

The Department of Environmental Regulation issued their Dredge and Fill permit to Hillsborough County Mosquito and Aquatic Weed Control contingent on having several environmental perimeters monitored for three years. They are described as follows: mosquito production, vegetation, and water quality.

MOSQUITO PRODUCTION SURVEY

Prior to the construction of our Mosquito Source Reduction Project for the Southeast and South tidal areas of Upper Tampa Bay Park we devised a larval survey form which we use weekly, that began in August of 1984. With this form we labeled sampling stations for all the identified mosquito producing areas, noting the stage and species of larvae, #/dip, depth of water and presence of fish. The preconstruction survey along with information obtained from seven years of aerial inspections indicated large broods of saltmarsh mosquitoes, <u>Aedes taeniorhynchus</u> and <u>Aedes Sollicitans</u>, being produced from within the project site. After construction of the minnow reservoir and radial ditches a significant decrease in mosquito production has been documented. Also a change of dominant mosquito species has been noted during our "mosquito seasons" to a less vicious biting species, <u>Anopheles Atropos</u>.

SALTMARSH VEGETATION SURVEY

Mosquito Control's initial vegetation survey was conducted on February 21, 1985, before any ditches were dug with the rotary ditcher, within the study area established for the project site. This survey will continue to be repeated utilizing the same transect lines every half year through 1987, and possibly longer before any conclusions are made.

Three vegetation transects were defined utilizing survey stakes set by Hillsborough Community College Engineering Department and Mosquito Control's perimeter stakes. A 200' ribbon was marked off and utilized to form straight lines for each transect. A square meter quadrat was then placed approximately every 20' along the measured ribbon where plant species were then identified and their percent coverage was estimated within each quadrat.

The three transects established within our study area for the vegetation survey are as follows:

1. Transect to "Double Branch Creek" 400' long with 21 square meter quadrat stations.

2. Transect to "Old Tampa Bay" 620' long with 32 square meter quadrat stations.

3. Transect perpendicular to the proposed ditches 500' long with 26 square meter quadrat stations.

The first two transects bisect the minnow reservoir and utilize Hillsborough Community College survey stakes with known elevations. Our third transect crossed over the study area where four proposed ditches were eventually excavated by the rotary ditcher. Our rotary ditcher scattered the spoil approximately 40' to one side of each ditch 1/2" thick over the saltmarsh, during their construction. Our surveys have not indicated an increase of upland plants within the project site as a result of scattered spoil.

WATER QUALITY SURVEY

The United States Geological Survey provided Mosquito Control with a tide gauge for their minnow reservoir, which was set to MSL and is accurate to 1/100 of a foot. They also provided us with a computer print out of Safety Harbor's tide gauge which along with the Park Ranger's rainfall data we can accurately interpret the project's pond tide gauge chart as to the sources of inundation. Salinity and temperature readings are taken weekly from the project's pond and are compared to the water of a natural saltmarsh pond, Double Branch Creek, and Old Tampa Bay. The minnow reservoir initially filled up with saltwater the first year after it was constructed and became very high in salinity before the summer months, reaching 116 ppt. The second year our minnow reservoir filled up with fresh water from rainfall before the summer months, and as the water percolated and evaporated it did not increase significantly in salinity before the summer's rainy season and high tides.

FISH SURVEY

University of South Florida graduate students Jeff Brown and Sue Davis, currently doing research on fish populations in the Feather Sound area of Pinellas County, came over to Hillsborough County and sampled the fish in our project's minnow reservoir as well as the natural pond during september of 1985. A 50' seine net with 1/8" mesh, plastic Breeder traps and minnow traps were used. Nine different species were found in both ponds. They are as follows:

Speckled Sea Trout	Cynoscion nebulosus
Silverside	Menidia beryllina
Sheepshead minnow	Cyprindon variegatus
Rainwater killifish	Lucania parva
Long-nose killifish	Fundulus similis
Gulf killifish	Fundulus grandis
Mosquito fish	Gambusia affinis
Sailfin Molly	Poecilia latipinna
Hogchoker (flatfish)	--

There were more speckled sea trout in the natural pond and more small sheepshead minnows and sailfin mollies in the project pond.

CLOSING COMMENTS

Wildlife utilization throughout the project site seems to be increasing, although no data has been routinely collected. The fiddler crabs are attracted to the project's minnow reservoir as well as the radial ditches. Blue crabs, grass shrimp, snapping shrimp, along with many birds, have been spotted as well.

This is a three year research project in which we hope to show that we have been able to maintain a permanent minnow population in the upper edge of the salt marsh, show a reduction of mosquitoes being produced and have not encouraged the encroachment of upland plants into the project site in response to our ditches construction.

CYPRESS SWAMP REGENERATION: A RECLAMATION ALTERNATIVE FOR WET DEPRESSIONS IN CLAY SETTLING PONDS

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ABSTRACT

Several thousand baldcypress (Taxodium distichum) seedlings were planted on phosphate clay settling ponds, a by-product from phosphate mining. Experimental plots were established during the drought winter of 1984-85. Treatments included cleared plots and those with dense vegetation as well as seedling type, bareroot vs. tubelings. Except for the most severely flooded sites, survival was between 55 and 77 percent, depending on reclamation methods. Drought and unsuitable water levels were the major cause of mortality. Grazing by wildlife stunted many of the trees. There was no significant difference in percent survival or height of trees between plots cleared of all above-ground vegetation at time of planting and those left uncleared ($P > 0.05$). Bareroot seedlings planted in the spring were more successful than tubelings planted during the winter ($P < 0.05$). Initial success with planted tree seedlings indicate clay settling ponds present suitable conditions for the establishment of baldcypress.

INTRODUCTION

A study of succession on clay settling ponds showed vegetation colonized along an environmental gradient (Ruston 1983, Rushton 1984). Drier locations were often dominated by bottomland hardwood species, while wet depressions were characterized by shrubby willow (Salix caroliniana) species. It was hypothesized these wet areas were suitable for cypress-gum ponds but the seeds were unable to reach the site.

The purpose of the present project was to break arrested willow succession by planting species common to cypress forests. Experimental transects were designed to test several theories. (1) To determine the role of hydroperiod, seedlings were planted along an environmental moisture gradient. (2) To understand the role of competition, half the plots were cleared of all existing above ground vegetation in some of the experiments. (3) To see if nursery practices have an effect, both bareroot and tubelings were used in paired experiments. (4) To compare various reclamation, disposal, and mining techniques on tree success, different clay settling ponds were used.

Clay settling ponds are a by-product of phosphate mining, a major industry in central Florida. Typically one ton of clay waste (dry weight) is produced for each ton of phosphate rock. The clays expand to many times their original volume in the mining process and require large above-ground storage impoundments ranging from 160 to 325 ha surrounded by earth dams from 7 to 20 meters in height. Approximately 50 to 70 percent of the land proposed for mining is designated for clay settling areas. Reclamation of clay impoundments is mandated by Florida state law, which requires restoration of all lands disturbed by phosphate mining after July 1, 1975. Since phosphatic clays have poor load bearing capacity, possibilities for productive use following mining are limited. Most reclamation projects have converted clay ponds to pasture.

In Florida, a state with a long, colorful history of drainage projects, interest in saving wetlands has increased steadily over the past decade culminating in the passage of the Warren S. Henderson Wetland Protection Act of 1984. Mitigation by restoration of wetlands could replace swamps being lost by current and past land use practices. Cypress swamps, which occur throughout the southeastern United States, are especially common in Florida, where they form lake fringes, strands, and domes. Clay settling ponds provide an opportunity to restore cypress forest to the post mining landscape.

STUDY SITES

Seven clay settling ponds representing different ages and reclamation techniques were planted during the winter of 1984-85. The locations are shown on the map in Figure 1 and summary information is listed in Table 1.

CF Industries used a sand/clay mix for clay disposal at their Hardee mining complex. This site was abandoned as an active clay pond in 1983. Trees were planted along the edge of a seasonally flooded pond.

Gardinier, Area A, located at the Ft. Meade mine was ditched, drained, and the dikes lowered in 1975. Outfall pipes are now above the level of the clays providing drainage only during extremely high water. Trees were planted in the wetter lower end which had been submerged for the past year. During the early establishment phase, however, a drought and subsequent fire caused considerable mortality.

Tenoroc, Area 4A, is a large clay settling pond located in a State Reserve under the jurisdiction of the Department of Natural Resources. The west end, where most of the trees were planted was mined and has many spoil piles protruding above the clay surface. Three transects are located on the edge of an intermittent pond. Four drier transects were planted in willows growing at the northwest corner.

IMC-H9 is a reclamation project for International Mineral and Chemical Corp. In 1985 it already had healthy, well-established 4 to 5

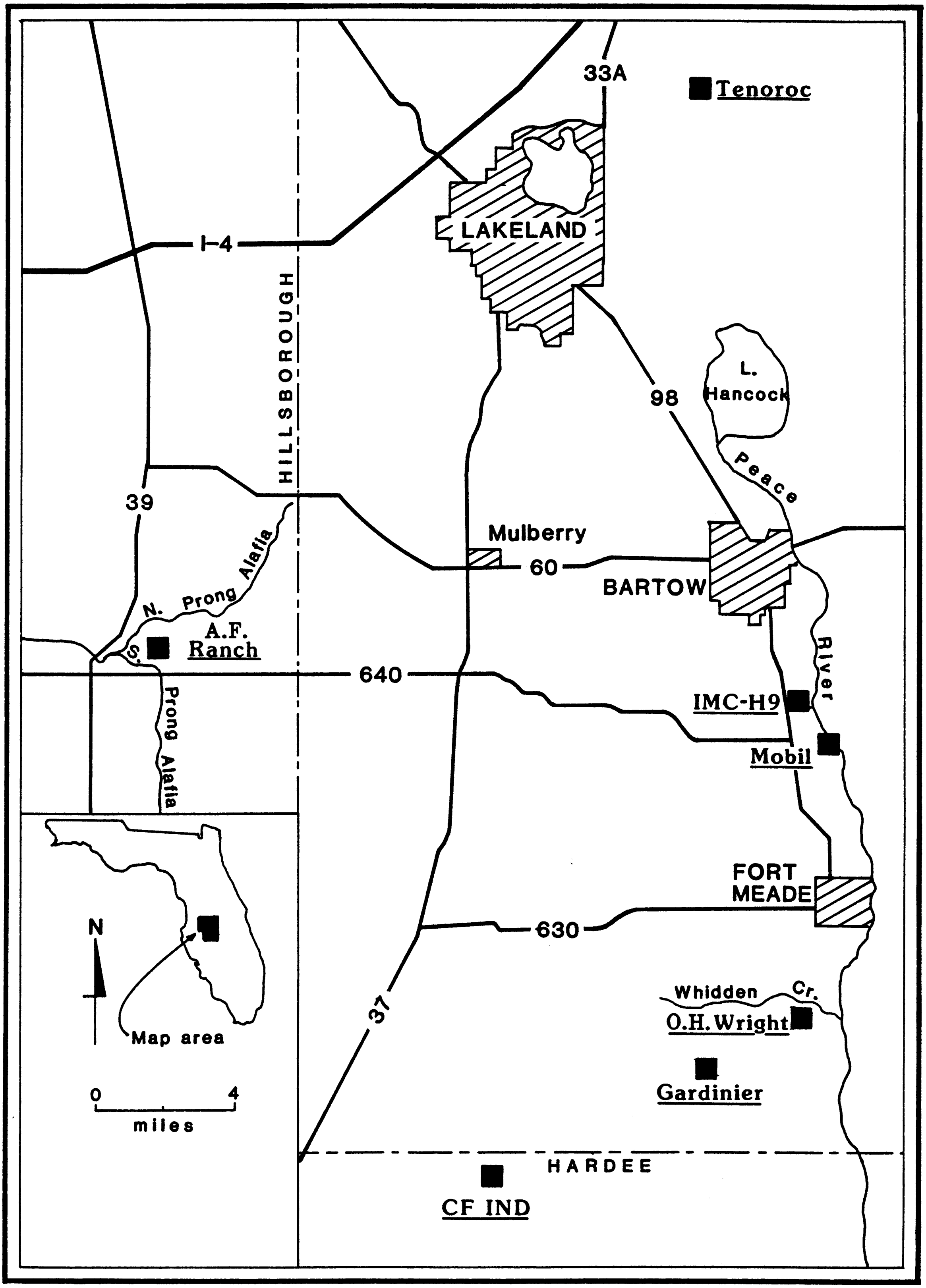


Figure 1. Location of study sites.

TABLE 1. Study site summary information.

SITE	ABANDONED (EST)	RECLAIMED (EST)	MINED	PRESENT USE	OWNER	LOCATION	Δ TREES PLANTED	DATE PLANTED
A.F.RANCH	1950	NONE	NO	PASTURE	C.L.KNIGHT	T30S,R22E SECTION 1	186 248	FEB 1985 TB* MAR 1985 BR**
O.H.WRIGHT	1955	NONE	YES	NATURAL	GARDINIER FT. MEADE	T32S,R25E SECTION 9	186 186	DEC 1984 TB MAR 1985 BR
GARDINIER AREA A	1973	1975 DITCHED	NO	NATURAL	GARDINIER FT.MEADE	T32S,R24E SECTION 2	558 310	OCT 1984 TB MAR 1985 BR
TENOROC ZONE 4A	1972	NONE	YES	NATURAL	FLORIDA DEPT. NATURAL RES.	T27S,R24E SECTION 2	248 248	NOV 1984 TB MAR 1985 BR
CF INDUSTR SP-1	1983	SAND/CLAY MIX	YES	RECLAIM PROJECT	CF INDUSTRIES HARDEE	T33S,R24E SECTION 7	186	MAR 1985 BR
MOBIL HOMELAND	1960	1975 SAND CAP	YES	PASTURE	MOBIL	T31S,R25E SECTION 3	248	MAR 1985 BR
IMC H9	1970	1979 SAND CAP	YES	RECLAIM PROJECT	INTERNATIONAL MINERALS CORP.	T30S,R25E SECTION 33	248	MAY 1985 BR

* TB TUBELING
** BR BAREROOT SEEDLING

year old cypress and other hardwood trees. It represents one of the first wetland reforestation efforts on clay settling ponds. The clay pond was deactivated about 1970 and capped with sand tailings about 1979. Two transects were in a willow forest adjacent to a lake and two were planted in the lake.

The Mobil site is a pasture pond located south of Highway 640 near Homeland. The clay settling pond has been capped with sand tailings. At least part of the site had been mined before clays were deposited. Seedlings were planted in a small shallow lake that seldom goes dry. Soil at the surface in the transects was 100 percent sand.

Alderman Ford Ranch is an older clay settling pond located above the confluence of the north and south prongs of the Alafia River. Aerial photographs show the site being filled with clay in 1948. Twelve seedling transects were planted in two swales which were known to be periodically flooded. One was colonized by maples and oaks, the other by willows.

O. H. Wright, owned by Gardinier, is located adjacent to the Whidden Creek floodplain. It is an old surface mine backfilled with clay. Aerial photographs from 1957 show the mine cuts being filled. Some transects were located in a periodically flooded low area while others were in drier narrow mine cuts.

METHOD

Replicate elongated quadrats (4-m x 30-m) were established through an environmental gradient from dry to wet where possible. One hundred transects with 93 trees each were planted with a KBC planting bar. Seedlings were arranged in 3 columns on 1-m centers and one of 3 species was randomly assigned to each column. In paired experiments, the tree order was duplicated. This paper discusses the fate of 3,000 baldcypress (Taxodium distichum) planted during the winter of 1984-85. See Table 1 for planting dates. Survival and tree height were measured in April, 1986, approximately one year after planting. Water table was measured in October, 1985, by digging down to water when it was below the surface and measuring the depth when it was above the surface. An estimate of water table depth was made for each tree using elevations taken with a level and stadia rod. This gives a relative moisture measurement for one point in time for each seedling.

Two types of seedlings were used. Tubelings were grown by Pete Wallace's Nursery, Rt. 1, 338F, Gainesville, Florida, 32608, and maintained in a shade house until planted. Tubelings were grown in styrofoam or plastic flats with dividers. The soil was a good potting medium. Bareroot seedlings came from the Division of State Forestry at Chiefland. They were grown in the ground form seed, fertilized at planting time with one or two more top dressings applied during the growing season. Seedlings were approximately one year old when pulled from the ground, tied into bundles, and kept in a cooler at 4°C until planted. The time of storage ranged from several days to several months. The 1,178 tubelings were pruned to 50 cm tall when planted. There was a wide range of sizes (30 to 80 cm) for the 1,674 bareroot seedlings. Paired plots at 4 clay settling ponds were used to compare seedling types.

To understand the role of competition from existing vegetation, other paired plots were planted with one of each pair cleared of all above ground vegetation with a machete, blank blade, or chain saw. Three clay settling ponds were used for these experiments.

Statistics were performed using the Statistical Analysis System (Ray 1982). For both the paired plot experiments seedling type (bareroot vs. tubeling) and competition (cleared vs. uncleared) the same statistical methods were used. Significance tests of frequencies for survival data were determined using the chi-square test. A t-test for the difference between two means analyzed height data.

RESULTS

Comparison Between Sites

Bareroot seedlings were planted at all seven sites in March, 1985, except for IMC-H9 which was planted in May. Average survival, height, and dept to water table for each clay settling pond are compared in Figure 2. Two sites had very poor survival, Gardinier and IMC-H9, 8 and 16 percent respectively. They also exhibited widely fluctuating water tables. Although dry when planted, both flooded during the summer rains and still had an average water depth over 40 cm in October, 1985. Trees at IMC-H9 were planted during the May drought of 1985, one of the worst on record, and immediately grazed by animals which were believed to be rabbits. Most trees were not tall enough to escape inundation when the rains arrived in June. At Gardinier the drought and fire had killed all but 30 percent of the trees, most of which were recovering as basal sprouts. When the rains came, flooding killed all but the tallest fire survivors.

The remaining sites had from 55 to 77 percent survival of bald-cypress bareroot seedlings after one year. Average water table depth below the surface didn't appear to have a detrimental affect on tree survival. Seventy-seven percent of the trees were alive at Alderman Ford Ranch where the water table is the lowest. The sand/clay mix used by CF Industries may enhance tree growth. Some of the tallest trees (average 75 cm) were found there with 68 percent survival. The Mobil pasture pond where seedlings are growing in sand tailings had a high survival (79%) and an average height of 57 cm. Poorer survival (56%) and growth (avg. 32 cm) at Tenoroc may be attributed to heavy grazing by wildlife. The older sites, O. H. Wright and A. F. Ranch, 25 and 35 years since deactivated respectively, didn't have any better growth and survival than younger sites. This is especially true when the post

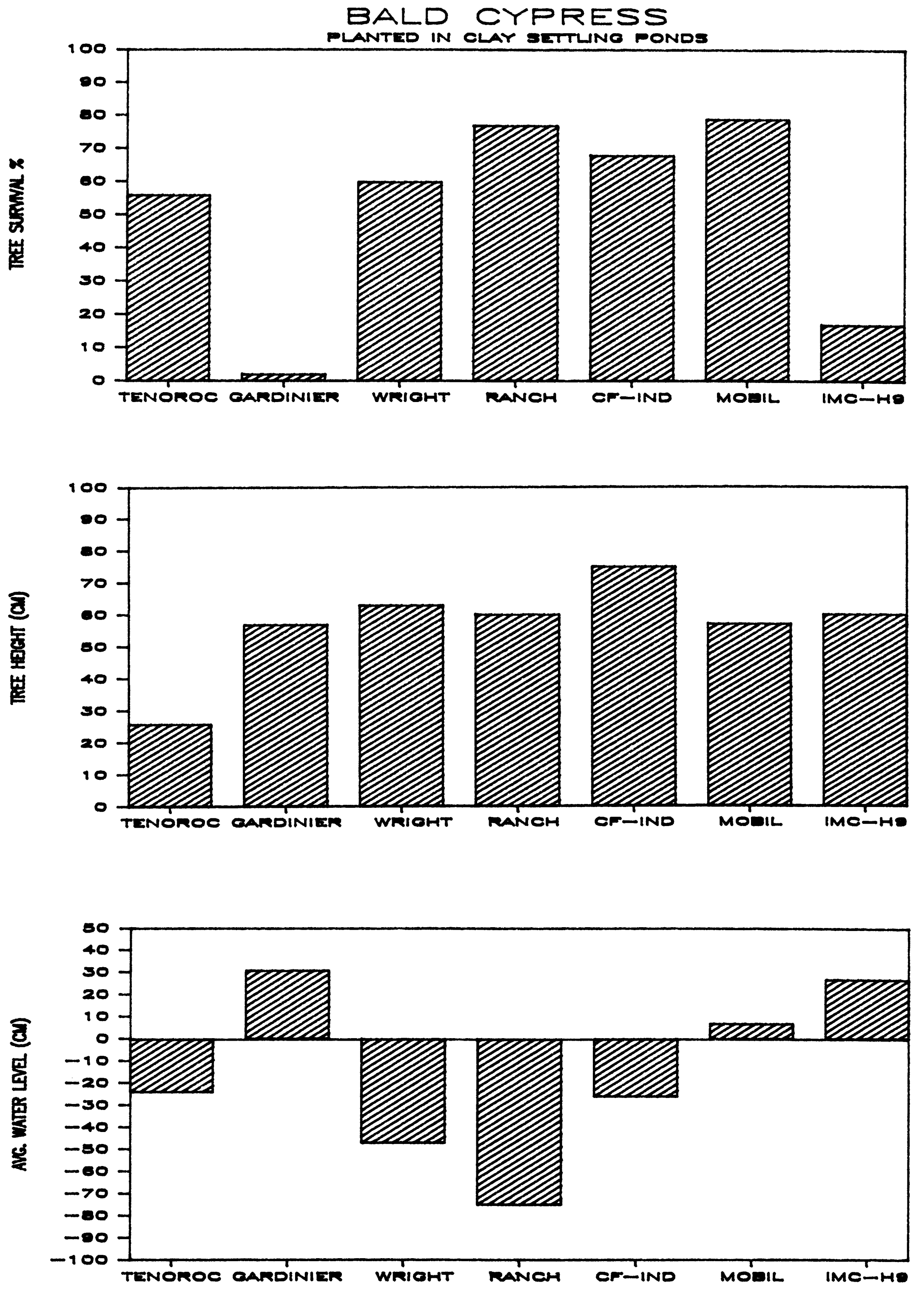


Figure 2. Comparison of baldcypress (Taxodium distichum) bareroot seedlings planted in seven clay settling ponds.

disposal history included adding sand to the clays.

Tubelings Vs. Bareroot Seedlings

Except for Gardinier, bareroot seedlings survived better than tubelings in paired plots experiments (Fig. 3). There was a significant difference in survival at all sites (Table 2). There was also no significant difference in growth measured after one year ($P > .05$). At Gardinier the bareroot seedlings were planted less than one month before a fire which especially affected the newer seedlings.

Cleared Vs. Uncleared Transects

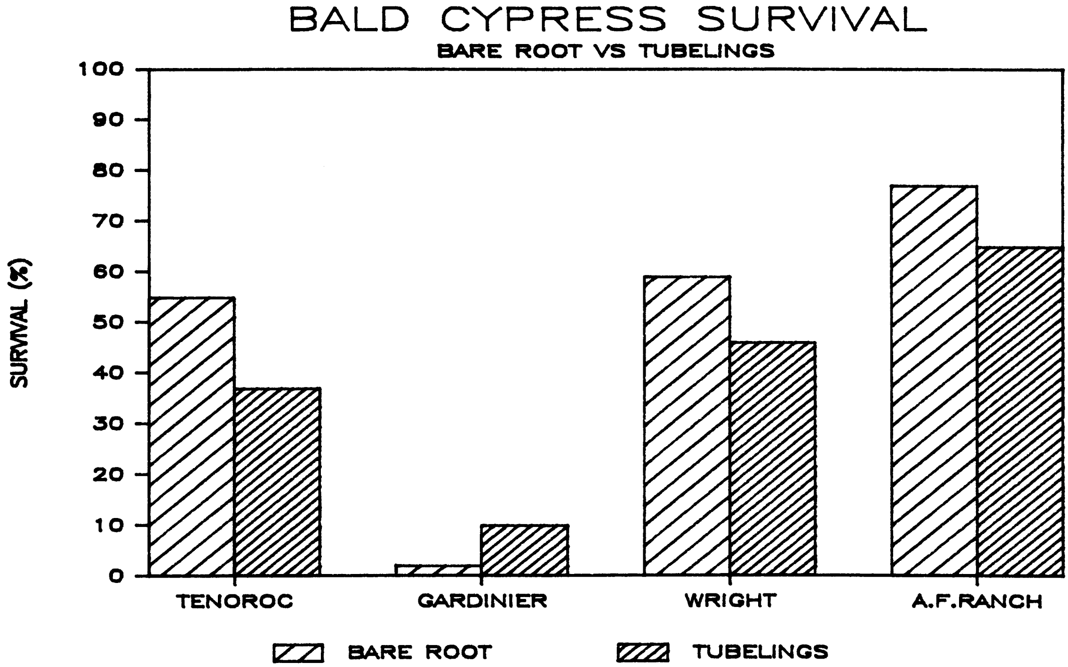
Clearing plots of all above-ground vegetation at time of planting produced no significant difference in survival (Table 2) at any of the sites (Fig. 4). There was no significant difference in height of trees after one year's growth ($P > .05$) except at Tenoroc which was significant at the $P = 0.04$ level. The cleared transects were rapidly recolonized by vines and herbaceous vegetation. Where trees were present and removed they produced abundant basal sprouts. Clearing of plots removed the canopy but increased competition from the herb layer.

DISCUSSION

Water Depth

Cypress (*Taxodium distichum*) planted in experimental transects demonstrated an amazing ability to survive, considering they were purposely planted over a wide moisture gradient. Water levels included land flooded 1-m deep to water tables 1.8-m below the surface when measured in October, 1985. A severe drought during the growing season caused the greatest mortality. Many trees were stressed during the winter from lack of water only to be drowned during the summer rainy season. Both Gardinier and IMC-H9, flooded for the past year, had the poorest survival. Once established, cypress can exist on anaerobic soils where water is present on a near permanent basis (Harms et al., 1980). However, cypress seedlings are unable to tolerate complete flooding for longer than two weeks (Demaree 1932), and can be killed by submergence for as little as two to three days (Williston et al., 1981). Even seedlings that escaped complete inundation on the flooded sites were not as tall or healthy as those growing on sites that are periodically underwater. This is consistent with other studies. Cypress growth rate was shown to be greatest where the average water table was between 0 and 15 cm for trees planted in a nearby phosphate reclamation project (Best & Erwin 1984).

Mean water depth appears to be a controlling factor for cypress dominance. Marois and Ewel (1983) found cypress importance values from



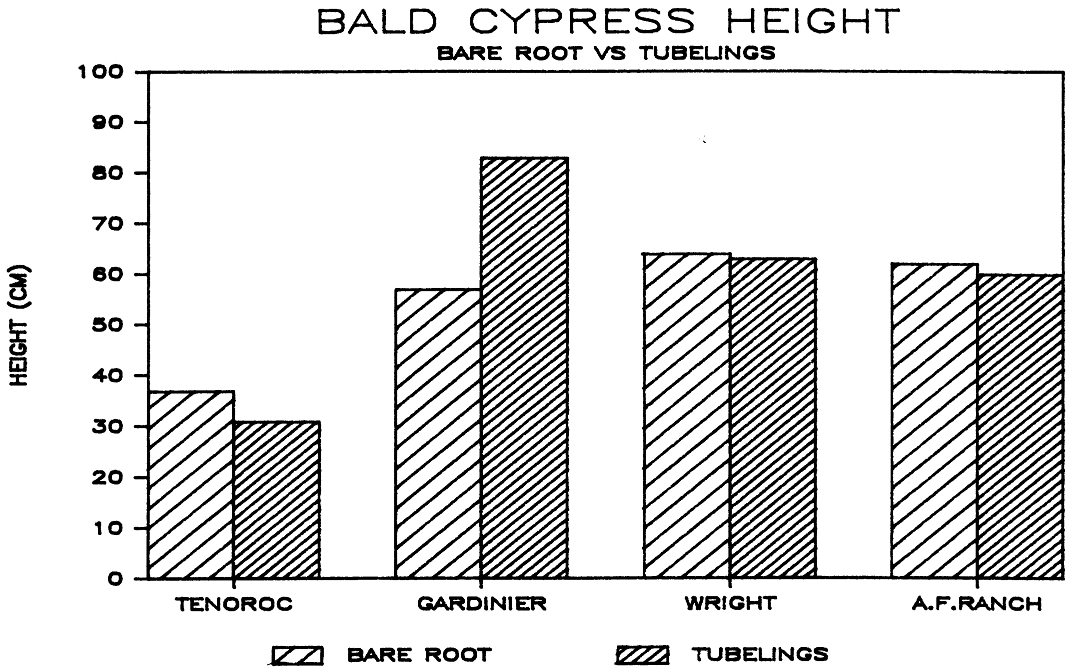


Figure 3. Baldcypress (Taxodium distichum) bareroot seedlings planted in the spring compared to tubelings planted in the winter of 1984-85 after one year of growth.

Table 2. Chi-square distribution for survival of baldcypress seedlings after one year of growth.

Tubelings vs. Bareroot Seedlings:

Site	Df	Chi-square	Probability
Tenoroc	1	9.310	P=0.002
Gardinier	1	13.467	P=0.000
Wright	1	4.885	P=0.027
A. F. Ranch	1	5.687	P=0.017

Cleared vs. Uncleared Transects:

Site	Df	Chi-square	Probability
Tenoroc	1	2.952	P=0.086
Gardinier	1	0.105	P=0.746
Wright	1	0.053	P=0.818

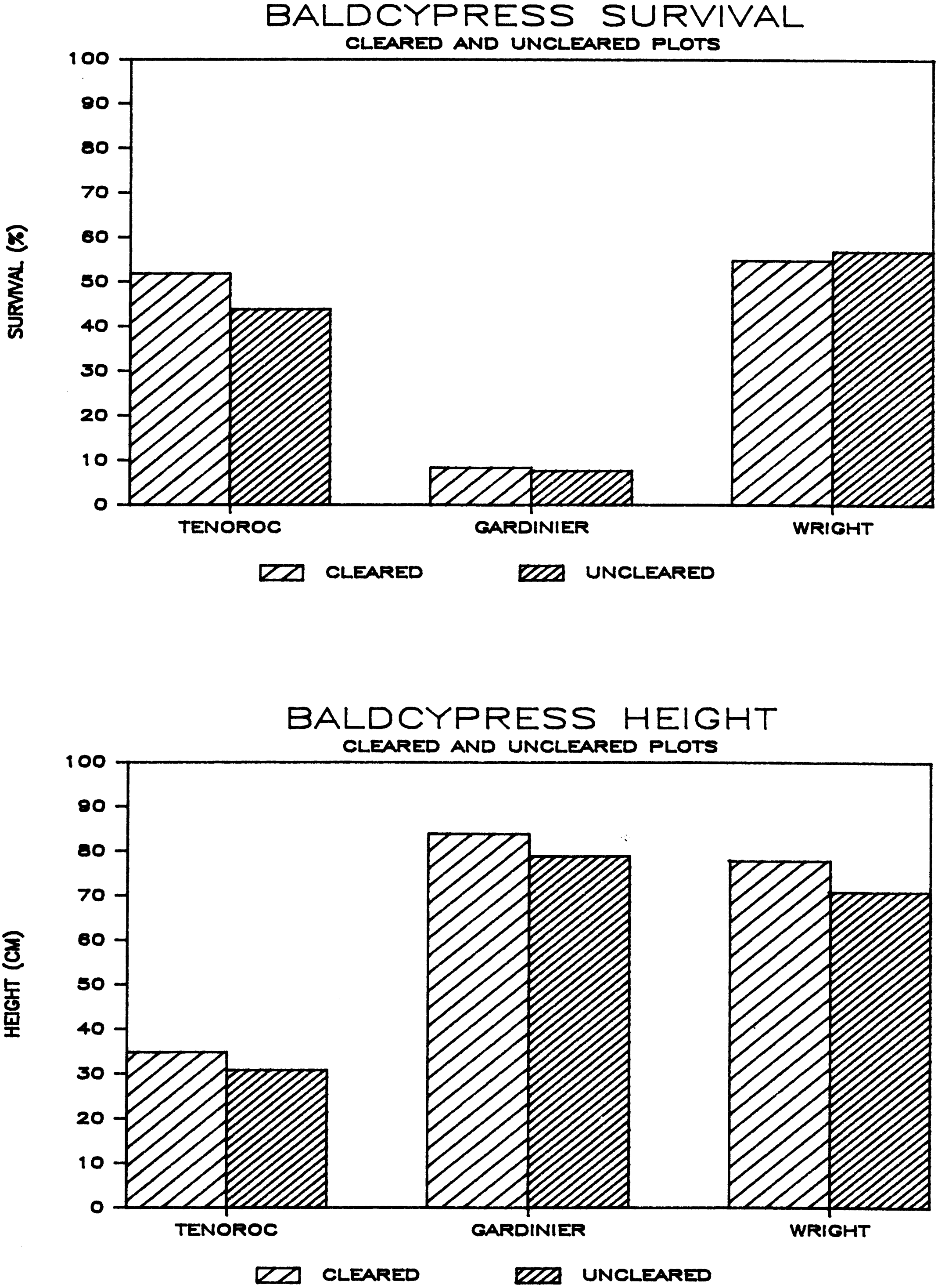


Figure 4. Baldcypress (*Taxodium distichum*) planted in cleared and uncleared plots after one year of growth.

unaltered wet domes were significantly higher than for drained drier domes which showed increasing invasion from other tree species. Stalter (1981) also cited competition from bottomland hardwood species as a major deterrent to baldcypress survival on drier sites. Cypress is an early colonizer on alluvial land but gives way to bottomland hardwoods where water is gradually receding (Williston, et al., 1981).

If clay settling ponds are to be managed for cypress, water level control will be an important tool. However, if diverse bottomland hardwood forest is a desired goal, the best course is to select plant species from a range of communities as recommended by the Florida Game and Fresh Water Fish Commission (King, et al., 1985). This plan would increase species richness which is inversely proportional to flooding frequency (Conner & Day, 1976).

Competition

Cypress trees can endure partial shading but require considerable sunlight for normal growth. Early cypress plantations in Louisiana failed because of shading by plant competition (Williston, et al., 1981). Forest industries routinely employ varying degrees of site preparation to insure better survival and increase growth rates. For success, however, most studies indicate cultural treatments have to be intensive and continue for several years. For example, there was no statistical difference between mowed plots and controls for several species of bottomland hardwood trees. But periodic disking significantly increased heights, diameters, and survival (Kennedy, 1981, Hung & Cleveland, 1979, Krinard & Kennedy, 1983). Davies (1985) observed moisture deficits increased the detrimental consequences of root competition.

Other alternatives require no pre-treatment. Reforestation of surface mined lands can be planned to maximize wildlife diversity (McComb, 1982, King, et al., 1985). Understory vegetation, anathema for the forest industry, is positively correlated with density of small mammals (Greier & Best, 1980), provides additional browse for deer (Murphy & Ehrenreich, 1965), and increases songbird diversity (MacArthur & MacArthur, 1961). Wildlife of this kind has been observed in the study sites.

Competition from vines is part of the ecological complex in bottomland forest. Tree species vary in their reaction, but with good stocking, stands usually outcompete vines when dominants are 5 to 7 meters tall (Johnson, 1975). Some trees respond by sending out new lateral shoots, others overcome the vines by sheer size and numbers. Forests on surface mines in the central states were established successfully by planting trees in preexisting ground cover over 30 years ago (Ashby, et al., 1980). Natural invasion of trees was also far greater on reforested areas than on adjacent unplanted lands on these coal strip mined sites.

The purpose of a reclamation project should be assessed before extensive alteration of the site is attempted. Because of "soupy" clays several years are required before decommissioned ponds can be reclaimed. In the meantime the sites are naturally revegetated with early successional species such as cattails and willows. It may be necessary to drain, grade, and recontour clay settling ponds for specific uses or to blend into the surrounding landscape. But if existing vegetation survives reclamation, the seedlings in this project demonstrated comparable growth and survival when plots were left uncleared and in the meantime existing vegetation continued to function as good wildlife habitat. In fact, a serious impediment to tree survival was grazing from rabbits, rats, and deer.

Nursery Stock Type

Woody plant seedlings grown in a greenhouse extend the planting season for reforestation as well as provide greater species selection. Bareroot plant stock is cheaper and easier to transport, which is better. In this experiment, bareroot seedlings showed significantly better survival than tubelings grown in styrofoam flats. This is not always the case. In Pennsylvania, survival of container-grown plants was no better than bareroot seedling planted in spring (Vogel, 1981). Bareroot seedlings had poorer survival when planted in March and about the same survival when planted in April, compared with paperpots, peat stick, and gro-blocks (Barnett & McGilvray, 1981). Survival of container and bareroot stock was similar for red pine (*Pinus resinosa*), but spring-planted bareroot stock had significantly greater survival than stock planted in the fall (Marion & Alm, 1986).

Bareroot stock made it possible to plant cheaper trees in this experiment. It's not clear if greater survival of bareroot seedlings was the result of spring planting or nursery stock type. Tubelings planted during the winter had to endure a major drought and freeze which contributed to the demise of many area orange groves.

CONCLUSIONS

New rules for mitigation and reclamation increase the importance of understanding species tolerance and survival to properly reclaim mined lands. Results from the first year of data indicate cypress trees may be suitable for wet depressions of clay settling ponds. Additional research about nutrients, nurse crops, soil amendments and time of planting should point the way to increasingly successful full scale projects.

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RED MANGROVE, RHIZOPHORA MANGLE, IN TEXAS: AN EXPERIMENT IN ESTABLISHMENT AND SURVIVAL

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ABSTRACT

Red mangrove, Rhizophora mangle L., is an important member of the coastal, littoral fringe vegetation of the more tropical shorelines of the Gulf of Mexico and Caribbean, including southern Florida and Mexico. Rhizophora provides shoreline stabilization, habitat for many estuarine and terrestrial fauna, and significant primary productivity to the estuarine food chain. Red mangroves occur northward along both coasts of Florida to approximately the same latitude as Galveston, Texas, but only black mangrove, Avicennia germinans (L.) L., occurs along the Texas coast. Studies have indicated that populations of both the black and red mangrove exhibit latitudinal genetic differentiation in their tolerance of chilling temperatures in the Gulf and Caribbean with increasing tolerance in more northerly populations.

Experimental plantings of red mangroves originating from Daytona Beach, Florida, were undertaken on the southern Texas coast near Brownsville to determine if these plants of northern Florida which experience periodic chilling and mild freezing temperatures could survive Texas winter conditions to be used for wetland creation and enhancement efforts on the Texas coast. The results of this study and others indicate that red mangrove can be readily established and may survive most normal Texas winters, but that the frequency and duration of freezing conditions which exceed their tolerance preclude the long-term survival of Rhizophora in Texas.

INTRODUCTION

The ecological value of red mangrove (Rhizophora mangle L.) and other mangrove species in the littoral fringe communities of coastal waters has been well documented (Davis, 1940; Odum, 1971; Lugo & Snedaker, 1974). Mangroves are also important shoreline stabilizers helping to prevent wave erosion, and in some cases, contributing to the accumulation of peats and sediments to result in land accretion (Davis, 1938, 1940; Scholl, 1964).

Four principal mangrove species occur in the northern Gulf of Mexico, predominantly along the southern Florida and Mexican coasts. However, one species, black mangrove (Avicennia germinans (L.)L.), occurs further northward along the Texas, Louisiana, and northern Florida coasts as a result of greater chill tolerance (Sherrod & McMillan, 1985; Markley, et al., 1982). Red mangrove occurs northward along the Florida coast of the Gulf and Atlantic along with black mangrove to approximately the same latitude as Galveston, Texas, near 29° N lat. (Sherrod, et al., 1986).

Genetic, latitudinal gradients in chill tolerance (2° to 4° C) have been demonstrated in black, red and white (Laguncularia racemosa (L.) Gaertn) mangrove populations in the Gulf and Caribbean with the more northern populations exhibiting greater chill tolerance with increasing latitude of occurrence (Markley, et al., 1982, Sherrod, et al., 1986, McMillan & Sherrod, 1986). As the populations of red mangrove of northern Florida occasionally experience chilling or mild freezing temperatures and have been shown to survive (Lugo & Zucca, 1977), field and laboratory experiments were conducted in Texas using Rhizophora propagules obtained from Daytona Beach, Florida, to determine if these red mangroves could survive Texas winter conditions. The results and conclusions of field plantings of the Florida Rhizophora on the southern Texas coast near Brownsville in 1983 are presented in this paper.

MATERIALS AND METHODS

Approximately 300 unrooted Rhizophora propagules were obtained from Daytona Beach, Florida, in early October of 1982 and were placed in one-gallon buckets with approximately 2-3 cm of potting soil and 5-6 cm of tap water for rooting. Approximately 50 propagules were placed in each bucket. The propagules were kept in an indoor environment at approximately average room temperature (20° - 25°C) with fluorescent lighting on 10-hour daytime cycles. No salts, fertilizers or root stimulants were used during the rooting period. Initiation of root development was noted within two weeks and rooting and leaf initiation were continued in the one-gallon buckets during the winter of 1982.

In mid-February, 1983, approximately 75 rooted propagules were transplanted to the field at a site on South Padre Island along the outer fringe of a Spartina alterniflora and Scirpus maritimus marsh at the outfall point of a sewage treatment plant (Figs. 1 & 2). Plants were transplanted directly from the rooting buckets with no attempt at preconditioning to salinity or the outdoor environment. Sediments at this planting site were generally firm sandy marl. The planting site had a northwestward exposure facing the Laguna Madre. Propagules were planted on approximately 1-meter centers along the outward fringe of the Spartina at an elevation of approximately MLW (mean low water). At time of planting, the sediments and bay water were still cold from the past winter (estimate 10° to 15°C).

In mid-April of 1983, approximately 80 to 90 additional red mangrove propagules were transplanted to another site at the mouth of the Rio Grande River along a tidal ditch in a clearing among a stand of black mangroves (Figs. 1 & 3). As with the previous planting effort, no preconditioning of the plants to salt or the outdoor environment was attempted. Propagules were again planted on approximately 1-meter

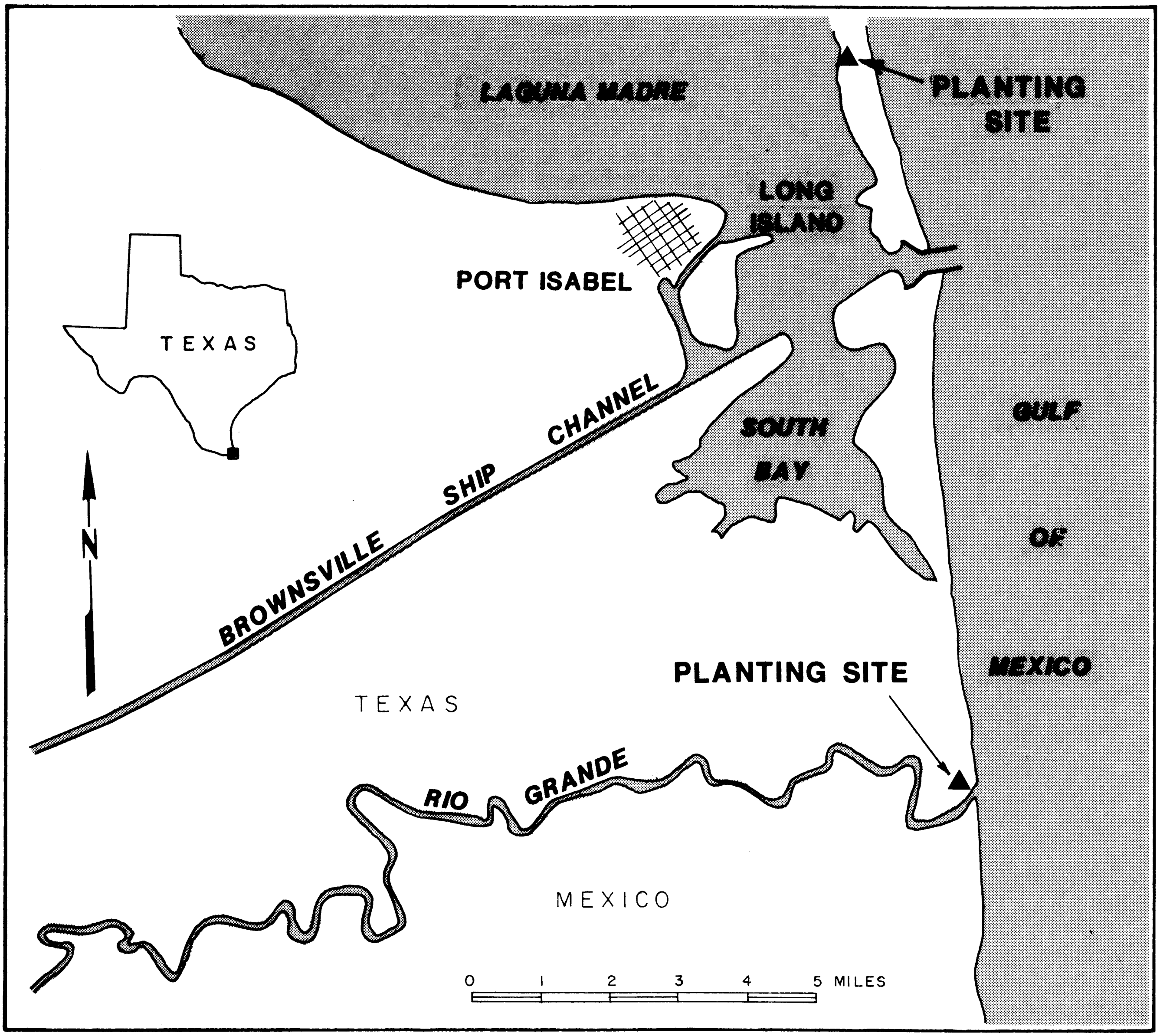

Figure 1. Location of Rhizophora planting sites.

Figure 2. Rhizophora plantings on South Padre Island in February 1983.

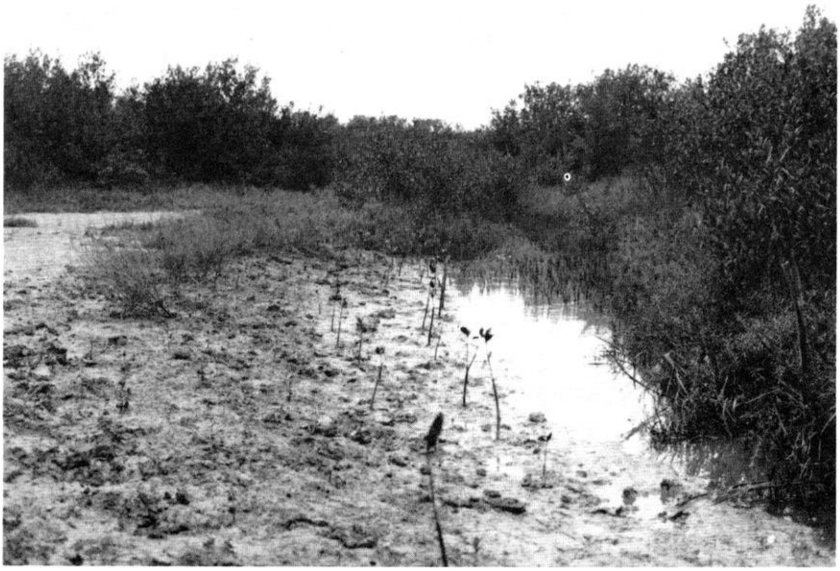

Figure 3. Rhizophora plantings at the mouth of the Rio Grande in April 1983.

centers in the soft silty-clay sediments characteristic of this site at an elevation of approximately MLW to MWL (mean water level). The planting area was generally surrounded by black mangroves 1 to 5 meters in height. The sediments and water were relatively warm at this time of year (estimate 20 °to 25°C).

Remaining propagules were remanded to growth chambers in Austin for chill tolerance testing, the results of which are reported by Sherrod, et al., 1986.

The transplanted propagules were periodically monitored during the remainder of 1983 and into 1984 to determine establishment and survival success.

RESULTS

The plants established at South Padre Island in February, 1983, were inspected in April, June, and August of 1983 for establishment success. Of the 75 seedlings initially planted, 50 survivors were accounted for during the summer. Most surviving plants were producing new leaves. During the summer, the *Spartina* colonized around and beyond the red mangroves, densely engulfing them by August, 1983.

The seedlings established at the mouth of the Rio Grande River in April, 1983, were inspected only once in June due to the remoteness of the site. Of the original 80-90 seedlings, 60 surviving plants were found in June. Nearly all of those plants exhibited new growth.

The planting sites were not inspected again until January, 1984, following the coldest period of record for the Texas coast during December, 1983. During that 9-day period in December, subfreezing temperatures prevailed with a 54-consecutive hour period below 0°C recorded at Brownsville (ca. 25 km southwest of South Padre Island) on December 24-26 and record lows of -6° to -10°C recorded along the Texas coast (NOAA 1983).

In late January, 1984, the plants were inspected for survival following the record freeze. All plants had brown leaves and drooping stem tips, but many of the seedling bases were still green and roots of several plants removed from the sediment appeared to still be viable.

The plants were again checked in March, 1984, and at that time no remaining green tissue was observed in the stems. All plants were determined lost to the freeze. In addition to the red mangrove mortality, approximately 80 percent of the black mangrove populations along the Texas coast were also lost to the freeze (Sherrod & McMillan, 1985).

DISCUSSION

Although this study was abbreviated by the record freezing conditions of December, 1983, several conclusions can be drawn from these results and other studies. While viable propagules of *Rhizophora*, presumably of northern Mexico origin, occasionally wash upon Texas beaches, no naturally established plants have been observed (Gunn & Dennis, 1973; McMillan, 1971; Markley, et al., 1982). However, in March, 1983, a group of established red mangroves was discovered at South Padre Island which had apparently been planted several years earlier from an unknown source (Sherrod, et al., 1986). These plants, found along the edge of a dense black mangrove stand, ranged in height from 1.5 to 2.5 meters and were observed to be flowering and producing viable propagules during the summer of 1983. Newly established seedlings, presumed to be progeny of the larger plants, were noted in the immediate vicinity as well as on Long Island (John Hook, personal communication, 1986), across the Laguna Madre from the established parent plants, where the prevailing southeasterly winds may have drifted the propagules.

The successful establishment and initial growth of the northern Florida propagules planted at South Padre Island and at the mouth of the Rio Grande River prior to the devastating freeze of December, 1983, and the discovered presence and fecundity of larger *Rhizophora* on South Padre Island indicate that red mangroves can be established in Texas and survive normal winter conditions.

However, the long-term survival success of *Rhizophora* in Texas is questionable due to the frequency, duration, and severity of hard freezing conditions. Tests of chilling tolerance (2° to 4°C) indicate that *Rhizophora* populations of northern Florida are genetically adapted to withstand lower temperature conditions than populations from southern Florida and the Caribbean to the south (Sherrod, et al., 1986; Markley, et al., 1982). The tolerance limits to freezing conditions in *Rhizophora* have not been studied, but established populations in northern Florida (Cedar Keys) have been noted to survive short exposures to mild freezing conditions (0° to 5°C) (Lugo & Zucca, 1977). The extreme duration and severity of the December, 1983, freeze in Texas obviously exceeded the low temperature tolerance limits of the northern Florida seedlings as well as the older, previously established plants of unknown origin which had apparently survived one or more previous winters with recorded mild freezing conditions. The natural populations of *Rhizophora* in northern Florida were also eradicated from their northern distribution limits in that state by severe freezes in 1984 (Steve Beeman, personal communication, 1986).

Due to meteorological and geographic conditions, the potential for more severe and longer duration freezes on the Texas coast may be higher than the northern Florida coastal areas. This, coupled with the extreme distance of a renewing natural seed source of *Rhizophora* at LaPesca, Tamaulipas, Mexico, 300 km to the south of Brownsville, essentially prevents the long-term survival success of red mangrove in

Texas. Artificial introduction of Rhizophora propagules could result in probable short-term survival, but relatively frequent reintroductions would most certainly be necessary to maintain populations over time following periodic eradications by severe freezes.

ACKNOWLEDGEMENTS

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MITIGATION FOR PORT DREDGING

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ABSTRACT

As a result of Port Expansion, approximately 40-60 mixed mangroves were destroyed during a dredging project on the Atlantic Intracoastal Waterway (IWW) in Fort Lauderdale in the summer of 1984. To offset this impact, 0.32 hectares of wetlands were created from uplands on the western shoreline of John U. Lloyd State Park, approximately 4,000 red mangroves were planted from seedlings grown in the Port's mangrove nursery, and approximately 317 lineal meters of native lime rock riprap was placed waterward of these plants to protect the plants from wave action generated by small, fast boats. The riprap also serves the purpose of stabilizing the shoreline as well as providing habitat for juvenile marine organisms.

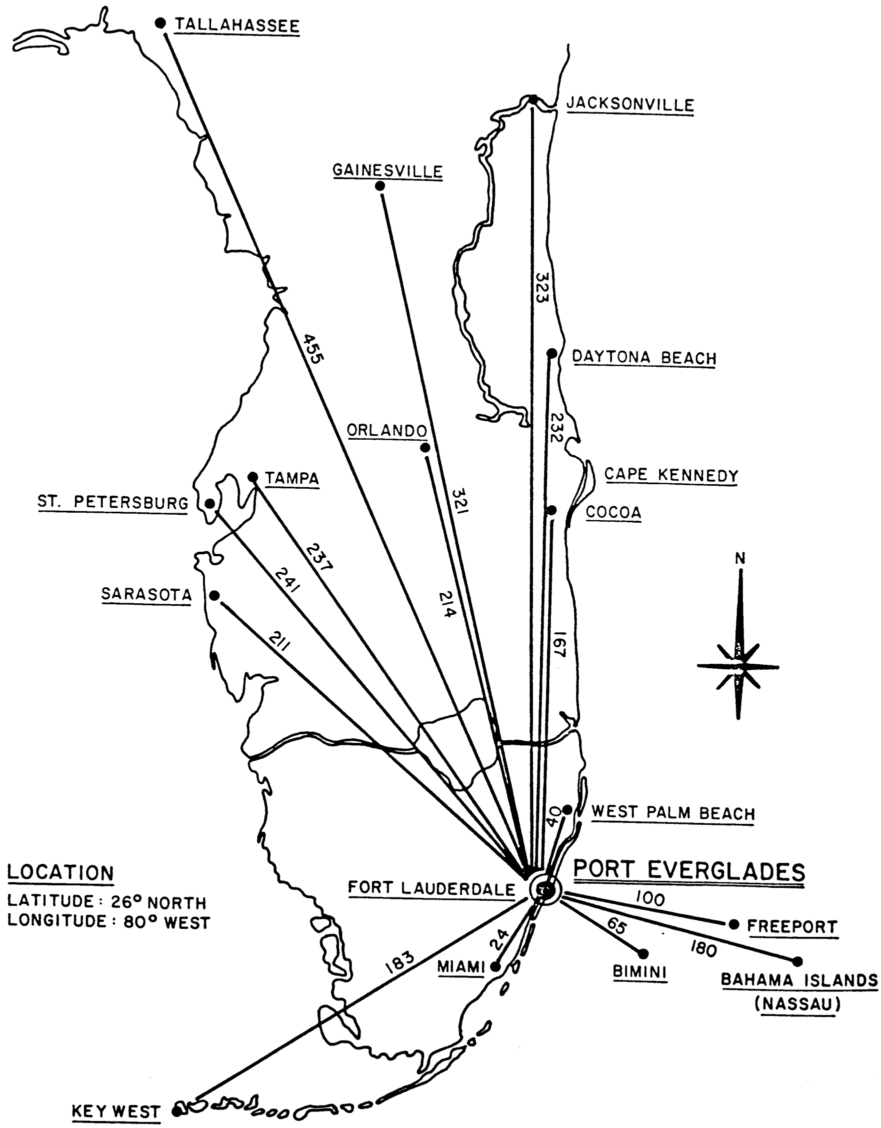
INTRODUCTION

The Port Everglades Authority is located on the southeast coast of Florida partly within the city of Fort Lauderdale (Fig. 1). The Port is Florida's deepest Port (-14.7 meters MLW) and represents the only opening to the Atlantic Ocean between the Hillsborough Inlet to the north and Bakers Haulover to the south.

The Port is completely man made and was opened to the Atlantic Ocean in 1928. Prior to the harbor opening, the Dania Cut-Off Canal was completed in 1911 and the IWW was completed in 1912. These three developments have changed this area from a fresh water system to a brackish/marine environment.

There are presently 33 berths either permitted to be constructed or in existence, for a total of 6,491 lineal meters of bulkhead. The Port owns about 344.0 hectares of uplands and 145.7 hectares of submerged lands in the Turning Basin, slips and channels. The jurisdictional extent of the Port Authority encompasses approximately an additional 809.4 hectares.

As a result of the Port's need to expand to meet the needs of the residents of South Florida, an impact to approximately 40-60 individual mixed mangroves located on the western shoreline of John U. Lloyd State Park occurred as a result of dredging operations associated with the deepening and widening the channel in the summer of 1984. The Port Authority proposed, as mitigation for this minor impact, to create a new wetland area of approximately 0.32 hectares from existing uplands and, to compensate for the 40-60 plants lost to expansion, planting



GEOGRAPHICAL LOCATION
PORT EVERGLADES, FLORIDA

FIGURE 1

approximately 4,000 red mangrove seedlings over this new wetland area.

It should be noted that this project was designed and implemented as a full scale pilot project for the mitigation of a future Port project of a much greater magnitude; the Port's Turning Notch program. The future mitigation effort is multifaceted and one aspect of the program involves the creation of 9.31 hectares of wetlands from uplands. The data obtained from this pilot project will be used in the final design of the Port's proposed Turning Notch Program with regard to the optimum grade and elevation of the mangrove planting and riprap setting.

METHODS AND MATERIALS

The chronological events of this project began with the design of the project, establishment of the Port's Mangrove Nursery, preparation of the site-grading of uplands to wetlands, placement of native lime rock riprap, final grading, planting of mangrove seedlings, and monitoring of the project.

Design of the Project

The Port's dredging project involved the deepening of the IWW to -14.67 meters MLW, channel width of 166.67 lineal meters and side slope of 1:1. Approximately 4587 cubic decimeters of material was scraped down from an elevation of +4.00 meters MLW to +0.63 meters MLW. This material was pushed into the IWW from the uplands and was dredged from the channel as part of the dredging project. Figures 2-4 depict project location within the Port, and the design of the mitigation area.

Site Preparation and Riprap Placement

The initial grading of the area was conducted by utilizing a D-9 bulldozer. The final grading was conducted with a "Bob-Cat" dozer. The placement of the riprap was conducted by the utilization of a clam shell/barge combination which mechanically set the riprap on site to the designed elevation. The riprap varied in size from 0.5 meters to 1.5 meters diameter.

Mangrove Nursery

An area of approximately 1 hectare was cleared for the Port's mangrove nursery in May of 1984. Although the project called for approximately 4,000 red mangrove seedlings to be planted on site, 50,000 flower pots were filled with muck and planted with red mangrove pods harvested from adjacent wetlands within the Port. An irrigation

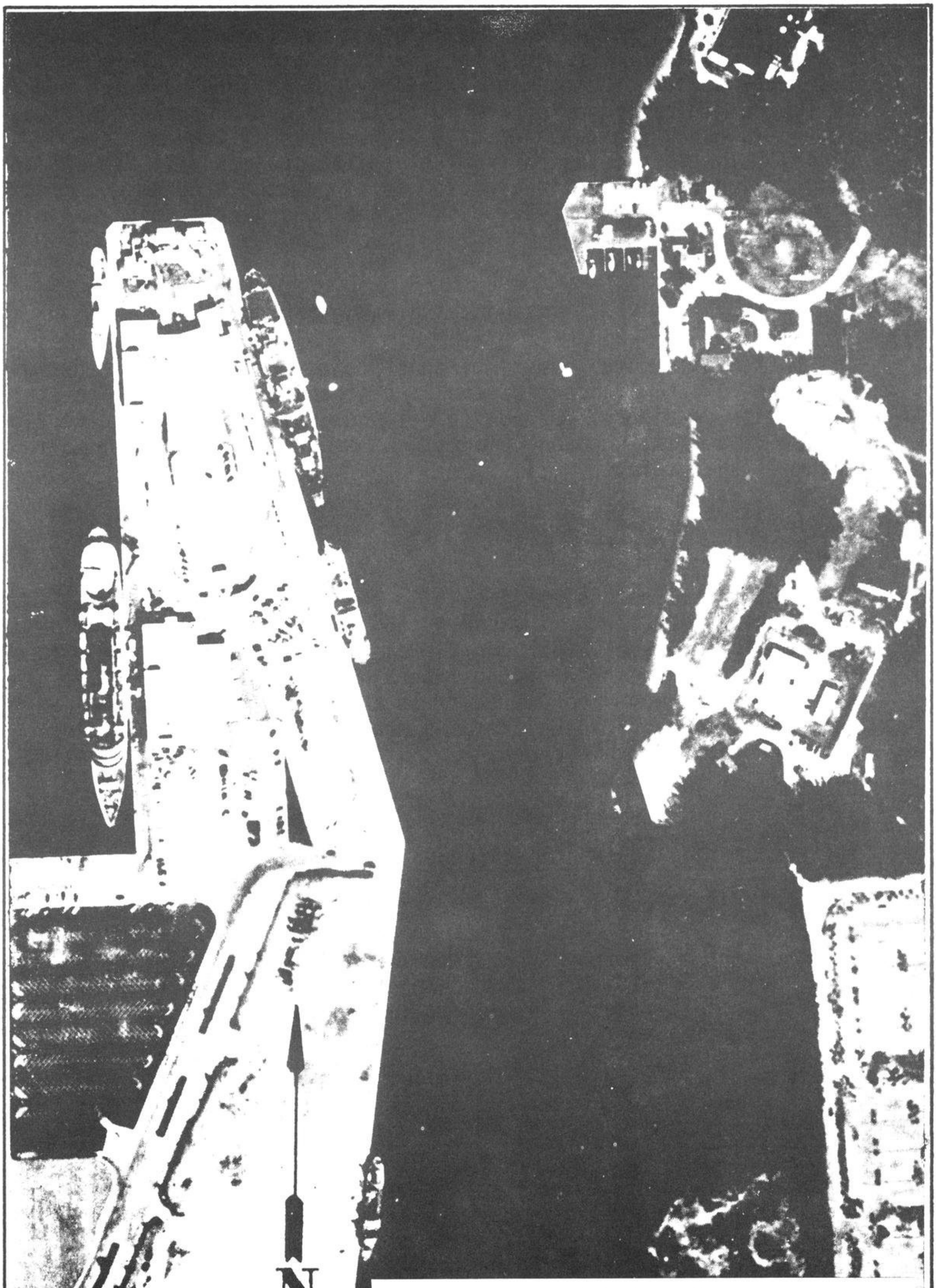


FIGURE 2
PROJECT LOCATION - PORT EVERGLADES

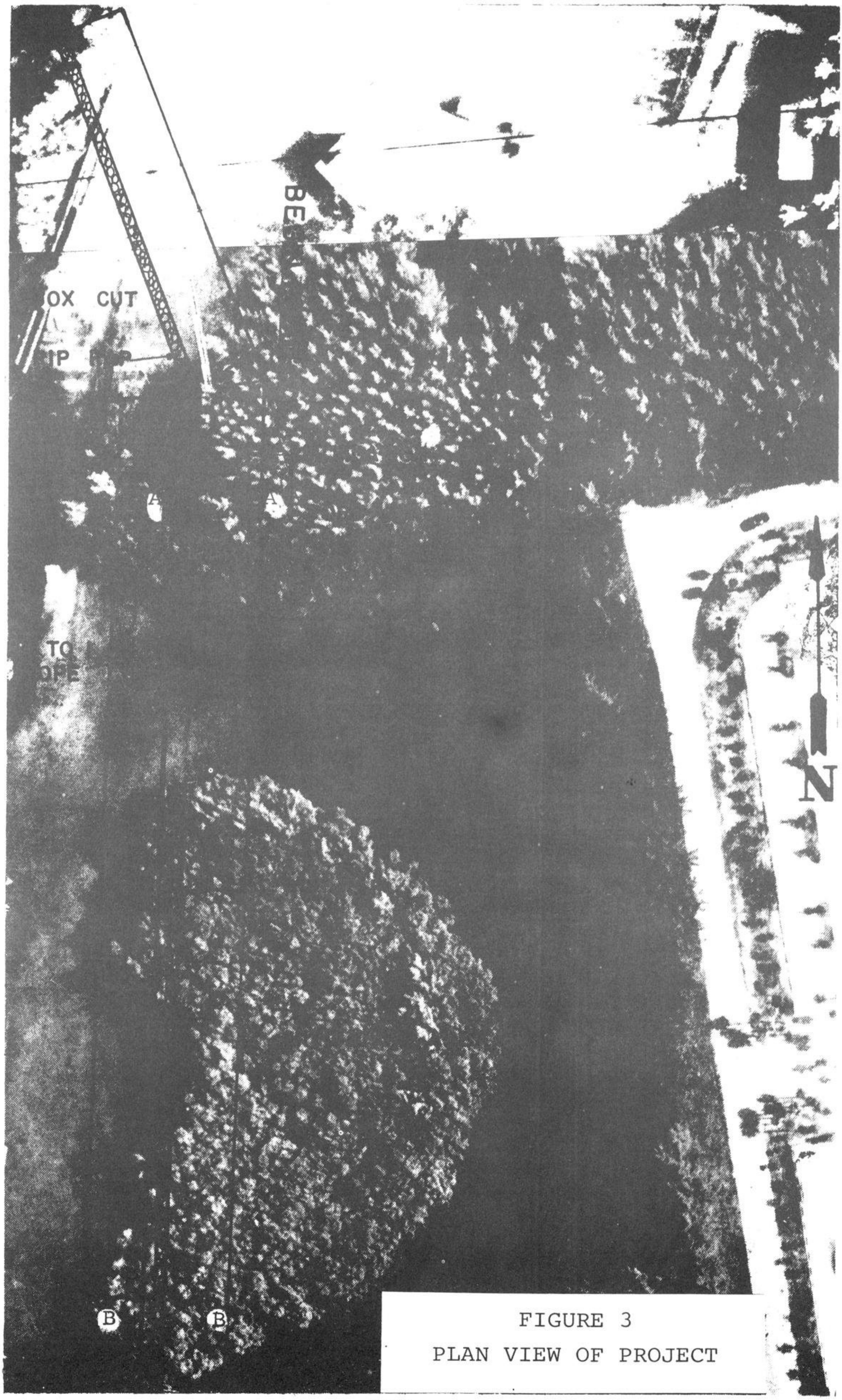


FIGURE 3
PLAN VIEW OF PROJECT

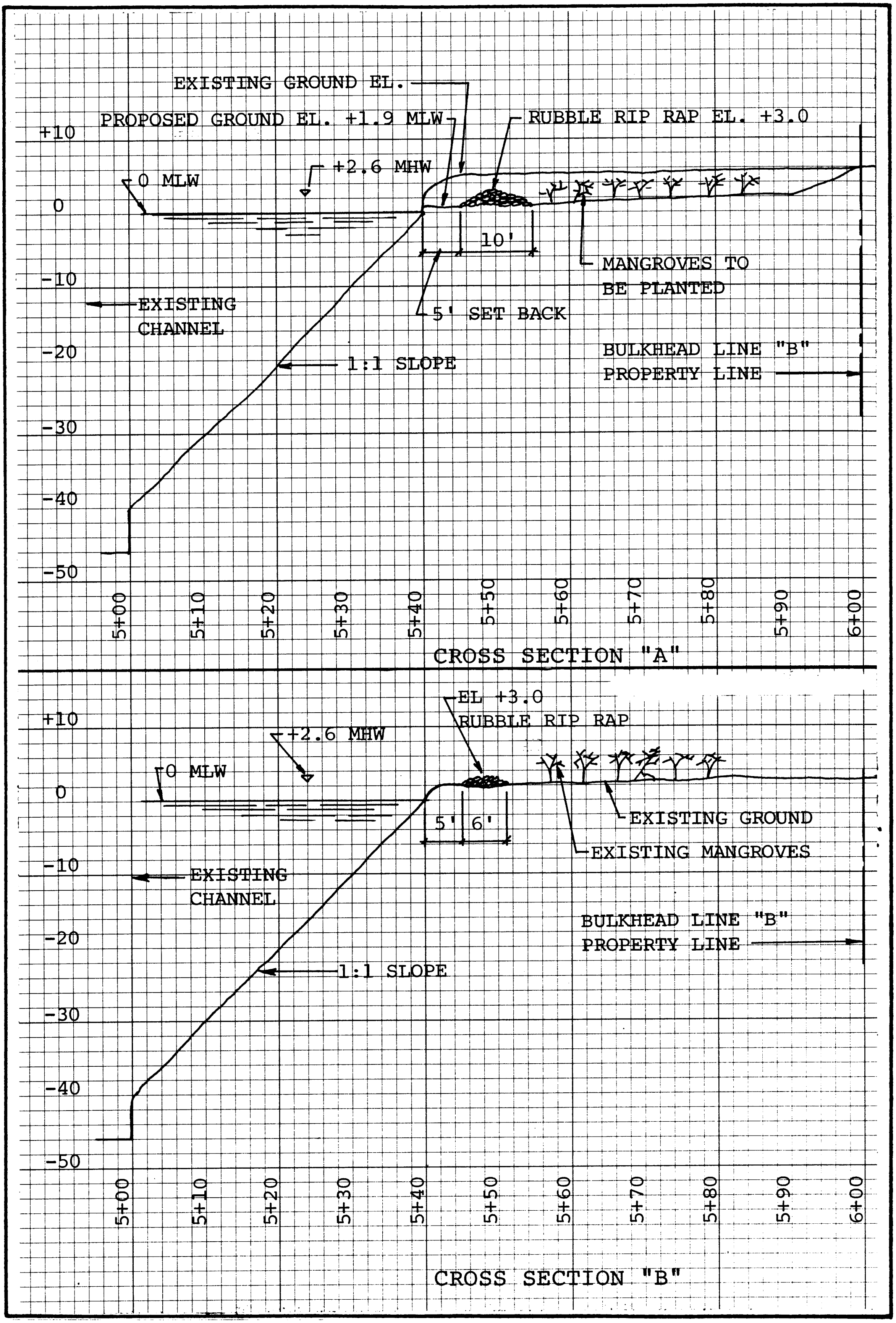


FIGURE 4

TYPICAL CROSS SECTION OF PROJECT

system was established that utilized the city's fresh water system. All pots were placed on wooden pallets to prevent the mangroves' root system from penetrating the flower pot drain holes and becoming embedded in the soil.

Planting of Seedlings

When the plants had grown to a four to six leaf stage, they were transported to the project site by trucks in December, 1984, after approximately a five to six month grow-out season.

At the planting site, strings were marked at one meter intervals and staked out in rows. All holes were dug manually to an approximate depth of 15 cm and filled with the root mass, dirt, and the plant from the flower pot.

RESULTS

The survival rate of the seedlings planted at the park was approximately 85 to 90 percent. However, an additional natural recruitment of 5 percent has added to the overall survival rate of the planting effort.

The survival rate of the pods potted in the nursery had been a little higher than those planted in the field. This rate approximates 95 percent survival during the grow-out portion of the project which was approximately 6 months before on-site planting took place.

A macrobenthic analysis of the study site and the surrounding area was conducted within six months of project completion and indicated that the new area was being colonized by marine organisms. Their diversity was high compared to previous levels with relative low abundance. It was anticipated that this condition would stabilize to reflect that of a brackish environment. This new area compared favorably with other stations within the study area which had elevations similar to that of the newly created wetlands.

The new area is being visited by several species of wading birds, osprey, various marine species of fish, macro/microinvertebrates such as crabs, barnacles, oyster spat, etc. In addition, a lush algae growth has attached itself to the riprap and many organisms can be seen utilizing this habitat.

DISCUSSION

The cost to establish 0.32 hectares is expensive. The major cost is land preparation and riprap placement. This aspect of the project ran approximately $90,000 for 317 lineal meters of riprap and $5,100 for the earth work. The total cost for the mangrove seedlings was approximately $.18 a plant. This value included the costs for flower pots, sprinkler system, supervisory time and transportation of the plants to the park. All labor associated with the planting effort was provided to the Port without cost by the Florida Ocean Sciences Institute as part of their Community Service Program. A considerable cost savings was realized by the Port Authority by this in-house effort when compared to the "street" estimate of $2.00 - $2.50 per plant in place value.

During the later summer months, a dense green algae mat formed and covered the young plants. The plants were monitored twice a week for this occurrence and it was necessary to remove as much of the algae as possible from the seedlings because the wave action plus the weight of the algae caused the uprooting of the young plants. This activity was necessary until the early fall when the algae disappeared due to the cooler weather and shorter daylight hours.

The placement of the riprap should follow the final grading of the area as soon as possible. Due to the fact that the Port is a high use area for small, fast boats, a secondary berm was formed before the riprap was set in place. This berm was removed by hand in some areas, while in other areas trenches were made to allow the water to flow into the new wetland. In addition, the elevation of the riprap for the Port Turning Notch mitigation program will be raised from +1 meter (MLW) in this project to +2 meters (MLW) due to the high tides that appear in the fall and the waves generated by the fast boats in the area.

It doesn't appear that the planting is seasonally dependent, but it is recommended that the fall to winter months may be the best. A good six months' growth can be realized before the algae mat develops and covers the plants. The extra effort of caring for the plants may be reduced if the plants have this extra growing time. This time of the year is much cooler than the summer months and produces less stress to the plants before planting occurs. It is also more comfortable for the workers to accomplish their task.

The only negative aspect of the project occurred in the form of vandalism from two 12 year old boys who destroyed approximately 800-1000 plants in the early summer of 1986. Surveillance of the new wetland area has been increased by both park and Port personnel and provisions have been made which will eliminate this type of problem in the future.

ACKNOWLEDGEMENTS

Recognition for the success of the total program must be given to the staff and students of the Florida Ocean Sciences Institute for work performed in the nursery and project site.

INNOVATIVE FLOW-THROUGH WETLAND FOR EFFLUENT DISPOSAL

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ABSTRACT

An existing wastewater facility in Kissimmee, Florida, with a flow of 1.0 MGD currently discharges to an experimental isolated wetland effluent disposal system that is in a "no discharge" drainage basin. The wetland is permitted for 1.185 MGD disposal capacity with provision for emergency overflow under a 10 year storm event. A proposed modified flow-through design will be capable of handling 2.2 MGD by routing the water through hyacinth ponds, wetland, and then percolating through a rapid infiltration system. Mass balances indicate nutrient concentrations of total nitrogen (1.25 mg/l) and total phosphorus (0.2 mg/l) can be achieved as a final effluent existing the rapid infiltration basins.

INTRODUCTION

The site for a proposed modified flow-through effluent disposal wetland is located in Osceola County, Kissimmee, Florida. Presently two wastewater treatment plants with a combined flow of 1.0 MGD discharge effluent to an experimental wetland. Treated effluent is discharged to the wetland and is lost to groundwater and evapotranspiration. Direct discharge to surface waters is prohibited except in the case of a 10 year storm event.

A modified system has been proposed to increase the design disposal capacity, yet remain within the limitations of "no direct discharge" and provide for 1 in 10 year storms. The target design capacity will be 2.2 MGD. The design features of the system include flow-through hyacinth ponds, wetland, and a rapid infiltration basin where specified materials in a filtration dike dispose of final effluent to groundwater (Fig. 1).

DESIGN CONCEPTS

Rapid Infiltration System (R.I.S.)

The proposed flow-through wetland system is illustrated in Figure 2. Figure 3 depicts Section A-A which illustrates the configuration of the hyacinth ponds, wetlands, the infiltration system and the respective elevations. A typical cross section of the Rapid Infiltration System design concept is shown in Figure 4. In concept, the R.I.S.

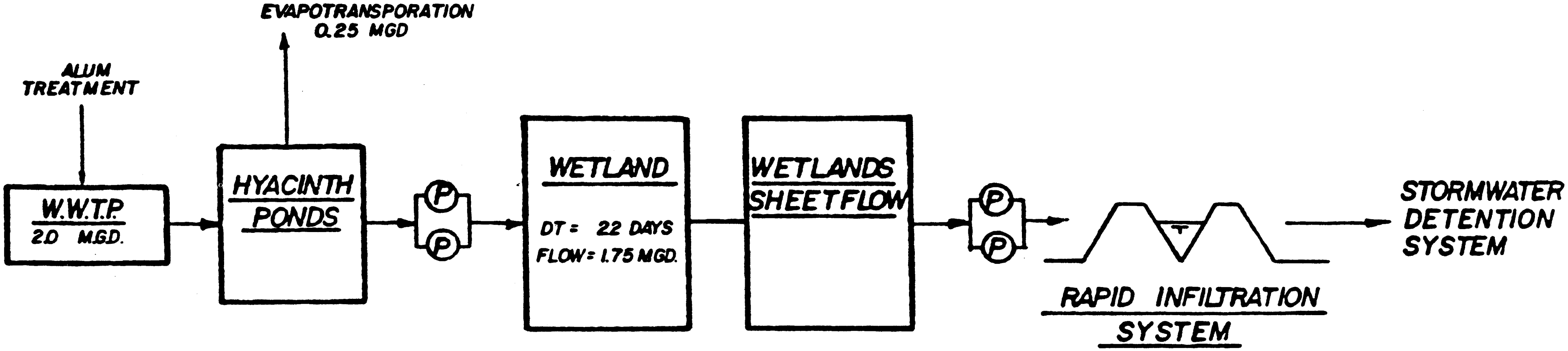


FIGURE 1 — FLOW SCHEMATIC

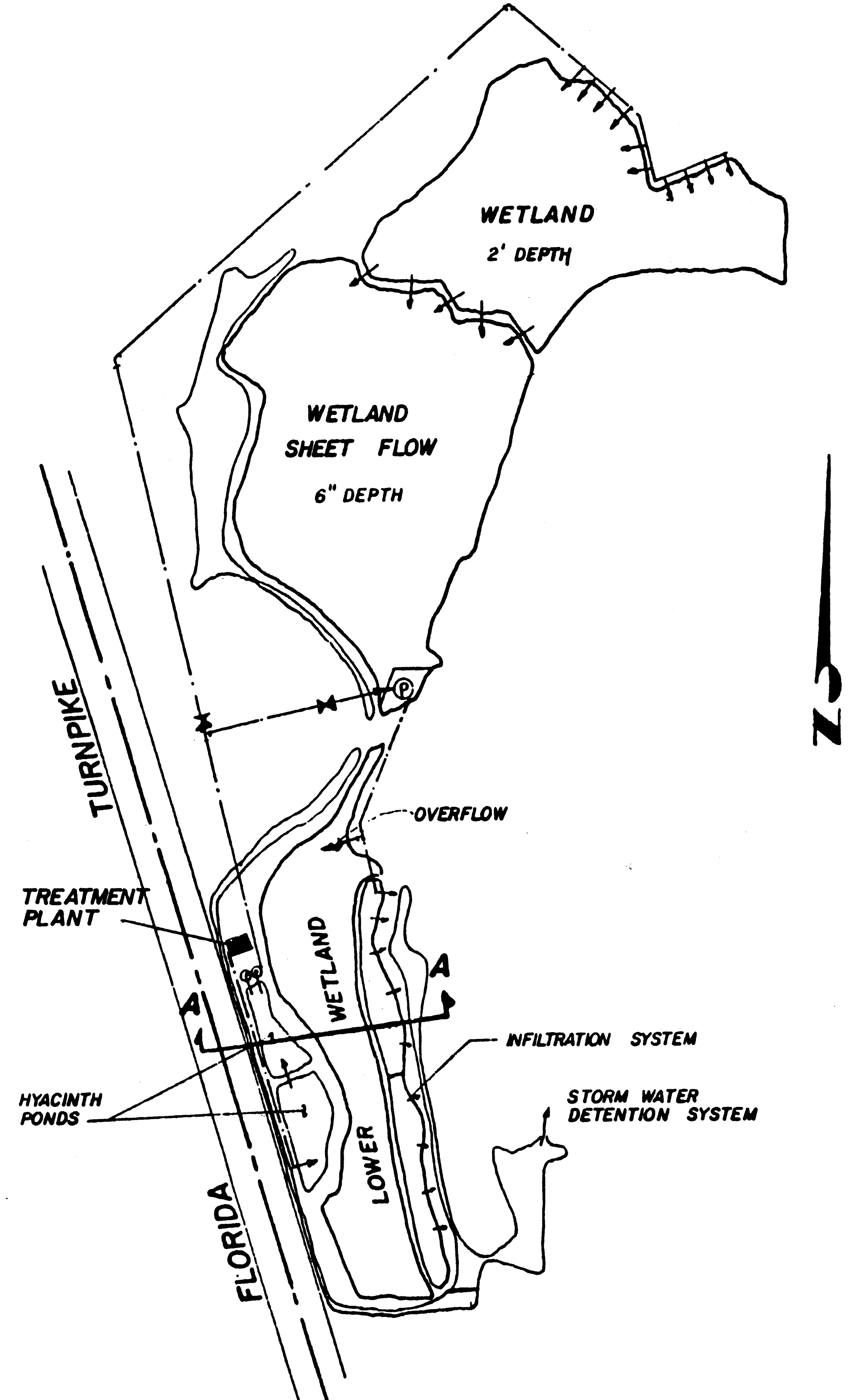
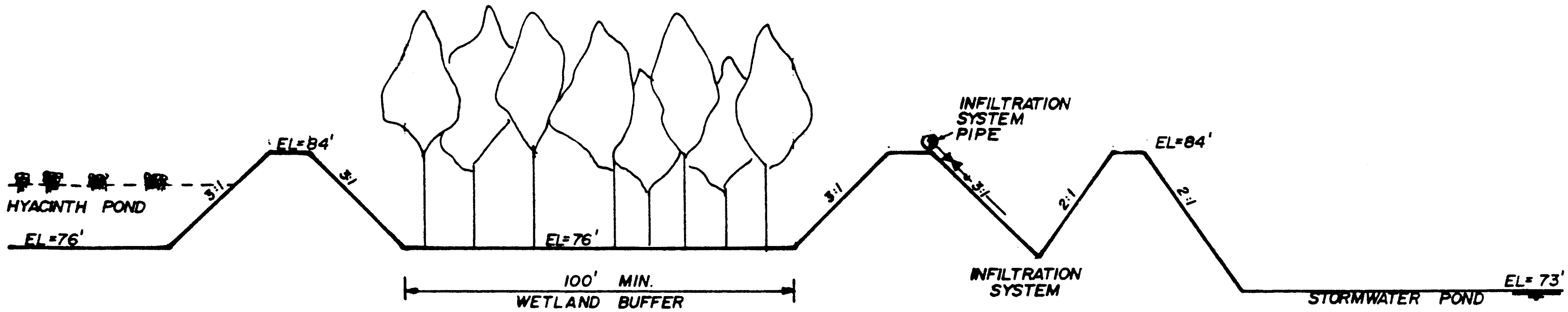


FIGURE 2 .. **FLOW THROUGH WETLANDS SYSTEM**



SECTION A-A

FIGURE 3__TYPICAL CROSS SECTION OF TREATMENT WETLAND SYSTEM

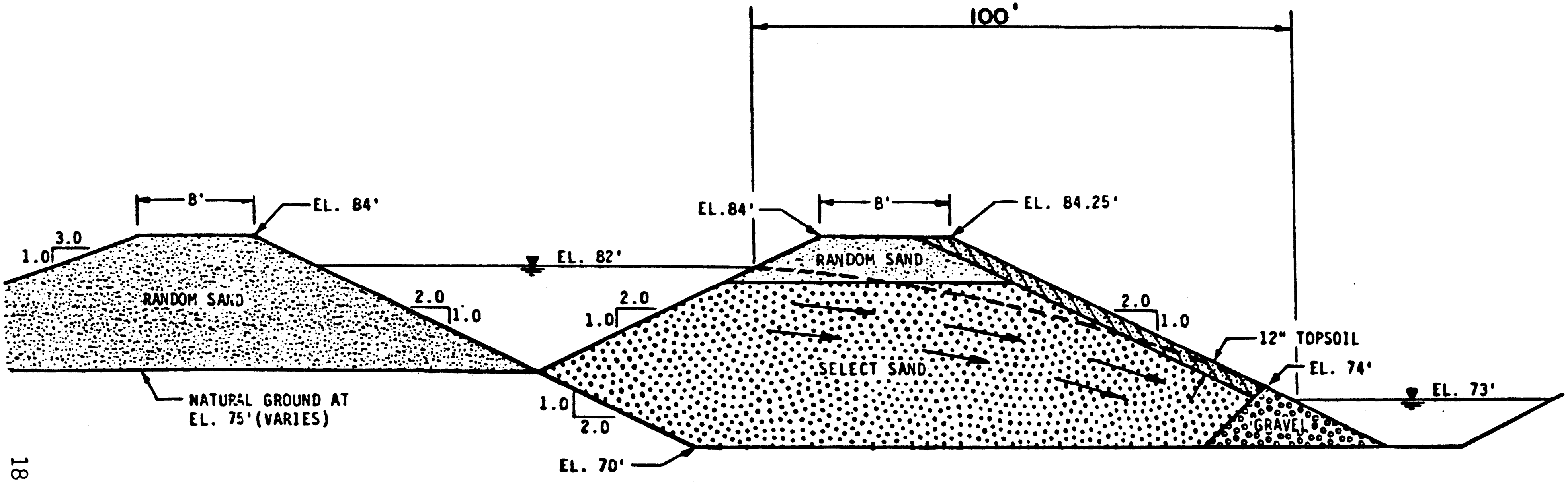


FIGURE 4_TYPICAL CROSS SECTION FOR INFILTRATION SYSTEM

will consist of a retaining dike and a filtration dike. The retaining dike between the wetland and the infiltration basin consists of random sand materials with the following characteristics: (Cheung & Garlanger)

1. An upstream slope of 2:1

2. A downstream slope of 3:1

3. An inside crest elevation at 25.62 m (NGVD) and an outside crest elevation at +25.68 m (NGVD)

4. A crest width of 2.4 m

5. A freeboard of 61 cm

The filtration dike which is a pervious dike with the following characteristics: (Cheung & Garlanger 1986)

1. Upstream and downstream slopes of 2:1

2. An inside crest elevation of +25 m (NGVD) and an outside crest elevation at +25.68 m (NGVD)

3. A head water elevation of +25 m (NGVD)

4. A tail water elevation of +22.25 m (NGVD)

5. A crest width of 2.4 m

6. A freeboard of 61 cm

The filtration dike is to be constructed of specified sand with a random sand cap and a gravel toe drain. The toe drain will prevent seepage on the outside face of the dike whereas the sand cap will stabilize the entire configuration and provide maintenance access. Erosion on the downstream slope will be controlled by 30 cm of top soil that will support vegetation.

For operational and maintenance purposes, the infiltration system will consist of two equal basins that are separated by a common dike. Overflow structures will return excess stormwater and treated effluent to the lower wetland component during large storm events.

The select sand materials for the filtration dike are recommended to consist of concrete sand with a permeability of 51.5 m per day and a design safety factor of 2.5. These materials will dispose of a 4.4 MGD design flow.

Wetland System

The existing wetland system will remain unaltered in regards to the introduction and flow within the system of treated effluent. Three individual wetland cells are dosed via header discharge piping. Flow through the wetlands will be to the south and then withdrawn by low volume low head pumps which will deliver water to the rapid infiltration system via a header pipe with laterals as shown in Figure 5.

This cypress dome wetland had been ditched by ranchers for the purpose of draining the swamp in order to provide cover for grazing cattle. Prolonged drought and these draining features had dried up the swamp to the point where the canopy of cypress, swamp tupelo and sweet bay was severely distressed, leading to the invasion of many upland species (i.e., wax myrtle, fetterbush, and sparkleberry).

The introduction of treated wastewater in April, 1982, has recreated a deep water swamp suitable for aquatic animals such as the American alligator and otter and wading birds, which are now nesting and feeding within the wetland. The tree canopy has experienced negligible impact with a 1.4 percent mortality rate which translates to an average life expectancy of seventy years for canopy species. Ground cover and sub-canopy changes have occurred with the return of standing water. Some ferns and shrubs have been replaced by littoral aquatics such as maidencane cattail, pickerweed, arrowhead, duckweed, and various sedges.

The establishment of emergent aquatic plants has improved the value of the wetland due to a much higher uptake of nutrients. An increase in evapotranspiration potential has been enhanced in addition to the increased absorption of nutrients by ferns and woody plants. This results in better water quality passing through the systems (Lotspeich, 1986).

The wetland system is divided into three separate cells for the purpose of rotational fluctuation of water levels within each wetland compartment. On 3-5 year intervals each compartment will be "dried-out" to simulate natural fluctuations for propagation and germination of wetland species. To encourage the well being of the wetland it is necessary to allow for soil aeration and biological oxidation at the tree base root zone. These single season "dry out" periods will not jeopardize the established flora and fauna.

Hyacinth Ponds

Two existing holding ponds at the project are to be converted to hyacinth ponds to enhance evapotranspiration and provide tertiary treatment for nitrogen and phosphorus removal. By the use of 20 acres of hyacinth ponds, Amasek, Inc. projects the effluent quality leaving the ponds will be 1.2-2.5 mg/l of Total Nitrogen (TN) and 0.20-0.50 mg/l Total Phosphorus (TP) based on a design input of 15 mg/l TN and 2.0 mg/l TP. Projections based on past data estimate evapotranspiration will remove 0.25 MGD. This assumes a mean daily harvest of 29 wet

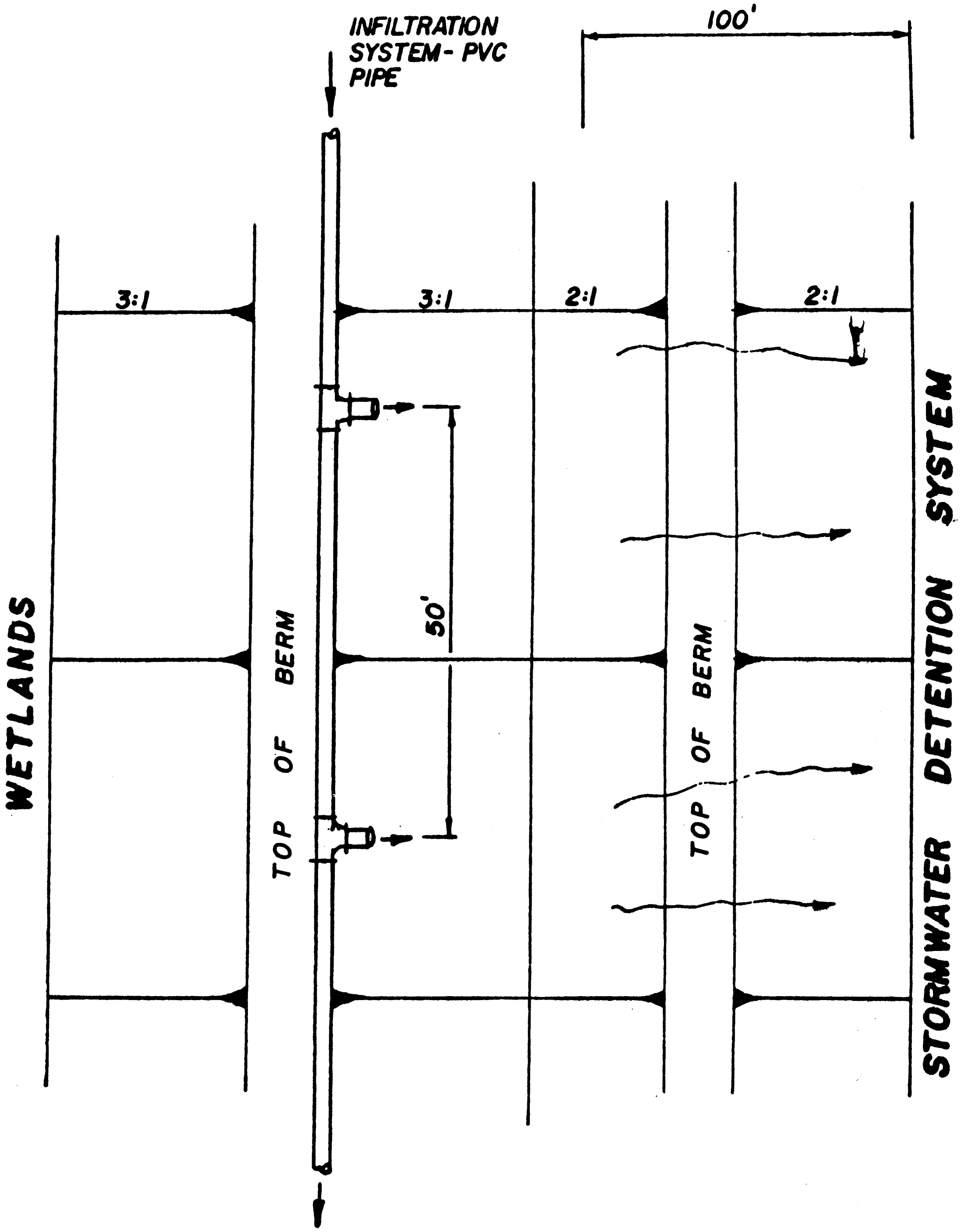


FIGURE 5_ INFILTRATION SYSTEM DETAIL

tons of hyacinths.

The ponds will need to be modified to include concrete harvesting ramps for each 3-4 acres. A 4" PVC manifold pipe will be installed to transport the hyacinth slurry to a composting area. Approximately 0.6 acre will be required for hyacinth composting. Adjustable weirs will need to be constructed to vary water depth from 2-4.5 feet (Stewart, 1986).

DISCUSSION

Nutrient removal analysis is based on concentrations of 15 mg/l and 2 mg/l for total nitrogen and total phosphorus respectively. To obtain such a low value for phosphorus an aluminum sulphate treatment will be introduced in the treatment plant. Further reduction of nutrient concentrations will take place in the hyacinth ponds to lower concentrations to 1.5 mg/l TN and less than 0.5 mg/l TP. The ultimate concentrations are projected to be 1.25 mg/l TN and 0.2 mg/l TP after passing through the wetlands and the rapid infiltration system. The flow schematic in Figure 6 depicts reduction of nutrient concentrations.

Similar effluent disposal systems in central Florida were evaluated for comparison to the proposed project. In terms of nutrient concentrations, none were able to obtain the low levels anticipated by this project.

LITERATURE CITED

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