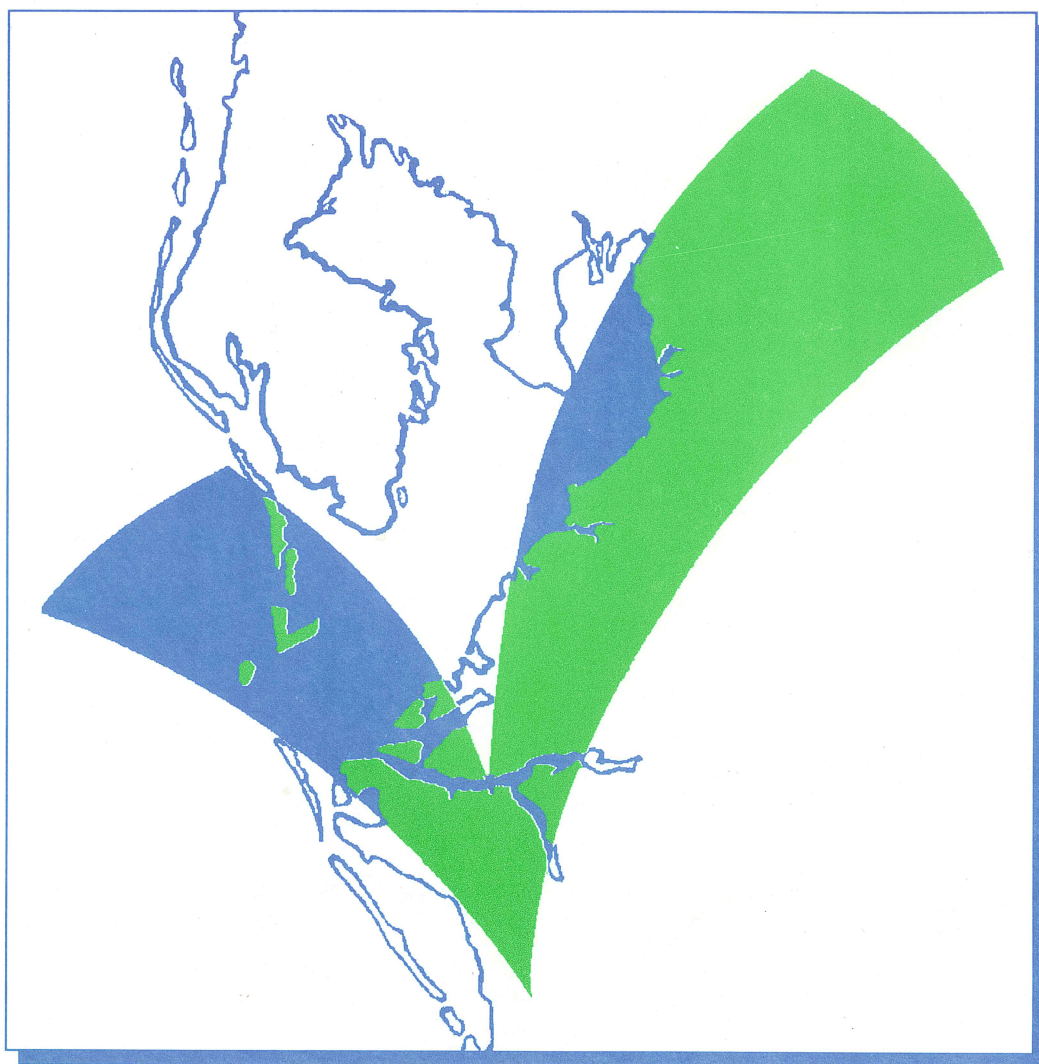

Tampa B·A·S·I·S 3

BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM

APPLYING OUR KNOWLEDGE



Tampa Bay National Estuary Program
Tampa Bay Regional Planning Council
Agency on Bay Management

PROCEEDINGS
TAMPA BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM 3
Applying Our Knowledge

Sally F. Treat
Editor



TAMPA BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM 3

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SENSITIVE COASTAL RESOURCE MANAGEMENT: THE TAMPA AREA CONTINGENCY PLAN

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Henry Norris
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ABSTRACT

The promulgation of the Oil Pollution Act of 1990 (OPA 90) inspired the upgrading of Tampa Bay's contingency plan for oil and hazardous material spills, bringing together federal, state, regional and local efforts to focus on a single, concise and easy-to-use information system. An aspect crucial to the success of the Area Contingency Plan (ACP) is the mapping of the sensitive coastal resources at risk during the occurrence of a spill. Displaying accurate and understandable information with a consistent format on maps of the U.S. Coast Guard Marine Safety Office Tampa's Area of Responsibility was a large part of this effort. Compiling the database and accurately depicting it on the maps in both electronic and hard copy versions for distribution and rapidly-deployable use during a spill was an early goal. In an attempt to avoid duplication of effort, federal, state, local and private input was solicited. A wealth of data was derived from this cooperative effort which continues with each revision of the ACP. Oil-sensitive shoreline habitats, endangered species, animal use areas, public resources, facilities and other spill-sensitive entities are represented. Compilation of this data into a functional database promotes more realistic strategy formulation and prioritized protection planning. Representation of specific responsible trustees of public and private preserves, parks, shorelines and facilities enables spill responders to more rapidly contact appropriate parties to mitigate possible damages during the imminent disaster of a spill event. Mapping of the sensitive areas must be complete yet uncomplicated. Regular revisions must be performed since neither nature nor people are static. Each ensuing edition of the ACP reinforces the need for the flexibility and ease of revision that the computerized version offers. Hard copy may be printed as needed with the most recent information from the computerized version and concentrating on the specific areas threatened by a spill. In areas where the computer version or technology is not immediately available it is vital to have available a copy of the most recently published hard copy of the ACP.

The Tampa Bay Area Contingency Plan (ACP) in its present format is a product designed by events of the past for events that may occur in the future. Major events such as the *Exxon Valdez* and *American Trader* spills prompted the promulgation of the Oil Pollution Act of 1990 (OPA90). The timeliness of the legislation was beneficial for the Tampa Bay area because it enabled an efficient and successful response to the August 10, 1993, three-vessel collision which resulted in the fire and oil spill at the mouth of Tampa Bay. The U.S. Coast Guard (USCG) Marine Safety Office (MSO) Tampa's ACP was completed prior to and given a true "road test" during the ensuing response and cleanup. There are many aspects to the ACP which were crucial to the success of the response, such as the initial tiered response, command control, public affairs, finance, logistics and claims. The prioritization and identification of the resources at risk are an integral part of all the other aspects of the plan. Four goals suggested by the National Oceanic and Atmospheric Administration (NOAA) were: 1) appropriate, clearly defined information on sensitive resources; 2) organization and representation of information in a consistent format; 3) clear relevance to other planning components; and 4) broad availability to planning entities in electronic and hard copy forms (Pavia, Michel, Petersen and Birk-Rishcim 1995). Sensitivity mapping for the ACP was well underway and on course when these goals were first considered. Public and natural resources and habitats which may be

sensitive to hazardous materials as well as those species endangered or otherwise which may lie in the path of an approaching spill must be protected in a manner which assesses their individual sensitivities and prioritizes the order of response. Receiving the highest level of protection were: endangered species; tidal habitats; breeding, spawning, nesting, foraging and migratory resting areas; drinking water intakes; protection of public health, and public nature parks and preserves. Those areas with the highest priority received the first protection efforts, those with a medium priority, second and so forth.

By utilizing the ACP, 80% of the guesswork is removed when addressing a crisis situation. Available to responders in the ACP are case scenarios and strategies as well as a vast database including inventories of personnel and equipment locations with contact persons and phone numbers. Since the priority protection criteria dictate the order of response, each priority area is depicted on the ACP Sensitive Area Maps. Although there may be several priority areas on a single map, each area has its own data sheet in the hard copy version of the ACP. These data sheets are a brief focus on important information necessary in the early moments of a response including: the name of the priority area; trustees and managers of management areas, parks, preserves and facilities; lists of shoreline habitats, wildlife, resources, and endangered species to be protected; a specific protection strategy for the area; collection points; access areas; directions, and available nearby equipment resources. These hard copy maps and data sheets are designed in a format that allow transmission via facsimile with good reproducibility. This is important in getting the necessary information to responders, responsible parties and others in remote areas that may be able to reach the threatened area prior to any other response.

The electronic format or computerized version of the ACP (all at-risk resources data) has been included in the Florida Department of Environmental Protection (FDEP) Florida Marine Research Institute's (FMRI) Marine Spill Analysis System (MSAS) as well as the NOAA Environmental Sensitivity Index. This not only enables the ACP data from the hard copy to be queried by specific incident needs but also tremendously increases the database of natural resources represented. The Scientific Support Subcommittee of the ACP has solicited data input from federal, state, regional, local and private sources. The U.S. Fish and Wildlife Service, National Marine Fisheries Service, Florida Game and Fresh Water Fish Commission, FDEP, Florida Park Service, Rookery Bay Research Reserve, Lee County Natural Resources Management, Hillsborough County Environmental Protection Commission, as well as the National Audubon Society have all supplied substantial wildlife and habitat data. The MSAS Geographic Information System allows spatially referenced data to be looked at in layers keeping the queried view as simple as possible. For example, if it is determined that there are no turtle nesting areas in a beach staging area due to the season, it is possible to delete the turtle symbols and show only the staging symbols at the appropriate locations. This can simplify things for out-of-state responders who are wondering how to drive their dump trucks through the turtle nesting areas. The hard copy map would illustrate both the turtle and staging area symbols, requiring the responder to check the nesting season which is contained both on the specific data sheets and on a single-paged nesting season chart for at-risk bird and turtle species. The computerized version of the ACP has additional advantages

including its ability to be updated as soon as data is submitted. A CD-ROM version of the ACP, produced by FMRI, has the advantages of the MSAS version including some additional resource coverage (beyond the hard copy) but like the hard copy has the drawback of being dated at the time of production.

The initial printing of the ACP covered the west coast of Florida only from the Anclote River to Fort Myers. The MSO Tampa's Area of Responsibility extends from Taylor County's Fenholloway River to Collier County's Cape Romano. New maps for all of the areas not covered previously have been created and are available in the MSAS version of the ACP. The data represented on these maps has been brought up to the standards of the previously existing maps. Conversion of these new maps to the format of the hard copy is being addressed by the USCG at this time. In addition, this upcoming revision will incorporate alignment with the Incident Command System allowing the ACP to parallel the response command structure, thus expediting and simplifying efforts when utilizing the ACP in the event of an actual spill. By December 31, 1996, the Hazardous Materials (HAZMAT) and Firefighting Annex will be added to the ACP as a stand-alone plan.

Since its inception, the ACP has been extensively utilized for numerous spills and exercises. The dynamic nature of Tampa Bay and the surrounding region demands that the ACP be equally dynamic. The plan continues to change as new and more effective response tools are developed. In 1995, FDEP and the Marine Spill Response Corporation sponsored research by Research Planning, Inc. to provide strategies for tidal inlet protection for oil spills (Hayes and Montello 1995). This information is included in the ACP hard copy as a reference volume and will be added to the MSAS when funded. Specific groundtruthed strategies have been developed for all Gulf tidal inlets from Hurricane Pass to Morgan Bay. With new hazardous materials (e.g., Orimulsion) being proposed for shipping through our waters, new technologies and evolving response strategies must be incorporated into the ACP as situations warrant. In addition, research for tidal inlet protection strategies is being proposed for those inlets within Tampa Bay.

When a spill actually occurs, the USCG's Spill, Planning, Exercise and Response System (SPEARS) goes into action. This is the first of four computer-based tools which are brought into play. SPEARS identifies facilities, potential incidents and response resources. The FDEP/FMRI's MSAS is utilized to identify resources at risk as the event unfolds. NOAA's On-Scene Spill Model provides oil spill trajectories utilizing real-time data from the University of South Florida's Physical Oceanographic Real-Time System (PORTS) as well as over-flight observations. All of this technology enables spill response managers to focus on the highest priority efforts to be initiated.

In conclusion, the protection of our sensitive coastal resources is in a state of continuing improvement resulting in part from the new additions to the ACP including the new ICS format, the HAZMAT/Fire Fighting Annex and the Tidal Inlet Protection Strategy, as well as development of response strategies for new and hazardous materials. Funding continues to be the biggest obstacle in some areas of the continued improvement. PORTS still needs a permanent source of funding. Funding also is a limiting factor in the upgrading of the hard copy ACP (addition of the new

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area maps), the addition of the tidal protection strategies to the MSAS and the development of a vessel information trafficking system for Tampa Bay (enabling pilots to be cognizant of all shipping traffic in all weather conditions). The final word and most successful measure of protection for the sensitive coastal resources must be to continue to prepare, exercise, and execute *prevention*.

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ADDRESSES: (EML) Environmental Protection Commission of Hillsborough County, 1900 9th Ave., Tampa, FL 33605; (HN) Florida Dept. of Environmental Protection, Marine Research Institute, 100 8th Ave. SE, St. Petersburg, FL 33701; (DM, WW) U.S. Coast Guard Marine Safety Office, 155 Columbia Dr., Tampa, FL 33606.

AFTER THE SPILL: LESSONS LEARNED

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ABSTRACT

On August 10, 1993, at 5:48 AM on a clear and calm morning, three vessels collided at the entrance to Tampa Bay. The collision caused an explosion and fire on board the Maritrans *Ocean 255* and the loss of 32,000 gallons of Jet-A fuel. The Bouchard barge *B155* sustained a major rupture and loss of 330,000 gallons of #6 fuel. The *Balsa 37* sustained major hull damage and was grounded to keep it from sinking. Maritrans and Bouchard Transportation assumed financial responsibility and activated their oil spill response cleanup contractors. Protective booms and removal equipment were rapidly deployed to the spill site.

The U.S. Coast Guard activated the Gulf Strike Team and the Regional Response Team, and established the Unified Command Center. The Florida Department of Environmental Protection activated the State Spill Contingency Plan and support personnel began arriving immediately. State response personnel joined the USCG in the Command Center where the Incident Command System was implemented. Although the OPA 90 response requirements did not become effective until August 18, all response activities were conducted under OPA's requirements. Response activities continued for months.

Subsequent to the response, State and Federal After Action Reports were produced with input from all response groups. Lessons learned included statutory changes, organizational changes, further coordination with USCG and NOAA, expansion of Florida Marine Spill Analysis System, preboom identification, expansion of FGFWFC role, expansion of the Area Contingency Plan, and further planning for wildlife impacts. This experience and the lessons learned have directed the work of response agencies for the last three years. Many of the recommended actions have been accomplished.

BACKGROUND

The Incident

On Tuesday, August 10, 1993, at 5:48 AM, just before daybreak and in calm waters, three vessels collided at the entrance to the channel leading to Tampa Bay, 1½ miles west of the Sunshine Skyway bridge. The collision cut off vessel traffic along the 600'-wide channel between the Gulf of Mexico and Tampa Bay's main ports, leaving ships anchored at sea and in the ports. The accident resulted in an oil slick 17 miles long extending from the mouth of Tampa Bay into the Gulf of Mexico.

The vessels involved in the collision were the freighter *Balsa 37*, carrying phosphate fertilizer and phosphate rock; the Maritrans barge *Ocean 255* transporting gasoline, diesel and Jet-A fuel totaling approximately 7.9 million gallons; and the Bouchard *B155* barge with 5.2 million gallons of #6 fuel oil bound for Florida Power & Light's terminal at Port Manatee. No one aboard the vessels was seriously injured.

Operational Response

Maritrans and Bouchard Transportation assumed financial responsibility for the spill and immediately activated their respective oil spill response cleanup contractors. Protective booms and removal equipment were rapidly deployed to the spill site. Sensitive areas requiring protection were identified and booms staged for deployment.

The U.S. Coast Guard activated the Gulf Strike Team, the Regional Response Team and established the Unified Command Center. They also implemented the Incident Command System and controlled the conduct of the oil spill response operations through establishing lines of communication, sharing of information, and promoting concurrence in the state and federal governments' directives to the responsible parties.

In accordance with the provisions of the *Florida Coastal Pollutant Spill Contingency Plan*, the State Response Team was activated and members were placed on telephone standby. Department of Environmental Protection (DEP) support personnel from around the state were notified and began arriving in Tampa on the day of the spill. Over 100 state employees were involved in the state's response and approximately \$500,000 was expended in this coordinated operation.

Natural resource habitat impacted by the spill included:

- approximately 13.12 miles of sandy beaches extending from Passe-a-Grille to North Redington Beach;
- 5.53 acres of moderately to heavily oiled mangroves and 9.2 acres of lightly oiled mangroves;
- 0.85 acre of salt marsh;
- 0.22 acre of oyster beds and an additional 20 miles of seawall encrusted with oysters and other associated organisms;
- 1.34 acres sandy bottom;
- 2.54 acres of moderately to heavily oiled seagrass and 255 acres of exposed seagrass;
- 300 square miles of gulf water and 27 square miles of bay waters.

Early into the spill response the responsible parties contracted with wildlife rehabilitators to provide emergency care and treatment facilities for the oil damaged wildlife. Rehabilitators treated and cared for 366 birds at the triage centers.

The spill occurred during the turtle nesting season and posed a hazard to turtles in all life stages of development. There were 96 turtle nests on the beaches where oil washed ashore. Two of these nests were oiled, and an additional unmarked nest was run over by response equipment. 212 loggerhead hatchlings were killed and 2,177 loggerhead hatchlings were potentially impacted. One juvenile green sea turtle was oiled and rehabilitated.

Cleanup and removal of the oil from the sandy beaches was completed prior to Labor Day. However, crews continue to monitor the beaches for oil contamination and initiate removal action as required. Re-oiling events continued to occur for two years. Cleanup activities continued in the back bay areas until Christmas 1993. Further cleanup and emergency restoration was initiated in 1996 for the oyster beds on Elnor Island in John's Pass.

State and federal trustees are working jointly to fully assess the damages to natural resources resulting from this incident. Funds recovered by the trustees from the responsible parties will be used to restore the natural resources impacted by this spill.

LESSONS LEARNED

The response tested a myriad of state and federal regulations developed subsequent to the *Exxon Valdez* spill of 1989. In the months after the cleanup, response activities were critiqued. The lessons learned focused attention on nine major areas of importance. These were formalized in the *State of Florida, Tampa Bay Oil Spill After-Action Report* and published for public review in December of 1993. Issues identified have helped to focus the development and funding of projects since that time. Most of the recommended corrective actions have been implemented, which will further enhance the state's operational response capabilities.

The response to this pollution incident was greatly facilitated by the Tampa Bay location. The state has a number of human and physical assets in the Tampa area that were quickly put to use in the response. Specifically, the proximity of the Florida Marine Research Institute (FMRI) with its extensive scientific support capability and Geographic Information System (GIS) were invaluable. Being able to take a helicopter flight, and use the Global Positioning System (GPS) to track the spill and download the data at the FMRI to produce a GIS chart in less than two hours, significantly enhanced the response effort. Similarly, the immediate availability of environmental specialists from DEP's regional offices allowed early and rapid resolution of potentially critical problems.

Many of the state's lessons learned and recommended actions focus on providing the capability for this level of response statewide. The establishment of Regional State Response Teams comprised of local technical and administrative support personnel, expected to be on site during an actual response, is proposed to take the place of the existing Tallahassee-based State Response Team. The establishment of these teams would not require additional positions. Existing personnel would be identified as team members and diverted from their regular jobs during an emergency response.

Spill Prevention

Lesson: Oil spills cause extensive damage to the environment and are expensive to clean up. Additional state resources should be dedicated to preventing spills. Although Chapter 376, F.S., gives the Department of Environmental Protection general authority to regulate prevention measures, the only specific programs that deal with prevention are those that regulate tanks and delivery systems.

Recommendation: The Department should identify and prioritize prevention measures, request statutory change, and seek appropriations to allow implementation. Identifying the most effective prevention measures would require analyzing statistical oil spill data to determine the most prevalent causes of oil spills. Oil spill records have been kept manually for over 20 years. A computer program has recently been developed to allow for records to be maintained electronically and to conduct trend analyses. However, financial support is needed to input historical data, while existing staff inputs new data as generated. The department should encourage the USCG to do the same for those areas where they have statutory authority.

Response: Because of the reduction of regulatory burden rule, no subsequent legislation has been passed. Previous rules and statutes have been modified to reflect

the merging of Department of Natural Resources with the former Department of Environmental Regulation (now DEP) and to reduce redundancy. In the last three years ongoing spill incidents have been tracked. Historical data is being input as time and resources allow.

Communications

Lesson: As has been the case in all exercises and drills to date, communication among individuals involved in the emergency response was a problem. As a result of exercises and drills, response personnel have been equipped with modern communications equipment. Assets used for communications are adequate. Current communication difficulties can be relieved through education and protocol revision. The primary cause of communication problems, in this response, is attributed to the tremendous amount of work being required from a few team members. These individuals are making many important decisions in a short time under prolonged duress and without administrative support.

Recommendation: Current State Response Team members are primarily located in Tallahassee, and with few exceptions would not be expected to travel to the scene of an emergency. The proposed corrective action is to establish Regional State Response Teams, composed of support personnel that are expected to be on site during an actual emergency and to assume specific identified tasks. DEP had begun the implementation of this concept for the assessment of damages to natural resources from pollutant discharges. This regionalized team concept approach needs to be expanded to include emergency response.

Response: DEP has formulated a directive to formally establish a Regional State Response Team. The Bureau of Emergency Response, with the assistance of Division Directors and District Managers, has identified the team members and cooperatively developed and implemented applicable operational policies and contingency plans. Team members can respond on scene or via telephone to help deal with issues that arise and which are in the team member's field of expertise.

Media

Lesson: The Unified Command Center established a joint media center shortly after the incident. This center was not fully utilized by the state. State media releases were not coordinated or consistent, and staffing occurred only during press conferences as an extra duty assigned to the response personnel. This resulted in the false impression that the USCG alone was directing all response activities.

Recommendation: The proposed corrective action is to include a press or public information officer as part of each regional team.

Response: DEP has requested the Office of Communications to provide a press or public information officer to assist the state on-scene coordinator during a major spill event.

Administrative Support

Lesson: The state's on-scene coordinator had no clerical or administrative support during the response. Such support is necessary during an emergency to record information, facilitate communications, receive and return messages, schedule meetings, and staff the media center.

Recommendation: The Regional State Response Team will have assigned personnel providing support to the state's on-scene coordinator.

Response: The Bureau of Emergency Response, with the assistance of division directors, will identify Regional State Response Team members. The members have been trained to meet the specific team response requirements.

Employee Identification

Lesson: State personnel on site were not easily identifiable. This was particularly troublesome as time went on and personnel were rotated in and out of the response team.

Response: The Department has procured windbreaker jackets and shirts which identify DEP emergency response personnel, to wear on-scene and in the command center.

Florida Marine Spill Analysis System

Lesson: The Florida Marine Spill Analysis System (FMSAS) and other geographic information system technology including the Global Positioning System (GPS) were used successfully to characterize changing spill conditions, identify resources at risk, prioritize protection measures, plan daily activities and brief the press. The FMSAS and related GIS data are maintained at the Florida Marine Research Institute (FMRI) in St. Petersburg; consequently, the proximity to the spill increased their utilization. Further resource data is unavailable or outdated for some areas.

Recommendation: Some of the critical GIS data used by responders in Tampa Bay is not available or outdated for other parts of the state. The state should expedite efforts to collect, update and input data to the FMSAS, starting with areas at greatest risk for a spill. The GIS databases of biological resources will incorporate biological data collected by the Florida Game and Fresh Water Fish Commission (FGFWFC) and Florida Natural Areas Inventory (FNAI) into FMSAS, both periodically and instantaneously, at the time of a spill. Furthermore, hardware should be purchased to allow for the mobilization of FMSAS and supporting data to spill sites outside of the Tampa/St. Petersburg area.

Response: At the time of the 1993 spill, FMRI had been working on a prototype of the FMSAS. Most of the data had been entered for the Florida Keys area, which had been identified as the area most at risk for a large spill. When the spill occurred in Tampa Bay, they incorporated the data available on the region and produced excellent maps of the spill. In the last three years the FMSAS has been expanded to include the whole state of Florida and has incorporated the FGFWFC and FNAI data. The system has also been redesigned so that each Emergency Response office has a

laptop computer equipped with ArcView 2 software containing all the resource data for each region. For larger spills, the FMSAS mainframe in St. Petersburg is now mobile. Both of these systems are available for immediate use and have been used in major spill response exercises.

The Environmental Sensitivity Atlas of Florida had been produced in 1984. In 1995, DEP contracted to have these maps updated. They were completed in May 1996 in both paper copy and disc format and have been included within the FMSAS database.

Scientific Support

Lesson: During the Tampa Bay spill, the environmental specialist, whose primary job was the coordination of the damage assessment, had to assume the additional role of scientific support coordinator. In a large scale response, this is too much work for one person.

Recommendation: The team concept approach to spill response will have someone on the team pre-designated as the scientific support coordinator and natural resource damage assessment coordinator.

Response: The Bureau of Emergency Response has identified Scientific Support Coordinators (SSC) and Natural Resource Damage Assessment Coordinators (NRDA) and has begun training them for these roles on the team. The SSCs will coordinate the activities of the response team members, identify resources at risk, evaluate new technologies, evaluate selected shoreline cleanup techniques, and ensure that emergency response techniques do not cause additional damage to the environment. The NRDA Coordinators will implement the NRDA protocols, coordinate with other state and federal NRDA trustees, coordinate the activities of the NRDA team members, identify resources at risk and document impacts, coordinate contracts for NRDA activities, and ensure that wildlife impacts are being documented.

A state manual for conducting the preliminary phase of an oil spill damage assessment was completed in April 1994. As the NRDA process has unfolded in the Tampa Bay case, updates and additions have been proposed. When the Tampa NRDA process is completed, the entire document will be updated.

Game and Fresh Water Fish Commission

Lesson: The role of FGFWFC as identified in the state response plan is to assess damages to wildlife populations and coordinate wildlife rehabilitation. FGFWFC staff were very eager to identify resources at risk and were distressed at not being relied upon to do so.

Recommendation: Expand the role of FGFWFC staff during an emergency response to include assisting in the identification and prioritization of resources at risk.

Response: DEP and FGFWFC have worked together to develop an ongoing mechanism to incorporate data collected by FGFWFC into the FMSAS. FGFWFC wildlife biologists have been identified as members of the Regional State Response Team.

In response to their own lessons learned, the Game and Fish Commission has employed a Hazardous Spill Coordinator who has been working with the USCG in incorporating wildlife data available through their offices.

In the Tampa Bay spill, problems arose with wildlife rehabilitators and a lack of volunteers. Section 39-9.006 of the Florida Administrative Code now states that "wildlife may be transferred or relocated to other licensed rehabilitation facilities at the discretion of the commission to facilitate alternative treatments and optimum care" and goes on to say that "under certain emergency conditions, such as oil spills... the commission may impose additional restrictions or provide for permit exemptions as may be necessary to safeguard affected wildlife such as, but not limited to, the coordination and direction of rehabilitation permittees and their facilities, the assignment of zones for implementing rehabilitative services, and the authorization for additional volunteers to aid in the capture and treatment of wildlife." These recent changes should result in Wildlife Officers having more latitude in working with wildlife rehabilitators and recruiting additional volunteers, especially during emergency situations such as oil spills.

Wildlife Rehabilitation

Lesson: The wildlife rehabilitation response in the Tampa Bay spill went smoothly because of the extensive pre-planning and training done by the Pinellas Seabird Rehabilitation Center (PSRC). Pre-training and preplanning are essential to a successful response effort.

Recommendation: DEP and the FGFWFC need to continue to support volunteer groups throughout the state to maintain their expertise.

Response: Started in 1990 as a nonprofit rehabilitation center, PSRC was asked to participate with the USCG in the Area Contingency Plan planning process. Concerned by the lack of trained personnel, PSRC trained hundreds of volunteers who were the backbone of the response team that served during the Tampa Bay spill. Maintaining a high level of commitment and expertise is essential. PSRC has continued to work with government officials, corporate officials and response personnel to increase response capabilities within Tampa Bay and the state.

Lesson: Record keeping and bird banding are essential to documenting the success (or failure) of the response.

Recommendation: During the NRDA process the apparent success of the Tampa Bay wildlife rehabilitation effort has been called into question.

Response: Wildlife rehabilitation in other areas has had varied success; in some areas it has been questioned as to whether rehabilitation is economically viable. During the Tampa Bay spill only 100 of the 261 released brown pelicans (*Pelecanus occidentalis*) were banded. Of these, only one band has been returned from a deceased bird whose injuries could have been linked to the spill. Four other banded birds have been returned to rehabilitation for reasons unrelated to the oil spill, such as fishing line and fishing hook injuries. When compared with rehabilitation efforts in other areas this

is amazingly successful. Banding of all birds prior to release needs to be standard operating procedure.

State and Federal Issues

Lesson: The location selected for the Unified Command Center was too small to accommodate necessary meetings and personnel.

Recommendation: Appropriate space for the command center should be selected and if necessary, it should be relocated as the event escalates. Specific sites should be pre-identified in high risk areas.

Response: The USCG Area Contingency Plan (ACP) identifies facilities that could house the Unified Command Center. The last major spill drill was held at the Hillsborough County Emergency Operations Center. The location was convenient and all of the communications systems were already available. However, it would not have been very close to a coastal spill. The need and logistical requirements for a forward command center have been addressed in the ACP.

Lesson: The NOAA trajectory model failed to predict oil coming ashore. Reliable trajectory modeling is essential to direct response efforts. Although it is difficult to keep oil out of inlets, the sensitive areas within inlets can be protectively boomed.

Recommendation: The state should work with NOAA and others to improve modeling capabilities for Florida waters.

Response: The Bureau of Emergency Response and FMRI have worked with NOAA, Florida State University and University of Florida to more reliably model the movement of oil in Florida waters, which would help direct response efforts. Furthermore, because inlet protection was a serious problem during the Tampa Bay spill, in April 1995, DEP and the Marine Spill Response Corporation jointly funded a study to assess passes in Florida. In USCG District 4, this includes 37 passes from northern Pinellas County to Marco Island. The study has completed three-quarters of the state and the booming strategy developed has been incorporated into the ACP for this USCG region.

Lesson: NOAA strongly objected to the use of dispersants on the offshore slick. State experts favored a trial run to determine effectiveness. No trial run was performed and the slick was not dispersed. Successful dispersion offshore would have minimized shoreline impacts when the wind changed.

Recommendation: The draft *Dispersant Usage Plan* should be finalized and adopted.

Response: The dispersant use plan is expected to be signed in December 1996, at the Regional Response Team Meeting. Effective April 20, 1995, the state and the USCG have a letter of agreement with sets forth the areas and facts under which pre-authorization of *in situ* burning is allowed. Areas are designated as preauthorized, as available for consideration on a case-by-case basis, or as areas where *in situ* burning would be excluded.

CONCLUSION

The only good that can be derived from the Tampa Bay oil spill is that we have taken the lessons learned and moved forward with them. If we have another spill we will be better prepared to cope with the situation. Over the last three years, DEP, FGFWFC and PSRC have worked very hard to enhance preparation for the next spill event. Hopefully, we will never be faced with actuality.

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NATURAL RESOURCE DAMAGE ASSESSMENT— TAMPA BAY OIL SPILL, AUGUST 1993

G.E. Henderson

ABSTRACT

Following the August 10, 1993 Tampa Bay oil spill the Florida Department of Environmental Protection, the U.S. Department of Commerce, National Oceanic and Atmospheric Administration and the U.S. Department of Interior (the Trustees) initiated a natural resources damage assessment (NRDA). The damage assessment process is used to determine the extent of direct injuries to natural resources as a result of a spill and the interim losses to ecological services during the period of resource recovery. The MMA process also considers the loss to human uses of these natural resources. These injuries and losses are then evaluated to determine the most cost effective restoration or appropriate compensation. Both state and federal regulations exist which, in general, prescribe how a damage assessment should be conducted. At the time of this spill final rules on exact conduct of an NRDA were not promulgated. This allowed the state and federal trustee agencies to use a flexible approach incorporating the most appropriate characteristics of various damage assessment formulas, models, cost methodologies, and scientific data collections to design an expedited process directed toward maximizing ecosystem benefits. The Trustees also determined that the technical process would be open to the parties responsible for the spill from the beginning and be as cooperative as feasible under existing laws. The NRDA is an attempt to plan and implement actions necessary to restore injured resources and their services. It is not a punitive procedure. The principle laws governing the NRDA are Section 1006 of the federal Ocean Pollution Act, 33USC2706 (OPA), and the Florida Pollutant Discharge and Control Act, FS 376.011 through 376.21 (1992).

The Trustees identified 13 injury categories, identified associated injuries and, for most, corresponding damages. The categories are: mangroves, seagrasses, water column, birds, sea turtles, salt marshes, shellfish beds (ecological), bottom sediments, beach physical injury, lost use of shoreline for recreation, lost use of surface water for recreation, shellfish beds (lost use for recreation) and surface water—lost use for navigation. A Damage Assessment and Restoration Plan for the natural resource damages (first 9 categories) has been prepared and distributed for public comment. A revised NRDA and National Environmental Policy Act (NEPA) Environmental Assessment is in preparation. The human use losses (last 4 categories) are still being assessed.

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MATHEMATICAL MODELING IN MARINE RESOURCE PROTECTION

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ABSTRACT

The practical application of mathematical models has a long history in which they have been used for predicting the fate and distribution of a wide variety of contaminants introduced into the environment. The efficient application of these models demands that the investigator understand the uncertainty introduced by the random nature of certain processes, particularly those mediated by biological action or turbulence phenomena. Further uncertainty can arise from incomplete or "fuzzy" information needed for algorithm formulation or for specifying initial and boundary conditions.

Model selection for a given scenario should be based upon the type of problem to be addressed, constraints imposed on the modelers, the ability of the model to accurately simulate relevant processes, and the acceptability of the uncertainties that accumulate in the modeling process. It is essential that experienced modelers trained in marine and atmospheric sciences apply their expertise to the interpretation of any model results to be used in decision making.

Properly selected and operated, models used for evaluation and guidance in pollutant fate predictions are valuable tools. In this paper, strategies for selecting and using mathematical models for resource management and environmental protection planning are discussed. The selection process is based on consideration of resource protection, identification of sensitive areas, and projection of probabilities for expected impacts under various geophysical conditions and pollutant loadings. The goal of this process is to support a "minimum regret" strategy rather than a "maximum win" strategy.

INTRODUCTION

Resource protection decisions associated with the discharge or spill of pollutants into marine waters demand accurate and efficient methods for evaluating and predicting the fate and distribution of the pollutants within those waters. The history of a pollutant distribution resulting from a discharge or spill into a dynamic water body is a complex function of existing and antecedent oceanography, meteorology and climatology, and the interacting chemistry and biology of the water, atmosphere and surrounding sediments. The predetermination of such a history for some future event requires accurate and efficient methods for estimating the environmental phenomena and material transformations that will control the pollutant distribution.

To accomplish this predetermination or "prediction," the physics, chemistry and biology of the event can be represented by mathematical constructions that in turn can be evaluated with high speed computing machines. These constructions are collectively called mathematical models.

For a mathematical model of an environmental system to be of value it must in some way reproduce phenomena associated with the modeled system. The nature and complexity of the model are determined by the characteristics of the phenomena being investigated and by the detail of "predicted" information required by the investigator. Three general characteristics define the essential nature of an

environmental model: the time scale of the problem, the geophysical dynamics of the system, and the kinetic reaction rates of the substances being modeled.

MODELING OVERVIEW

Constituent Mass Balance Models

Fundamental to the modeling of a pollutant introduced into a marine water is the concept of constituent mass balance. This balance embodies a relationship among the material change of the pollutant, the diffusive flux, and any local sources and sinks including any physical or chemical degradation of the pollutant.

For dissolved fractions, this relationship involves the behavior within the water body as a whole. For undissolved liquid fractions, as with spilled oil, this relationship exists within the pollutant mass itself. The dynamics of the water body will affect the movement of an undissolved pollutant mass and may aid in the separating of a single discrete mass into several smaller discrete masses or vice versa. It should be noted that the distribution histories of a dissolved fraction and an undissolved fraction introduced into a water body at the same point in space and time may be very different from each other.

There are numerous physical and chemical transformations which can alter the nature of a pollutant in a marine environment. These typically include:

- dissolution;
- biological and chemical degradation;
- evaporation;
- photolysis;
- adsorption to suspended particulates or the bottom;
- coalescence;
- emulsification;
- settling and flotation;
- entrainment; and
- biological uptake.

Hydrodynamics Models

The movement of a pollutant due to the dynamic character of a water body is a primary factor determining its distribution history. The movement characteristics of a marine water body can be represented by the mathematical equations describing the system's hydrodynamics. These equations are derived from consideration of conservation of mass and energy and of Newton's second law of motion in a rotating coordinate system.

Analytic solution of these equations is impossible. However, the nature of the system being modeled often allows simplifying assumptions regarding the relative significance of competing forces. Furthermore, the continuum equations can be evaluated by various numerical approximations which can then be solved with high speed computing machines.

For shallow tidal waters with low freshwater inflows, it is often assumed that the water is vertically well mixed and that density induced currents are negligible

compared with the tidal currents. These assumptions allow the governing equations to be vertically integrated resulting in a three-equation system that conserves both mass and momentum. This type of model is called a two-dimensional hydrodynamic model and is easily and quickly solvable for a variety of situations.

Two-dimensional models can provide accurate estimates of sea level variations and can give reasonable estimates of tidal excursions about a fixed point in the water body. The disadvantage of two-dimensional models is that they estimate the mass transport (the vertically averaged current) at a given time and place rather than the actual current velocity. Frequently, the results of these models are divided by the depth and presented as velocity. This is the vertical mean velocity and not the current velocity at a point.

To overcome the deficiencies due to the two-dimensional model's inability to describe vertical current structure, a vertical profile can be inferred from the mean two-dimensional velocity and a balance between the vertical eddy viscosity and the inertial flow. Conservation of mass requires the addition of a three-dimensional equation from which the vertical velocity can be determined. These eddy viscosity models are efficient and, when the eddy viscosity is considered to decrease near the surface, can produce an accurate description for the surface velocity.

Models that can describe the coupled hydrodynamics of shallow, non-steady, coastal waters require the solution of a complete set of equations that includes the conservation of turbulence energy as well as conservation of mass and momentum. These models are called turbulence closure models and yield a full description of the three-dimensional flow field. The disadvantage of these models is that they are computationally intensive, requiring computers with large memories and very fast computing speeds.

The prediction of constituent mass distribution for a pollutant is driven by the information provided by the selected hydrodynamics model. For a dissolved pollutant, this information is used directly in a constituent mass balance model that simultaneously evaluates the movement and transformations of the pollutant throughout the water body. Undissolved fractions are generally treated as an ensemble of Lagrangian parcels that travel a path or trajectory defined by the results of the flow model. In this model, each parcel is assumed to advect with the surrounding water body and to diffuse as the result of random processes. The chemical and physical transformations that occur within a parcel are then applied at each new location defined by the trajectory path and the model time step.

Biological Models

Biological modeling can be applied at the population level or at the ecological effects level. Biological populations can be viewed as time varying, piecewise continuous density functions of the spatial domain and population structural variables such as size, age, and measures of physical condition or genetic alteration. From this perspective a population model is essentially the same as that used for modeling of the dispersion of a pollutant. Consequently, the short-term issues are similar to those addressed in modeling the aquatic system. That is, the components interact locally

and must be coincident in space and time for there to be any interaction, whether it is foraging and predation, or exposure to an introduced substance. Also, these density functions are not constant with respect to time, typically having compact support, and vary in space, some solely due to advective transport and diffusion, others due to behavioral responses to sensed conditions in the local environment.

Mechanistic models for this type of system can be formulated using a series of mathematical equations. Each equation describes the time varying spatial distribution of a density function for a population in response to the marine physical environment (temperature, salinity, current velocity, light level) and to the co-occurrence of predator, prey, or competitor populations.

Ecological effects models seek ecological relevance, usually by incorporating innovations in matrix population modeling. These models usually operate on the level of an individual (e.g., survivorship, growth, and reproduction), but may be used to infer effects at the population level (e.g., the chance of population falling below certain thresholds). This is referred to as population viability analysis (PVA) in the conservation biology literature and includes the following attributes:

- Identification of key factors (separating natural variability from human impact);
- Determination of model structure to use;
- Estimation of parameters (field observations and laboratory studies);
- Statistical analysis of the data (power analysis, multivariate analysis, metanalysis);
- Modeling and risk analysis, combining the existing information into predictions about the persistence and resilience of the affected species;
- Implementation of management/conservation options, long-term monitoring and evaluation;
- Establishing risk-based criteria for PVA and levels of threat.

MODEL UNCERTAINTY AND RISK

Uncertainty and Reliability

The efficient application of predictive models demands that the investigator understand the uncertainty (the occurrence of an event that is beyond explicit definition) introduced by the random nature of certain processes, particularly those mediated by biological action or turbulence phenomena. Further uncertainty can arise from incomplete or "fuzzy" information needed for algorithm formulation or for specifying initial and boundary conditions. Any strategy proposed that includes the modeling of a pollutant history must allow for these uncertainties.

The reliability of a system (ecosystem, population, or organism) is defined as the probability that the strength of the system is greater than or equal to the stress on the system. Conversely, risk is the probability that the stress will exceed the strength of the system. Risk, then, refers to a lack of predictability about structure, outcomes, or consequences in a decision or planning situation. Risk analysis provides a broad approach for structuring the process of decision making and a strategic thinking methodology for handling uncertainty. Risk analysis is a vehicle for examining the data surrounding a decision problem in light of all the pervasive uncertainties of the world. Risk analysis is not aimed at eliminating uncertainty, or even minimizing it,

but rather at encouraging entrepreneurial activity through a better awareness of risk (Hertz and Thomas 1983).

Comparative Ecological Risk Assessment

A comparative ecological risk assessment is a process that estimates the differences in risk, or probability and magnitude, of adverse ecological effects for two or more alternative events. A comparative risk assessment need not provide an explicit quantification of absolute risks, but rather focuses on the differences in likelihood of exposure, environmental pathways, ecological consequences, and recovery prospects of the alternatives.

A comparative ecological risk assessment is designed to consider several levels of biological organization and time-scales—molecular/cellular (seconds to hours), organismic (minutes to days), and population and community (days to months). Scales of organization run from response sensitivity at the low end to ecological relevance at the upper end. The questions being pursued include evaluating whether big changes at the low end manifest themselves as small changes on the high end, or vice versa.

To describe the biological dynamics of a marine resource a comparative ecological risk assessment would employ a suite of population models sufficient to encompass the range of trophic levels and interactions relevant to the marine resource. The biological dynamics models broadly utilize database resources of at least three types: existing historical resource databases in GIS and visualization formats; outputs from a physical/chemical fates and transport model (hydrodynamics tied to constituent mass balance); and demographic statistics providing initial conditions and recruitment boundary conditions from survey analyses, and toxicological data.

MODEL SELECTION

Model selection for a given scenario should be based upon the type of problem to be addressed, constraints imposed on the modelers, the ability of the model to accurately simulate relevant processes and the acceptability of the uncertainties that accumulate in the modeling process. To be comprehensive, the model must be able to (Cekirge et al., in press):

- forecast the movement of a pollutant;
- hindcast the movement of a pollutant to locate possible sources;
- predict the chemical fate of a pollutant;
- provide information for shoreline and biological community impact assessment; and
- adjust and update the forecasted results with field observations.

Furthermore, the model should be able to operate in the following modes:

- *tactical mode* (rapid response providing short-term forecasts when reliable meteorological data are available);
- *strategic mode* (long-term response providing long-term movement and fate analysis using an historical meteorology and climate data base);
- *receptor mode* (hindcasting providing back-calculation of potential contaminate sources for planning for protection of sensitive habitats);
- *training mode* (providing model operators experience in various situations).

For a model to be able to operate in all of these modes, requires that it can be used for rapid response regardless of location, that it provides accurate predictions for forecasting and hindcasting, that it can be easily adjusted for field observations of input parameters, that it be user friendly, and that it can be used in remote locations. Without careful model selection, these requirements may be mutually exclusive. For example, if rapid response is required, a model may need to ignore computationally intensive processes which govern the behavior of a spilled pollutant and would therefore sacrifice a measure of accuracy as an *a priori* condition. Neither rapidity nor accuracy can be ignored. Consequently, the model must use efficient computational algorithms and high performance computation machines and it must have easily addressable data entry procedures.

SUMMARY

Many of the complex processes resulting from the discharge or spill of a pollutant into marine environments are presently approximated in the available models. Many of these approximations are based on knowledge and experience of the behavior of pollutants in the marine environment and the presumption that they will behave similarly in a given situation. These approximations and presumptions are often supported at best by a meager database.

A paucity of data relating to the behavior of a pollutant in the marine environment must be compensated for by incorporating observed field data into the model as a part of response forecasting. While incorporating continually changing field data into a model presents a problem for modelers, it acts as a necessary corrective feature for predicting the coupled and complicated processes of pollutant behavior in marine environments. Consequently, the model must use efficient computational algorithms and high performance computation machines and it must have easily addressable data entry procedures.

Long term planning for the possibility of a pollutant discharge or spill should be a major part of any contingency plan. For long term planning, a more complex modeling approach may be more appropriate. Such a plan should be based on considerations of resource protection, identifying sensitive areas and projecting probability distributions for expected impacts of spills under various geophysical conditions. In this process the goal should be aimed at supporting a "minimum regret" strategy rather than a "maximum win" strategy (Lehr et al. 1995).

Properly selected and operated, models used for evaluation and guidance in contaminate fate predictions are valuable tools. However, they cannot represent all of the complex interactions between the environment and the contaminate. It is essential that experienced modelers trained in physical oceanography and meteorology apply their expertise to the interpretation of any model results to be used in decision making. It is also imperative that laboratory and open ocean investigations regarding the behavior of potentially discharged or spilled pollutants be vigorously pursued and that the information obtained be prudently incorporated into the design of the transport and fate models.

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DEVELOPMENT OF AN END-TO-END MARINE CONTAMINANT MANAGEMENT SYSTEM

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ABSTRACT

We propose to develop an integrated end-to-end marine contaminant management system by building the software interfaces to link existing components in Tampa Bay with those under development. This system will incorporate real-time data acquisition, hydrodynamic modeling, spill trajectory modeling, a geographical information system (GIS) resources-at-risk database, and data dissemination into a user-friendly problem-solving environment designed to assist local, state and federal decision makers to quickly respond to, manage and remediate accidental releases of petroleum products into Tampa Bay. Although we will focus on oil spills in Tampa Bay for our testbed problem, the system we will develop is equally applicable to any contaminant in the marine environment and can be ported to other estuarine systems.

The Tampa Bay Physical Oceanographic Real-Time System (PORTS) provides all the data necessary to provide boundary conditions and independent verification for a high resolution 3-D hydrodynamic circulation model of Tampa Bay. Output fields of current from the hydrodynamic model will drive a Lagrangian trajectory model to simulate the movement of contaminant plumes. The real-time observations, the output from the circulation model and the plume trajectories will be incorporated as layers in a GIS that also includes layers of resources-at-risk in Tampa Bay. Maps produced from the GIS will be disseminated to resource managers in electronic form on notebook computers in an easily understood format. The circulation and trajectory models can be run in hindcast, nowcast or forecast modes to provide guidance for contingency planning as well as for optimal utilization of resources in an actual spill.

INTRODUCTION

The management of petroleum transportation in the marine environment and the containment and remediation of oil spills have significant effects on the environment and economics of estuaries and coastal regions. On one hand, petroleum products and their marine transportation, are an integral facet of our economy; on the other hand, spills can have both short- and long-term effects on fisheries, water quality and recreation industries. Therefore, there exists a need to develop technology with which to base prudent management decisions concerning contingency planning, mitigation and containment. Specifically, this technology should allow for the accurate prediction of the trajectory of both real and simulated oil spill plumes and the dissemination of this information in a timely and easy-to-use fashion to pertinent local, state and federal agencies. This technology would combine hydrodynamic modeling with spill trajectory modeling and link the output to environmental database information. To create this technology, several criteria need to be met: the use of accurate forcing data for modeling; the use of data and model results to accurately predict the trajectory of an oil spill; incorporation of the predicted oil spill trajectory information into a geographical information system (GIS) database of resources at-risk; and a mechanism for quickly disseminating this valuable information to environmental decision makers. Additionally, the technology would operate in several ways, each applicable to different management needs—a simulation or hindcast mode to explore contingency plan options and nowcast/forecast modes to

respond to spills as they develop. This would allow for proactive rather than reactive management of oil spills, which is a very important improvement over existing technologies.

We are building an integrated end-to-end marine contaminant management system by building the software interfaces to link existing components in Tampa Bay with those under development, forming a problem-solving technology for resource managers. Although we will focus on oil spills in Tampa Bay for our testbed problem, the system we will develop is equally applicable to any contaminant in the marine environment and can be ported to other estuarine systems. The individual components of the system are themselves highly computationally intensive. Linking them together in an integrated end-to-end system constitutes a task in high performance computing.

A complete integrated system of this type is not currently available, hampering the development of management practices and the effectiveness of response measures. Methods attempted in the past have been limited by the use of inaccurate data, the application of crude model physics, lack of adequate data transfer and slow response times. For example, the approach of the National Oceanographic and Atmospheric Administration (NOAA) Hazardous Materials Response and Assessment Division (HAZMAT), which is responsible for responding to significant marine petroleum spills in the United States, concentrates on the portability and adaptability of their response strategy to any location and situation (Galt 1995, pers. comm.). However, the hydrodynamic and meteorological forcing data and model physics employed by their modeling strategy are typically very general and approximate. Because the proposed end-to-end integrated system for Tampa Bay is site-specific, the best possible forcing data and model physics can be effectively employed. In particular, the Physical Oceanographic Real-Time System (PORTS) provides real-time oceanographic and meteorological data every six minutes in Tampa Bay. Both archived and real-time PORTS data drive the hydrodynamic model of Tampa Bay circulation. This component of this integrated technology greatly improves the ability to model spill trajectories. Working with NOAA HAZMAT, the spill trajectory program will include physical and chemical characteristics for pertinent petroleum products.

THE TESTBED SITE: TAMPA BAY

Environmental, economic and technological factors all combine to make Tampa Bay an ideal testbed for addressing local environmental management issues pertaining to oil spill contingency planning and mitigation by using and adapting existing tools and databases. The integration of modeling, database and GIS resources through cooperative effort between local, state, university and federal entities will allow development of an easily used and disseminated tool for examining mitigation and contingency planning for oil spills in Tampa Bay.

Physical Oceanographic Real-Time System (PORTS)

PORTS is an information acquisition and dissemination technology developed by the NOAA National Ocean Service (NOS) in order to increase navigational safety by providing more accurate water level and current data for Tampa Bay. A not-for-profit organization, PORTS is funded by local and state agencies and supported through a

cooperative agreement by technical assistance from NOS. Through a cooperative agreement between PORTS and the University of South Florida (USF), PORTS is located at USF's Department of Marine Science. PORTS integrates real-time current, water level, temperature and wind measurements collected every six minutes at multiple locations in Tampa Bay (Fig. 1). Because the bay's tides and currents are influenced strongly by nontidal forces such as winds and river flow, PORTS provides important real-time information to both recreational boaters and professional pilots navigating in Tampa Bay.

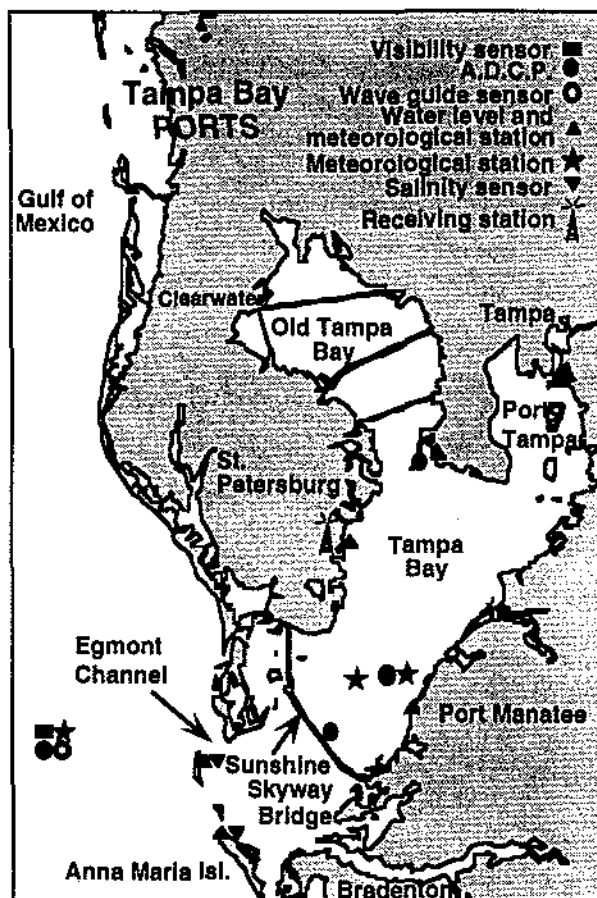


Figure 1. Location of PORTS sensors.

In addition to improving the safety and efficiency of navigation within Tampa Bay, PORTS also provides oceanographic and meteorological data to aid rapid response to hazardous material spills. In this capacity, PORTS is an initial responder to hazardous spills as part of Tampa Bay's Contingency Plan for Oil and Hazardous Substance Pollution Response (USCG MSO 1995) and participates in oil spill drills for Tampa Bay. PORTS also aids in search-and-rescue missions and assists in environmental management of the bay.

PORTS data are archived at USF's Department of Marine Science and represent a significant source of oceanographic and meteorological information for Tampa Bay. The archive, which is within the public domain, contains PORTS data from June 1992 through the present and can be accessed in a variety of ways, including

anonymous FTP. The PORTS Internet site (<http://ompl.marine.usf.edu/PORTS>) contains additional information about PORTS and its associated facilities and projects.

Although specific to Tampa Bay, the end-to-end system will serve as a prototype for other estuaries and harbors. NOS, which developed Tampa Bay's PORTS, is currently installing similar systems in several other large ports in the United States, including San Francisco Bay, Galveston Harbor and New York Harbor. As a result, real-time and archived data will be available for modeling efforts in those ports.

Tampa Bay

The largest estuary in Florida, Tampa Bay covers about 1,031 km² and stretches about 53 km in length. Most of the bay is shallow, with an average depth of only 3.7 m, but the navigational channels reach depths of up to 13 to 14 m (Zervas 1993). The tides in Tampa Bay are small in amplitude—the diurnal range is 70 cm (NOS Tide Tables)—and are mixed semi-diurnal/diurnal. Tidal constituents account for only 52% of sea level fluctuations in Tampa Bay, with coastal set-up and synoptic scale set-up contributing significantly to error in sea level prediction (Zhang 1994). These same factors that make sea level prediction difficult in Tampa Bay also potentially introduce error into oil spill modeling using predicted tidal constituents.

An ecologically sensitive and important area, the bay contains extensive seagrass beds, salt marshes and mangrove stands that serve as fish and shellfish nurseries, breeding and nesting areas for colonial water birds, and protection for its over 1,450-km shoreline (Tampa Bay National Estuary Program [TBNEP] 1993).

Tampa Bay is also home to the largest port in Florida and the fourth largest port in the United States in terms of tonnage handled and vessels called to port (Tiffany and Wilkinson 1989). A substantial portion of this cargo consists of petroleum products and other hazardous materials that are detrimental to the estuarine environment if spilled. Annually, over 4 billion gallons of these products are transported through Tampa Bay (TBNEP 1995). The bay's three largest ports (Ports of Tampa, Manatee and St. Petersburg) contribute over \$6 billion annually to the area's economy. In addition, recreational uses and commercial fishing add at least \$7 million annually to the economy (TBNEP 1993). In summary, the natural and recreational features of Tampa Bay coexist with commercial shipping and fishing industries, combining to make Tampa Bay a high-risk area in terms of hazardous marine spills.

The 1993 Tampa Bay Oil Spill

On August 10, 1993, a collision occurred at 0600 hours in Tampa Bay between two inbound fuel barges and an outbound phosphate freighter. One of the barges leaked No. 6 fuel oil into the water, eventually spilling approximately 300,000 gallons. Much of the existing technology described in this proposal was operational or provisionally operational during the oil spill; however, an end-to-end integrated system was absent. For example, using a simple vector analysis routine and wind and current data from PORTS, researchers at the USF Department of Marine Science constructed a trajectory of the spill that realistically predicted the movement of the spill in Tampa Bay over short (12- to 24-hour) time periods (Chapin and Luther

1993; Figs. 2 and 3). Simultaneously, the state Department of Environmental Protection's Florida Marine Research Institute (FMRI) used its sophisticated GIS resource database for Tampa Bay to provide responding state and federal agencies with detailed information on the bay's natural resources. In addition, FMRI produced maps of the oil spill as it progressed, using GPS and helicopter flyovers (Friel et al. 1993). The trajectory predicted by Chapin and Luther (1993) was verified by both aerial and vessel surveys as well as by the distribution of No. 6 fuel oil in sediment samples taken September 1, 1993, from seagrass beds and mangrove islands (Wetzel and Van Vleet 1994).

Although unfortunate, the 1993 oil spill (and the lessons learned from it) provided the impetus for much of the technology development, improvement, and, especially, integration described in this paper.

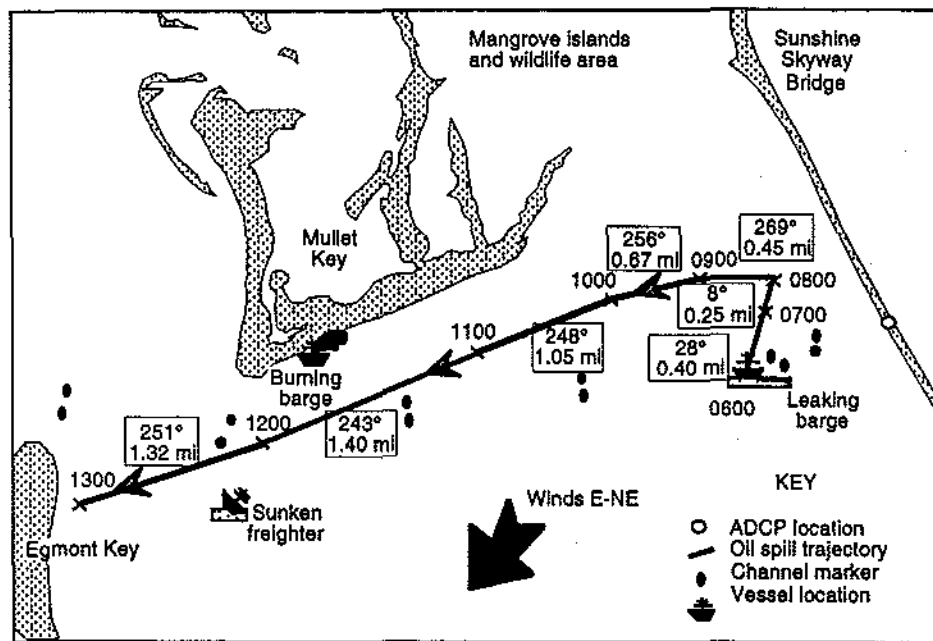


Figure 2. Oil spill trajectory for the 1993 Tampa Bay oil spill using PORTS data and a simple progressive vector scheme. Winds E-NE.

OBJECTIVES

In addition to its environmental and economic significance, several other factors make Tampa Bay an ideal testbed to address environmental management issues at the local level by integrating and improving existing technologies. Briefly, we will enhance an existing three-dimensional hydrodynamic model of Tampa Bay by linking it to the data stream from meteorological and oceanographic instruments that monitor the conditions in Tampa Bay in real-time. The resulting velocity fields from the hydrodynamic model will drive a Lagrangian oil spill model whose output will be integrated with a sophisticated GIS catalog of resources-at-risk in Tampa Bay. By using this integrated technology in simulation (hindcast), nowcast and forecast modes, local managers and authorities will be better equipped to make critical management

decisions concerning oil spill contingency and emergency response planning in Tampa Bay.

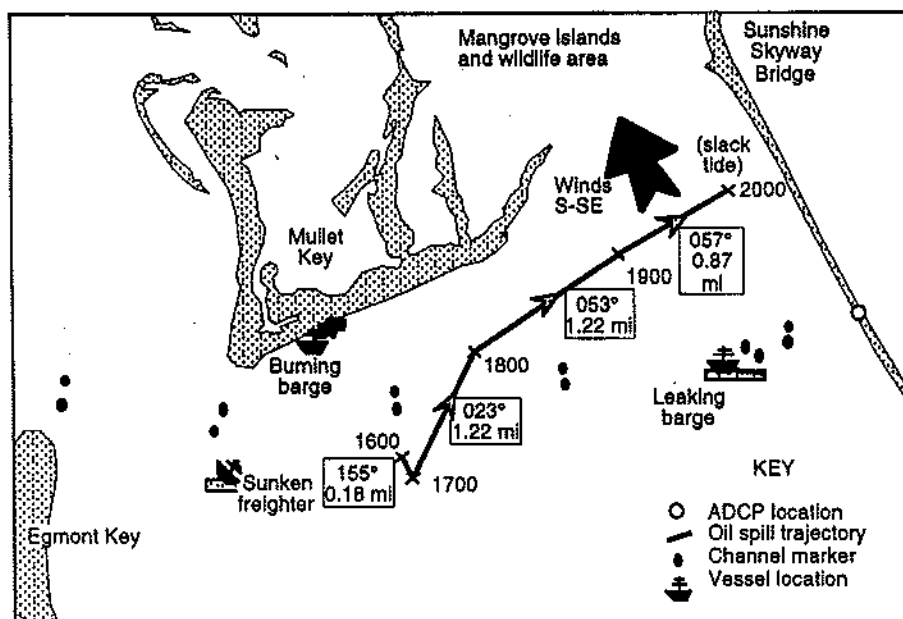


Figure 3. Oil spill trajectory for the 1993 Tampa Bay oil spill using PORTS data and a simple progressive vector scheme. Winds S-SE.

As discussed in the introduction, this project encompasses the integration of three main components: enhancements to (including nowcast/forecast modes) and simulations with (most likely spill cases) the hydrodynamic model; development of a Lagrangian oil spill trajectory model driven by the output of the hydrodynamic model; and transfer and dissemination of the data, hydrodynamic model output and oil plume trajectory model output to a readily accessible GIS and Internet site. Figure 4 provides an overview of the project framework.

This technology could be readily extended to address modeling of other hazardous products and water quality, as well as biological (e.g., larval dispersal) and geological (e.g., sediment transport) processes. The objectives, benefits and methods of the components of this technology are discussed in the following sections.

Objective 1: Hydrodynamic Model Enhancements and Simulations

The first objective of this project is to enhance the existing Blumberg-Mellor Estuarine Coastal and Ocean Model (ECOM-3D) for Tampa Bay, Florida, by adapting it to use real-time hydrodynamic and meteorological data from PORTS as the forcing boundary conditions. The ECOM-3D model is a state-of-the-art, time-dependent, three-dimensional hydrodynamic model. The orthogonal curvilinear grid developed for Tampa Bay contains 40-by-60 cells in the horizontal plane and 11 sigma levels in the vertical (Fig. 5). This discretization allows for horizontal and vertical resolution of important hydrodynamic parameters such as currents, tide height, salinity, temperature, etc. at about 2,000 locations across the bay.

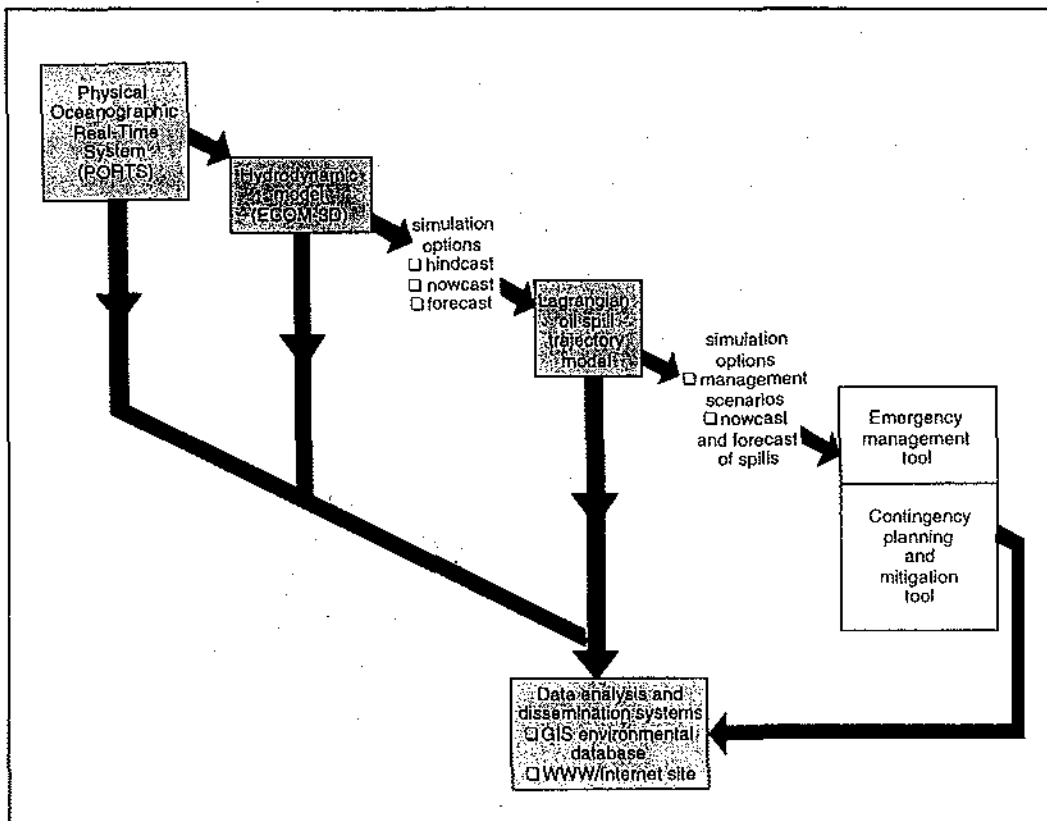


Figure 4. Flowchart of project framework.

ECOM-3D is an advanced version of the Princeton Ocean Model (Galperin et al. 1991). The governing equations consist of conservation of mass and momentum and conservation equations for thermal energy and salt. Equations are also solved for the turbulence kinetic energy and turbulence macroscale. Salient features include a curvilinear orthogonal grid in the horizontal plane, and a bed and free surface following sigma coordinate system in the vertical axis (Blumberg and Herring 1987). Turbulence closure is provided by an embedded Mellor-Yamada 2.5 level closure submodel (Mellor and Yamada 1982) as modified by Galperin. Time splitting allows for the fast external or barotropic waves to be solved for explicitly, and the slower internal baroclinic waves implicitly. Specified forcing boundary conditions include the free surface elevation and temperature salinity profiles at the open water boundary; the flow rate, temperature, salinity and level of inflows or outflows; surface heat flux; and surface stresses due to wind, precipitation and rainfall. Among the important parameters computed are free surface height, magnitude and direction of current velocity fields, and temperature and salinity fields. Various model versions have been deployed and tested at numerous sites such as the Hudson-Raritan Estuary, Chesapeake Bay, Delaware Bay, River and adjacent continental shelf, and the New York Bight. Recent applications of the model at the University of South Florida include Florida Bay, Appalachicola Bay, Florida Straits, Louisiana Coast and Tampa Bay. Mode splitting time steps of 24 seconds for the external mode and 240 seconds for the internal mode are used. Boundary conditions for the Tampa Bay model are provided by PORTS. The model is currently run on a SGI mini-supercomputer that requires approximately 3 hours of CPU time for a 30-day simulation (Model run time

is expected to decrease dramatically after the installation of a newer, more powerful SGI computer in 1997). Post-processing capabilities include graphics and graphical animation of all variables (plan view, cross sections and time series) written in NCAR and GASP. For more information, browse the ECOM-3D Internet site (<http://ompl.marine.usf.edu/TBmodel>).

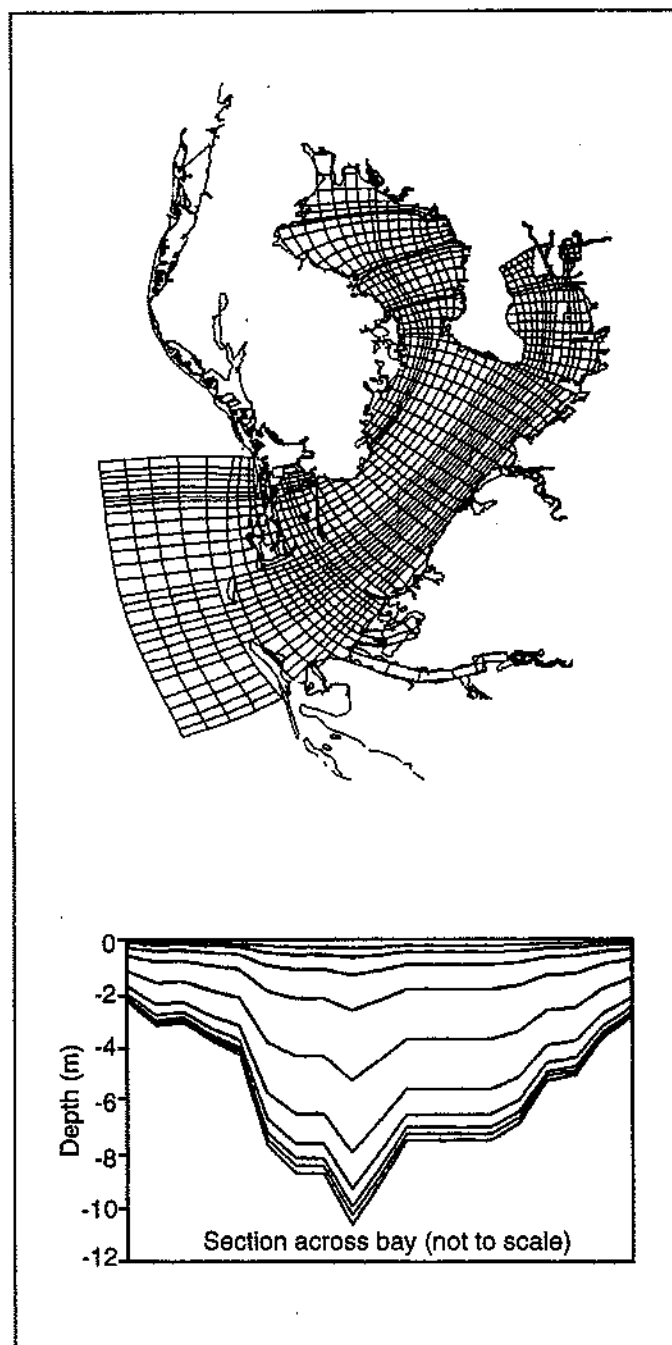


Figure 5. 40×60 horizontal curvilinear orthogonal grid (top figure) and typical cross-section of 11 sigma layers in the vertical dimension (bottom figure).

The enhancements will enable us to run the model in nowcast and/or forecast modes as well as standard hindcast mode. In nowcast mode the model will run using real-time boundary conditions from the PORTS data stream with six-minute sampling intervals. When needed, the model will be switched to forecast mode, using the "spin-up" nowcast model output as initial conditions and combinations of corrected astronomic tides and predicted meteorological parameters as boundary conditions. Calibration of the various model modes will be conducted to demonstrate that ECOM-3D accurately reproduces the relevant physics of Tampa Bay. Included in this exercise will be calibration using four years (June 92-present) of archived PORTS data. In addition to nowcast and forecast hydrodynamic simulations, numerous hindcast or specified scenario simulations will be performed. The latter simulations will be used as hydrodynamic engines that will drive the oil spill scenarios as described in Objective 2.

Expected Results and Benefits

The hydrodynamic model will provide prompt, accurate, high resolution and high quality circulation information (current velocities, tide heights, temperature and salinity) at about 2,000 locations and 11 levels in Tampa Bay. Because the hydrodynamic model will be operated in nowcast and/or forecast modes using high performance computers, this valuable information will be visualized and made immediately available to estuarine managers and field-response personnel. For this effort, the key utility of ECOM-3D will be to produce the circulation database that will drive the oil spill trajectory model (Objective 2). Other obvious benefits of the modeling will be comprehensive salinity, temperature, flushing and water quality predictions and analyses as well as help in search-and-rescue operations conducted in Tampa Bay by the USCG and other organizations.

Approach

The modification, testing and application of the ECOM-3D model will entail the following tasks:

Integration of the ECOM-3D model with the real-time PORTS data stream—PORTS sends real-time hydrodynamic and meteorological data every six minutes to a specially designed computer workstation with full Internet capabilities. Methods will be developed to automatically process these data to provide the boundary conditions for the ECOM-3D. The ECOM-3D can be run in a sequential mode that allows for the model simulation to be halted and all the flow field information to be saved for later use as initial conditions on subsequent simulations. This process, known as a "hot start," will be employed to develop the nowcast version of the model. More specifically, we shall start simulations from some initial state reconstructed from PORTS, as well as other available data, about three months prior to the actual time, in order to allow sufficient time for baroclinic spin-up. When the model is brought up to date, it can be executed into the future using PORTS and meteorological data. For these simulations, the model will use the last saved database as initial conditions (the so called "hot start") and will be executed for some predetermined time intervals that may vary from six minutes (PORTS sampling interval) to several hours. Then, the data will be immediately processed, analyzed, visualized and made available for dissemination. The above process will then be automated in a sequential loop, which

will allow for the continuous real-time or nowcast simulation of Tampa Bay circulation. Various combinations of model time-steps and "hot start" frequencies will be tested in order to maximize computational efficiency, accuracy and possibilities of utilization of the model output by other computers and/or users.

Development of a forecast protocol for ECOM-3D—In certain events, such as an oil spill, accurate forecasts of the hydrodynamic conditions will be needed 24 to 72 hours in advance. For such cases, a rapid transition method from nowcast mode to forecast mode will be developed. This procedure will allow the operator to select the specific time-frame of archived data (previous data sets of the nowcast simulations) to use as spin-up initial conditions. Boundary conditions will now be provided from combinations of adjusted astronomic tides (based upon recent deviations from predicted values and offshore conditions) and National Weather Service (NWS) meteorological conditions. The use of high-speed computers will enable us to accomplish forecast simulations in approximately ten minutes.

Develop automated procedures for the transfer, dissemination and display of model output—Output from the hindcast, nowcast and forecast modes of simulation will automatically be made available to affiliated users. This will include posting of the archived data sets and processed graphics on a World Wide Web (WWW) and anonymous FTP Internet site. Most importantly, the model output will be made instantly available to drive the oil spill trajectory model (Objective 2) and to the GIS database (Objective 3). Provisions will also be made to enable the transmitting of nowcast and forecast model output to field-operated notebook computers.

Provide spatially variable surface wind stress—The ECOM-3D and PORTS data stream will be revised to allow for spatially variable surface wind stress fields across the model domain. Currently the model allows for time variable but spatially homogeneous wind stress fields. This enhancement will allow better simulation of the bay's circulation and its effects on the conveyance of oil spills. Data from five PORTS stations will be interpolated using bicubic splines to provide this surface boundary condition.

Provide temporally variable surface heat flux—The surface heat flux is important in the modulation of estuarine temperatures. The PORTS data will be used to provide the necessary parameters (air temperature, water temperature, wind speed, relative humidity, solar input etc.) to calculate the diurnal time-scale heat flux. Presently, ECOM-3D employs monthly averaged heat flux values.

Improve hydrologic boundary conditions—Freshwater sources (rivers, streams, non-point sources, rainfall) and sinks (evaporation) control the bay's salinity, which, in addition to having important ecological effects, also influences the buoyancy or density-driven circulation of the bay. Currently, historical monthly mean values are used for these hydrologic source/sink terms. The prescription of surface inflows will be enhanced by specifying hourly to daily time-scale inflows provided by combinations of real-time gage data and/or a hydrologic model such as Hydrologic Simulation Program-FORTRAN (HSPF). A version of HSPF for the entire Tampa Bay watershed is currently under development at the USF Center for Modeling

Hydrologic and Aquatic Systems. Similar to the wind data, spatially variable rainfall values will be incorporated from PORTS data and NWS NEXRAD data and bulk aerodynamic formulae. Evaporation will be incorporated using meteorological data from PORTS.

Calibrate and validate the ECOM-3D—Almost four years (June 1992–present) of quality-controlled PORTS data have been archived and are available for modeling applications. These hydrodynamic and meteorological data will be used to provide the forcing conditions for model spin-up and calibration/validation simulations. The hindcast, nowcast and forecast modes of ECOM-3D operation will be calibrated and validated in order to demonstrate their ability to replicate PORTS data with sufficient quality. Methodology will follow that of Hess and Bosley (1992).

Hindcast hydrodynamic simulations—Based on the identified or hypothetical most likely oil spill scenarios, numerous simulations will be performed to provide the hydrodynamic input to the Lagrangian spill trajectory model. These simulations will include variations in tidal cycle (ebb versus flood, spring versus neap), wind and storms, and freshwater inflows, which have been demonstrated by Galperin et al. (1991) to be important in the circulation of Tampa Bay. The extensive bank of PORTS data archives will be used to identify appropriate forcing conditions.

Nowcast and forecast simulations—Once operational, one version of ECOM-3D will be maintained in a continuous nowcast simulation mode. Periodic forecast simulations of planned or real emergency events will also be conducted in parallel. Information from nowcast and forecast simulations will be made promptly available to a WWW and FTP Internet site, a GIS environmental database and field-based notebook computers.

Objective 2: The Trajectory Model

In order to examine the fate of oil spilled in Tampa Bay, a Lagrangian trajectory model will be developed to simulate the movement of the pollutant over the first few days after a spill. The velocity fields from ECOM-3D will drive the trajectory model, and the output trajectories from the model will in turn serve as input to an existing resources-at-risk GIS database for Tampa Bay. Several scenarios of potential oil spills will be developed using a range of environmental conditions. This will support management decisions concerning environmentally sensitive areas and mitigation strategies. The trajectory model will also operate in real time during an oil spill, driven by the nowcast and forecast outputs from ECOM-3D.

Approaches and Results

Development of a Lagrangian trajectory model to simulate the dispersal of spilled pollutants in Tampa Bay—A Lagrangian approach to the trajectory model will be taken. There are two ways of describing fluid motion, Lagrangian and Eulerian. The Eulerian description, which is used in most fluid flow solvers, concentrates on what happens at a spatial point x , and the independent variables are x and time t . The Lagrangian description traces the history of individual fluid particles. The two independent variables, then, are time t and a label for fluid particles. Typically, the fluid particle is labeled by its position vector x_0 at some reference time t_0 . This is

useful in examining particle paths of fixed identity (e.g., particles representing spilled oil) and this approach will be utilized for the modeling of oil trajectories.

With regard to spill trajectory modeling, the use of an Eulerian description of fluid motion introduces unrealistically high numerical diffusion. This numerical diffusion can only be reduced by decreasing the grid size, which may result in prohibitively long and expensive simulations. This is because in a model using an Eulerian frame of reference, diffusion of the spilled contaminant through a grid box is instantaneous. In contrast, with a Lagrangian frame of reference, there is no numerical diffusion (because fluid particles are tracked).

To simulate a spill, the trajectory model is initialized with velocity data from ECOM-3D and seeded with a variable number of particles, which represent the spilled oil and which are introduced into the model grid box nearest the spill location. The particles are advected through the model grid in the model time; the particle locations at any point in time are found by using a fourth-order Runge-Kutta solver (Press et al. 1992). The density of particles at any point in model time will be assessed by counting the number of particles per grid box and dividing by the total number of particles. In terms of the trajectory model output, the density values will be used to contour spill maps of Tampa Bay in hourly increments and to assess spill moves in Tampa Bay over the spill's duration. The trajectory model will operate in both a simulation mode (to address contingency planning options) and a nowcast/forecast mode (to model a spill as it occurs).

Dissolution, dispersion and evaporation dominate the physical processes in the first hours to days of a spill; processes such as emulsification, sedimentation, biodegradation and photo-oxidation occur typically in the days to months following a spill. Due to its vertically well-mixed nature, relatively small size and abundance of environmentally sensitive areas, Tampa Bay faces significant risks from a spill during its first hours and days. The trajectory model will incorporate a dissolution/evaporation term, which will simulate the loss of oil to these processes through model time. This term will vary with the type of oil (e.g., crude vs. bunker) spilled and will allow a more realistic simulation of the oil spill trajectory through model time.

Incorporation of ECOM-3D output into the trajectory model in order to drive the model with the best available hydrodynamic input—The Blumberg-Mellor model of Tampa Bay (ECOM-3D) will provide the flow fields used to drive the spill model. This hydrodynamic model is currently being modified to use both archived and real-time climatological and oceanographic data from Tampa Bay's PORTS as the forcing boundary conditions. As a result, the trajectory model will be run in three modes: simulation (hindcast), nowcast and forecast modes. The simulation mode will test oil spill scenarios over a range of potential environmental conditions; the nowcast and forecast modes will be used to monitor and predict the spread of oil spills in Tampa Bay.

Identification of pertinent oil spill scenarios based on USCG MSO priorities—Hazardous spill trajectories will be simulated in Tampa Bay for several

potential spill locations. The details and locations of the simulated hazardous spills will correspond to spill scenarios developed by the USCG Marine Safety Office (MSO) as part of the Area Contingency Plan for Oil and Hazardous Substance Pollution Response (USCG MSO 1995) and scenarios created for USCG MSO oil spill response drills. These locations have been identified as the most likely sites for a spill to occur, based on shipping routes, volume of oil transported and known hazards to safe navigation in the bay. Simulating oil spills for these locations will provide local environmental management agencies with information useful for oil spill contingency planning.

Evaluation of several oil spill scenarios over a range of environmental conditions using the trajectory model—In order to examine the fate of spilled oil in Tampa Bay, the trajectory model will test the effects of a spill over a wide variety of different conditions for each of the USCG MSO scenarios and tests. The variables include precipitation, tides and winds. For example, for each USCG MSO scenario and test, combinations of the following conditions will be used to generate the flow field input from ECOM-3D (Objective 1) into the trajectory model:

- Precipitation—wet or dry annual conditions
- Tides—spring vs. neap tide conditions
- Winds—calm, dominant southerly or dominant northerly conditions

The significance of these variable conditions is discussed in Objective 1. Also, dispersal of the particles by the trajectory model over the course of the simulated spill may be examined at the surface, bottom and middle of the water column, and over a depth-integrated flow field. The trajectory model may be initialized to simulate not only quasi-instantaneous spills but also those in which the particles are spilled over a period of time. Again, the scenarios for each spill will be available to local environmental management agencies involved in oil spill mitigation and planning.

Objective 3: Dissemination of Products

In order for this technology to support environmental decision-making at the community level, the trajectory model projections for oil spills, both simulated and real, must be available to the managers and policy makers at the local level. By integrating the trajectory model output with existing environmental databases and dissemination technologies for Tampa Bay, oil spill projections will be easily accessible for interpretation by local management agencies. The Florida Marine Research Institute (FMRI) is an active and logical conduit for this dissemination.

FMRI works closely with federal, state and local agencies, and private sector firms to provide timely, accurate information during marine spill emergencies. One of FMRI's primary mandates is to provide the Florida Department of Environmental Protection (FDEP) Bureau of Emergency Response (BER) with the capability and technical support to facilitate their oil-spill contingency planning, response and damage assessment responsibilities. The ultimate goal is to provide map products showing ecological resources-at-risk in near real-time. The philosophy of making data available rapidly fills a critical need in marine resource management. More than 550 requests for information were answered last year with the majority being oil spill related. The products delivered include maps, tabular output, images, prints and digital data on

a variety of media. FMRI information delivery efforts will be enhanced in several areas through this project.

Tampa Bay GIS Database

Although many resource protection issues in the coastal zone could be addressed using a GIS, data for marine environments are relatively scarce. The availability of spatial data in the United States reflects our country's preoccupation with land-based mapping. The ubiquitous USGS quadrangle map series which forms the basis of database development efforts at many GIS installations are simply not available for offshore areas. GIS specialists charged with analyzing marine resources must face the fact that their study area begins where most existing map products end. Therefore, the availability of critical GIS databases for the Tampa Bay region represents a strong opportunity to this effort. FMRI has been working closely with regional resource protection organizations such as the Tampa Bay National Estuary Program (TBNEP) to create a rich array of key databases in GIS format. There are presently more than 1.5 gigabytes of current, high-resolution GIS data available to analyze in conjunction with trajectory model output and create derivative information products.

Approaches and Results

Development of World Wide Web site featuring all aspects of this integrated project and linkage to GIN—With the exception of PORTS, the components of this integrated approach (e.g., hydrodynamic modeling, GIS resource databases) to oil spill management and planning are widely available in many U.S. ports. NOAA NOS, which developed the Tampa Bay's PORTS, is creating similar systems in several large U.S. ports, including San Francisco Bay, Galveston Bay and New York Harbor. By featuring all aspects of approach, integration and results of this problem solving technology in an easily accessed WWW forum, this research can serve as a model for other locations in the United States with similar needs, resources and problems.

The WWW site will be linked to the Gulf of Mexico Information Network (GIN). In order to make its resource-at-risk maps available as quickly as possible and free up FMRI GIS analysts for more sophisticated spill planning and response analyses, FMRI has entered into a partnership with the U.S. Environmental Protection Agency (EPA), Gulf of Mexico Program, NOAA, and several other state and federal partners to create an Internet-based information retrieval system for the Gulf of Mexico. The GIN system will allow anyone with basic Internet capabilities to directly download resource-at-risk data and derivative maps within minutes of generation to be plotted at any Internet site worldwide. The World Wide Web site featuring all aspects of this integrated project will be linked to the FMRI site to provide worldwide seamless access to all the associated data and information.

Development of an interface between the trajectory model output and FMRI's resources-at-risk database in order to assist in resource protection planning—Output from both the simulated and nowcast/forecast spill trajectory scenarios will also serve as input to FMRI's GIS of resources-at-risk for the BER Tampa field office. This ArcView application includes resource information specific to Tampa Bay, such as environmental sensitivity indices for the shoreline, bathymetry, boating facilities and habitat data. Its parent application, FMRI's Florida Marine Spill Analysis System

(FMSAS), integrates a variety of information (digital maps, imagery and tabular data) with targeted analytical routines needed to implement an oil-spill response strategy focused on resource protection. By combining the simulated spill trajectory scenarios with the resources-at-risk database, better mitigation and contingency planning decisions may be made by local environmental management agencies. In the event of an oil spill, this integration will enhance local and state response to containment, especially in environmentally sensitive areas. The ArcView tool is used both by FMRI staff with expertise using this specialized GIS software and by scientists, managers and researchers associated with the BER office who are less experienced with the GIS environment. As a result, the software platform is versatile and accommodates a wide range of user capabilities.

FMRI has devoted considerable resources to developing the ArcView tool as an open-ended software architecture with applicability to estuary management, fisheries modeling, water quality monitoring etc. The long-term implementation plan for widespread GIS use at the FMRI is to deliver the ArcView interface to the desktop of more than 200 scientists at the FMRI. Developing of an integrated link to trajectory model output will leverage the ArcView and model development efforts into entirely new marine resource protection decision-making arenas.

Evaluation of proposed mitigation strategies such as location of permanent boom anchor sites—In addition to examining various oil spill scenarios, the trajectory model output will be used to evaluate and improve existing mitigation strategies in Tampa Bay. For example, FMRI recently contracted for detailed bay and inlet protection strategies to be created to assist responders with localized booming strategies. Insight from the trajectory model into the movement of a spill under various conditions combined with FMRI's resource-at-risk data will improve FMRI's ability to pick appropriate anchor sites. Boom site selection is but one example of many types of mission-critical contingency planning that depend upon the availability of realistic current, trajectory and resource data in a compatible format to simulate likely scenarios.

Delivery of model trajectories to a notebook computer-based system—By combining electronic navigational charting software with model output using a portable notebook computer equipped with wireless networking capabilities, nowcasts and forecasts of model circulation and spill trajectories will be available remotely. This will assist in field-based operations and decision-making.

An important lesson learned during the Tampa Bay oil spill of 1993 was that the computing resources (and associated data) available could be utilized most effectively if they could be mobilized and transported directly to the site of field operations decision-making. Remote access to resource-at-risk data and model output could be facilitated using portable computers and communications equipment to provide point-of-impact information delivery to federal, state, regional and local agencies with a mandate or vested role in ecological protection from spills. The ArcView application has been optimized to run in remote mode and could accept model output anywhere in the Tampa Bay region (or at any number of sites in the region simultaneously) to

facilitate distributed decision-making. This capability is critical in the spill response environment and would have been most useful during the Tampa Bay spill of 1993.

Integration of the trajectory model output with the Resource Impact Map (RIM) series of map products—Managers statewide use the RIM series of 12 chart-sized maps in making resource decisions. Each map includes many GIS data layers such as a section of Florida's shoreline and critical marine structural habitats that support ecosystem integrity. These communities are the equivalent of terrestrial land cover and include mangroves, salt marshes, sea grasses, oyster reefs, coral reefs, hard bottom and bare bottom. Bathymetry (or bottom depth) also is shown. That is the equivalent to terrestrial elevation and is an important controlling factor for human and marine resources. In addition, channels and navigation aides such as markers and buoys are displayed to help users orient themselves, much like road networks on land-based maps. The combination of features on the RIM is not available on any other map series, hence their popularity.

The Tampa Bay RIM proved to be one of the most useful maps for command-center and field response operations during the 1993 oil spill in Tampa Bay. Once the interface is created to the ArcView application, the trajectory model output can be added to the RIM for Tampa Bay. This will create a hardcopy map product with widespread coastal and marine resource management utility. More than 100,000 copies of the existing Tampa RIM are in circulation and customized map products with circulation model output would be valuable decision-making aids.

SUMMARY

In summary, this paper describes a fully integrated end-to-end marine contaminant management system that is currently under development at the University of South Florida's Department of Marine Science. The system incorporates data acquisition, hydrodynamic modeling, spill modeling, a geographic resources-at-risk database and data dissemination into a user-friendly problem solving environment designed to assist local, state and federal decision makers to quickly respond to, manage and remediate accidental releases of petroleum products into Tampa Bay.

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FISHERIES MONITORING AND ITS USE IN FISHERIES RESOURCES MANAGEMENT

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ABSTRACT

Successful management of fisheries resources requires information on the life history, ecology, population dynamics and harvesting patterns of exploited species. Data used by the Florida Department of Environmental Protection (FDEP) to assess the status of populations of fish and invertebrates found in Tampa Bay come from several state and federal monitoring programs. The Fisheries-Independent Monitoring (FIM) program at FDEP's Florida Marine Research Institute was initiated in 1989 to monitor changes in the abundance and size structure, identify critical habitats and seasonality, and predict trends in recruitment of populations of fishes and selected invertebrate taxa in Tampa Bay. The FDEP's Fisheries-Dependent Monitoring (FDM) program and the National Marine Fisheries Service's Marine Recreational Fisheries Statistics Survey (MRFSS), initiated in 1985 and 1979, respectively, provide data on size and catch compositions of species harvested by commercial and recreational fishers. Information from these programs is currently used in advanced fisheries-assessment models that provide data used to regulate commercial and recreational fishing of spotted seatrout (*Cynoscion nebulosus*), redfish (*Sciaenops ocellatus*), and snook (*Centropomus undecimalis*) in Tampa Bay. Without long-term monitoring programs, data would not be available to address the concerns of resource managers, biologists and the general public regarding the condition of Florida's fisheries resources.

INTRODUCTION

Successful management of fisheries resources requires information on the population biology, ecology, dynamics and harvesting patterns of exploited species. Information used by scientists from the Florida Department of Environmental Protection (FDEP) and council members of the Florida Marine Fisheries Commission to assess the status of fish and invertebrate populations in Tampa Bay come from two general categories of long-term monitoring programs: fisheries-independent monitoring and fisheries-dependent monitoring. In fisheries-independent monitoring, scientists using statistically valid sampling methods catch the fish themselves rather than depending upon commercial and recreational fishers. Data from a fisheries-independent monitoring program can be used to provide unbiased estimates of biological attributes of fish resources, identify ecological requirements (e.g., habitats) necessary for the survival of exploited species, and document ecosystem changes (Wolfe et al. 1987). In fisheries-dependent monitoring, information about fish caught is obtained directly from the commercial and recreational fisheries. A fisheries-dependent monitoring program provides data that characterize exploitation patterns, landings, effort, and species composition of commercial and recreational activities (Demory and Golden 1983).

In this paper, we discuss the background and uses of data from three monitoring programs—two state (FDEP's Fisheries-Independent Monitoring [FIM] and Fisheries-Dependent Monitoring [FDM]) and one federal (the National Marine Fisheries Service's [NMFS] Marine Recreational Fishery Statistics Survey)—in the management of fisheries resources in Tampa Bay.

HISTORY OF PROGRAMS

Fisheries-Independent Monitoring

The FIM program at FDEP's Florida Marine Research Institute (FMRI) began in 1989 and is funded by the Federal Sport Fish Restoration Grant and Florida Saltwater License fees. The major objective of the FIM program is to collect data on the abundance, size structure, and habitat associations of fishes and selected invertebrate taxa in Tampa Bay and other major Florida estuaries. The FIM program is designed to be a long-term sampling program that is directed toward collecting an array of species and sizes of fish within a variety of habitats. Sampling gear currently used includes small center-bag seines (21 m $\times$ 1.8 m, 3.2-mm stretched mesh) and otter trawls (6 m, 38-mm stretched mesh with a 3.2-mm stretched mesh cod-end liner) to collect juvenile and subadult fishes, and large center-bag seines (183 m, 38.5-mm stretched mesh) and trammel nets (366 m, 308/71-mm stretched mesh and 549 m, 3895/151-mm stretched mesh) to collect adult fishes (McMichael 1991; FMRI 1996).

Prior to 1995, FIM staff collected data on juveniles and sub-adults using a stratified-random sampling design in spring and fall, a fixed station design monthly throughout the year, and a directed approach to target schools of adult mullet (*Mugil cephalus* and *Mugil curema*) and redfish (*Sciaenops ocellatus*) (McMichael 1991; FMRI 1996). In 1996, seasonal stratified-random and monthly fixed station sampling was replaced with monthly stratified-random sampling in order to eliminate the biases associated with the fixed station design (Cochran 1963; Johnson and Nielsen 1983) yet maintain sampling on a monthly basis. A monthly stratified-random sampling component in which the 183 m center-bag seine was used was also added in 1996.

Since 1989, a total of 14,911 samples has been collected throughout Tampa Bay (Fig. 1; Table 1). At each sampling site, environmental data on dissolved oxygen, pH, salinity, conductivity, temperature, habitat characteristics, and physical parameters such as current and tidal conditions are recorded. Sampling procedures are described in detail in McMichael (1991) and FMRI (1996).

All fish and selected invertebrate species (*Callinectes sapidus*, *Menippe* spp., and *Penaeus* spp.) collected at each site are identified and counted, and representative length frequencies (standard length for fish, carapace width for crabs and postorbital head length for shrimp) are recorded. Animals are released alive except for representative samples of each taxon (to confirm field identifications) and samples needed for specific research needs (e.g., aging structures, mercury analysis). Since 1989, more than 10 million fishes and selected invertebrates, representing 217 taxa, have been collected (Table 1).

Fisheries-Dependent Monitoring

The Fisheries-Dependent Monitoring (FDM) program at FDEP's Florida Marine Research Institute collects data primarily on the commercial aspects of fisheries resources in Florida. In 1983, the Florida legislature passed Statute 370.021, which required wholesale and retail dealers who produce or purchase saltwater products to report the amounts landed or bought on a monthly basis. Confidential trip information, which includes date of purchase, length of time fishing, county in which fish were landed, gear used, number of sets, species and size descriptions, amount of

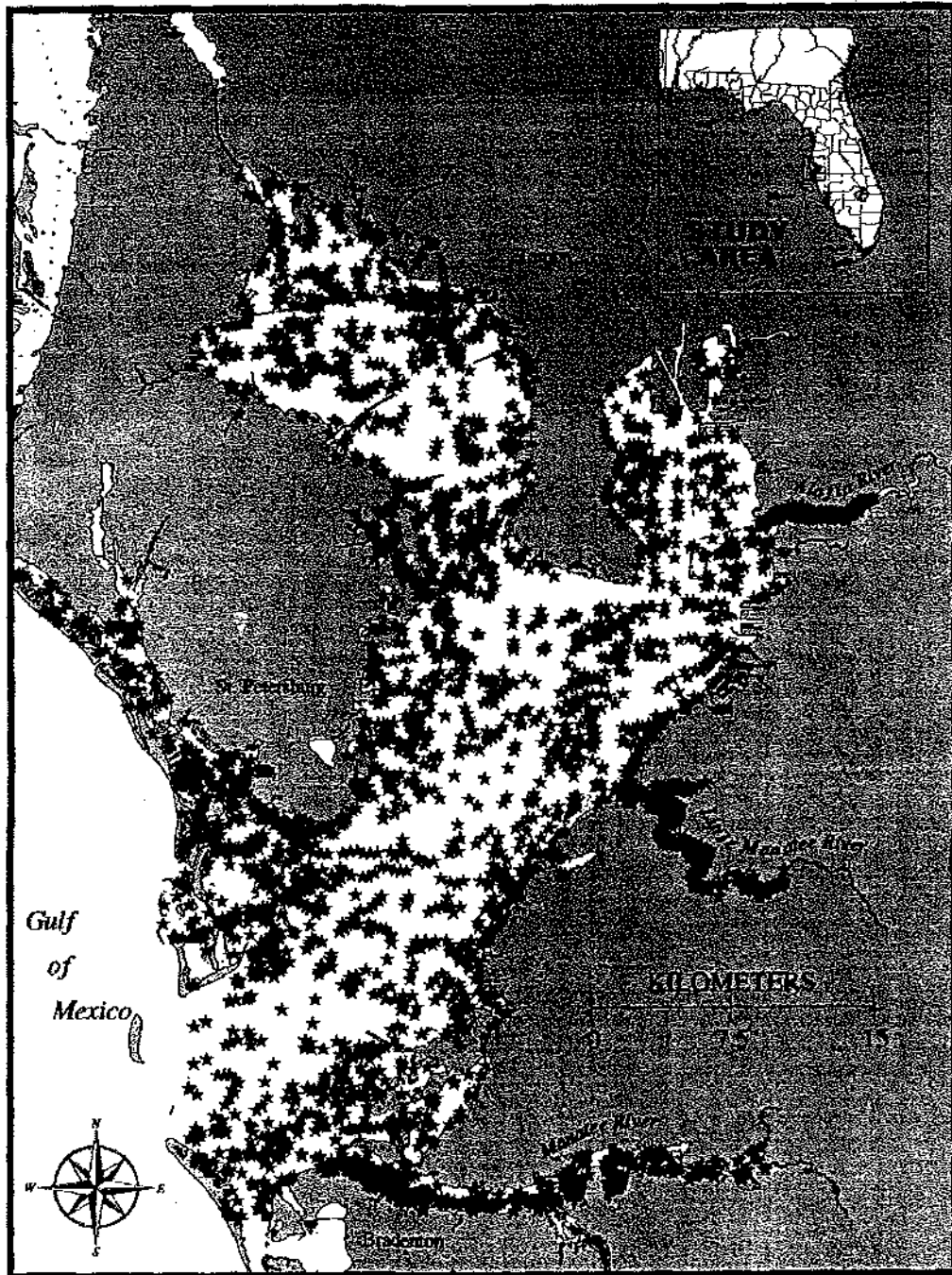


Figure 1. Locations sampled by FDEP's Fisheries-Independent Monitoring Program from 1989 to 1995 in Tampa Bay.

catch, area fished, depth, unit price, and dollar value, has been collected since 1985 through mail-in trip tickets. Annually, more than 22,000 trip tickets are submitted on which landings of over 18 million pounds of fish worth in excess of \$24 million are reported from counties surrounding Tampa Bay (Table 2).

Table 1. Number of samples, animals, and taxa collected in Tampa Bay during the Fisheries-Independent Monitoring Program's fixed station and stratified-random sampling surveys, 1989-1995.

Year	STRATIFIED RANDOM SAMPLING		FIXED STATION SAMPLING	
	No. of Samples	No. of Fish	No. of Samples	No. of Fish
1989	1,142	310,567	710	1,194,610
1990	1,228	390,415	1,175	1,110,019
1991	1,286	402,053	1,136	1,175,282
1992	1,284	415,543	1,032	1,311,205
1993	1,280	504,084	900	780,219
1994	1,280	548,778	895	1,519,887
1995	675	384,229	888	440,090
Total Number	8,175	2,955,669	6,736	7,531,312
No. of Taxa	205		187	

Table 2. Summaries of the number of trip tickets collected from retail and wholesale dealers, estimated catches (in pounds) and values of saltwater products landed from 1986 to 1995 in counties (Pinellas, Hillsborough, and Manatee) surrounding Tampa Bay.

YEAR	TRIP TICKETS	LANDINGS (pounds)	VALUE (dollars)
1986	28,541	36,027,851	27,719,633
1987	31,065	37,968,846	29,354,841
1988	30,401	27,754,521	26,364,040
1989	32,947	32,725,949	31,654,528
1990	34,293	30,721,228	30,130,769
1991	30,411	27,407,976	27,982,859
1992	33,907	27,243,694	27,160,909
1993	30,912	26,172,938	29,616,536
1994	28,040	21,890,324	24,634,928
1995	22,843	18,933,762	28,375,833

To collect information on the biological aspects of commercial catches, port samplers visit wholesale dealers' establishments and identify species and measure subsamples of commercial catches for length composition. Proper identification of species and measurement of fish sizes landed in the commercial fisheries are essential for successful management because each fish species has distinctive rates of growth, mortality, reproduction and harvesting that vary with size and age (Pitcher and Hart 1982; Wootton 1990). For some species, structures used in aging fish (e.g., scales and otoliths), somatic tissues and gonadal tissues are collected and returned to FMRI for

analyses. Port samplers in the Tampa Bay area average more than 200 trip interviews per year and measure more than 10,000 fish and invertebrates at fish houses in Pinellas, Manatee and Hillsborough counties.

The FDM program also collects data associated with marine recreational fisheries. Information on 10% (more than 70,000) of the Florida saltwater fishing license, tag (e.g., tarpon), and stamp (e.g., snook) holders has been computerized by FDM personnel to construct mailing lists and sampling frames for mail-in catch and effort surveys. In 1995, FDM staff began a pilot study in Tampa Bay to examine the feasibility of conducting a statewide saltwater recreational fishing survey, the results of which could be compared to those of the National Marine Fisheries Service's regional creel survey. Boat counts from aerial surveys, a boat-based roving-effort survey, an access point survey of boat-based fishing, and a roving creel survey of shore-based fishing are used to estimate catch and effort in Tampa Bay and nearshore Gulf waters (to 10 miles).

Marine Recreational Fisheries Statistics Survey

The NMFS' Marine Recreational Fisheries Statistics Survey began collecting recreational fisheries catch and effort data on a regional basis in 1979 (Van Voorhees et al. 1992). Information on location, fishing mode (party/charter boat, private/rental, or shore-based fishing), length of time fishing, and number of fishers is collected in a telephone survey of randomly selected households within 25–100 miles of the coastline every two months (a sampling wave). Telephone sampling is allocated on a county basis, and a single household is considered to be the sampling unit. Intercept creel surveys of the three fishing modes are also conducted to collect data on species composition, numbers and sizes of released and kept fishes, length of time fishing, and number of fishers. Intercept sampling is stratified by state, mode and two-month wave, and is conducted seven days a week. Interview sites are chosen randomly from a list of access sites weighted by estimates of expected fishing activity (Van Voorhees et al. 1992). Since 1986, more than 61,000 telephone interviews and 33,828 creel intercepts have been made in Pinellas, Hillsborough, and Manatee counties (Table 3).

Table 3. Total number of phone interviews and creel survey intercepts made annually from 1986 to 1995 in the National Marine Fisheries Service's Marine Recreational Fishery Statistics Survey in the counties (Pinellas, Hillsborough, Manatee) surrounding Tampa Bay.

YEAR	PHONE INTERVIEWS	CREEL INTERCEPTS
1986	900	1,339
1987	2,428	2,485
1988	4,435	3,565
1989	2,407	2,500
1990	4,889	2,546
1991	4,194	1,521
1992	9,810	4,042
1993	10,833	5,191
1994	10,803	5,224
1995	10,856	5,415

DATA USES

Fisheries-Independent Monitoring

The statistical sampling design of the FIM program ensures unbiased data on the biology, the ecology, and population aspects of fishes and selected invertebrates in Tampa Bay that scientists and resource managers can use in stock assessments. Data gathered in this program include information on length composition, age structure, habitat requirements, and spatial and temporal abundances of fishes and selected invertebrates (McMichael 1991).

Length data can be used to identify newly spawned fish (FMRI 1996), to determine monthly growth rates of individual cohorts, and to identify changes in size structure that may occur naturally over time or that may be anthropogenically induced. For example, scientists at FMRI suspect that the increase in median length of the largest size of post-spawning adult mullet observed in Tampa Bay during the 1996 FIM trammel net survey (Fig. 2) was a result correlated to reductions in fishing pressure, brought about by the Florida inshore net ban (Florida Constitution Article X, Section 16).

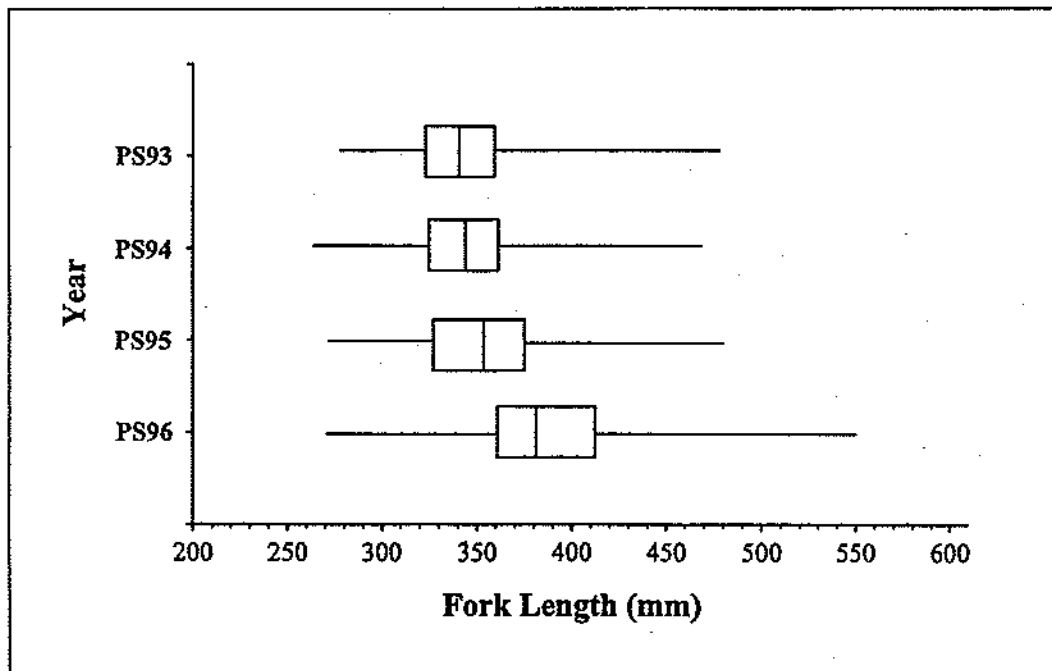


Figure 2. Box plots of the length composition of adult post-spawning mullet captured in trammel nets during FDEP's Fisheries-Independent Monitoring Program directed survey from 1993 to 1996. The vertical bar is the median value; the box presents the first and third quartiles; and the horizontal line represents the smallest and largest length within 1.5 interquartile ranges from the first and third quartiles, respectively.

Age data have been used to generate growth models for many fish species found in Tampa Bay. Growth curves, such as that shown in Figure 3 for the commercially and recreationally important sheepshead (*Archosargus probatocephalus*), are used to determine how rapidly species grow, how much time is required for species to reach

certain sizes, and at what age they reach sexual maturity if length and size at maturity are known. Age data are used by the Florida Marine Fisheries Commission to set bag and slot limits that regulate commercial and recreational fishing of spotted seatrout (*Cynoscion nebulosus*), redfish, and snook (*Centropomus undecimalis*) (Muller and Murphy 1994a; Taylor et al. 1996).

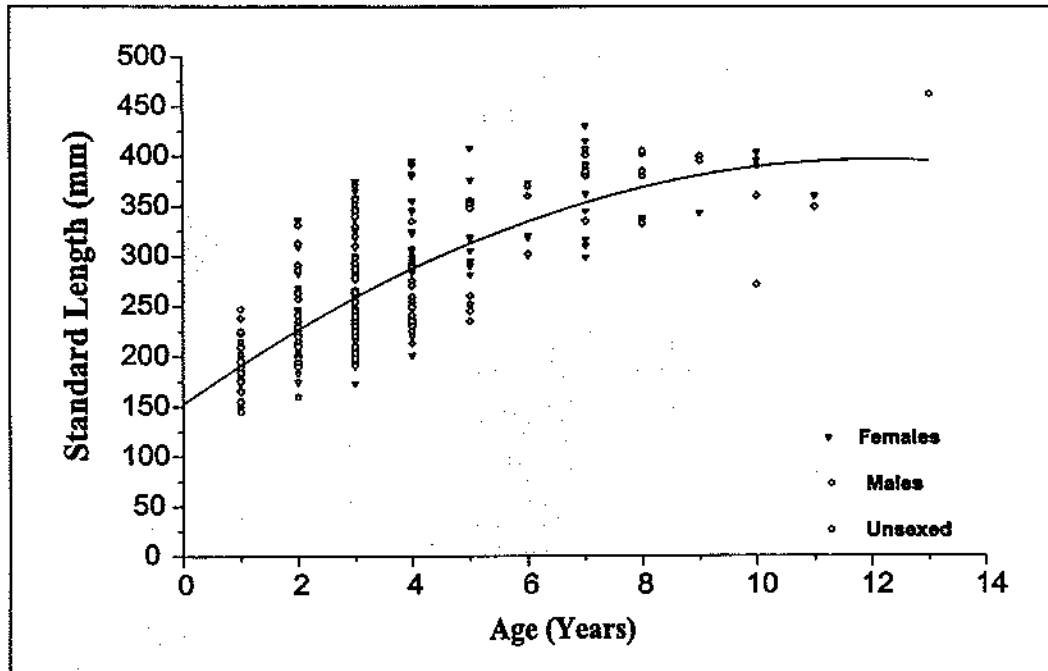


Figure 3. Von Bertalanffy growth curve for sheepshead (*Archosargus probatocephalus*) in Tampa Bay.

Data on habitat and physical characterizations of sampling locations have been used by scientists to model potential impacts of oil spills in Tampa Bay (Harwell et al. 1995); to examine salinity, temperature and oxygen effects on fish abundances (Acosta 1995; MacDonald and McMichael 1996); and to identify nursery and feeding areas in Tampa Bay that may need protection from human activities. Habitat characterizations for juvenile snook developed from several years of FIM seine data show that more than 98% of the snook were collected along shoreline rather than offshore habitats (Fig. 4). Of the animals collected along shorelines, 80% were collected from vegetated habitats, and 82% of these snook were collected from shoreline associated with overhanging vegetation such as mangroves (Fig. 4). Knowledge of the importance of these habitat types to this highly prized recreational fish species can be used to protect these areas.

Data concerning the abundances of species at sampling locations have multiple uses. Using latitude and longitude coordinates and state-of-the-art mapping systems such as the Geographical Information System (Haddad 1989), spatial associations between abundances of fishes and land masses, man-made structures, natural reefs, submerged vegetation and water characteristics in Tampa Bay can be determined. Abundance data can also be used to examine seasonal cycles in recruitment and emigration of fishes in Tampa Bay; to estimate mortality rates of individual cohorts (Ricker 1975);

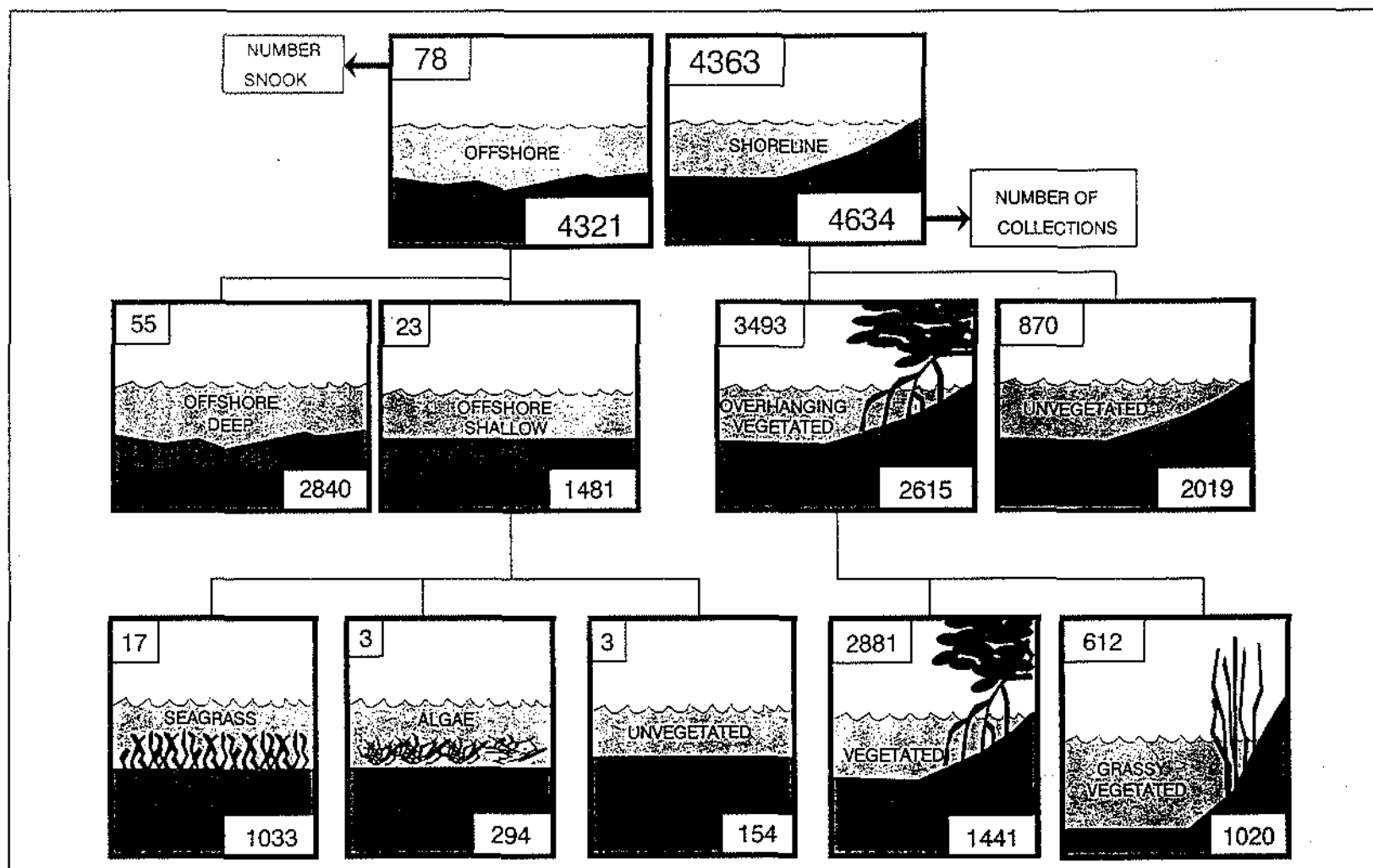


Figure 4. Characterization of habitats in which snook (*Centropomus undecimalis*) were caught in Tampa Bay.

and, in conjunction with environmental data, to examine factors that influence abundance (Tyler 1992). The statistically sound design of the FIM program allows generation of indices of relative abundance that reflect unbiased trends or shifts in Tampa Bay fish populations. Such time series allow FMRI scientists to determine if fish stocks are declining, remaining stable, or increasing over time (Muller et al. 1996). An example of this use is shown for juvenile redfish (≤ 35 mm), which recruit to Tampa Bay in the fall (Fig. 5). Notice that the relative abundance of these young has been increasing since the early 1990s which may be an indication that the redfish spawning stock in the Gulf of Mexico is recovering after being severely overfished in the mid-1980s (Goodyear 1996; Muller et al. 1996).

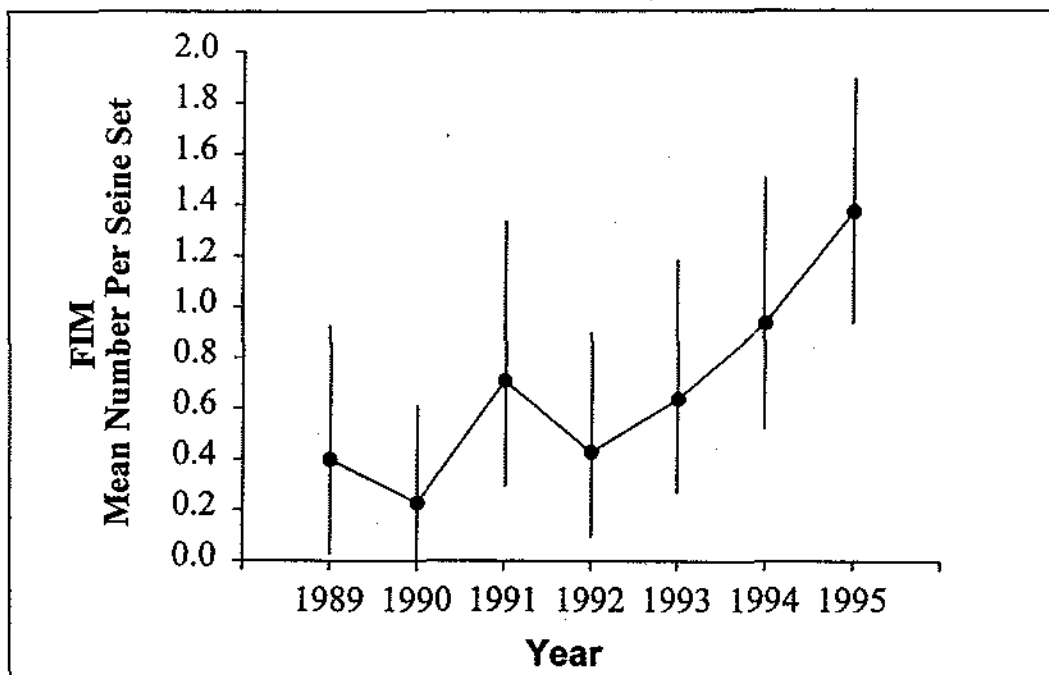


Figure 5. Indices of relative abundance of young-of-the-year redfish (*Sciaenops ocellatus*) from FDEP's Fisheries-Independent Monitoring Program during fall in Tampa Bay.

Fisheries-Dependent Monitoring Data

Commercial and recreational catch and effort data collected through the FDEP's Fisheries-Dependent Monitoring program and the NMFS' Marine Recreational Fisheries Statistics Survey are essential to the management of fisheries resources. Data on commercial landings and recreational catches provide estimates of the amount of fish removed from populations and can be used to show the direct effect of fishery regulations on landings (Ricker 1975; Pitcher and Hart 1982). For example, under restrictive management measures (slot and bag limits), recreational catches of redfish on the Gulf coast of Florida dropped from 1,243,000 fishes in 1984 to 151,000–362,000 fishes between 1989 and 1993 (Muller and Murphy 1994a). Similarly, commercial landings of all finfishes dropped by 47% from July 1995 to June 1996 after the implementation of the Florida net ban, whereas food shrimp and other invertebrates catches remained relatively constant (Fig. 6).

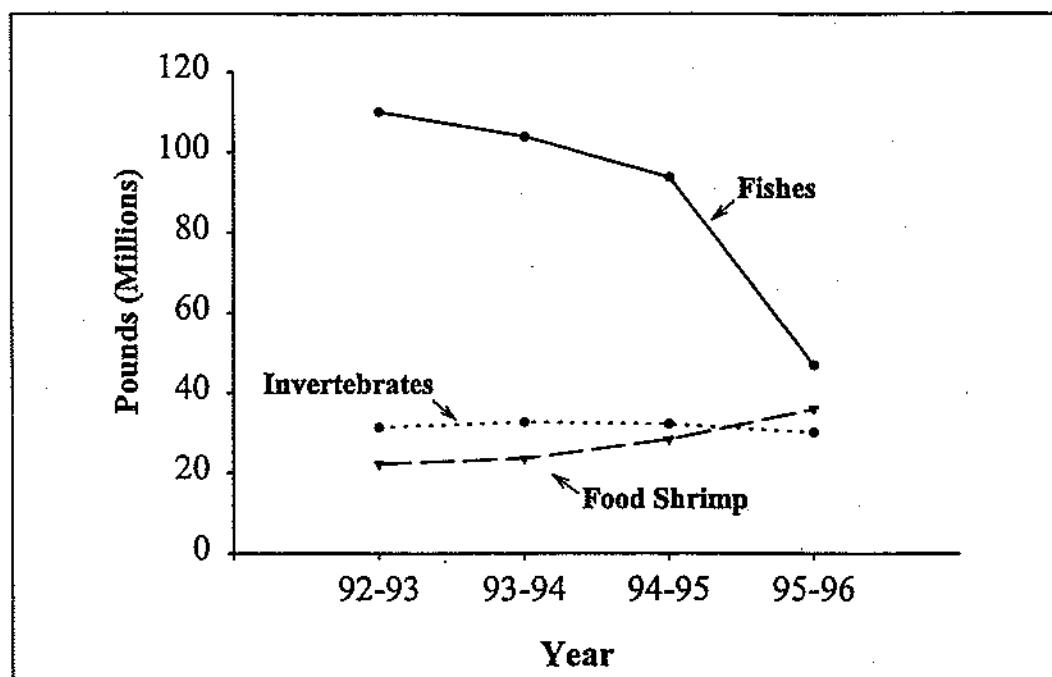


Figure 6. Summarization of Florida commercial landings of fishes, invertebrates and food shrimp from July of the first year to June of the second year for years 1992 to 1996. The Florida net ban was implemented in July 1995.

Data on commercial and recreational fishing effort can indicate when and where fishing occurs (Demory and Golden 1983). Such information can be used by resource managers to create areal or seasonal closures, to resolve gear conflicts, and to examine historical changes in spatial fishing patterns (Pitcher and Hart 1982; Demory and Golden 1983). For example, the FDM aerial survey of recreational boats showed that effort in Tampa Bay during March and April of 1996 was concentrated along the eastern shoreline of the Mullet Key / Boca Ciega Bay area, the eastern shore of Old Tampa Bay south to McDill Air Force Base, and near man-made structures such as the Skyway Bridge (Fig. 7).

Measures of fishing effort can also be used as approximations of fishing mortality. The rate of fishing mortality is a required variable in advanced fisheries assessment methods such as yield-per-recruit (YPR) analysis (Pitcher and Hart 1982), spawning biomass per recruit (SBPR) analysis (Gabriel et al. 1989), and spawning potential ratios (SPR) (Goodyear 1993), which are all used to assess the status of exploited stocks and to set harvesting restrictions (Goodyear 1993). The Florida Marine Fisheries Commission has adopted SPR as a tool to determine the status of fisheries resources and the potential need for regulating specific fish populations in the state (Taylor et al. 1996). Landings and fishing effort data from commercial and recreational fisheries can be used together to determine changes in stock abundance over time by estimating catch-per-unit-effort indices where the stock comprises the harvestable-sized individuals (Demory and Golden 1983; Malvestuto 1983). Trends in commercial and recreational relative abundance, however, may often be masked by changes in vessel power, gear types, fishing effort and patterns, experience of

fishers, unreliable reporting of catch and effort statistics, and changes in fish distribution (Ulltang 1977; Gulland 1983).

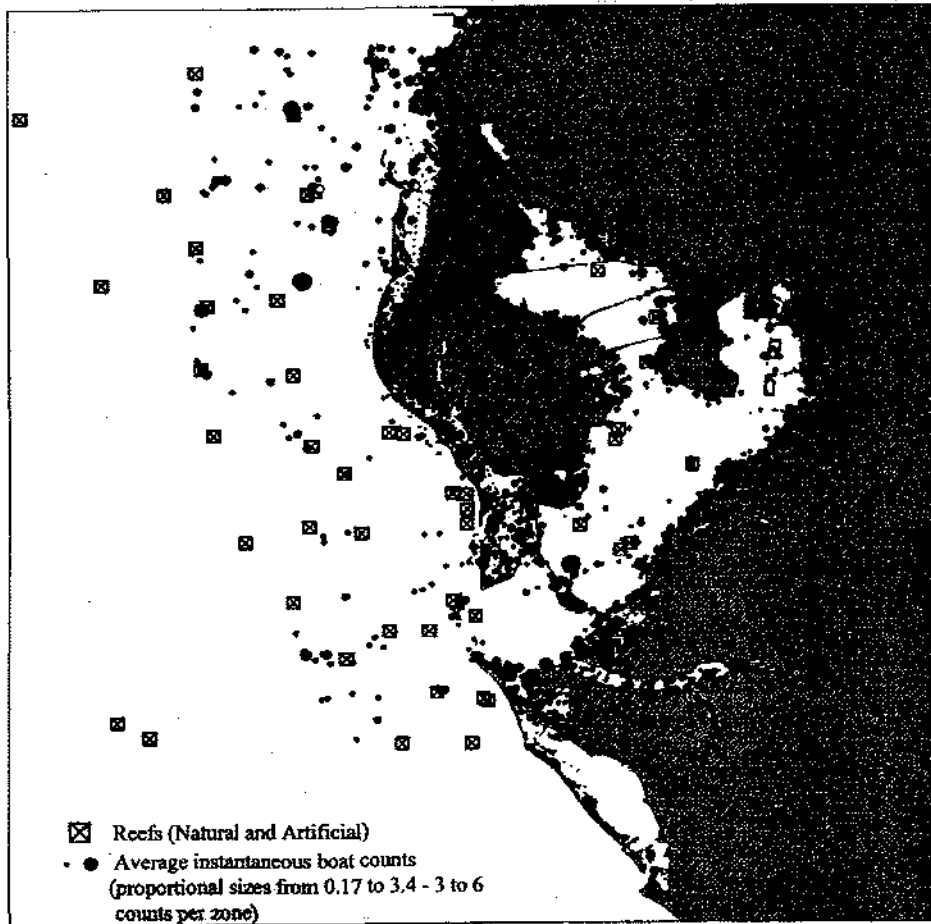


Figure 7. Instantaneous boat counts made from aerial surveys in Tampa Bay during March and April 1996.

Data from fisheries-independent and -dependent monitoring programs can be used together to examine relationships between life stages of exploited populations. Assessment scientists at FMRI use indices of juvenile fish abundance in Tampa Bay derived from the FIM program to fine-tune biomass estimates derived from virtual population analyses (Pitcher and Hart 1982) of commercial landings using procedures such as ADAPT (Mohn 1993). Spawning stock-recruitment relationships, which are useful for predicting the numbers of prefishery recruits spawned by the adult spawning biomass (Rothschild 1986), can also be derived from juvenile and adult abundance data, as shown in Figure 8 for pinfish (*Lagodon rhomboides*). A direct, positive relationship between indices of young-of-the-year abundance derived from the FIM program in Tampa Bay and adult pinfish abundance on the west coast of Florida derived from the MRFSS database indicates that when the adult abundance was high, the juvenile abundance was also high (Fig. 8). This relationship should seem

intuitively obvious, but direct spawning stock-recruitment relationships are often difficult to identify because of the marked variability in recruitment caused by random variations in demographic rates and processes (Fogarty et al. 1991). If data on prefishery recruits and exploited adults are available, relationships predicting future strengths of recruits entering a fishery can be discovered and used to make management decisions before exploitation occurs (Pitcher and Hart 1982; Rothschild 1986).

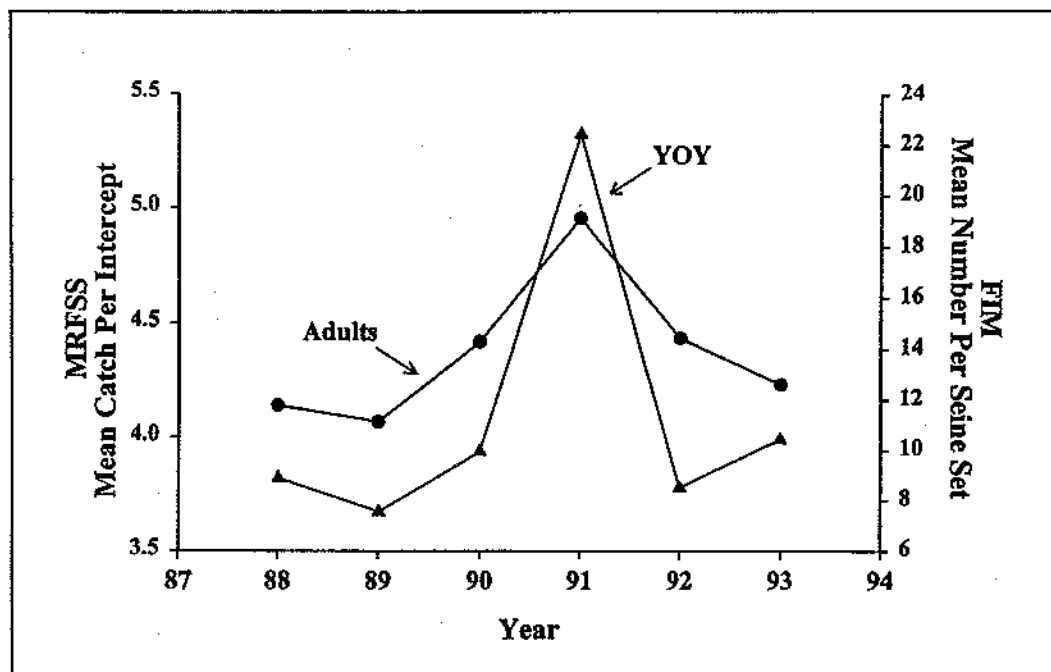


Figure 8. Indices of young-of-the-year (YOY) pinfish (*Lagodon rhomboides*) abundance in Tampa Bay from FDEP's Fisheries-Independent Monitoring Program from 1989 to 1994, and adult abundance from the NMFS' Marine Recreational Fisheries Statistics Survey from 1988 to 1993. Indices for YOY pinfish are lagged one year to match the year and adult abundance that spawned the individuals.

CONCLUDING REMARKS

Management of fisheries resources is often a complex and difficult task because little is known about the dynamic processes (e.g., mortality, growth and recruitment) that regulate fish abundance. Management with the goal of sustained harvest is an attempt to balance what fishers remove from the fish populations with what is *naturally* replenished and removed from them. If fish biomass is removed at a rate faster than it can be replenished, the fish resource will be detrimentally affected, which will ultimately affects future yields. Long-term monitoring programs like the FDEP's Fisheries-Independent and Fisheries-Dependent Monitoring Programs and the NMFS' Marine Recreational Fisheries Statistics Survey supply the information on the population biology, ecology and dynamic processes of exploited populations needed by the resource managers, biologists and general public that are concerned about the condition of Florida fisheries. Future sustained use of Florida's fisheries resources will require continued long-term monitoring of all aspects of the fisheries because

conservation and improvement of Florida's resources are high priorities of the State leadership and the Florida public.

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EGG PRODUCTION BY THE BAY ANCHOVY (*ANCHOA MITCHILLI*) IN RELATION TO ADULT AND LARVAL PREY FIELDS

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POSTER ABSTRACT

Abundances of copepod nauplii, copepodite/adult copepods, and the larvae of iteroparous anchovies (primarily the bay anchovy *Anchoa mitchilli*) were monitored in Tampa Bay, Florida at 2-week intervals for 2 years. All possible pairings of the three time-series variables yielded significant positive correlations. Nearly all (>98%) of the collected anchovy larvae occurred with prey (nauplius) densities higher than those reported to affect larval starvation (<100/L). To evaluate whether spawning was concentrated in zooplankton-rich waters, the diet of adult *A. mitchilli* was analyzed, and egg/adult prey surveys were conducted across a 290 km² area of Tampa Bay. In 5 of the 6 spatial surveys, egg abundance was correlated with abundance of calanoid copepods, a principal adult prey. Calanoids were never correlated with net plankton biomass. Calanoids were aggregated near sites of stable freshwater discharge during a dry season, but became dispersed as discharge increased during a rainy season. Among spatial surveys, egg abundance exhibited a strong relationship with calanoid aggregation ($r^2=0.96$, $n=6$, $p=0.001$). These findings suggest that the bay anchovy's size-specific fecundity is related to adult prey availability. We suggest that iteroparity serves to fine-tune reproductive effort to environmental parameters relevant to larval survival.

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TAMPA BAY BENTHOS: SPECIES COMPOSITION OF MOLLUSKS AND POLYCHAETES, 1963 vs. 1993-1995

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ABSTRACT

Comparisons of the mollusk and polychaete fauna of Tampa Bay from the 1963 Bureau of Commercial Fisheries survey and the current National Estuary Program benthic monitoring program (1993-1995) are made on the basis of species richness, evenness, and presence-absence. Some discrepancies between the two surveys can be ascribed to differences in study design and methodology; however, qualitative changes in polychaete and molluscan communities appear to indicate improvements in habitat quality in Hillsborough Bay.

INTRODUCTION

The Tampa Bay estuarine system has been the subject of a number of benthic investigations but the focus of individual studies has usually been on a particular locale or specific problem. These studies include Mote Marine Laboratory's long-term benthic monitoring program in the vicinity of the Big Bend electric generating station (Leverone et al. 1991) and a number of research projects conducted by J.L. Simon and his students at the University of South Florida (Bloom et al. 1972; Dauer and Simon 1976a, 1976b; Simon and Dauer 1977; Santos 1979; Santos and Simon 1980a, 1980b; Santos and Bloom 1983). In none of these studies, however, was the entire Tampa Bay system surveyed.

The only baywide effort was conducted in 1963 by the then Bureau of Commercial Fisheries (BCF, later National Marine Fisheries Service) Biological Laboratory at St. Petersburg Beach (Sykes 1972). Unfortunately, only limited results of this survey were published (e.g., Taylor and Saloman 1969; Taylor et al. 1970; Taylor 1971; Hall and Saloman 1975).

The objective of this report is to compare, by bay segment (cf. Lewis and Whitman 1985) the polychaete and mollusk assemblages present in 1963 with those found since 1993 in benthic monitoring studies conducted for the Tampa Bay National Estuary Program (TBNEP). The effects of confounding factors on these comparisons are also addressed.

METHODS

Study Design

The BCF sampled the Tampa Bay estuary extensively. Benthic samples were collected along 20 transects at 324 stations (Hall and Saloman 1975), of which 261 are analyzed in this study (Fig. 1). Transects crossed the long axis of the bay at two- to six-kilometer intervals; sampling locations were ≤ 1 km apart along each transect.

The design employed in the TBNEP study is a random, probability-based sampling design stratified by bay segment (VERSAR 1992; Coastal Environmental Services, Inc.

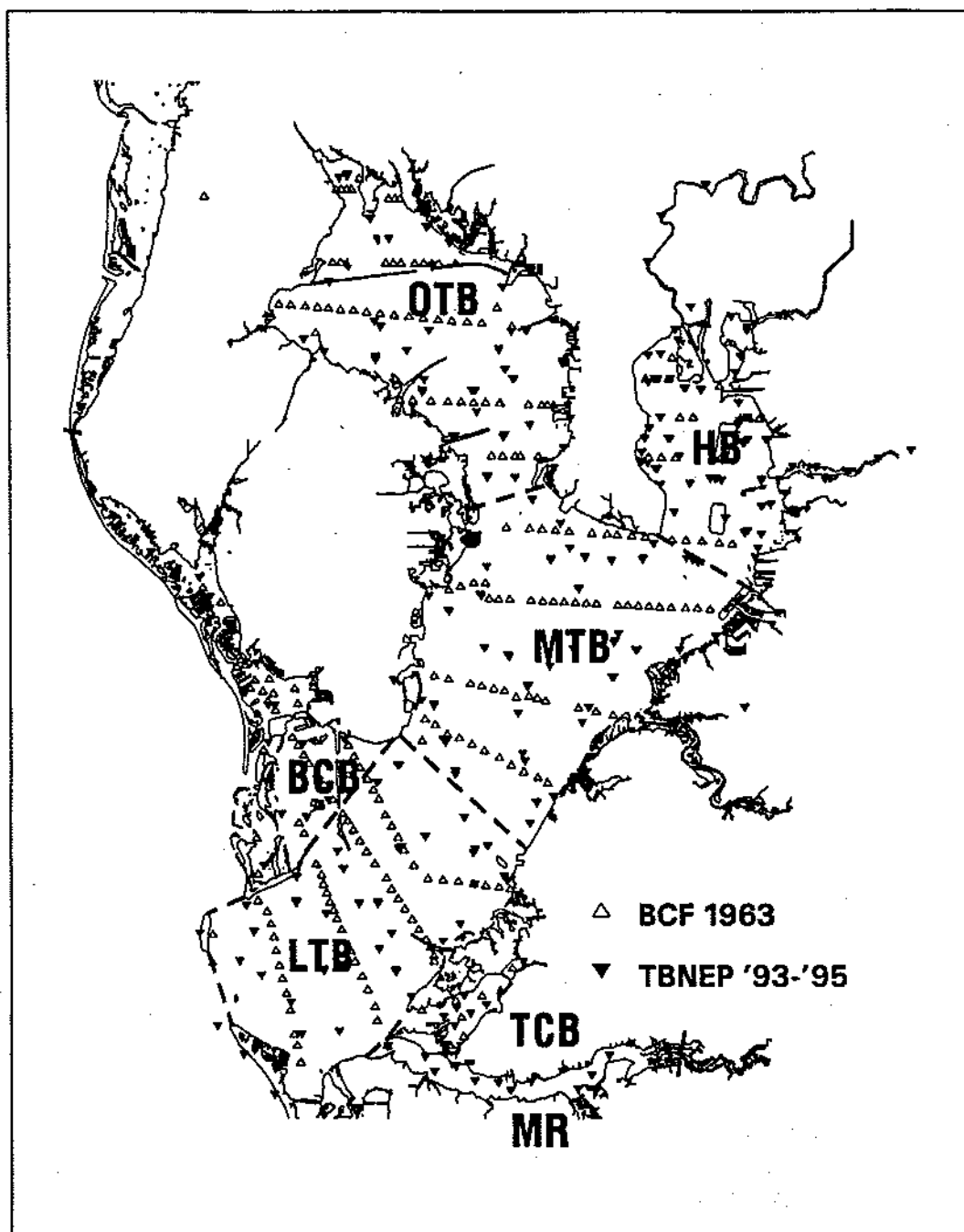


Figure 1. Sampling locations in 1963 and 1993-1995.

1994). One of three hexagonal grids was randomly superimposed over segments of Tampa Bay as follows: for the main stem of Tampa Bay (Old Tampa Bay [OTB], Middle Tampa Bay [MTB] and Lower Tampa Bay [LTB]), the grid size was 13 km^2 ; more dense grids were used for Hillsborough Bay (HB) (4.4 km^2) and for the Terra Ceia Bay (TCB), Manatee River (MR) and Boca Ciega Bay (BCB) segments (1.9 km^2). Within each hexagon, the sampling location was randomly determined, with a known probability of inclusion. Sampling locations are depicted in Figure 1. Data from the

MR and TCB segments were not analyzed because an insufficient number of samples were taken in 1963 for comparison with those taken in the TBNEP study.

The BCF sampled during June–December 1963. TBNEP sampling occurred during September and October. All bay segments were sampled in 1993–1995 with the exception of BCB, which was sampled only in 1995. Polychaetes were analyzed in only the 1993 TBNEP samples; mollusks were analyzed in the 1993 and 1994 samples; and both polychaetes and mollusks were analyzed in the 1995 BCB samples.

The BCF used different samplers for different substrates and depths. Only those samples collected with a 0.3-m wide “bucket dredge” were compared with samples collected during the TBNEP study. The BCF dredge dug to a depth of about 5 cm and was pulled about one meter, sampling approximately 0.3 m². TBNEP samples were collected with a Young-modified Van Veen grab sampler, which sampled an area of 0.04 m² to an average depth of about 10 cm.

Procedures for hydrographic measurements in the BCF survey were the standard for that time and are outlined in Taylor and Saloman (1969). Water quality measurements were made *in situ* with a Hydrolab Surveyor 3 during the TBNEP study.

The BCF samples were sieved through a 0.701-mm mesh screen and preserved in a 10% seawater-formalin solution (Taylor 1971). The TBNEP samples were sieved through a 0.5-mm mesh screen and preserved in a 10% solution of borax-buffered formalin. Rose bengal was added to stain the organisms in both studies prior to removing the animals.

Laboratory Methods

The animals were removed from the sediment and sorted into major groups under a dissecting microscope in the TBNEP study. In the BCF study, however, a dissecting microscope was used only occasionally in picking and sorting the specimens (J.L. Taylor, pers. comm.). Animals were identified to the lowest practical taxon in both studies. Two of us (WGL and THP) reviewed and corrected the identifications and the species names reported in the BCF data and confirmed those of the present study so that nomenclature would be consistent between the two studies.

Taylor and Saloman (1969) analyzed their sample sediments for a variety of grain-size characteristics of which only the percentages of silt+clay (% SC) are presented here. Sediment grain-size analyses for the BCF study were accomplished by wet sieving through a 62- μ m mesh screen (Taylor and Saloman 1969). The fraction retained on the screen was then dried and processed through a series of sieves. The particles that passed through the sieve were measured with a Coulter counter. Subsample cores were taken from the sediment grabs and grain size was analyzed only for % SC (<63 μ m) in the TBNEP study (see Courtney et al. 1993).

Data Analyses

We compared the BCF assemblages with those obtained in the TBNEP study from each bay segment using measures of species richness (S), evenness (J'), and similarity.

The most frequently occurring polychaete and mollusk taxa and the percentages of polychaete and mollusk species unique to each segment were compared between the two studies. Species richness (S) is the number of distinct taxa, and evenness (J') is the apportionment of individuals among the species present (Pielou 1975). Similarity was based on the Jaccard "presence-absence" index (Boesch 1977). Only presence-absence, a binary measure of resemblance, was appropriate because of the effects of sieve size on abundance estimates (Reish 1959; James et al. 1995). The software used for these analyses was Bloom's (1994) *Community Analysis System*. The Kolmogorov-Smirnov test (Sokal and Rohlf 1981) was used to test for differences in the frequency distribution of % SC within each bay segment, by survey period. Analysis of variance (ANOVA, Sokal and Rohlf 1981) was used to test for differences in mean species richness and evenness between survey periods for each bay segment. Species richness was $\ln(n+1)$ transformed and evenness was arc sine transformed prior to testing in order to normalize the distributions (Sokal and Rohlf 1981). Statistical tests were computed using the SYSTAT software package (Wilkinson 1992).

RESULTS

Bay Segment Characteristics

Percent Silt+Clay: The frequency distribution of % SC showed no difference ($p > 0.05$) between survey periods for OTB and HB (Fig. 2; Table 1). Significant differences ($p < 0.01$) in % SC distributions (Table 1) were observed for MTB, LTB, and BCB (Fig. 2).

Hydrographic Data: The mean station depth of all bay segments (Table 1) was greater in 1963 than in 1993–95. Mean water temperature (Table 1) showed some differences between the two sampling periods: mean water temperatures of OTB and HB were higher in 1963, while mean water temperatures were lower in 1963 in LTB and BCB. Mean salinity (Table 1) was slightly higher in 1963 than in 1993–95 in all bay segments.

Table 1. The mean percentage of silt+clay in sediments, mean sample depth, mean near-bottom water temperature, and mean near-bottom salinity by bay segment and survey period.

BAY SEGMENT	PERIOD	PERCENT SILT+CLAY	DEPTH (m)	TEMPERATURE (°C)	SALINITY (ppt)
Old Tampa Bay	1963	7.0	3.3	30.1	24.7
	1993–95	7.3	2.0	28.6	21.1
Hillsborough Bay	1963	16.4	3.6	30.3	20.5
	1993–95	18.7	2.2	29.3	19.8
Middle Tampa Bay	1963	16.4	5.5	28.9	24.3
	1993–95	3.3	2.6	29.3	24.1
Lower Tampa Bay	1963	2.1	5.0	23.4	32.8
	1993–95	2.5	4.4	28.9	29.4
Boca Ciega Bay	1963	14.4	2.8	23.0	33.1
	1995	7.5	1.4	27.3	30.2

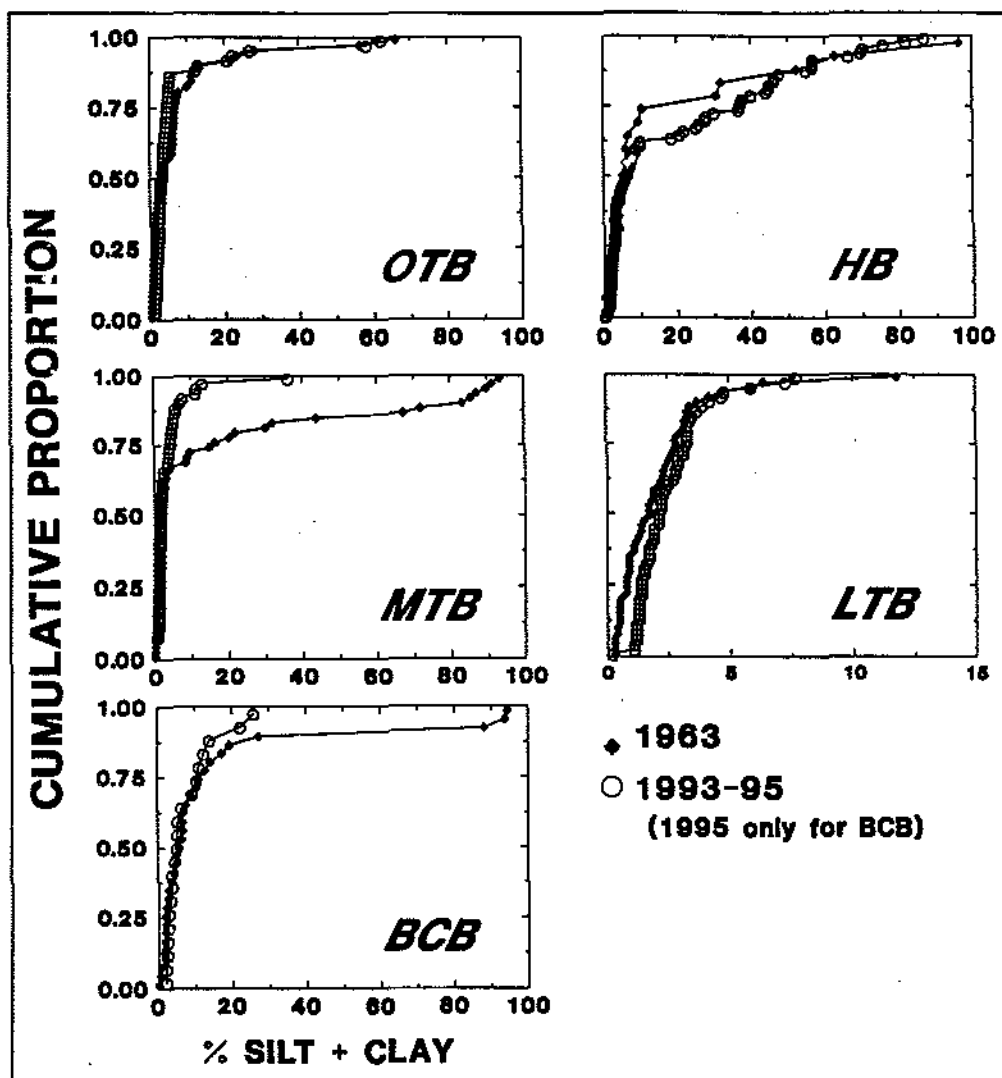


Figure 2. Frequency distribution of percent silt+clay for each bay segment in 1963 vs. 1993-1995 (1963 vs. 1995 only for BCB).

Polychaetes

Number of Species: No significant difference between the two studies was evident in the mean number of polychaete taxa present in OTB, MTB, LTB, or BCB 1995 (Table 2, Fig. 3). The number of polychaete species present in HB was significantly higher in 1993 than in 1963.

Evenness: Mean J' of polychaetes in OTB, HB, and LTB (Fig. 4) was significantly higher in 1993 than in 1963 (Table 2). Mean J' was not significantly different between sampling periods in MTB or BCB (Table 2, Fig. 4).

Species Similarity and Occurrence: Jaccard coefficients for the two study periods ranged from 24% (LTB) to 32% (HB) (Table 3). The percentage of species unique to the BCF samples ranged from 12% (HB) to 33% (OTB and BCB), whereas the percentages of polychaetes unique to the TBNEP survey ranged from 36% (OTB) to

56% (HB)(Table 3). Table 4 shows the most frequently occurring (>50% or top five) polychaete taxa in each bay segment during both surveys.

Table 2. ANOVA for species richness (S) and evenness (J') by bay segment; BCF survey vs. TBNEP survey (S data $\ln(n+1)$ transformed; J' data arc sine transformed). df = degrees of freedom. Significant results ($p < 0.05$) are indicated by asterisks.

BAY SEGMENT	TAXON	SPECIES RICHNESS (S)			EVENNESS (J')	
		df	F-ratio	p	F-ratio	p
Old Tampa Bay	Polychaetes	(1,94)	0.09	0.77	5.94	0.02*
	Mollusks	(1,93)	3.35	0.07	0.81	0.37
Hillsborough Bay	Polychaetes	(1,62)	11.80	0.00*	3.99	0.05
	Mollusks	(1,67)	6.28	0.02*	0.65	0.42
Middle Tampa Bay	Polychaetes	(1,96)	0.40	0.53	3.07	0.08
	Mollusks	(1,101)	16.60	0.00*	0.12	0.73
Lower Tampa Bay	Polychaetes	(1,93)	3.44	0.07	7.59	0.01*
	Mollusks	(1,94)	3.32	0.07	0.84	0.36
Boca Ciega Bay	Polychaetes	(1,65)	0.05	0.82	0.06	0.80
	Mollusks	(2,61)	4.84	0.01*	3.65	0.03*

Table 3. Total polychaete taxa present, 1963, 1993 and 1995 (BCB); species richness (S) by survey and overall; percent taxa common (Jaccard coefficient) and unique to each study by bay segment.

BAY SEGMENT	SPECIES RICHNESS (S)		TOTAL SPECIES	JACCARD COEFF. (%)	UNIQUE (%)	
	1963	1993-95			1963	1993/95
Old Tampa Bay	74	78	116	31	33	36
Hillsborough Bay	42	85	96	32	12	56
Middle Tampa Bay	90	109	154	29	29	42
Lower Tampa Bay	123	191	254	24	25	51
Boca Ciega Bay	123	141	210	26	33	41

Mollusks

Number of Species: There was no significant difference in the number of molluscan taxa between the two studies in OTB or LTB (Table 2, Fig. 5). However, the mean number of mollusk taxa was significantly higher in 1993-94 in HB and MTB and in BCB in 1995 (Table 2, Fig. 5).

Evenness: Significant difference in the mean J' of mollusks between the two studies was observed only in BCB (Table 2) where J' was higher in 1995 than in 1963 (Fig. 6).

Species Similarity and Occurrence: Similarity of mollusk taxa between the two studies ranged from 14% (HB) to 36% (BCB) (Table 5). The number of unique taxa collected in 1963 ranged from 29% (HB) to 60% (LTB); the percentage of taxa unique to the TBNEP survey ranged from 17% (LTB) to 58% (HB) (Table 5).

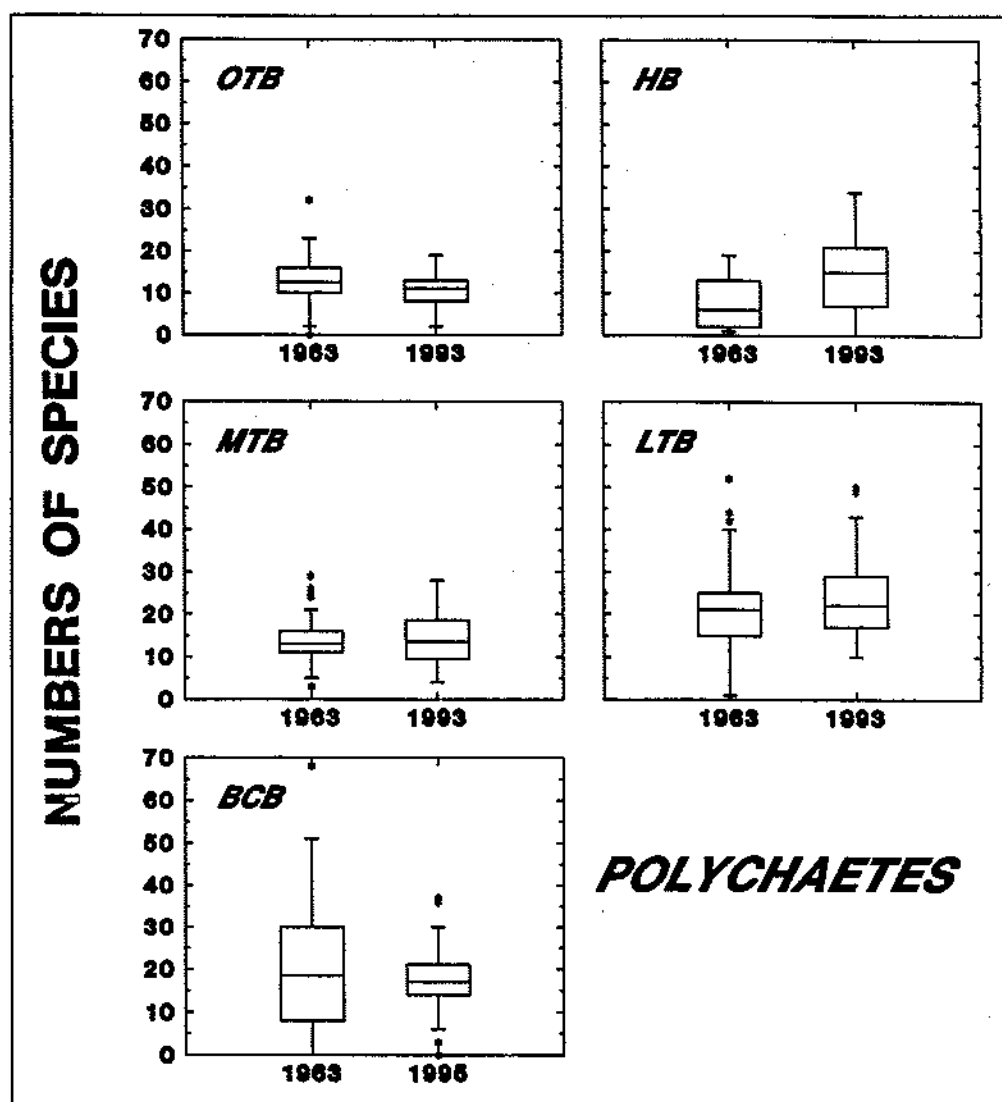


Figure 3. Polychaete species richness (S) of each bay segment in 1963 vs. 1993 and 1995 (BCB). Horizontal lines represent the sample median; boxes represent the first and third quartiles of the sample distribution, and bars represent 1.5 of the interquartile range beyond the box. Outlying values are indicated by asterisks (Wilkinson 1992).

Table 4 shows the most frequently occurring (>50% or top five species or species groups) mollusks by bay segment from both studies.

DISCUSSION

Observed trends in water quality and seagrass coverage during the past 20 years indicate improvement in the habitat quality of Tampa Bay, particularly of Hillsborough Bay (Johansson 1991; Lewis et al. 1991; Boler 1995). A dramatic improvement in overall water quality, attributed to improvements in sewage treatment (Johansson 1991; Boler 1995), has been observed in Hillsborough Bay since the early 1980s. The qualitative changes in the polychaete and molluscan communities between the BCF and TBNEP studies reported here also appear to indicate improvements in habitat quality in that segment of the bay.

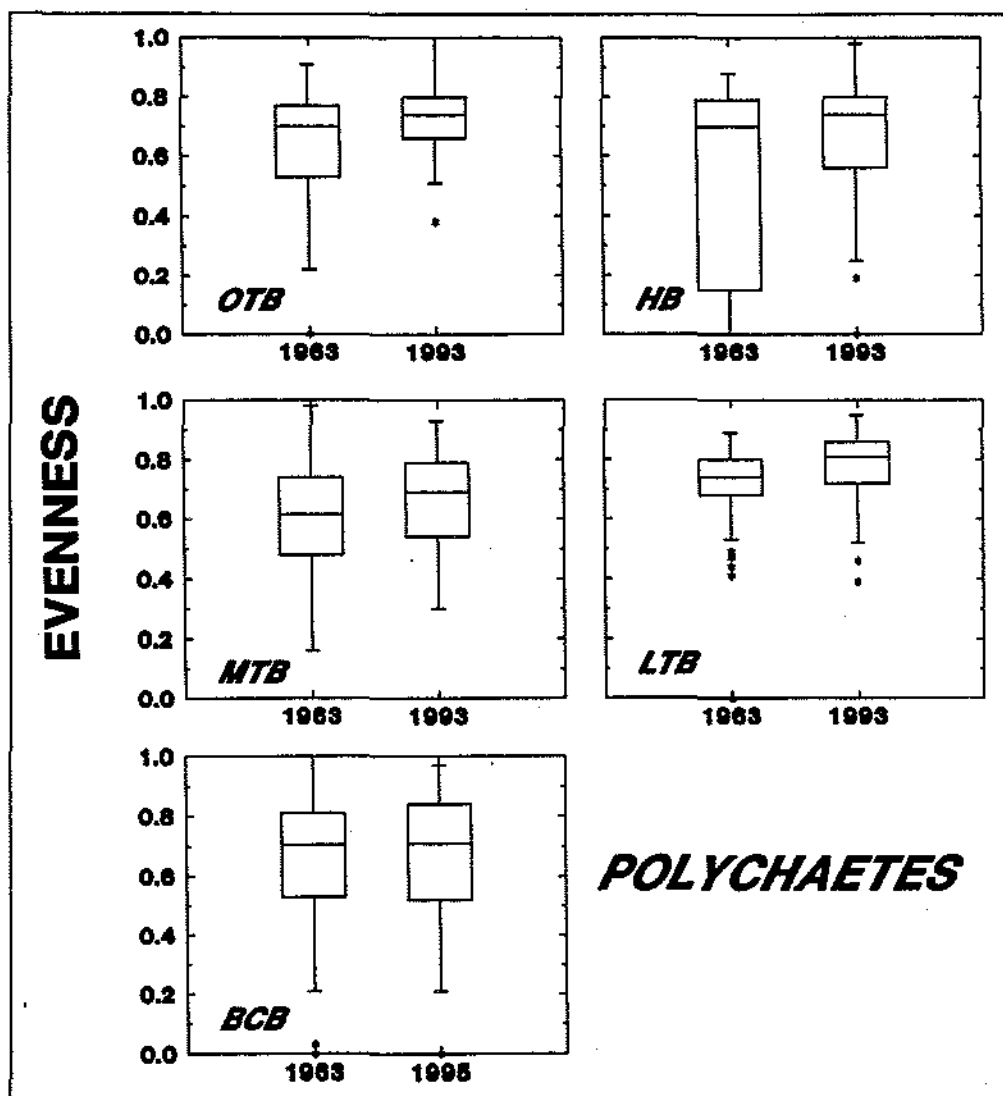


Figure 4. Polychaete species evenness (J') of each bay segment in 1963 vs. 1993 and 1995 (BCB). Horizontal lines represent the sample median; boxes represent the first and third quartiles of the sample distribution, and bars represent 1.5 of the interquartile range beyond the box. Outlying values are indicated by asterisks (Wilkinson 1992).

Overall, the hydrographic and sediment characteristics were fairly similar between the two sampling periods, and any observed variations can likely be explained by differing seasons of the sampling (e.g., lower water temperature in 1963 in Lower Tampa Bay and Boca Ciega Bay was due to sampling in November and December). Additionally, the large differences between the two studies in the % SC of sediments in Middle Tampa Bay and Boca Ciega Bay (Table 1) are believed to be the result of sampling at a few stations that had extremely high % SC (Fig. 2).

Number of Species

Reduced benthic species richness has often been associated with stressed systems (Dauer 1993; Dauer and Alden 1995). Any observed increase in the number of species could then be interpreted as an indication of improved habitat quality. In fact,

Hillsborough Bay showed a significant increase in the number of both polychaete and mollusk taxa present between the two studies, with the mean number of polychaete taxa per sample being nearly twice as high in 1993 than in 1963. The mean number of mollusk taxa was also higher during the 1993–94 study period in Hillsborough Bay, Middle Tampa Bay, and Boca Ciega Bay (1995). The total number of mollusk taxa in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay was higher in 1963 than in 1993–94, but the means were not significantly different.

Table 4. Ranked frequency of occurrence of polychaetes (1963 vs. 1993 and 1995 [BCB] and mollusks (1963 vs. 1993–94 and 1995 [BCB]). Taxa occurred either in $\geq 50\%$ of the samples or constituted the five highest frequencies occurring among taxa (ties counted as equal rank). Dotted line represents $\geq 50\%$ frequency of occurrence where top five taxa are listed. n=number of samples.

OLD TAMPA BAY					
Polychaetes		1963	%	1993	%
n=62				n=17	
<i>Paraprionospio pinnata</i>			88.71	<i>Prionospio perkinsi</i>	88.24
<i>Glycera americana</i>			83.87	<i>Mediomastus</i> spp.	82.35
<i>Glycinde solitaria</i>			69.35	<i>Prionospio pygmaea</i>	70.59
<i>Spiochaetopterus costarum</i>			66.13	<i>Phyllodoce arenae</i>	64.71
<i>Neanthes succinea</i>			59.68	<i>Paraprionospio pinnata</i>	58.82
<i>Scoloplos rubra</i>			58.06	<i>Sthenelais</i> sp. A	58.82
<i>Podarkeopsis levifuscina</i>			53.23	<i>Travisia hobsonae</i>	52.94
<i>Phyllodoce arenae</i>			51.61		
Mollusks		1963		1993–94	
n=61				n=34	
<i>Nassarius vibex</i>			65.57	<i>Nucula crenulata</i>	76.47
<i>Tellina versicolor</i>			63.93	<i>Prunum apicinum</i>	73.53
<i>Macoma tenta</i>			45.90	<i>Olivella</i> sp.	64.71
<i>Tagelus divisus</i>			39.34	<i>Diplodonta semiaspera</i>	61.76
<i>Mulinia lateralis</i>			39.34	<i>Tellina versicolor</i>	58.82
<i>Bittium varium</i>			36.07		
HILLSBOROUGH BAY					
Polychaetes		1963	%	1993	%
n=26				n=19	
<i>Spiochaetopterus costarum</i>			76.92	<i>Prionospio perkinsi</i>	94.74
<i>Streblospio benedicti</i>			61.54	<i>Podarkeopsis levifuscina</i>	89.47
<i>Paraprionospio pinnata</i>			61.54	<i>Paraprionospio pinnata</i>	89.47
<i>Polydora websteri</i>			50.00	<i>Carazziella hobsonae</i>	73.68
<i>Neanthes succinea</i>			50.00	<i>Mediomastus ambiseta</i>	57.89
<i>Diopatra cuprea</i>			46.15	<i>Neanthes succinea</i>	57.89
<i>Parabesione luteola</i>			42.31	<i>Glycinde solitaria</i>	57.89
				<i>Sigambra tentaculata</i>	57.89
				<i>Pseudeurythoe</i> sp.	52.63
				<i>Scoloplos rubra</i>	52.63
Mollusks		1963		1993–94	
n=31				n=38	
<i>Mulinia lateralis</i>			51.61	<i>Mysella planulata</i>	60.53
<i>Nassarius vibex</i>			32.26	<i>Tellina versicolor</i>	44.74
<i>Amygdalum payprum</i>			32.26	<i>Prunum apicinum</i>	44.74

(continued)

Table 4 continued.

(HILLSBOROUGH BAY)

<i>Tellina versicolor</i>	16.13	<i>Tellina</i> spp.	31.58
<i>Mercenaria</i> sp.	16.13	<i>Amygdalum papyrium</i>	31.58
<i>Ensis minor</i>	16.13	<i>Tectonatica pusilla</i>	26.32
<i>Tagelus plebeius</i>	12.90	<i>Rictaxis punctostriatus</i>	26.32
<i>Macoma tenta</i>	12.90	<i>Mulinia lateralis</i>	26.32
<i>Astiris lunulata</i>	9.68	<i>Acteocina canaliculata</i>	26.32
<i>Asthenothaerus</i> sp. A	9.68	<i>Parvilucina multilineata</i>	21.05

MIDDLE TAMPA BAY

Polychaetes	1963	%	1993	%
n=62			n=20	
<i>Neanthes succinea</i>		69.35	<i>Prionospio perkinsi</i>	85.00
<i>Phyllodoce arenae</i>		67.74	<i>Mediomastus</i> spp.	80.00
<i>Glycinde solitaria</i>		58.06	<i>Phyllodoce arenae</i>	75.00
<i>Spiochaetopterus costarum</i>		54.84	<i>Travisia hobsonae</i>	65.00
<i>Travisia hobsonae</i>		51.61	<i>Malmgreniella maccroryae</i>	55.00
<i>Podarkeopsis levifuscina</i>		50.00	<i>Nephtys</i> cf. <i>homborgii</i>	55.00
<i>Paraprionospio pinnata</i>		50.00	<i>Podarkeopsis levifuscina</i>	50.00
			<i>Brania wellfleetensis</i>	50.00
			<i>Prionospio pygmaea</i>	50.00

Mollusks	1963	%	1993-94	%
n=63			n=40	
<i>Nucula crenulata</i>		42.86	<i>Nucula crenulata</i>	70.00
<i>Tellina versicolor</i>		34.92	<i>Diplodonta semiaspera</i>	70.00
<i>Mercenaria</i> sp.		34.92	<i>Prunum apicinum</i>	60.00
<i>Crepidula plana</i>		30.16	<i>Caecum strigosum</i>	52.50
<i>Diplodonta semiaspera</i>		25.40	<i>Tellina</i> spp.	45.00
<i>Crassinella lunulata</i>		25.40	<i>Tornatina inconspicua</i>	45.00
<i>Anadara transversa</i>		25.40	<i>Tectonatica pusilla</i>	45.00
<i>Oliva sayana</i>		23.81	<i>Parvilucina multilineata</i>	45.00
			<i>Tellina versicolor</i>	42.50

LOWER TAMPA BAY

Polychaetes	1963	%	1993	%
n=61			n=17	
<i>Phyllodoce arenae</i>		81.97	<i>Prionospio perkinsi</i>	76.47
<i>Axiobella mucosa</i>		81.97	<i>Armandia maculata</i>	76.47
<i>Travisia hobsonae</i>		77.05	<i>Travisia hobsonae</i>	70.59
<i>Ophelina</i> sp.		59.02	<i>Phyllodoce arenae</i>	70.59
<i>Mooreonuphis</i> sp. A		59.02	<i>Prionospio steenstrupi</i>	70.59
<i>Isolda pulchella</i>		59.02	<i>Sphaerosyllis taylori</i>	64.71
<i>Scoloplos rubra</i>		57.38	<i>Spio pettiboneae</i>	64.71
<i>Exogone dispar</i>		57.38	<i>Mediomastus californiensis</i>	58.82
			<i>Prionospio pygmaea</i>	58.82
			<i>Syllis cornuta</i>	58.82
			<i>Brania</i> sp. A	52.94
			<i>Poecilochaetus johnsoni</i>	52.94
			<i>Exogone dispar</i>	52.94
			<i>Prionospio cristata</i>	52.94
			<i>Cautleriella</i> sp. D	52.94
			<i>Galathowenia</i> sp.	52.94

(continued)

Table 4 concluded.

(LOWER TAMPA BAY)					
Mollusks			1993-94		
n=62			n=34		
<i>Crepidula plana</i>	66.13		<i>Nucula crenulata</i>	73.53	
<i>Tellina versicolor</i>	64.52		<i>Olivella</i> sp.	64.71	
<i>Crassinella lunulata</i>	56.45		<i>Diplodonta semiaspera</i>	58.82	
<i>Nucula crenulata</i>	54.84		<i>Tornatina inconspicua</i>	52.94	
<i>Chione cancellata</i>	50.00		<i>Tellina</i> spp.	52.94	
			<i>Tectonatica pusilla</i>	52.94	
			<i>Caecum strigosum</i>	50.00	
BOCA CIEGA BAY					
Polychaetes			1995		
1963			1995		
n=45			n=21		
<i>Paraprionospio pinnata</i>	75.56		<i>Paraprionospio pinnata</i>	61.90	
<i>Glycinde solitaria</i>	64.44		<i>Monticellina dorsobranchialis</i>	61.90	
<i>Streblospio benedicti</i>	57.78		<i>Podarkeopsis levifusca</i>	57.14	
<i>Spiochaetopterus costarum</i>	57.78		<i>Prionospio pygmaea</i>	47.62	
<i>Aricidea</i> cf. <i>fragilis</i>	57.78		<i>Mooreonuphis</i> sp. A	47.62	
<i>Monticellina dorsobranchialis</i>	55.56		<i>Glycinde solitaria</i>	47.62	
<i>Axiobella mucosa</i>	55.56		<i>Nereis acuminata</i>	42.86	
<i>Polydora socialis</i>	51.11		<i>Carazziella hobsonae</i>	38.10	
<i>Diopatra cuprea</i>	51.11				
Mollusks			1995		
1963			1995		
n=44			n=21		
<i>Tellina versicolor</i>	54.55		<i>Tellina</i> spp.	80.95	
<i>Nassarius vibex</i>	50.00		<i>Parvilucina multilineata</i>	61.90	
<i>Prunum apicinum</i>	45.45		<i>Tellina versicolor</i>	47.62	
<i>Chione cancellata</i>	40.91		<i>Mysella planulata</i>	47.62	
<i>Parvilucina multilineata</i>	27.27		<i>Jaspidella blanesi</i>	42.86	
<i>Laevicardium mortoni</i>	27.27		<i>Prunum apicinum</i>	38.10	
			<i>Nucula crenulata</i>	38.10	
			<i>Acteocina canaliculata</i>	38.10	

Table 5. Total molluscan taxa present; 1963, 1993-94 and 1995 (BCB); species richness (S) by survey and overall; percent taxa common (Jaccard coefficient) and unique to each study by bay segment.

BAY SEGMENT	SPECIES RICHNESS (S)		TOTAL SPECIES	JACCARD COEFF. (%)	UNIQUE (%)	
	1963	1993-94/95			1963	1993-94/95
Old Tampa Bay	70	57	95	34	40	26
Hillsborough Bay	28	47	66	14	29	58
Middle Tampa Bay	93	79	129	33	39	28
Lower Tampa Bay	153	75	185	23	60	17
Boca Ciega Bay	94	95	139	36	32	32

Evenness

Leverone et al. (1991) observed a general trend of decreasing J' during the summer and autumn months and increasing J' in the spring. Because the sampling periods of the two studies were similar, seasonality does not appear to account for the significant

increases in J' for polychaetes and mollusks observed in Hillsborough Bay, Old Tampa Bay, Lower Tampa Bay and Boca Ciega Bay.

Evenness trends can also be interpreted as an indication of improving habitat quality. Typically, stressed habitats show a large percentage of the faunal abundance concentrated in one or a few species (Dauer 1993). The general increase of S and J' , particularly for Hillsborough Bay, is a positive sign for the overall health of the bay.

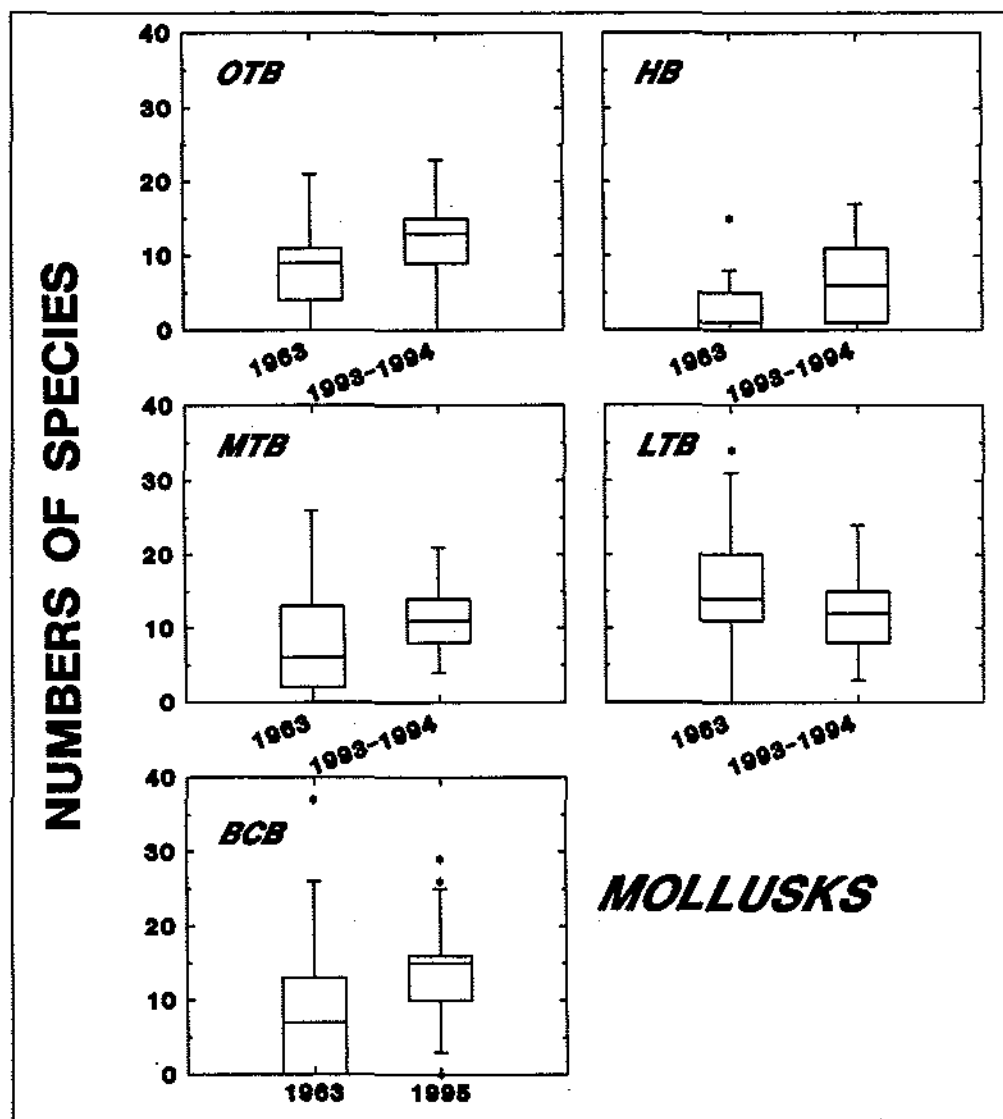


Figure 5. Mollusk species richness (S) of each bay segment in 1963 vs. 1993-94 and 1995 (BCB). Horizontal lines represent the sample median; boxes represent the first and third quartiles of the sample distribution, and bars represent 1.5 of the interquartile range beyond the box. Outlying values are indicated by asterisks (Wilkinson 1992).

Species Occurrence

Each of the bay segments showed low similarity (24% to 32%) of polychaete taxa between the two studies. These low similarity values indicate that changes in polychaete community structure have occurred since the 1963 survey. However, in

Lower Tampa Bay (similarity=23%), this may have been affected by seasonality since samples were collected during October to December in 1963 rather than during September.

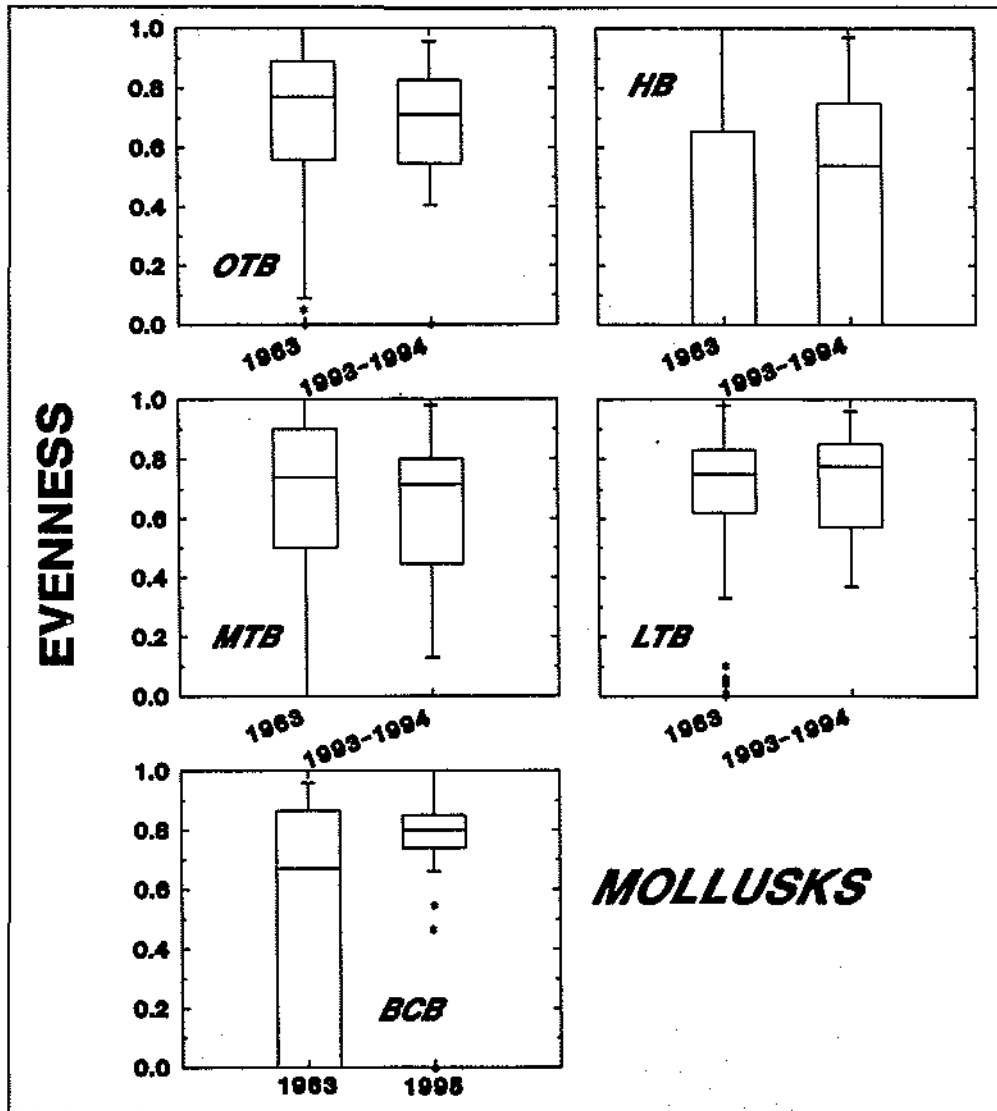


Figure 6. Mollusk species evenness (J') of each bay segment in 1963 vs. 1993-94 and 1995 (BCB). Horizontal lines represent the sample median; boxes represent the first and third quartiles of the sample distribution, and bars represent 1.5 of the interquartile range beyond the box. Outlying values are indicated by asterisks (Wilkinson 1992).

Because of the differences in the sampling design and the sieve mesh sizes used in the two studies, we cannot accurately compare the quantitative results of the two studies. The sieve mesh sizes employed in these two studies (0.7 mm vs. 0.5 mm) have been shown to strongly affect the number of individuals apparently present, although the number of taxa should not be significantly affected (Reish 1959; James et al. 1995). Frequency of occurrence would also have been less affected than the number of individuals sampled. Most of the frequently occurring polychaete species (e.g.,

Paraprionospio pinnata, *Prionospio perkinsi*, *Glycinde solitaria*, and *Phyllodoce arenae*) were present in both studies.

One particularly enigmatic polychaete genus is the capitellid *Mediomastus*. Two species of *Mediomastus* are known to occur in Tampa Bay, *M. ambiseta* and *M. californiensis* (Ewing 1984; Grabe et al. 1996). These species are notoriously difficult to identify to the species level; nevertheless, neither was detected in the 1963 survey (Taylor 1971). As a group, however, they were dominant in several bay segments in 1993 in both abundance and frequency of occurrence. *Mediomastus californiensis* was also reported off Ballast Point by Santos and Bloom (1983), and "*Mediomastus* spp." was identified from the Tampa Harbor Project by Amson (1988).

Capitellids are generally believed to be nonselective deposit feeders (Fauchald and Jumars 1979). Both species of *Mediomastus* are reported to occur in fine, muddy sand, and *M. ambiseta* is known to construct a mucus tube (Warren et al. 1994). *Mediomastus* has been considered to be an opportunistic genus and has been interpreted to be an indicator of organic enrichment in several past studies (Grassle and Grassle 1974, 1976; Dauer and Alden 1995; Chapman et al., 1996). However, this is apparently contradicted by our observations. In 1993, *Mediomastus* occurred most frequently (in >80% of samples) in Old Tampa Bay, Middle Tampa Bay, and Lower Tampa Bay. Each of these segments appears to have healthy benthic habitats with low % SC content and acceptable bottom dissolved oxygen levels (Grabe et al. 1996). Furthermore, both *Mediomastus ambiseta* and *M. californiensis* are common in well-oxygenated, coarse sand in nearshore areas off Hutchinson Island on the southeast coast of Florida (THP, pers. obs.). It is more likely that, rather than being an indicator of organic enrichment, *Mediomastus* has broad habitat requirements and is adapted to a diverse set of environments. The absence of *Mediomastus* in the BCF survey may also be a result of the larger sieve size. However, as previously discussed, sieve size is believed to more strongly affect the apparent abundance rather than occurrence of species. Thus, it seems that the presence of *Mediomastus* in the TBNEP survey may indicate a significant change in the benthic fauna, but does not necessarily indicate degradation in the benthic habitat over time.

Noteworthy among the mollusks is *Mulinia lateralis*, a eurytopic species (Dauer and Alden 1995). This was the most frequently occurring mollusk in Hillsborough Bay in 1963. *Mulinia lateralis*, however, was not among the most frequently occurring species there during the 1993–94 study. Although seasonality can affect the species present to some extent, Hillsborough Bay was largely sampled during the same season in both studies. Furthermore, the presence of *M. lateralis* tends to fluctuate and may be affected by changes in salinity (Walker and Tenore 1984). However, little difference in salinity was seen between the two studies. *Mulinia lateralis* is considered to be an opportunistic species and is associated with degraded habitats (Dauer and Alden 1995). The decrease in frequency of *M. lateralis*, therefore, may be interpreted as an indication of improving benthic habitat in Hillsborough Bay.

Overall, the higher S and J' values seen in the 1993–1995 TBNEP survey of both polychaetes and mollusks relative to the 1963 BCF survey seem to indicate an overall

improvement in the benthic habitat quality. This improvement is most notable in Hillsborough Bay.

ACKNOWLEDGMENTS

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SURVIVAL OF ORGANISMS ENTRAINMENT BY THE ANCLOTE POWER PLANT NEAR TARPON SPRINGS, FLORIDA

B.R. Melton

POSTER ABSTRACT

Florida Power Corporation (FPC) owns and operates the Anclote Power Plant at the mouth of the Anclote River on the Gulf of Mexico near Tarpon Springs, Florida. The circulating water system for the plant consists of six circulating water pumps, four cooling tower pumps serving two sidestream mechanical draft cooling towers, and four dilution pumps. The dilution pumps transfer cooler water from the intake canal to the discharge canal and are capable at times of achieving FPC's thermal discharge limitations. However, dilution pump usage has been severely limited by the NPDES permit because of the agency assumption that no zooplankton survived after passing through these pumps. During a recent renewal of the NPDES permit for Anclote, FPC agreed to perform a study of entrainment survival through the plant during September and November 1995. The results of this study demonstrated that overall entrainment survival for selected life stages and species of zooplankton, including ichthyoplankton, was significantly greater than had been previously hypothesized. Interestingly, the data demonstrated that significant survival occurred through the unit condensers, where a temperature differential of up to 7°C may be experienced. This information was used by the Florida Department of Environmental Protection as the basis for a permit revision allowing increased usage of the dilution pumps for control of thermal discharges.

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ABUNDANCE AND DISTRIBUTION OF MARINE TURTLES IN TAMPA BAY

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STUDENT POSTER ABSTRACT

Four species of marine turtles (*Lepidochelys kempii*, *Chelonia mydas*, *Caretta caretta* and *Eretmochelys imbricata*) occur in the Tampa Bay area. All are listed as either threatened or endangered under the Endangered Species Act. In the past, very little has been documented on marine turtle abundance and distribution in Tampa Bay. A recent grant from the Tampa Bay National Estuary Program was used to evaluate existing monitoring programs for marine turtles in the area, and to develop recommendations for future assessment of the status and distribution of these animals. A byproduct of this work was the first synthesis of information about the occurrence of marine turtles in Tampa Bay depicted in thirteen Geographic Information System (GIS) coverages and incorporated into the Florida Marine Research Institute's Marine Resources GIS. These maps show nesting, stranding and in-water distributions of marine turtles in Tampa Bay. Future studies will involve overlaying and analyzing these coverages to identify patterns of marine turtle habitat use, seasonality and mortality factors in Tampa Bay. These evaluations will assist in identifying important habitats for marine turtles in Tampa Bay.

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LOW LEVEL MONITORING OF BOTTLENOSE DOLPHINS, *TURSIOPS TRUNCATUS*, IN TAMPA BAY, FLORIDA

K.W. Urian
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R.S. Wells

ABSTRACT

Systematic photographic identification census surveys of bottlenose dolphins, *Tursiops truncatus*, were conducted in Tampa Bay waters during September–October 1988–1993. The main goals of these surveys were to detect large-scale changes in dolphin abundance and to establish archival databases for long term trend detection. The findings from these surveys help to determine if modification of management plans is necessary.

Photographs taken during the 1988–1993 NMFS surveys, which included 858 different dolphins, built on an existing Tampa Bay catalog of 150 animals identified during 1975–1987. The year-to-year catalog size of distinctive dolphins provided a minimum population estimate for the Tampa Bay study area ranging from 319 identifications in 1990 to 456 in 1992. Using other abundance estimate techniques by factoring in unmarked dolphins, the year-to-year point estimates ranged from 416 dolphins to 675 dolphins. Other factors such as natality, mortality, immigration and emigration were examined.

Repeated sightings of a number of these dolphins over multiple (up to 18) years indicate the existence of a mosaic of overlapping home ranges through this area. In those regions where a year-round survey effort has been conducted, individuals have been observed throughout the year. Recommendations for further study in the Tampa Bay area are: 1) to continue monitoring on an annual and seasonal basis; 2) to examine community structure in more detail to define biologically meaningful management units; and 3) to examine patterns of habitat use through integration of GIS habitat data with our sighting data.

INTRODUCTION

Essential prerequisites to the management of wildlife populations are an understanding of the structure of the population, knowledge of the numbers of animals in the population, and estimates of vital rates such as natality, mortality, immigration and emigration. Because of the potential impacts of human activities such as commercial live capture operations, habitat alteration and pollution, the status of the bottlenose dolphins of Tampa Bay has been of concern to the National Marine Fisheries Service (NMFS), the federal agency charged with responsibility for their protection. During 1988–1993, the NMFS supported research to obtain updated information on the numbers of dolphins using Tampa Bay, as well as trends in their vital rates. Earlier efforts to study the Tampa Bay dolphins had been conducted in the form of aerial surveys that included portions of Tampa Bay and waters immediately offshore (Leatherwood and Show 1980; Odell and Reynolds 1980; Thompson 1981; Blaylock et al. 1995), and photographic identification studies (Wells 1986; Weigle 1990), but there had been no complete systematic estimation of the numbers of dolphins using Tampa Bay until the mid-1980s. NMFS regional aerial surveys conducted during June–August 1985 (summer), September–October 1985 (autumn), and January–February 1986 (winter) provided the first available estimates of abundance for Tampa Bay proper (Scott et al. 1989, Table 26):

SEASON	ABUNDANCE ESTIMATE	LOWER 95% CL	UPPER 95% CL
Summer	198	78	318
Autumn	248	148	348
Winter	217	130	304

The most recent NMFS aerial survey of Tampa Bay produced an abundance estimate of 559 with a coefficient of variation of 0.24 (Blaylock et al. 1995).

The approach selected for our census of Tampa Bay dolphins was photographic identification (photo-ID) surveys from small boats (see reviews by Würsig and Jefferson 1990; Scott et al. 1990). This technique has proven effective in long-term studies of population-rate parameters in Sarasota Bay, immediately to the south (Wells and Scott 1990). The large numbers of distinctive dolphins photographed by Wells (1986) during surveys initiated in 1975, and later by Weigle (1990) indicated that Tampa Bay would be an excellent case study for photo-ID surveys.

Photo-ID offers several advantages over aerial surveys for measuring certain population rate parameters. The greatest advantage of using photo-ID methods is the accumulation of information on the occurrence, distribution and ranging patterns of specific individuals. The ability to recognize individuals over time provides opportunities to estimate abundance using mark-resight methods, to evaluate possible cases of immigration, emigration or transience, to monitor individual female reproductive case histories and count newborns, to determine the origins of carcasses for mortality estimates, and to examine community structure (Wells 1986).

This report briefly summarizes the results of six years of NMFS-sponsored bottlenose dolphin research in Tampa Bay, conducted by the Dolphin Biology Research Institute (DBRI) and the Chicago Zoological Society. Annual photo-ID surveys were conducted during September and October of each year from 1988 through 1993. Photographs and sighting data were collected to examine trends in abundance, natality, mortality, immigration, and emigration. A more detailed account of these surveys, methodology and results can be found in Wells et al. (1996).

METHODS

Study Area

The Tampa Bay study area includes the enclosed bay waters eastward of the chain of barrier islands at the mouth of Tampa Bay, Old Tampa Bay, Hillsborough Bay as well as the shallow Gulf coastal waters and passes immediately surrounding the barrier islands. The southern boundary includes the waters just north of Anna Maria Sound and the Manatee River.

Survey Schedule, Field Techniques and Logistics

A six-week window during September–October was selected to provide ample opportunity to fully survey each region of the study area at least three to five times. Surveys were conducted from 6–7 m outboard-powered boats. Two, three or four boats were used during each survey. Each boat was equipped with a VHF radio, depth sounder, compass, thermometer, and eventually a hand-held LORAN. Survey crews

ranged in size from two to six people per boat. Survey routes were selected each day based on predicted weather conditions and the status of survey coverage. While searching for dolphin schools, the boats were operated at the slowest possible speed that would still allow the vessel to plane, typically 33 to 46 km/hr, depending on the vessel. Once schools were encountered, the boats were slowed to match the speed of the dolphins and moved parallel to the schools to obtain photographs.

Every dolphin school encountered along a survey route was approached for photographs. We used Nikon camera systems with zoom-telephoto lenses, motor drives and data backs with Kodachrome 64 color slide film to photograph each school. We remained with each dolphin school until we were satisfied that we had photographed the dorsal fin of each member of the school, or until conditions precluded complete coverage of the group. A suite of data including date, time, location, activities, headings and environmental conditions was recorded for each sighting. Numbers of dolphins were recorded in real time as minimum, maximum and best point estimates of numbers of total dolphins, calves (dolphins $\leq$ about 80–85% adult size, typically swimming alongside an adult), and young-of-the-year (as a subset of the number of calves). A young-of-the-year is defined as a calf in the first calendar year of life and is recognized by one or more of the following features: 1) small size, 50%–75% of the presumed mother's length; 2) darker coloration than the presumed mother; 3) non-rigid dorsal fin; 4) characteristic head-out surfacing pattern; 5) presence of neonatal vertical stripes; 6) consistently surfacing in "calf position".

Photo-Identification Catalog

The patterns of nicks, notches, and scars on the dorsal fin and visible body scars have been used successfully in numerous studies of bottlenose dolphins to identify individuals over time (Scott et al. 1990; Würsig and Jefferson 1990). Our photographic catalog is based on exclusive categories that classify individuals with similar features together. Each of the 14 categories of the catalog is based on: 1) the division of the trailing edge of the dorsal fin into thirds and distinctive features located in each third; 2) distinctive features on the leading edge of the fin; 3) distinctive features on the anterior portion of the peduncle; and 4) evidence of permanent scarring or pigmentation patterns on the fin or body.

The photo-ID catalog included 150 dolphins identified from the Tampa Bay study area during 1975 through 1987 when the census was initiated in 1988. In 1993 we collaborated with Eckerd College (J. Reynolds, pers. comm.) in examination of a portion of the photo-ID catalog established by B. Weigle (Weigle 1990). We made no additions to our catalog, but found 94 matches to dolphins in our existing Tampa and Sarasota catalogs.

Analysis of Photographs

Photographs were analyzed for each dolphin group sighted (see Wells et al. 1996 for details on photo-analysis procedures). A grading system that integrates recognizability, photographic quality and coverage was used to identify the quality of a given sighting:

Grade 1—All dolphins in the group were photographed or otherwise positively identified. All the animals in the best field estimate are accounted for as: a)

confirmed positive identifications; or b) as individuals that can be distinguished within a sighting from a high quality photograph but do not warrant status as a 'marked' dolphin in the catalog.

Grade 2—There are photographs of some dolphins with distinctive fins that may be in the catalog, but because of the quality of photographs it is not possible to make appropriate comparisons with the catalog and make a match or assign an identification.

Grade 3—Photographic coverage is known to be incomplete, because all dolphins were not approached for photographs, no photos were taken, film did not turn out, sighting conditions were poor, etc.

Data Processing and Analysis

Sighting data and results from photo-analysis are entered into the Dolphin Biology Research Institute (DBRI) database (Wells et al. 1996). The database currently includes 13,500 sighting records (group encounters) from Sarasota Bay, Tampa Bay, Charlotte Harbor and the inshore Gulf waters from 1975 to 1996. Group size estimates were derived from adjustments of field estimates based on photo-analysis (Wells et al. 1996). The basic questions considered by this project were, "How many dolphins use the Tampa Bay study area during the September–October survey period, and how does this number vary from year to year?" A closed population was assumed because of the short interval during which the surveys took place. There are a variety of ways to calculate indices of abundance of bottlenose dolphins inhabiting Tampa Bay. We used four different abundance estimation techniques: Catalog-size (Method 1), Mark-proportion (Method 2), Mark-resight (Method 3), and Resighting-rate (Method 4) which are described in detail in Wells et al. (1996). In addition we used estimation procedures to examine natality, mortality, immigration and emigration (also described in Wells et al. 1996).

RESULTS

Survey Effort

Surveys were conducted during windows of 34–42 days each year (Wells et al. 1996). On average, 42 boat days were spent in the study area each year (range=30–54 days). An average of 113 hours of on-effort search time was spent each year (range=85–141 hours).

Dolphins were seen throughout the study area, but they were not uniformly distributed. Larger groups tended to be found in the more open and deeper waters (Wells et al. 1996). The total number of sightings and dolphins seen each year closely track the level of survey effort (Wells et al. 1996). The number of photographs taken was related to the number of dolphins. On average, 5–6 photographs per dolphin were taken each year (Wells et al. 1996).

Photo-ID Catalog Development

The level of survey effort was considered sufficient to warrant generation of abundance estimates based on mark-resighting analyses. This conclusion was supported by the high proportion of identifiable dolphins in the population (62% to 82%), and the frequency distribution of resightings of identifiable dolphins within survey years (Wells et al. 1996). One-third to one-half of the dolphins were sighted

at least twice during a given survey year, up to a maximum of 13 times each (Wells et al. 1996).

Our Tampa Bay catalog for 1988–1993 included 858 different dolphins. The catalog size provided a minimum population estimate for the Tampa Bay study area ranging from 319 identifications in 1990 to 456 in 1992 (Wells et al. 1996). On average, 57% of the dolphins in an annual catalog were also seen in either the previous or subsequent year, 52% were seen two years earlier or later, 47% were seen three years earlier or later, 44% were seen four years earlier or later, and 35% were seen five years earlier or later (Wells et al. 1996).

Photographs taken during the 1988–1993 NMFS surveys built upon an existing Tampa Bay catalog of 150 animals identified during 1975–1987 (Wells 1986, Wells et al. 1996). As expected, during the initial years of the surveys a large number of identifications were added to the catalog. New fins were added to the catalog at a slower rate during subsequent years (Wells et al. 1996). The proportion of first-time identifications comprising the total catalog each year declined from 74% in 1988 to 14% in 1993 (Wells et al. 1996). These results are comparable to those from the Sarasota community (Wells and Scott 1990), suggesting a relatively closed population for the Tampa Bay study area. Identifications added to the catalog over the years may represent changes to the fins of known animals, non-distinctive calves acquiring new markings (only a small number of calves are in our catalog), or animals that may have been missed in previous years. We found that overall there were few changes to fin markings throughout the surveys, and minor changes could be detected by a skilled observer familiar with the catalog. However, dramatic changes to fin markings could easily be undetected and could result in a previously identified animal being entered twice in the catalog.

Abundance Estimates and Trends

The catalog size method provided a minimum estimate for each year. The other three methods (mark-proportion, mark-resight, and resighting-rate) used abundance estimation techniques taking into account proportions of unmarked dolphins to provide a more reliable population estimate for Tampa Bay (Wells et al. 1996). The average population size estimate from these three estimation techniques ranged from a low of 416 in 1993 to a high of 675 in 1991 (Wells et al. 1996).

DISCUSSION

Photo-ID Catalog

The ability to identify individuals over time using natural markings has proved to be a valuable and benign research tool and has become a standard in population studies of marine mammals. Maintaining a photographic database of individual dolphins enables researchers to monitor not only population parameters but also habitat use, social association and distribution patterns.

The high proportion of marked dolphins and the high frequency of resightings underscores the importance of including only excellent quality images of distinctively marked individuals in the photo-ID catalog. This minimizes subjectivity in the

matching process and reduces the chance of making incorrect identifications or missing them altogether.

Abundance Estimates and Trends

Our estimates are considerably larger than the aerial survey estimate of 148–348 (95% CL) reported by Scott et al. (1989) for the same months in 1985. In most cases the numbers of dolphins from the catalog-size method exceeded the aerial survey estimates as well. It seems unlikely that the differences in the estimates over the three years from 1985 to 1988 were due to dramatic changes in abundance, given the lack of change in abundance over the six-year period from 1988 through 1993. A more likely explanation may be the differences in survey methods.

The estimates we have derived reflect the numbers of dolphins found in the Tampa Bay study area at least once during a six-week period in September and October of each year. The estimates are based on a catalog that includes all of those dolphins for which satisfactory identification photographs were obtained during the survey period, without distinguishing between differences in the degree of use of the study area waters by different dolphins.

The catalog makes no distinction between those dolphins using the waters of the study area on a regular basis and those photographed during an infrequent passage through the study area. A number of overlapping home ranges occur along the central west coast of Florida, including Tampa Bay (Wells 1986). The degree of overlap in home ranges in the Tampa Bay study area varies. The probability of finding a given dolphin occupying a partially overlapping home range would be a function of the degree of overlap. The limits of our study area are not biologically based. They do not necessarily coincide with home range boundaries, for example, and therefore do not address the relative importance of waters and habitat features in the study area. Evaluation of the biological basis of population units has important management implications, but this requires more detailed analysis of the community structure of dolphins in the Tampa Bay area.

Summary of Population Rate Parameters for Tampa Bay

Under stable circumstances during September–October, between 437 and 728 dolphins use the Tampa Bay study area (Wells et al. 1996). The best average point estimates place the population size at about 524 to 564 dolphins during any given year (Wells et al. 1996). About 0.035 of these animals are young-of-the-year, but this is likely an underestimate (Wells et al. 1996). At most, 0.055 of the dolphins present are recent immigrants, but this value is likely elevated from the inclusion of dolphins that have not immigrated, but have fins that have changed, or may have been present but not photographed in previous years (Wells et al. 1996). About 0.023 of the dolphins were considered to have been lost, through emigration, death, or because of undetected fin changes (Wells et al. 1996). Transients accounted for 0.045 of the total population size (Wells et al. 1996). Immigration, emigration and transience are not major influences on the number of animals present at any given time, but they may be important ecologically by providing a means of genetic exchange between populations, as demonstrated for the Sarasota dolphin community (Duffield and Wells 1991).

RECOMMENDATIONS

- Monitoring should be continued at least annually. The more frequent the surveys the better the chance of detecting a trend towards a catastrophic decline. More intensive surveys would permit more refined determinations of natality, immigration, emigration, transience and mortality.
- Community structure needs to be examined in more detail to define biologically meaningful management units. Existing information on residency, ranging and social patterns, and genetics should be integrated to arrive at population designations. Analysis of community structure is necessary to interpret immigration, emigration and transience relative to population size.
- Photo-ID efforts should be expanded to greater distances offshore and north along the coast to examine immigration, emigration and transience in greater detail.
- Patterns of habitat use in Tampa Bay should be examined through integration of GIS habitat data with our sighting data.
- Additional data are needed to describe community structure. In particular, sample sizes for examination of mt-DNA haplotype distributions in Tampa Bay should be augmented through biopsy darting or capture-release efforts. The genetics data should be supplemented with telemetry data on movements and additional photo-ID efforts.
- Photo-ID work should be expanded to other seasons to examine previous reports of seasonal fluctuations in abundance. If we have surveyed during the peak of abundance, then which of these animals move out during other seasons? Do others move in? The results of other studies indicate that at least some of the Tampa Bay dolphins are present year-around (Bassos 1993).

ACKNOWLEDGMENTS

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DIGITAL MANATEES IN TAMPA BAY: A CD-ROM FOR RESEARCH AND MANAGEMENT

B. Weigle

ABSTRACT

Rapidly increasing utilization of Geographic Information System (GIS) software to display and analyze data having discrete spatial coordinates has generated a growing need for high quality data on marine ecosystems and their inhabitants. Scientists at the Florida Marine Research Institute (FMRI), a bureau of the Florida Department of Environmental Protection (FDEP), recognized the utility of GIS systems for marine research projects in the early 1980s and established the Marine Resources GIS in 1982. The Marine Mammals group started using GIS in 1987 to plot distribution of manatee deaths and aerial survey results. During a 1989 workshop sponsored by the Marine Mammal Commission, long-term plans to establish a comprehensive GIS to aid in recovering the manatee population were prepared and implementation was initiated by the FMRI Marine Mammals program. Staff and equipment have been added to the program and an interagency Manatee GIS Coordinating Team and Working Group have been functioning for over three years. Concurrent growth of the Marine Resources GIS within FDEP has generated base-layer data sets necessary to analyze the manatee data and other marine resources databases.

A CD-ROM containing both statewide manatee data and environmental data in GIS format—Florida Atlas of Marine Resources, Version 1.0—was released by FMRI in the summer of 1996. Base data included on the CD-ROM are the state's shoreline, bathymetry, seagrass extent, aids to navigation, roads and county boundaries. Staff from the Coastal and Marine Resource Assessment (CAMRA) section of FMRI prepared the base data. Manatee data include locations and causes of manatee mortality from 1974 to 1995, data from most aerial surveys flown after 1984, and manatee abundance maps based on the aerial survey data. Also included on the CD-ROM are agency reports and plans, citations, and meeting documents from the Manatee GIS Coordinating Team and Working Group. The manatee portion of the CD-ROM was produced by the FMRI Marine Mammals staff with assistance from the Sirenia Project of the U.S. Geological Survey, U.S. Fish and Wildlife Service, and other members of the Manatee GIS community.

GIS software to access the data sets is not included on the CD-ROM. However, software that can read the ARC/INFO™ export files is affordable for most agencies and individuals interested in using the data. Using an easily learned software package like ArcView™, data queries and production of maps using a wide variety of data themes are possible to give research staff a useful tool in the formulation and testing of hypotheses and administrators a way to plan, justify, and implement management plans.

The CD-ROM is available to all parties with access to GIS software by contacting the FMRI Marine Mammals Program at 100 8th Avenue SE, St. Petersburg, FL 33701 (813/896-8626). An updated version of the CD-ROM with additional data layers is planned for release during the second quarter of 1997.

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AERIAL SURVEYS OF MANATEES IN TAMPA BAY, FLORIDA

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POSTER ABSTRACT

Fixed-wing aerial surveys of manatees were conducted monthly in Tampa Bay, from November 1987 through October 1992 and from April 1993 through May 1994. The purpose of the surveys was to establish a long-term database for assessing trends in abundance, reproductive performance and habitat use. Data was incorporated into a Geographic Information System to analyze and map seasonal density estimates and spatial distribution patterns.

Tampa Bay is the largest estuary in Florida. The human population of the three counties bordering the bay has grown by nearly 24%, making it the nation's third fastest-growing metropolitan area. Despite this urbanization, the past decade has seen improvements in Tampa Bay's water quality and bottom coverage by submerged aquatic vegetation, a primary food source for manatees.

A total of 5,358 manatee sightings was recorded during 88 surveys. Counts were significantly higher in the "cold" season (December–February) (F-test, $p < 0.0001$) than in the "warm" (March–November) season. There has been an 8% annual increase in the number of manatees at winter aggregation sites in Tampa Bay; the maximum single day count was 190. Warm season counts have remained relatively constant, at a mean of 51, but habitat use patterns have shifted somewhat between years, likely due to changes in the density and distribution of seagrass beds. Regulatory measures for manatee protection need to protect habitats used consistently or predictably by manatees, but should also be flexible enough to accommodate seasonal or annual changes in manatee habitat use.

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MAINTAINING STABLE POPULATIONS OF COLONIAL WATERBIRDS IN THE TAMPA BAY SYSTEM

R.T. Paul
A.F. Schnapf

ABSTRACT

"Colonial waterbirds"—pelicans, cormorants, herons, ibises, spoonbills, gulls, terns, skimmers and allies—breed at some 18 sites within the Tampa Bay system. The population is one of the largest of any bay system of the country, exceeding 34,000 breeding pairs of 20–25 species annually. Although some rare species are increasing in numbers, several of the most common species are declining in response to loss or alteration of foraging habitats, especially freshwater wetlands. Habitat specialists like Black Skimmers, Least Terns and Snowy Plovers are most vulnerable to human disturbance of breeding sites, and are most at risk. The U.S. Fish and Wildlife Service and National Audubon Society have protected some of the key nesting sites for decades. In the last 15 years, area municipalities, the Florida Game and Fresh Water Fish Commission, Tampa Port Authority, local Audubon chapters, other volunteers, new organizations like Tampa BayWatch, and the National Estuary Program have initiated or assisted with a variety of activities to improve the protection of nesting colonies. These actions help but must be considered in light of the increasing numbers of recreational boaters and beachgoers, and their vast potential for annual disturbance of breeding birds.

INTRODUCTION

Florida is remarkable for the number and diversity of "colonial waterbirds" (birds that nest in groups or aggregations, called colonies) that occur here. With the loss of 50% of the state's wetlands and alteration of most of the rest, wetland-dependent animals have been profoundly affected. In the Tampa Bay area, despite significant alteration of both freshwater and coastal wetland habitats, significant populations of colonial waterbirds remain. In part due to intensive protection and management efforts, some rare species have increased despite continuing habitat losses and intensive public recreation. Other species, on the other hand, continue to decline. This paper briefly summarizes the current status of 28 colonial (and "near-colonial") species of birds nesting in the Tampa Bay system, reviews efforts to protect them, and outlines additional measures that are needed if stable populations are to remain.

SPECIES STATUS AND TRENDS

At least 18 nesting colonies are known in the Tampa Bay system (R.T. Paul, in ABM 1995). Approximately 35,000 breeding pairs of birds nested at these sites in 1996 (Table 1). Of the 28 colonial species included here, 12 are state-listed (1 endangered, 2 threatened, 9 species of special concern). At least ten species have declined locally since 1984, while nine have increased (Table 1).

The increasing species include Reddish Egret, Cattle Egret, Glossy Ibis, Roseate Spoonbill, Wood Stork, American Oystercatcher, and Caspian, Royal and Sandwich Terns. Except for the Cattle Egret, these are among the rarer species in the state and several (Reddish Egret, Roseate Spoonbill, perhaps the Oystercatcher and Royal and Sandwich Terns) are still recovering from historic impacts of a century ago (Paul and Woolfenden 1985).

Declining species include Brown Pelican, Snowy Egret, Little Blue Heron, Tricolored Heron, Black-crowned and Yellow-crowned Night-Heron, White Ibis, Snowy Plover,

Laughing Gull, and Black Skimmer. Most of these species depend on freshwater wetlands for food. The Brown Pelican reached its historic local population high of 3,330 pairs in 1987 (S.A. Nesbitt, pers. comm.) and declined thereafter, possibly due to a combination of excessive commercial net fishing and improvements in water quality, which may have reduced the phytoplankton food supply of the pelicans' preferred prey (Paul and Johansson 1996). Snowy Plovers and Black Skimmers nest on beaches precariously close to the high tide line, where they are vulnerable both to flooding and increasing numbers of human beachgoers. Laughing Gulls, not normally regarded as a declining species, decreased by about 80% since the early 1980s, the largest decline of any species in this study. While one factor may have been changing vegetative cover at colony sites, a more important cause probably was the improvement in solid waste treatment at the many municipal dumps in the region.

Table 1. Colonial waterbirds of Tampa Bay, 1996. All population estimates represent nesting pairs and are rounded off to nearest 5.

SPECIES	TAMPA BAY POPULATION	NUMBER OF COLONIES	POPULATION TREND SINCE 1984 ¹	LISTING US	FL
Brown Pelican	1,550	7	- since 1989	—	SSC
Double-crested Cormorant	545	7	=?	—	—
Anhinga	335	6	=	—	—
Great Blue Heron	335	12	=	—	—
Great Egret	785	9	?	—	—
Snowy Egret	885	12	-	—	SSC
Little Blue Heron	255	9	-	—	SSC
Tricolored Heron	700	9	-	—	SSC
Reddish Egret	65	5	+	C2	SSC
Cattle Egret	4,340	8	=/+	—	—
Green Heron ²	—	8	?	—	—
Black-crowned Night Heron	265	9	-?	—	—
Yellow-crowned Night Heron ³	180	8	-?	—	—
White Ibis	9,100	4	-	—	SSC
Glossy Ibis	740	3	+	—	—
Roseate Spoonbill	110	3	+	—	SSC
Wood Stork	105	1	+ only 1 TB site	E	E
Snowy Plover ²	—	—	- <10 pr in region	C2	T
Wilson's Plover ²	—	—	?	—	—
Willet ²	30	4	?	—	—
American Oystercatcher	80	7	+ 300 pr est. for Fla.	—	SSC
Laughing Gull	10,500	4	- down 80% in TB	—	—
Gull-billed Tern	{occasional nester in Tampa Bay; not found in 1996}				
Caspian Tern	95	1	+ 2 colonies in Fla.	—	—
Royal Tern	2,255	2	+ 4-6 colonies in Fla.	—	—
Sandwich Tern	445	2	+ 2 colonies in Fla.	—	—
Least Tern ³	85	2	?	—	T
Black Skimmer	685	3	=/-	—	SSC
TOTAL	34,470	18			

¹Based on Paul and Woolfenden 1985.

²Not truly colonial but often nests adjacent to colonies of other species; no reliable estimate possible.

³Several colonies not censused.

SPECIES VULNERABILITY

In general, colonial waterbirds are at risk because of threats to nesting sites, foraging habitats, or both. In Tampa Bay, most colonial species (pelicans, cormorants, anhingas, herons and egrets, ibis, spoonbills, storks) nest in trees on islands. In so doing they gain protection from terrestrial predators, people and their pets, the effects of sun and rain, and fire ants. The other colonial (gulls, terns, skimmers) and non-colonial species (plovers, willets, oystercatchers) nest on the ground, in grass or on bare sand and shell substrates. These species are especially vulnerable to disturbance, weather and ants.

Historically, many colonies have been lost to dredge and fill projects (i.e. Bird Key in Clearwater Harbor, Bird Key in Sarasota Bay; Scott 1887). Likewise, extensive shallow flats in Boca Ciega Bay, important as foraging areas, were destroyed by dredge and fill 3-4 decades ago. Terrestrial predators have also caused the abandonment of such sites as Indian Key (Scott 1887; Paul unpubl. data), Terra Ceia Bird Key and Green Key. On the other hand, some dredging projects have unintentionally created important nesting areas including Alafia Bank, Islands 2D and 3D in Hillsborough Bay, and Piney Point.

In our opinion, the four species most at risk in the Tampa Bay area are Snowy Plover, American Oystercatcher, Least Tern and Black Skimmer. All nest on beaches just above the high tide line, and rely on the cryptic coloration of their eggs and young for protection. The latter three species have shown some adaptability in the face of the overwhelming public use of virtually all beaches in the region, and now nest commonly on artificial dredge-material islands and even rooftops. The Snowy Plover has shown little such flexibility, however, and must be regarded as an obligate inhabitant of certain barrier beaches adjacent to extensive intertidal sand flats (T.H. Below, pers. comm.) This bird is very small and difficult to find, its eggs and young even more so. Since it is not colonial, only a few pairs at most can be expected in any locality. As a result, this species is the most difficult to protect of all 28 species treated here. With the local population already below 10 pairs (J. Gore, pers. comm.), the continued persistence of Snowy Plovers as a local breeder is very much in doubt.

WHAT IS BEING DONE? WHAT NEEDS TO BE DONE?

The first task is to identify, monitor and protect the nesting colonies in the Tampa Bay area. This is an annual priority of personnel of Audubon's Florida Coastal Islands Sanctuaries. We are fortunate to have the assistance and cooperation of the U.S. Fish and Wildlife Service (which protects Passage Key, Tarpon Key, Egmont Key and several other islands as National Wildlife Refuges), the Florida Game and Fresh Water Fish Commission, Florida Park Service, Tampa BayWatch, Tampa Port Authority, Cargill Fertilizer Inc., Tampa Electric Co., and volunteers from St. Petersburg Audubon Society, Tampa Audubon and elsewhere. Essentially all colonies of any size (>100 breeding pairs) receive some measure of protection, and all nine large colonies (>1,000 pairs) receive specific attention. However comprehensive this effort may seem, it is extremely porous and the breeding birds at Shell Key and Dot-Dash (see ABM 1995) remain highly vulnerable.

Other Sanctuary activities include the following:

- Marsh grass planting projects to stabilize eroding shorelines;
- Prescribed burning to maintain habitats for ground-nesting species;
- When possible, addition of fill from permitted dredging projects to enhance nesting areas on Alafia Bank;
- Service on the Migratory Bird Protection Committee with Corps of Engineers, Tampa Port Authority and others to ensure that nesting birds on Islands 2D and 3D are included in the dredge project planning process;
- Alafia Watershed Area Restoration Effort (AWARE), to encourage acquisition, restoration and management of wetlands and other environmental lands for fish and wildlife benefits;
- Live-trapping and removal of raccoons from colony sites;
- With Tampa BayWatch, conduct of the "Catch Fish, Not Birds" monofilament cleanup at 50 area islands;
- Public education through media interviews, slide talks, boat tours and other means.

A variety of issues remain. Despite federal, state and local wetlands protection measures, wetlands continue to be lost or impacted by adjacent activities. The recent gutting of mangrove protection ordinances is a warning that legal protections can be removed. Jet skis and ultra-light aircraft represent recreational toys that also present new sources of disturbance to wildlife. The human population of the Tampa Bay area continues to increase, creating new demands on water resources and requiring ever more space for homes and businesses.

The survival of stable populations of wildlife is not assured. The day is long past that we can safely assume that wildlife will thrive regardless of whatever we do. Their best hope is a better educated public, committed volunteers, and program funding that allows wildlife agencies and conservation groups to continue, and even expand, their efforts.

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DREDGED MATERIAL MANAGEMENT—A FEDERAL PERSPECTIVE

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ABSTRACT

Tampa Bay has three major Federal ports. Tampa Harbor, Port Manatee and St. Petersburg Harbor are a microcosm of dredged material management typical of that of the rest of the country. Management of the dredged material is environmentally and economically important to the ports and the citizens of Tampa Bay. It is also of importance to the taxpayers of this country. The U.S. Army Corps of Engineers is responsible for creating and maintaining this country's Federal navigation projects in conjunction with local sponsors for each project. To show that there is local interest in having a Federal project, local sponsors are selected who are willing to cost share in the project. These local sponsors provide lands, right-of-ways, and easements for the projects and with the development of navigation projects provide and maintain the disposal areas.

To ensure that the taxpayers are getting a fair investment, current projects are being evaluated to determine if they are economical, designed properly, and environmentally sound. Part of this evaluation reviews the dredged material management plans; each port has determined if there is enough capacity in the disposal area. This usually entails a 20-year life cycle. If this threshold cannot be met, what can be done to extend the life of the Dredged Material Management Area (DMMA)? One such solution is the Beneficial Uses of Dredged Material (BUDM). The most common method is to restore aquatic or wetland habitats with the material. There is also an economical side to the BUDM. Over the long-term, it extends the life of the existing upland disposal area. The project, including the DMMA, must also be environmentally sound. All environmental resources must be given consideration. The project must also be a sound investment to the taxpayers, i.e., the commodities and cargo handled must provide economic stimulus to the local community. Unfortunately only cargo is being considered important and sometimes small recreational navigation projects or passenger vessels will not get future Federal support.

The Army Corps of Engineers has been involved in navigation since the beginnings of this country and its westward movement. Our waterways were considered important not only for interstate commerce but for the national security. Before the development of railroads, river systems provided a cheap and efficient means of transporting goods long distances. Control of these systems and harbors was often a major military objective throughout our history. If one considers the Civil War and the War of 1812 campaigns as examples, it can be seen that this was true. Battles such as Chattanooga, Shiloh, Nashville, Fort Sumter, New Orleans and Vicksburg were fought to control waterbodies that were used as transportation systems. Developing and maintaining these waterways and harbors became the responsibility of the U.S. Army Corps of Engineers.

The Jacksonville District encompasses the State of Florida, part of Georgia, and Puerto Rico and the Virgin Islands. Within its boundaries the District maintains 16 deepwater ports, 30 navigation locks, and 2100 miles of navigation channels. In the state of Florida, this includes the Intracoastal Waterway, the Okeechobee Waterway, and the Ports of Miami, Jacksonville, Canaveral, Palm Beach, Everglades, Ft. Pierce, St. Augustine, Fernandina, Ponce de Leon, Tampa, Manatee and St. Petersburg.

The District dredges approximately 1.4 million cubic yards of material annually from these waterways. Most of this material is beach quality sand that is placed either

directly on the beach or in the littoral zone where it helps maintain the sand budget of the coastline.

Tampa Bay contains three ports. Tampa Harbor is the eighth largest port in the United States and handled 49 million tons of cargo in 1994. Ships transport phosphate rock and various phosphate products, petroleum products and sulfur to numerous foreign ports.

The Tampa Harbor federal project runs from the ocean 34 miles inland to the Port of Tampa and Hillsborough Bay channels. The deeper main channel was constructed in 1976. Approximately 850,000 cubic yards of material are dredged from the Bay annually from the various federal and private navigation projects (USACE 1996b). The Port has three disposal options for dredged material. The newly designated Ocean Dredged Material Disposal Site (ODMDS) is located 18 miles off the coast of Florida. Two upland disposal areas—*islands* CMDA-2D and CMDA-3D—are located in Tampa Harbor in the vicinity of the Alafia River and Big Bend Navigation Channel.

Manatee Harbor is located in the lower Bay on the Manatee River. Port Manatee handles asphalt and other petroleum products, cement, gypsum, fertilizer and phosphate rock. The federal part of the Manatee Harbor project is a 3-mile channel connecting the turning basin to the main Tampa Harbor channel. Manatee Harbor has been redesigned and Phase I construction is almost complete. This involves bringing the channel to design depths. Phase II involves the reconfiguration of the entrance channel widener and the turning basin. Phase II construction will likely occur in fiscal year 1998. The project uses several upland disposal areas including DA-5 and DA-6.

The third port in Tampa Bay is St. Petersburg Harbor. It is located on the west side of the Bay near the downtown area of St. Petersburg. The Port of St. Petersburg handles cruise ships and small commercial fishing vessels. The harbor and the entrance channel have not been maintained recently due to the lack of disposal options. The primary disposal site, the ODMDS, was closed prior to this year. During the planning process, the Harbor Isles subdivision lake was identified as a potential beneficial use site for the dredged material. The concept was to raise the bottom elevation of the lake using the dredged material from the harbor maintenance dredging to foster better water quality by allowing light penetration to the lake bottom (USACE 1996a). During the completion of the NEPA documentation, the EPA designated the ODMDS as usable, thus making it the least expensive, most environmentally acceptable disposal alternative. The Corps is still trying to use the Harbor Isles site but additional non-federal funds are needed to complete this project.

The Corps Dredged Material Management Program has been developed as a result of the Harbor Maintenance Trust Fund and Section 204 of the Water Resources Development Act of 1992. With the increased demand for coastal properties by developers, increased demand for commerce, increased environmental awareness, tight budgetary constraints, and increased non-Federal responsibilities for the development and management of navigation projects, the Corps was required to

review each of the Federal navigation projects and where needed develop a long-term management strategy for facing problems at the project site. The Corps is preparing Dredged Material Management Plans (DMMP) on a priority basis for all Federal navigation projects where problems exist (EC 1165-2-200, USACE 1994a).

As part of the development of new projects, the development of DMMPs or the maintenance of existing projects, the identification of Beneficial Uses of Dredged Material is a major component. The first step in the DMMP process is the Preliminary Assessment (PAS) of the Federal navigation project. The purpose of the PAS is to see if:

1. Maintenance of the project is still economically justified: this is done to determine if it is in the public interest to maintain the project;
2. The project is environmentally sound: to determine if the dredging and disposal operations can be accomplished in an environmentally acceptable manner; and
3. If the project has disposal options for the life of the project.

If it is determined in the PAS that the project has a problem, a Feasibility Study is conducted to reevaluate the project. This detailed study goes to the same lengths as the initial authorization study that created the project. If the project is not justified, it could be deauthorized as a Federal project.

Beneficial Uses of Dredged Material (ER 1165-2-27, USACE 1994b) is a major component of all new and existing project studies. This has always been part of the Corps dredging and disposal plans, but has now been given more emphasis both economically and strategically. The state of Florida and the Corps have a Memorandum of Understanding that states if the material is beach quality that the Corps will place it on the beach. This slows the erosion of the downdrift beaches, providing protection to sea turtle nesting grounds and colonial bird nesting habitat.

Under the new legislation (WRDA 1992), the Beneficial Uses program was expanded to allow for the protection, creation and restoration of aquatic and ecologically related habitats. It is the local sponsors' responsibility to provide areas for dredged material placement for the navigation projects. Prior to this new legislation there was no incentive for the Corps and their local sponsors to look for these beneficial options. If an option cost the same as the base plan for disposal, then it might be utilized. But often it was rejected because it had additional costs to the local sponsor. Now, with WRDA 1992, there is an economic incentive added to assist the local sponsors. Any additional cost of these alternatives would be cost-shared 25% non-Federal and 75% Federal. This incentive was enough to turn the tide in favor of environmental good and financial benefits to the Ports. Now the life of the traditional sites can be extended by using a Beneficial Use site. In conjunction with our new studies, we have identified several possibilities here in Tampa Bay—Cockroach Bay, Harbor Isles Lake, Whiskey Stump Key, the MacDill Air Force Base borrow hole, and Bird Island expansion.

In addition to the Corps program, the National Estuary Program (NEP) is currently developing a Comprehensive Conservation Management Plan (CCMP) for Tampa

Bay. As part of that effort, the NEP has contracted with the Corps to develop a Bay-wide Dredged Material Management Plan. Another facet of the CCMP would be to establish a Dredge Advisory Committee made up of representatives from the Ports, private industry, the Southwest Florida Water Management District, Florida Department of Environmental Protection, the Corps and local governments. The primary focus of this group would be to identify dredging and disposal problems and potential solutions, and to identify beneficial use sites. Identifying sites and obtaining approval from DEP and other local governments, including the Tampa Bay Regional Planning Council, to use those sites is a key component to creating or restoring habitats. Without having these sites identified and approved prior to scheduling dredging, there is insufficient time to plan or design the beneficial use project.

A current long-term option for dredged material disposal in Tampa Bay is the use of the Ocean Dredged Material Disposal Site. This is an EPA-approved site located 18 miles off the coast of Florida. It has a site management plan which details what materials are to be placed with the site and what monitoring will be conducted. Other sites include CMDA-2D and 3D. These sites are used by the Tampa Port Authority. Special management to protect bird nesting activities has been implemented by the Corps and the Port. Two other locations have been mentioned earlier in conjunction with Manatee Harbor, DA-5 and DA-6. These sites are currently used for maintenance of the harbor. There are numerous other private facilities located around the Bay that are used for maintenance. Some of these other sites also are managed for bird use.

The Corps and private industry are working together to identify potential uses of dredged material. The Corps Waterways Experiment Station in Vicksburg, Mississippi, is working with K-mart to develop a technique to desalinate dredge material and use it as commercially packaged topsoil. In Jacksonville, the Jacksonville Transit Authority mines the Buck Island Disposal Area for construction grade material. Other individuals and government agencies are looking for ways of handling contaminated dredged material. In Miami Harbor, the Corps and EPA are looking at the use of geo-textile tubes to contain dredged material to be placed in the Miami ODMDs. Another technology being considered at the same project is the use of a hydrocyclone pump which separates finer material from the sandy material. The fines containing the contamination would be removed from the dredged material and placed in a confined area. A local Florida-based company has developed technology used around boat yards that uses a diver and hydraulic pump to dredge material from confined spaces where either there is no disposal area nearby, such as in residential areas, or where the material is contaminated and needs to be hauled to a special containment area.

The next steps in dredged material management are the Tampa Bay Regional Planning Council's Agency on Bay Management development of the Comprehensive Conservation Management Plan and the Corps of Engineers' planning of new navigation projects, identification of beneficial use sites, and development of a Dredged Material Management Plan for Tampa Bay. And finally, public input is needed to find sites, develop plans and obtain approval to use them.

ACKNOWLEDGMENTS

I would like to thank the Ports of Tampa, Manatee and St. Petersburg for their assistance in developing this paper.

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ADDRESS: U.S. Army Corps of Engineers, P.O. Box 4970, Jacksonville, FL 32232.

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BEACH NOURISHMENT, THE KEY TO FLORIDA'S LONG-TERM BEACH MANAGEMENT

**R.A. Davis, Jr,
J. Terry**

ABSTRACT

Beaches are Florida's most valuable natural resource yet they are threatened by loss of sediment from at least two major directions, erosion and development. Historically, beach management has been attempted through various types of hard construction—seawalls, groins, riprap, breakwaters and other protective means. During the past several years this methodology has been dropped in favor of beach nourishment, a soft approach to beach management and protection. Although expensive, nourishment provides a natural and aesthetically pleasing beach that is easily managed under most circumstances.

The major drawback to this type of long-term beach management is the cost, as much as \$12–15/cubic yard. Experience has shown that performance varies greatly among various coastal settings. With expected durations ranging from 5 to 8 years, some projects have exceeded these and others have fallen far short. For example, projects at Wrightsville Beach, North Carolina and south of Port Canaveral, Florida have lasted only a couple of years whereas most of those on the Gulf coast of the Florida peninsula have exceeded predicted performance. Variables that must be considered are wave climate, sediment characteristics and sediment availability.

Design and construction of nourishment projects is reasonably consistent with the most notable difference from place to place being one of scale. Gulf of Mexico beaches tend to be designed with berm elevations of 5–6 feet above sea level whereas the Amelia Island project was constructed at 13 feet. Design beach width tends to range from 50 to 150 feet. Construction techniques also may vary in terms of both the recovery of borrow material and its delivery to the construction site. Most of the differences are invoked to keep the costs to a minimum.

Environmental considerations must also receive careful attention in both the borrow area and at the location of the construction. The bottom line is that beach nourishment is the universally accepted technique for beach management and protection. It is expensive but it is here to stay!

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BENEFICIAL USES OF MUCK SEDIMENTS FROM THE INDIAN RIVER LAGOON ESTUARY

S.K. Patel
W.K. Ericson
J.S. Steward

ABSTRACT

The beneficial uses of muck sediment from the Indian River Lagoon estuary (IRL) is a component of the St. Johns River Water Management District's program to develop muck remedial strategies that include source control, removal and final disposition. As part of this program a horticultural study was conducted to investigate and demonstrate the environmental and commercial or entrepreneurial uses of muck sediments from the IRL. The work consisted of sampling muck sediments and their chemical and physical characterization. Generally, the muck sediments consist of >5% dry weight as organic matter, >60% dry weight as silt and clay, and >50% water by weight.

The horticultural study showed very encouraging results for several plant species, such as holly (*Ilex cornuta*), liriope (*Liriope muscara*), oyster plant (*Rhoeo spathacea*), and Florida 419 Bermuda grass (*Cynodon dactylon* [L.] Pers.). Detrimental effects were observed on plumbago (*Plumbago auriculata*), but it appeared to recover as indicated by new leaf growth. Complete death of wax myrtle (*Myrica cerifera*) plants was observed. Bermuda grass grown in muck showed increased root growth and dark green coloration of the leaf blades as compared to Bermuda grass grown in soil. Chemical analyses of the muck sediment showed its potential as a nutrient source. This was further exemplified by the adequate and comparable nutrient levels in tissue of Bermuda grass grown in muck and soil.

The positive response of Bermuda grass and other plants indicates there is a potential for beneficial use of typical muck sediments in the horticultural industry. Such uses include soil composite additives, nursery soil amendments, and landscaping or topsoil materials for golf courses, roadway embankments and other green spaces. Despite very encouraging results, only a limited number of species and sediment mixtures were tested due to the preliminary nature of this study. Therefore, additional greenhouse and open area horticultural testing is recommended to further screen plants that have a tolerance to salt in the muck sediments.

ADDRESS: (SKP) Bromwell & Carrier, Inc., PO Box 5467, Lakeland, FL 33807.



**First Prize
Student Poster Awards**

**GEOLOGIC HISTORY AND MORPHODYNAMICS
OF EGMONT KEY, HILLSBOROUGH COUNTY, FLORIDA**

J.A. Kling

STUDENT POSTER ABSTRACT

Egmont Key is located amid the west central Florida barrier island chain adjacent to the mouth of Tampa Bay. Recently there has been considerable erosion along the gulfward side of the island although little is known as to its cause. There is also concern that the recent dredging in the Egmont ebb tidal delta, north of the shipping channel, is increasing the erosion rates on the island. In order to understand the modern dynamics affecting Egmont Key and to develop the geologic history of the island, this study synthesizes data from beach profiles, current meters, wave refraction models, historical map analysis, vibracores and radiocarbon dating.

Initial beach profile data indicate that significant shoreline modification is occurring monthly on Egmont Key. The shoreline adjacent to the channel at the north end of the island retreated 5.21 meters from January through April of 1996 while the same location experienced a positive shoreline change of 40.49 meters from April through August. Concurrent with this was landward shoreline movement on the gulf side of the island and a seaward accretion at the southern end of Egmont Key. Other profile locations, principally those on the bay side of the island, have been less dynamic showing little or no change in shoreline position. These data also indicate a fluctuation between winter and summer profiles with a net loss of sediment occurring from January to April and a net volume increase occurring from April through August.

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WEST FLORIDA INNER SHELF PROVINCES: LINKS TO THE PRESENT COASTAL SYSTEM AND THE GEOLOGIC PAST

A.C. Hine
S.D. Locker
S.E. Harrison
G. Brooks
D.C. Twichell
R.A. Davis, Jr.

ABSTRACT

Recent high-resolution seismic and side-scan sonar surveys have demonstrated that the west Florida inner continental shelf is dominated by a Cenozoic limestone bedrock unconformity supporting a thin, mixed siliciclastic/carbonate sedimentary veneer. The mid-carbonate platform setting explains the extensive dissolution and extremely low regional gradient. The karstified limestone unconformity, which is exposed at the seafloor over large areas, has various spatial scales of antecedent topographic relief: 1) pits, depressions, ledges from centimeters to several meters of relief and centimeters to hundreds of meters in width/length; to 2) broad rise, flat bedrock plain and shelf valleys from meters of relief to kilometers in width/length. The sedimentary cover is commonly arranged in: 1) linear ridges (0.5 to 4 m in relief, tens of meters in width, hundreds of meters of spacing, and kilometers in length); 2) broad, very thin sheets; or 3) active ebb-tidal deltas located just off tidal inlets.

Ongoing mapping has allowed us to define distinct areas or shelf provinces that transition from one to another both alongshore and vary within themselves onshore/offshore. These provinces are: 1) broad rises supporting linear sand ridges seaward of coastal headlands; 2) estuarine retreat paths; 3) sand-ridge plains; and 4) sediment-barren rock terraces. Provinces 1-3 are closely linked to the modern coastal system which also features significant alongshore variations. In spite of its low bathymetric relief, low gradient, and thin sedimentary veneer, the west Florida shelf (including the Tampa Bay system) reveals surprising geologic complexity.

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THE WEST-CENTRAL FLORIDA COASTAL STUDIES PROJECT

G. Gelfenbaum
G.R. Brooks
R.A. Davis, Jr.
L.J. Doyle
A.C. Hine
S.D. Locker
R.H. Weisberg

POSTER ABSTRACT

Approximately 65% of the beaches of west central Florida are considered "critical erosion areas" according to a report by the Department of Environmental Protection. The designation of "critical erosion areas" is used for segments of the shoreline where substantial development or recreational interests are threatened by the erosion process. To address this erosion problem Congress directed the U.S. Geological Survey's Marine and Coastal Geology Program in 1993 to initiate the West-Central Florida Coastal Studies Project. The overall goal of this coastal project is to understand the recent geologic history of the barrier island system from Anclote Key to Venice and the processes that control the distribution and transport of sediment on the inner shelf. Specific objectives are:

- To understand the geologic control on the position and development of the barrier islands and tidal inlets;
- To determine a sediment budget including sources, sinks and pathways for sediment on the inner shelf and barrier islands;
- To determine the effects of past and present geologic and oceanographic events that might control the morphology and sedimentary processes of the coastal system.

In cooperation with the University of South Florida and Eckerd College, a multidisciplinary plan was developed to address these objectives. The research plan is divided into four major categories: Data Management, Processes, Framework and Morphodynamics. The Data Management portion of this project is designed to allow easy sharing of data among investigators, and ultimately to give access to local and state managers and planners. All digital data is being added to a project Geographical Information System (GIS) centrally located at the USGS's Center for Coastal Geology in St. Petersburg. The Processes portion of the project included field studies of the circulation and hydrography on the west Florida shelf, numerical modeling of the shelf circulation, and the interpretation of satellite imagery to document the complex spatial patterns of shelf processes. The Framework portion of the project includes reconnaissance high resolution seismic and side-scan sonar surveys across the entire study area, detailed side-scan sonar mosaics of selected sites to identify patterns of hard grounds and sediment cover, and coring of sediment to document historical development of the inner shelf and coastal system. The Morphodynamics portion of the project includes characterizing the stratigraphy and geological development of the barrier islands, and understanding the Holocene evolution of the flood and ebb tidal deltas.

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WEST-CENTRAL FLORIDA COASTAL STUDIES PROJECT: REGIONAL GEOLOGIC FRAMEWORK

Stanley D. Locker
Albert C. Hine

POSTER ABSTRACT

Side-scan sonar and high-resolution seismic data have been collected throughout the coastal zone from Anclote Key to Venice, Florida, as part of a U.S. Geologic Survey and University of South Florida cooperative study. Our objective is to understand the overall geologic framework associated with coastal evolution. This involves mapping sediment thickness and bedform distribution patterns, and bedrock structure and exposures.

Major subsurface shelf-valley systems are identified off Tampa Bay and Venice which are attributed to large-scale warping and infill of the carbonate bedrock. Solution and karst structures (sinkholes) are also common. The bedrock characteristics are important in several regards: 1) the structural antecedent topography may influence barrier island location and evolution; 2) exposed bedrock can provide a relict sediment source or provide substrate for production of biogenic carbonate grains. Hardground exposures are common throughout the study area and may occur up to the beach.

Estuarine retreat paths and thicker surficial sediment deposits tend to associate with the buried valley systems. Sediment cover of 5 m thick or more is most continuous in the Tampa Bay ebb tidal delta area. Away from the Tampa Bay influence, sediment thickness is highly variable. Within a few kilometers from shore sediment cover is very discontinuous, usually <2 m. Thicknesses increase farther seaward to over 2 m but occur in localized sand bodies of more limited extent. This offshore trend suggests patterns controlled by recent sea level rise and sediment sources left behind from shoreline retreat. The bedform patterns, scales and orientations reflect both past and present active sediment transport.

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Third Prize (tie)
Student Poster Awards

**MORPHOLOGY AND EVOLUTION OF A SILICLASTIC/CARBONATE
SAND RIDGE FIELD, SAND KEY, FLORIDA**

Scott Harrison

STUDENT POSTER ABSTRACT

Two high-resolution side-scan sonar mosaics have provided the first detailed view of a series of small-scale sand ridges along the moderate energy coastline of west central Florida. This imagery, in conjunction with seismic profiles and sediment analysis, has revealed that sand ridges located off Sand Key, Florida, commonly range from 1 to 4 m in height, strike oblique angles with the coastline, and stretch from the toe of the shoreface to more than 25 km seaward. Sand ridges are found not only on the west Florida coastline, but have been identified throughout the world along low gradient, passive margin inner shelves. The Sand Key ridges appear morphologically similar to the storm-built ridges along the U.S. Atlantic margin inner shelf, but their smaller size appears to be a function of the lower energy west Florida setting.

This study was conducted to determine possible modes of origin of the Sand Key ridges and to identify how these ridges may be influenced by modern hydraulic processes. The side-scan mosaics identify that sand ridges are mantled by a hierarchy of bedforms suggesting that they are in equilibrium with the modern hydraulic regime. The analysis of the two side-scan sonar mosaics has revealed short-term localized southward shifts in ridge morphology of at least 5 m over a 6-month period. Asymmetric surficial grain size sediment profiles across a ridge also reveal the imprint of a dominant southward-directed bottom flow.

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THE REGIONAL WILDLIFE HABITAT PLAN IN THE TAMPA BAY REGION: ACCOMPLISHMENTS AND AN ASSESSMENT

J.W. Beever III

ABSTRACT

The need for regional wildlife habitat planning (RWHP) is critical in the Tampa Bay region because of high rates of growth and habitat destruction. The commitment to RWHP in order to help maintain regional species viability and diversity has been adopted in regional and local government comprehensive plans. The plan includes groundtruthed identification of documented wildlife habitat, and protection of large preserves linked by coastal, riverine and large mammal wildlife corridors, utilizing a variety of preservation tools. Implementation techniques to protect identified wildlife habitats include regulatory, acquisition and incentive programs. Successes in implementation of the RWHP in the Tampa Bay region have occurred in northern Pinellas County, the Hillsborough River system, the Alafia River, the Little Manatee River and the Myakka River basin. Important contributions to RWHP goals have been made since 1990 by Hillsborough, Manatee and Pinellas Counties, the Southwest Florida Water Management District Save-Our-Rivers Program, the Preservation-2000 land acquisition program, and the Florida Department of Transportation mitigation program. The plan has applied conservation biology theory to real world situations and has significantly improved the information on wildlife biology in the Tampa Bay region. Difficulties encountered in RWHP implementation included coordination with wetland regulatory entities, coordination of some public and public-private partnership projects, the need for interagency coordination in mitigation bank planning and location, and an acceleration of listed species habitat conversion to developed land uses, particularly in xeric uplands.

INTRODUCTION

The protection and restoration of regional wildlife habitat is essential to the preservation of the biodiversity and watershed values of the Tampa Bay region. Based on Landsat satellite imagery (Florida Game and Fresh Water Fish Commission 1989), approximately 68.38% of the watershed of Tampa Bay is upland. In 1989, developed lands constituted 41.3% of the watershed (60% of all uplands). Based on soils, elevation and hydrology, it is estimated that at least 70% of the uplands of the Tampa Bay region were pine forest habitats. As a group, xeric, mesic and hydric pine flatwoods were reduced to approximately 50% of their historic extent in Florida by 1970 (Birnhak and Crowder 1974) by agricultural activities, speculative real estate clearing and urban development. Wade et al. (1980) reported that in 1980, pine flatwoods occupied more area in south Florida than any other kind of plant community except the Everglades marsh. By 1989, Florida Game and Fresh Water Fish Commission (GFC) mapping of southwest Florida indicated that pine flatwoods had dropped to fifth in areal extent behind grasslands, cypress swamp, dry prairies and freshwater marsh. For the first time, urban areas occupied more acreage in southwest Florida than did pine flatwoods. Today, only approximately 21% of the watershed (31% of the uplands) of the Tampa Bay Region is upland pine habitat, with almost all of the coastal pine forest systems on the shores of Tampa Bay eliminated. Recent estimates indicate that less than 5% of the land within one mile of Tampa Bay is native upland vegetative cover.

Long (1974) lists 361 species of plants in the wet pine forest habitat of south Florida, the highest plant species diversity of any habitat in south Florida. Hardwood hammock is second (306 species) and dry (xeric) pine flatwood third (303 species) in

plant species diversity. The natural habitats of the Tampa Bay region provide critical or essential habitat for 39 mammal, 331 bird, 67 reptile, 27 amphibian and 269 fish (66 freshwater and 203 marine and estuarine) species (Schomer and Johnson 1990). The natural habitats of the Tampa Bay region provide critical or essential habitat for at least 37 federally and state listed species, including Florida black bear, wood stork and Eastern indigo snake. Hayes (1991) determined that habitat destruction is a major factor contributing to the status of threatened and endangered mammal species.

During the process of RWHP, the relationship of vertebrate species with habitats has been documented and tabulated (Table 1). The utilization of different habitats by the various vertebrate groups in southwest Florida, including the Tampa Bay region, varies among major groups and with species. The pattern of habitat use indicates that all habitat types must be included in RWHP. Amphibians use a wide range of freshwater wetlands (marsh, wet prairies, swamps, ponds, streams) and uplands (pine flatwoods, hammocks, scrub, and sandhills) (Fig. 1). Reptile use includes the full range of habitats with wet flatwoods, coastal strand, hammocks, xeric uplands and forested wetlands having the highest species richness (Fig. 2). Bird use spans all habitats with mangroves, coastal strand, hammocks, freshwater wetlands and wetter uplands high in species number but with unique and rare species distributed throughout all habitat types (Fig. 3). Mammal use is high in freshwater swamps, pine forests, hammocks, mangroves and xeric uplands (Fig. 4). Combined vertebrate use of upland habitats (Fig. 5) demonstrates that all habitats are important to vertebrate species diversity and the edges of the urban area provide habitat for some bird species. Clearly, all habitat types are needed to provide resources for the full biodiversity of vertebrate species found in southwest Florida. The process of preserving species diversity through large-scale habitat protection favors the listed species of the Tampa Bay region.

Table 1. Vertebrate use by habitat type in southwest Florida (Pasco County to Collier County).

HABITAT	MAMMALS	BIRDS	REPTILES	AMPHIBIANS
Open saltwater	2	60	4	0
Mangroves	24	191	24	4
Saltwater marsh	18	103	21	1
Freshwater marsh	16	126	25	18
Wet prairie	25	109	27	17
Freshwater swamps	35	101	34	18
Ponds	13	82	26	18
Streams	6	64	22	15
Coastal strand	7	136	32	1
Hammocks	28	132	31	14
Mixed oak and pine	11	125	15	9
Pine flatwoods	33	93	32	11
Hydric pine flatwood	22	139	15	11
Scrub	25	90	33	14
Sandhills	15	65	32	11
Dry prairie	19	54	9	2
Agricultural	3	162	26	11
Urban edge	2	99	8	3

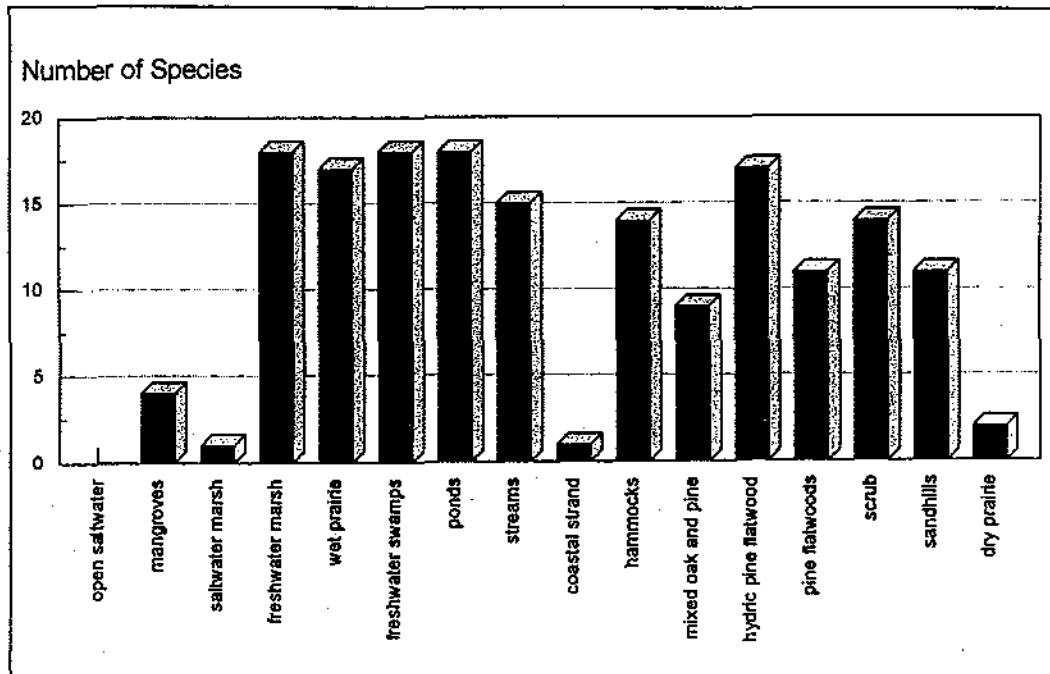


Figure 1. Amphibian use by habitat type, southwest Florida (Pasco County to Collier County).

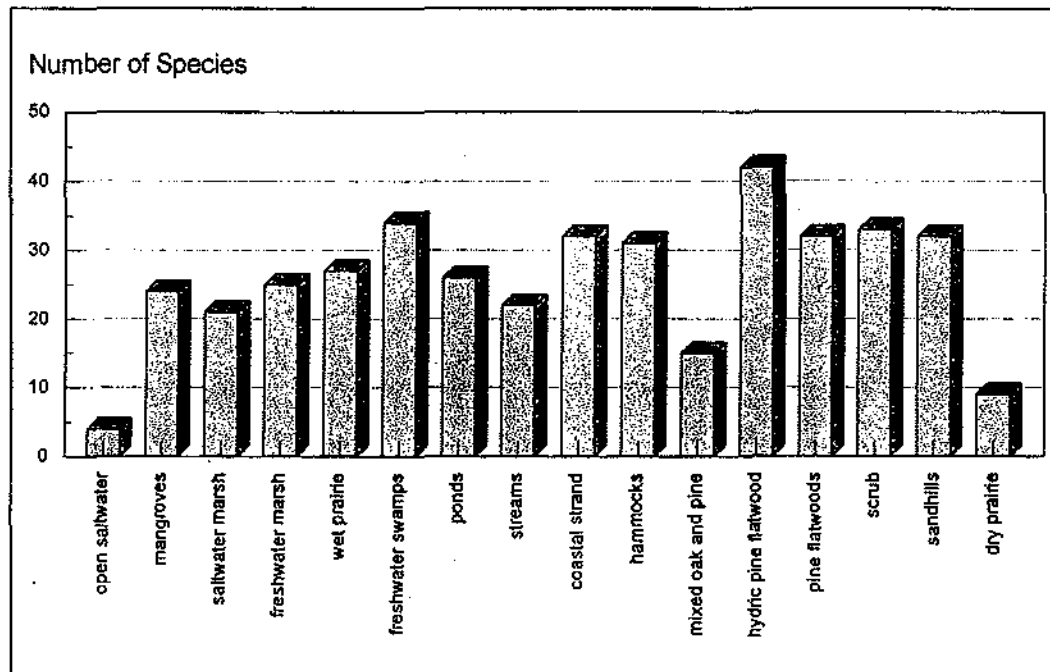


Figure 2. Reptile use by habitat type, southwest Florida (Pasco County to Collier County).

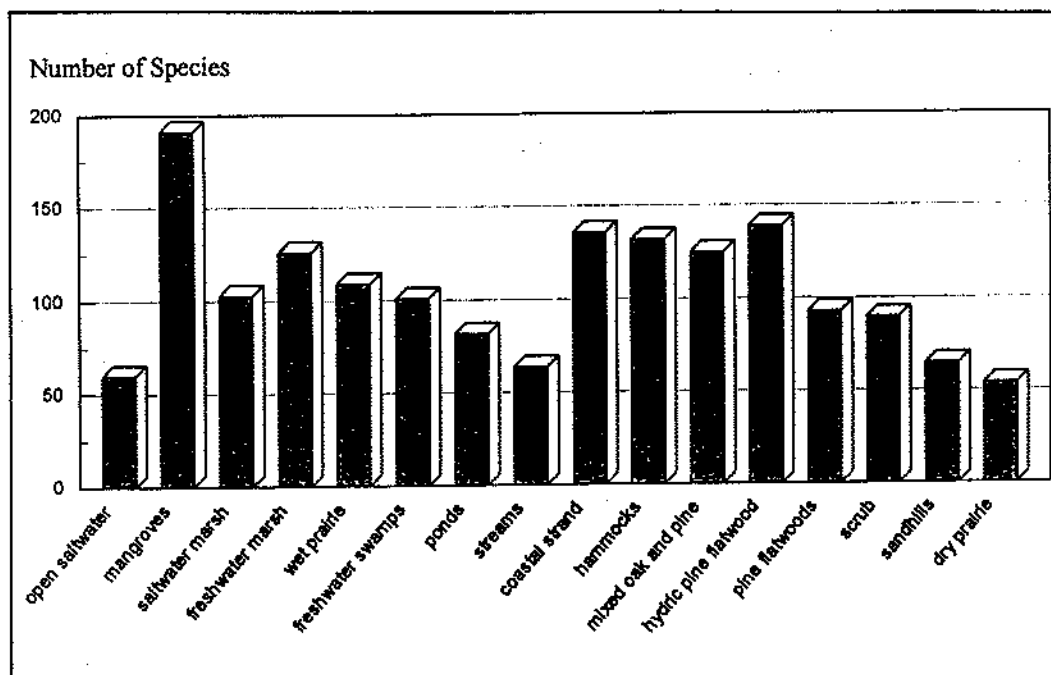


Figure 3. Bird use by habitat type, southwest Florida (Pasco County to Collier County).

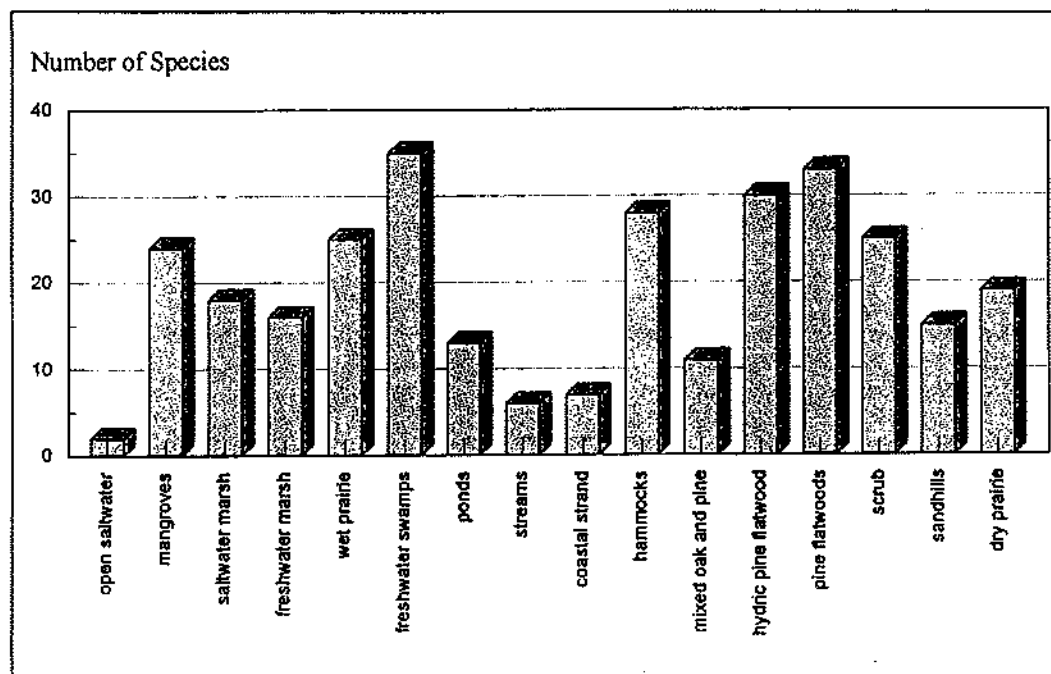


Figure 4. Mammal use by habitat type, southwest Florida (Pasco County to Collier County).

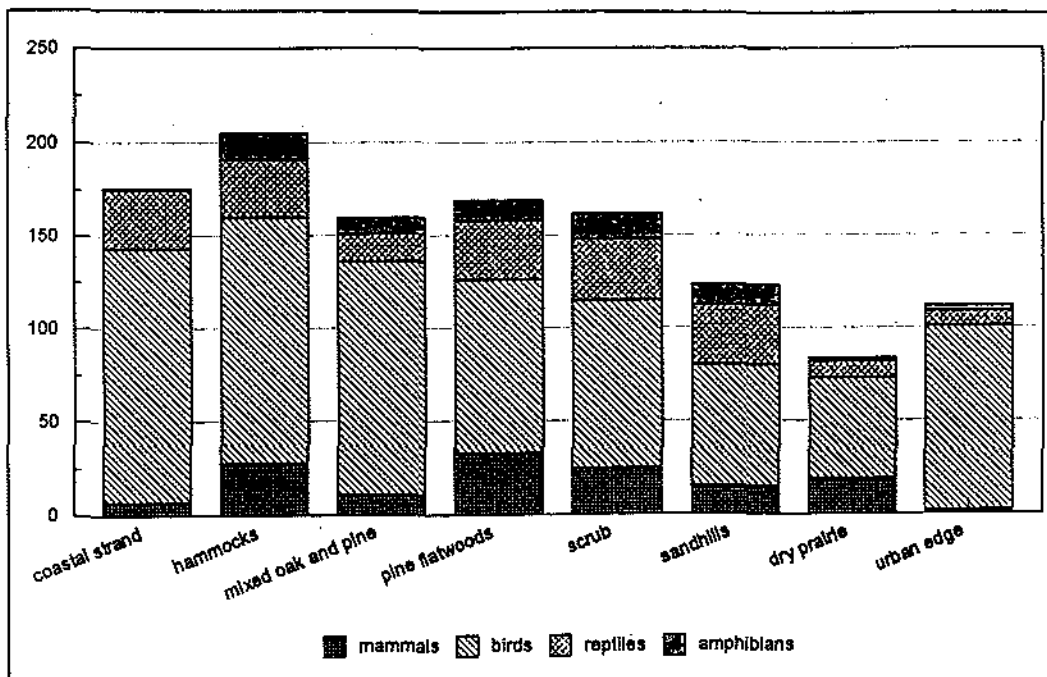


Figure 5. Vertebrate species by habitat type in southwest Florida (Pasco County to Collier County).

There are federal, state, and local requirements and initiatives for regional wildlife habitat planning. The goals of the Migratory Bird Treaty Act and the Endangered Species Act are fostered within the protection of the habitats designated in the Tampa Bay Regional Wildlife Habitat Plan.

The Florida Growth Management Act and the implementing administrative rule, 9J-5, require all local jurisdictions to adopt implementing policies for the "protection and conservation of the natural functions of existing ... wildlife habitats". The Florida Game and Fresh Water Fish Commission published the *Model Local Government Comprehensive Plan, GFC Policies and Recommendations* (July 1986) to propose implementation policies for local governments to gain compliance with the Growth Management Act. This document recommended a policy that wildlife corridors should be established in order to maintain species viability and diversity. The Tampa Bay Regional Planning Council has adopted the GFC Comprehensive Plan and other policies that protect listed species and their habitats.

The Florida Game and Fresh Water Fish Commission has implemented the above statutes, rules and plan policies, in part, through statewide habitat mapping and statewide regional wildlife habitat planning (Kautz 1989, 1991). This planning effort is titled the Comprehensive Statewide Habitat System. It is a special project funded through the GFC operation plan and administered by the Office of Environmental Services and the Non-Game Program. The Tampa Bay Regional Wildlife Planning includes parts of this statewide analysis.

MATERIALS AND METHODS

Regional wildlife habitats are habitats used by populations of wild native animals to fulfill life cycle requirements. These requirements include finding food, shelter, water and mates. Fragmentation of habitat interrupts critical life history activities and natural movement patterns, resulting in reduction of population sizes and potentially in local extinction (Dennis et. al. 1991).

A wide variety of mapping tools are utilized in the Regional Wildlife Habitat planning methodology, including Florida Game and Fresh Water Fish Commission Landsat habitat maps, false color infrared aerials, Soil Conservation Service maps, United States Geological Service maps, U.S. Fish and Wildlife Service (USFWS) habitat mapping, National Wetland Inventory maps, maps produced by National Estuary Programs and Surface Water Improvement Management (SWIM) Plan projects, existing published and gray literature, and maps associated with development review, including Developments of Regional Impact (DRI).

Existing and proposed public lands, easements and rights-of-way held by local, state and federal agencies, and other properties designated for conservation and preservation purposes are identified as large preserve areas and habitat links (Fig. 6). Large preserve areas and their linkages are essential to a regional wildlife habitat system. Where of appropriate habitat and location, utility and abandoned easements and rights-of way are considered to add width and continuity to regional wildlife habitat.

Proposed public and private lands that are designated for acquisition for conservation/preservation purposes are included when on a substantiated list, such as Conservation and Recreation Lands (CARL), the Save Our Rivers (SOR) and Surface Water Improvement Management (SWIM) Programs, Florida Communities Trust (FCT) Preservation 2000, and county bond issues and capital improvements programs (e.g., Hillsborough Environmental Lands Acquisition Program). Lands designated as preserve/conservation areas by local governments in their comprehensive plans and lands designated by the regional planning council in their Regional Comprehensive Plan are included. Lands under review or on candidate lists, but not finalized or ranked, are not included.

The forty-five target animal species used to identify regional wildlife habitat are derived from the Florida Game and Fresh Water Fish Commission list of rare and endangered species (Wood 1992), and their occurrence in the Tampa Bay Region as determined by direct observation and documented sources. The target species are:

- MAMMALS—Florida black bear, Florida panther, river otter, bobcat, long-tailed weasel, Southeastern big-eared bat, Sherman's fox squirrel, Florida mouse, round-tailed muskrat;
- BIRDS—brown pelican, wood stork, Florida sandhill crane, mangrove clapper rail, little blue heron, reddish egret, snowy egret, tricolored heron, roseate spoonbill, limpkin, piping plover, southeastern snowy plover, least tern, roseate tern, American oystercatcher, bald eagle, merlin, Arctic peregrine falcon, southeastern American kestrel, eastern American kestrel, northern harrier,

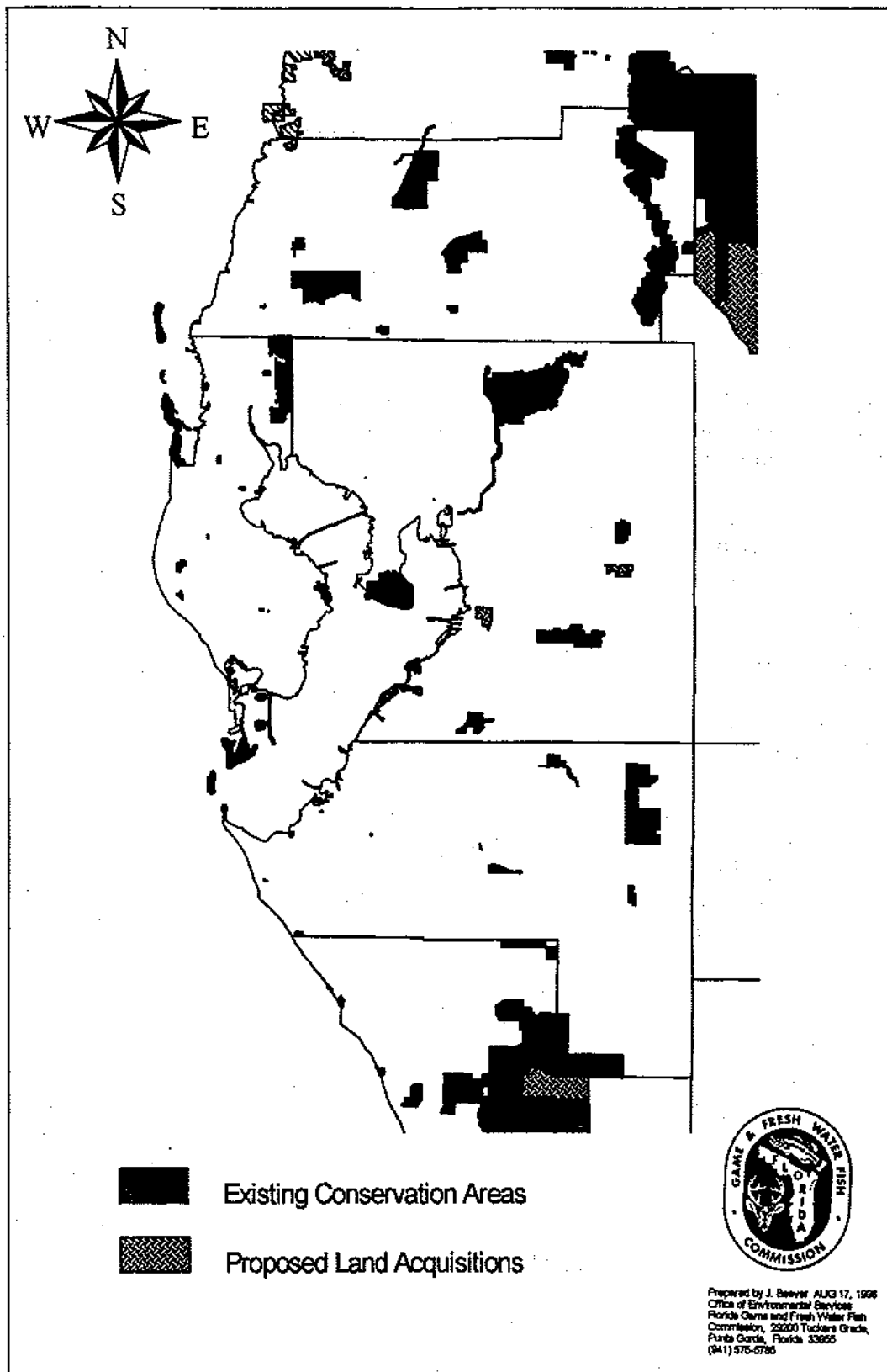


Figure 6. Wildlife habitat protection areas, Tampa Bay region, 1989.

Beever

Audubon's crested caracara, burrowing owl, red-cockaded woodpecker, Florida scrub jay, Bachman's sparrow, Florida grasshopper sparrow;

- REPTILES—Atlantic green turtle, Atlantic loggerhead turtle, Suwannee cooter, gopher tortoise, eastern indigo snake, Florida pine snake, short-tailed snake, American alligator;
- AMPHIBIANS—gopher frog;
- FISH—common snook.

Documented animal use areas and travel corridors were initially identified utilizing existing wildlife databases (Florida Natural Areas Inventory, the Florida breeding bird atlas, wading bird surveys, shorebird surveys, Wildlife Observation System Database) and habitat mapping of habitats documented to be necessary for and utilized by the target species. Significant gaps were present in existing databases for many of the target species. These gaps were addressed by direct field investigation of areas of suitable habitat that did not have records of target species occurrence.

Where large tracts of suitable documented habitat were indicated by existing maps, these sites were field-investigated and groundtruthed to determine if suitable habitat was currently present and if target listed species were present. In addition, during the execution of other duties for the Florida Game and Fresh Water Fish Commission, including project review, habitat planning, and other research projects, suitable habitat was recorded and surveyed for target species. Consequently, this new data on areas of habitat and target species presence provided additional information to Florida Game and Fresh Water Fish Commission habitat maps and databases that was not in the existing documentation.

Where large tracts of suitable habitat and target species are present, expansions of existing preserves or new preserves were designated. Where existing suitable habitat and target species are present in smaller parcels of land that connect the existing large preserve areas through existing habitat preserves, linkages were designated. Corridor alignments consisted only of documented animal use areas and habitats documented to be essential for the target species.

In the overall design of the Regional Wildlife Habitat Plan, the following criteria were utilized. Wider corridors and larger preserve areas are the preferred design. The following widths were the minimums set, for the purposes of this plan, to accommodate large mammal habitats: ¼-mile width for a mile-long corridor, connecting large preserve areas and a ½-mile width for 4-mile long corridor connecting large preserve areas. A one square mile area (640 acres) of suitable habitat, documented for target species, is considered a large preserve. Upland buffers along wetlands are recommended to be at least 1000 feet wide. Although it was not possible to include upland buffers on all sides of a wetland, it was preferred. Where only one side of a wetland includes an adequate upland buffer, the one-sided buffer was designated to be at least 2000 feet in width. In areas where wildlife corridors are narrow (e.g. ¼ mile in width), minimum buffers are recommended at 500 feet. Recommended riverine buffers are a minimum of 550 feet landward of mean high water. Where they exist in coordination with suitable habitat documented for wildlife

use, natural agricultural lands such as native range and existing surface water management conveyances are included as links in the network.

The Tampa Bay Regional Wildlife Habitat Plan was coordinated with adjacent counties, municipalities, and regions to maintain inter-county/-city wildlife habitat linkage and preserve connections. The Florida Game and Fresh Water Fish Commission has also identified regional wildlife habitat for the Southwest Florida Regional Planning Council. Identification of Regional Wildlife Habitat Plans for the Central Florida Regional Planning Council area is in progress.

RESULTS

A composite map of the Tampa Bay Region Wildlife Corridor System as of October 1996 is presented in Figure 7. (The working version of the map on computer is in color.) The Tampa Bay Regional Wildlife Habitat Plan is a work in progress as new preserves are acquired, existing habitat is lost to development, and new target species information is gathered. This map reflects approximately 7 years of data collection and regional wildlife habitat planning.

For the Tampa Bay Region, three general types of regional wildlife habitat were identified—coastal, riverine, and large mammal. The designated coastal habitats buffer and interconnect estuaries and their tributaries. This design provides migratory flyways for waterfowl, shorebirds and passerine birds, and protects rookeries and nesting areas. These habitats include coastal strand and dunes, tropical hardwood hammock, coastal oak hammock, coastal scrub, mangrove forest, saltmarsh, high marsh, riverine riparian forest and pine forest.

The Tampa Bay Region includes one of the least intact coastal zones in Florida. The mangrove and saltwater wetland fringe of most of the region is fragmented and relatively small. This was due, in large part, to the absence of regulatory controls and acquisition programs during the period of major coastal development in the region. Coastal scrubs, oak hammocks and pine flatwoods compose the upland buffers adjacent to the remaining coastal wetlands. Tropical hardwood and coastal cedar hammock are present in limited relict tracts. Many migratory birds use the coastal zone as flyway, feeding and breeding areas. The coastal scrubs and hammocks harbor a variety of listed and endemic plant species. Scrub jays, gopher tortoises, indigo snakes and gopher frogs are found in the Tampa Bay region's coastal scrubs. Only a small percentage of the Tampa Bay region's coastal wetlands and coastal uplands are conserved by federal, state, local and land trust ownership.

The designated riverine habitats are, by their natural shape, linear corridors that link interior wetland system headwaters to the coastal and receiving estuarine waters, following rivers, creeks, major canals with naturalized banks and flooded sheetflow slough systems. These areas are important to the protection of riverine species, estuarine and riverine fisheries, and seasonal migratory routes for game and non-game species. Riverine habitats include riverine forest, mangroves, marshes, riverine scrub, oak hammock, hydric hammock, cypress slough and mixed hardwood swamp forest. Riverine corridors are a focus of regional biodiversity (Naiman et al. 1993). Greatest species diversity is achieved by including a complete upland buffer. The designated

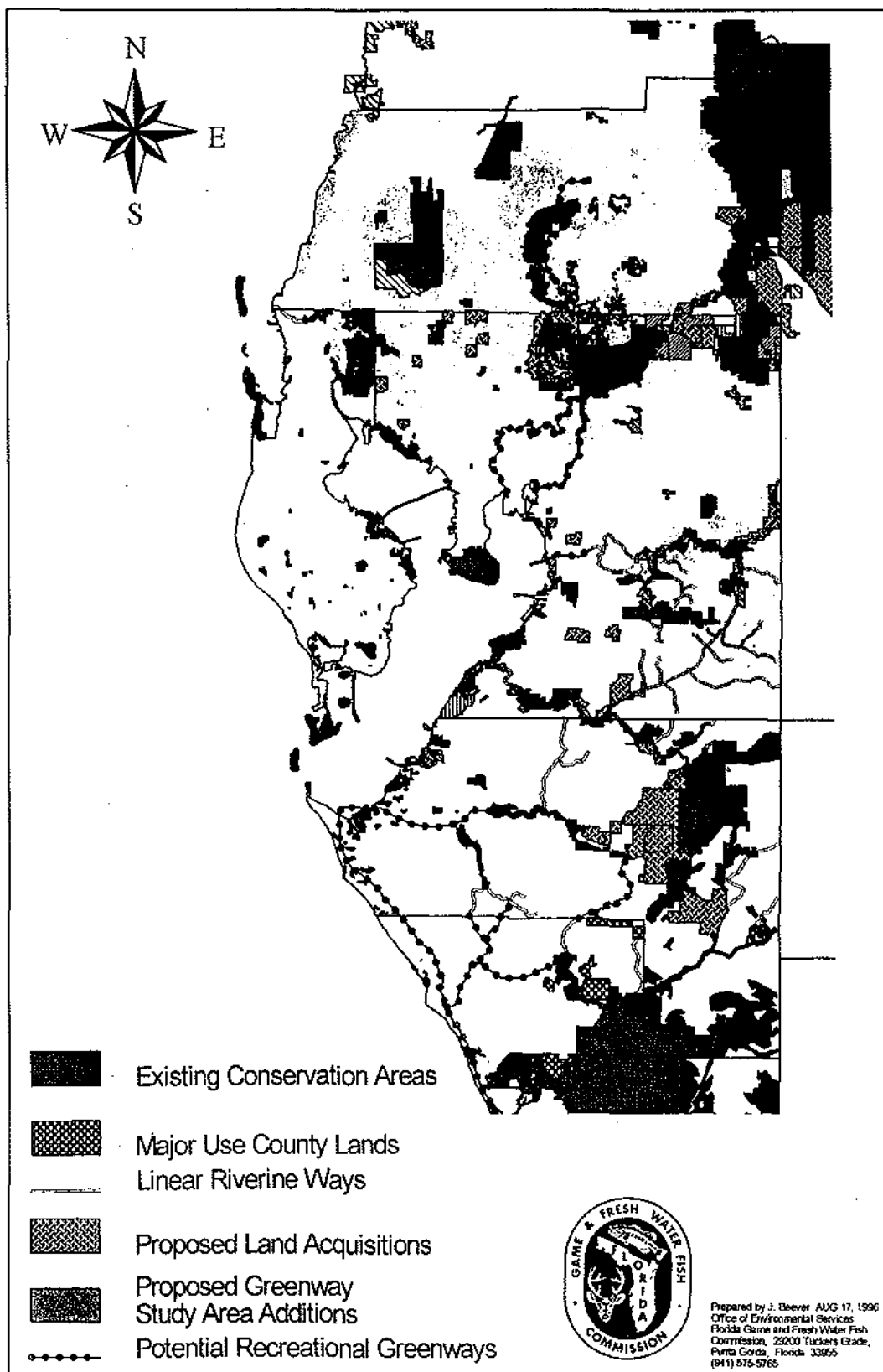


Figure 7. Regional wildlife habitat plan, Tampa Bay region, 1996.

riverine corridors have been identified based on the health of the adjacent vegetative systems and on the potential for the river to connect coastal habitats to large mammal habitats. The Hillsborough River, for example, is substantially developed at its lower extent. However, it passes through the highest quality upland forests in Hillsborough County and its headwaters are in the greater Green Swamp system, which is a major node in the statewide habitat protection planning. Likewise, the Manatee River connects a wide variety of scrub, pine and wetland habitats with the coastal regional wildlife habitat of the lower Tampa Bay. Other riverine systems provide similar critical links. Rivers that do not connect the coastal regional wildlife habitat to a large mammal regional wildlife habitat are included if the riverine habitat system is intact and target species are present.

The designated large mammal habitats consist of large mammal preserve areas and their linkages. Large mammal habitats are either wetland and upland, or upland alone. The habitats utilized were the preferred habitat types documented for large mammals, including pine forest, oak forest, oak-pine mixtures, sabal palm, oak and hardwood hammocks, hydric pine flatwoods, upper cypress slough, mixed hardwood swamp forest, wet prairies and cypress prairies.

The vegetative communities preferred by and documented for use by large mammals substantially determine the location and alignments of large mammal regional wildlife habitat. Both Florida panther and Florida black bear use forested systems, including cypress swamps, pine flatwoods and hardwood associations (Belden et. al. 1988; Maehr and Brady 1984; Maehr 1986). Both species will travel through wetlands during the dry season and uplands year-round. Travel is associated with moving to better feeding and watering areas and mating. Long distance travel is performed by young animals that are in search of a territory and/or mates (Maehr 1992).

In the Tampa Bay Region, radio-collaring and tracking data, such as performed in southwest Florida, are not available for these species. The presence and movement of large mammals in the Tampa Bay region are documented by sightings, sign and nuisance reports. This information is augmented by literature and wildlife surveys for development projects. The low abundance of large-ranging predators eliminates the ability to achieve statistical significance and high levels of replication with occurrence data. However, all collected data corresponds to the locations of existing preferred habitat types. These habitats are also documented for other target species, including Bachman's sparrow, Eastern indigo snake, Southeastern American kestrel, gopher tortoise, Florida sandhill crane, bald eagle, river otter, bobcat, wood stork, Florida mouse and Sherman's fox squirrel.

Four large preserve areas consisting of expansions and new preserves are recommended. They include: the major Hillsborough River-Blackwater Creek system of northeastern Hillsborough and southeastern Pasco Counties which also extends into Polk and Sumter Counties; the Anclote River-Pithlachascotee River-Brooker Creek system of western Pasco and northeastern Pinellas County; the upper Manatee River system; and the Myakka River complex in Manatee and Sarasota Counties.

The difficulties of developing and establishing the plan include resolving multiple land-use conflicts, the applicability of conservation biology theory to real-world situations, and the need for accurate, basic information on regional biology. During the process of this study, significant gaps concerning the regional knowledge on several target species, including Sherman's fox squirrel, Southeastern American kestrel, Florida scrub jay, red-cockaded woodpecker, Florida mouse, Florida sandhill crane, Florida black bear and Florida panther were evident in existing databases and literature. The absence of information is exacerbated by entrenched paradigms that these species were not present in or could not be present in portions of the Tampa Bay Region. Ongoing theoretical conflicts concerning the design and method of preserves (Levin 1993) impairs practical implementation of the Regional Wildlife Habitat Plan, while the listed species habitat under consideration is lost to development.

The continued policy of wetland regulatory agencies of establishing small, isolated preserve sites within the developing urban landscape contributes to the process of habitat fragmentation. Without a coherent plan and in isolation, these small preserve efforts will not provide the wildlife value and functions sought. The Tampa Bay Regional Wildlife Habitat Plan can serve as a tool to ensure continuity among the various development preserves and conservation areas to avoid habitat fragmentation.

CONCLUSIONS

The Tampa Bay Regional Wildlife Habitat Plan was written with a long-term perspective. Many years will be required to implement this plan. It represents a tool to be used to focus land acquisition, regional planning and regulatory recommendations. This plan is designed to assist decision makers and planners in the siting of facilities and in determining priorities for sensitive lands acquisition.

Implementation techniques to protect the wildlife habitats identified in this plan will include regulation, acquisition, and incentive programs. Different planning tools will need to be utilized in each jurisdiction. Hillsborough County has adopted a wildlife habitat ordinance and plan that corresponds with portions of the Tampa Bay Regional Wildlife Habitat Plan. Other portions of the plan have been nominated for FCT, CARL and SOR acquisition projects by various entities. Several land developments, such as East Meadows, have incorporated wildlife corridors within the project design to address concerns for listed species and biodiversity. The Hillsborough River Greenways Project has adopted and concurs with the Tampa Bay Regional Wildlife Habitat Plan.

The Tampa Bay Regional Planning Council, the Tampa Bay National Estuary Program, the Florida Department of Environmental Protection, the Southwest Florida Water Management District, Hillsborough County, Manatee County, Pinellas County, and private entities such as CF Industries have contributed significantly to the implementation of the RWHP in the Tampa Bay Region.

The Southwest Florida Water Management District has coordinated closely with GFC in regard to protecting regional wildlife habitat in the Save Our Rivers Program. SWFWMD has purchased and preserved 94,933 acres of regional wildlife habitat in

the RWHP in coastal, riverine and interior forested habitats. Areas of particular note include coastal Tampa Bay, the Hillsborough River, the Green Swamp, Little Manatee River, Alafia River, major xeric scrubs including the Golden Aster and Balm-Boyette scrubs, and Brooker Creek system. Approximately 138,266 acres of additional regionally significant wildlife habitat are proposed to be acquired.

The Hillsborough County Environmental Lands Acquisition Program has purchased and preserved 23,455.7 acres of regional wildlife habitat in Hillsborough County in coastal, riverine and interior forested habitats. Areas of particular note include the Hillsborough River, Little Manatee River, Alafia River, major xeric scrubs including the Golden Aster and Balm-Boyette scrubs, and portions of the greater Brooker Creek system. Approximately 53,636.3 acres of additional regionally significant wildlife habitat are proposed to be acquired.

As the Tampa Bay Regional Wildlife Habitat Plan takes physical form, recreational and tourism opportunities will be available adjacent to, and in some places, within, the preserve system. As large and linear tracts of wildlife habitat are preserved, multiple land-use conflicts can be expected to occur as competing public interests desire use of the land. To date, in the Tampa Bay region, these conflicts have taken the form of consumptive versus passive recreation interests, utility siting for water supply, linear utility and road project planning through habitat that is perceived as vacant and available for public easement, and differential management goals of competing conservation interests.

The Tampa Bay Regional Wildlife Habitat Plan, with its large preserve areas and linkages, will function as a wildlife reservoir. With its implementation, the protection of regional wildlife habitat and the preservation of the biodiversity and watershed values of the Tampa Bay region will be significantly enhanced, allowing the species that exist in Tampa Bay Region today to continue to survive, and to be enjoyed by residents, visitors and future generations.

ACKNOWLEDGMENTS

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MITIGATION BANKING AS AN ENVIRONMENTAL RESTORATION TOOL

Suzanne T. Cooper

EXECUTIVE SUMMARY

The term "Mitigation Banking" has several interpretations. The banking concept grew out of the now-common use of habitat creation or restoration—mitigation—as compensation for wetland impacts. Mitigation on-site has often resulted in small, isolated, non-functional tracts which do not provide suitable replacement habitat and are not properly managed for long-term viability. The expected outcome of a mitigation bank is generally the creation of a large, more successful habitat preserve as mitigation for several small, isolated natural resource impacts which have been legally permitted. Usually the habitat restoration or creation banking effort occurs "off-site" and is begun before credits to use the bank are made available. An accounting system is usually established to track the generation and dispersal of the mitigation credits in accordance with adopted guidelines or regulations. The concept is gaining popularity with the private sector as well as with public sector land developers (such as transportation agencies), environmental regulators and natural resource managers. In late 1995 final federal policy guidance was issued regarding the establishment, use and operation of mitigation banks, as a means to provide compensatory mitigation in advance of authorized impacts to similar resources. The State of Florida approved rules on this topic in 1994 and incorporated the rules into Florida Statutes in 1996. By late 1995, 11 permits for mitigation banks, public and private, had been issued statewide. Work continues between federal and state agencies to refine and standardize guidelines and permitting procedures.

In the Tampa Bay region the concept has been implemented on at least two levels. Over the past few years Pinellas County has intentionally "over-built" its mitigation projects, where feasible, with the expectation of using the excess mitigation area as credit for other county-generated impacts. This will test the ability of the state to accommodate this type of banking activity while recognizing the powers and constraints of county government. Under legislation passed in 1996, the Florida Department of Transportation is allowed to pay the Water Management Districts to provide the mitigation required for permitted wetland impacts associated with highway construction. The Southwest Florida Water Management District has purchased over 1,000 acres in Pasco County as mitigation for the Suncoast Parkway project.

Action BH-2 within the *Comprehensive Conservation and Management Plan* of the Tampa Bay National Estuary Program (TBNEP) calls for the establishment and implementation of special mitigation criteria for the Tampa Bay watershed and efforts to direct mitigation to priority areas identified in *Restoring the Balance*, the bay's habitat restoration and protection master plan. At TBNEP's request, the Agency on Bay Management, the natural resources committee of the Tampa Bay Regional Council, has established a Mitigation Criteria Workgroup. The Workgroup is considering a number of mitigation and mitigation banking issues, including criteria for on- and off-site mitigation; safeguards to protect productive native upland habitats from conversion to wetlands; bank siting, management and associated cost issues; and

whether mitigation conducted by local governments and private developers should count toward overall habitat restoration goals established for the Bay. Additionally, Action BH-2 calls for the development of a map of existing and potential restoration sites, regardless of ownership. That map is under development. It is the intent of the TBNEP that final recommendations for mitigation criteria in Tampa Bay be adopted and used by local government and agency partners in the TBNEP.

Draft recommendations which have been presented to the Workgroup include:

- Before compensatory mitigation can be considered, impacts should be avoided or minimized.
- Restoration and enhancement should be emphasized *before* creation because of the higher failure rates associated with habitat creation and because creation involves converting an existing habitat.
- Local government or private mitigation which results in a net increase in valuable estuarine, oligohaline or native upland habitats should "count" toward the overall restoration goals for Tampa Bay. That portion of a project which is to be credited to mitigation must be agreed upon and clearly stated up front in the contract between an agency and local government.
- Native upland habitats should not be converted to wetlands as mitigation.
- Conversion of one non-nuisance native wetland type to another native wetland type does not constitute mitigation.
- The mitigation site should be **publicly-owned or provided an easement**, initially or ultimately. For example, a private mitigation banker would be required to provide a permanent conservation easement to a public conservation entity.

The Working Group will incorporate the information from *Restoring the Balance* as well as results of various TBNEP research contracts which depicted the historic state of the estuarine and adjacent Bay area and described the current state of the ecosystem. It will also use previous work done to characterize the Bay's tidal streams and identify restorable components. The pertinent literature is included in the References section below.

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THE FUNCTION AND APPLICATION OF PRESERVATION LAND ACQUISITION

K.G. Gremley

ABSTRACT

Preservation land acquisition fills a void between what needs to be accomplished to properly preserve the environmental qualities and other resources associated with certain property that can not be achieved through the regulatory process afforded government entities. The public has continued to support the concept of the purchase of real property to assure that it is preserved and available to the public so that these resources can be properly managed.

Preservation land acquisition needs to have a multi-leveled approach through state, regional and local perspectives. There are various projects that warrant preservation and respective benefits. A large wildlife refuge may be important to a local community and the state, but the local government may not have sufficient resources to preserve or manage the site on its own. Additionally, small isolated tracts may not warrant the interest of a state program; however, they may be of extreme local significance.

Another benefit of multiple preservation programs is that while they all may have certain common objectives, they can each be customized to address specific objectives. These can include recreational lands, beach access, water resources, trails, or even specific projects. This is an important feature since all of these programs require the approval of elected officials, who typically respond to the needs of their constituents. It is essential that the integrity of these programs be maintained in order to keep public support.

While these programs typically utilize the purchase of real property (fee simple acquisition) there are other tools available. These include acquisition of development rights, conservation easements of various types, and life estates, to name a few. Assistance can be provided through various non-profit organizations to assist local governments in their purchases. These preservation techniques have certain applications, benefits and constraints. Preservation land acquisition provides the means for preserving real property and makes it available for appropriate resource management.

ADDRESS: Hillsborough County Environmental Lands Acquisition and Preservation Program,
Real Estate Dept., 601 E. Kennedy Blvd., Tampa, FL 33602.

HABITAT RESTORATION FOR TAMPA BAY: THE PAST, PRESENT AND FUTURE

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EXECUTIVE SUMMARY

The Past And Present

Degradation and destruction of Tampa Bay estuarine habitats have been well documented, quantifying thousands of hectares of impacts to subtidal and intertidal communities. In response to public and governmental awareness of declining habitat acreage and values, efforts were begun in the 1970s to begin the restoration of habitats and water quality of Tampa Bay. While improvements to water quality have been garnered through advanced wastewater treatment, complementary projects have begun the process of reversing habitat degradation and destruction. While early projects typically represented simple plantings of intertidal marshes, maturation of the restoration process now yields sophisticated and complex multifunctional projects embracing the strategy of "ecosystem restoration." Projects now often incorporate habitat mosaics providing many differing habitats important for various wildlife species: tidal creeks, open water lagoons, seagrass beds, live bottom substrates, salt marsh and mangrove platforms, mudflats, salterns, islands, transitional habitats, uplands and freshwater wetlands. As practicable, restoration projects also often help restore sheetflow and polish stormwaters.

From 1971 to 1997, exclusive of mitigation projects or seagrass restoration, at least 76 projects (ranging in size from 0.00081 to 24.4 ha [0.002–60.2 ac]) have returned a minimum of 130.3 ha (322 ac) of estuarine and coastal habitats to the Tampa Bay ecosystem. This restored acreage represents 2.1% of the estimated 6,067 ha (14,991 ac) of emergent wetlands that have been lost since 1900. Wetland restoration projects apportioned by county are as follows:

- Pinellas County—28 projects (35.9 ha=88.9 ac);
- Hillsborough County—32 projects (87.5 ha=216.3 ac);
- Manatee County—16 projects (6.8 ha=16.8 ac).

For the 19-year restoration period of 1971 through 1989, 36 projects restored 9.6 ha ($\bar{x}$ =0.5 ha/yr [23.72 ac or $\bar{x}$ =1.24 ac/yr]). In comparison, the eight-year period from 1990 through 1997 resulted in 40 projects restoring 120.7 ha ($\bar{x}$ =15.09 ha/yr [298.2 ac or $\bar{x}$ =37.28 ac/yr]).

Restoration Programs

The significant increase after 1989 in the rate of restoration primarily was due to two programs, the Surface Water Improvement and Management (SWIM) Program of the Southwest Florida Water Management District (SWFWMD) and the Florida Pollution Recovery Program (FPRP) of the Department of Environmental Protection (FDEP). As established by the SWIM Act of 1987, SWIM is a state mandated, tax supported program administered by FDEP through the state's water management districts; the

SWIM program of SWFWMD was charged to write and implement a management plan addressing the environmental problems of Tampa Bay, identified as a priority water body in the SWIM Act. While very interdisciplinary and in various stages of implementation, habitat restoration is an important component of the SWIM management plan for the bay; SWIM restoration projects represented the first use of "habitat mosaics" as a type of ecosystem restoration. By partnering with local governments and agencies (i.e., FDEP), the SWIM program has completed 30 restoration projects, totaling 98.8 ha (244.1 ac, December 1989 to December 1997). This total represents the largest number of restoration projects and total acreage of habitat restoration associated with a single restoration program for the bay (75.8% of total restored coastal habitats). SWIM currently has 30 additional projects in various stages of development that could result in up to 1,215 ha (3,000 acres) of additional enhanced/restored/created habitats. The SWIM program has relied heavily on SWFWMD staff for construction and construction management services, a move which has significantly reduced per-acre costs of habitat restoration. To date, SWFWMD staff have cooperatively or solely constructed 21 of the 30 projects (70% of total). Coupled with volunteer labor for certain project aspects (e.g., marsh plantings), total per-acre restoration costs are estimated at \$25,000–30,000/acre, a savings of 25–50% of private construction expenses. With maturation of the SWIM program, inhouse staff continue to assume increasing responsibility for design and permitting as well as construction of projects.

A second important restoration program for the bay involves the FDEP's FPRP and the Pollution Recovery Trust Fund (PRTF, Section 403.165, Florida Statutes). The purpose of the program was to provide funding to qualified governmental entities for environmental restoration, enhancement, and/or protection activities. Projects that were appropriate for this program could be in the areas of natural systems, surface water quality, ground water and air quality. Through various levels of partnering with local governments and SWIM, PRTF programs have been involved with 85.06 ha (210.19 ac) of habitat restoration for the bay (65.3% of all restoration performed). Restoration efforts of the PRTF were financed using fines collected by the State in retribution for violations of environmental laws by public and private parties. The statute stipulates that fine monies were to be used "to restore polluted areas of the state to the condition they were in before pollution occurred or to otherwise enhance pollution control activities in polluted areas." There are times when fine monies collected are put in accounts that place restrictions on the use of those dollars. Restrictions may include the types of projects that are appropriate and/or geographical limitations.

During the 1996 legislative session the PRTF was abolished and the Ecosystem Management and Restoration Trust Fund (EMRTF) was established. While the EMRTF will continue to receive monies collected for violations of Chapter 373, F.S. and for injury to coral reefs, there are now multiple purposes for the fund. In addition to the original purpose of the now defunct PRTF, the EMRTF is to be used for planning and implementation of programs for the management and restoration of ecosystems, development and implementation of SWIM programs, and activities to restore or rehabilitate injured coral reefs. At this point, it is uncertain whether the

FPRP will continue as a DEP program and/or will continue to receive funding from the EMRTF.

Seagrass and Upland Communities

Two important components of ecosystem restoration receiving additional attention include subtidal and upland habitats (inclusive of freshwater wetlands). Of particular subtidal importance are seagrass beds. Seagrass restoration efforts and passive recruitment are well documented for the bay. In apparent correlation with gradual improvements in water quality, seagrasses have colonized thousands of hectares of bay bottom throughout the estuary during the last decade. Continued passive recruitment throughout the bay in response to stable or still improving water quality is anticipated (see Johansson and Ries, this volume).

Additional recognition also is being given to the importance of coastal uplands and freshwater wetlands as components of the bay's ecosystem restoration and management. In an effort to document historical trends of coastal habitats within the bay's watershed (and for the first time known to these authors), an analysis of the areal extent of both freshwater wetland and upland assemblages was performed employing 1985 data from the National Wetlands Inventory of the U.S. Department of the Interior (Fish and Wildlife Service). This data provided the areal extent of each wetland habitat and seven upland classifications for each of 20 USGS 7.5-minute quadrangles covering Tampa Bay and the adjacent coastal areas for three time periods: 1940-50s (1943, 1950, 1951, 1952 and 1956), 1972 and 1982. For these periods, the total area within the mapped area averaged 358,339.13 ha (885,456 ac). Uplands occupied 51.9% of the study area in the 1940-50s and 53.5% during the 1982 census. Wetlands, including the open waters of Tampa Bay and adjacent (mapped) coastal waters of the Gulf of Mexico, represented 48.1% during the 1940-50s, and 46.5% in 1982. These figures indicate a conversion of 5,644 ha (13,946.3 ac) from mapped wetlands in the 1940-50s to mapped uplands by 1982.

Four of the seven upland classifications—upland-urban, upland-agricultural, upland-rural, and upland-forest—made up more than 98% of the uplands within the study area in all three periods. The most notable trend evident is the decrease in the rural classification and an increase in the urban category. Rural land uses accounted for 65.6% of mapped uplands during the 1940-50s while only 13.3% of uplands in 1982 were mapped as rural. This represents a 52.3% decrease in rural lands from the 1940-50s through 1982, while a 35% increase in urban lands is documented over the same time period. By 1982, urban lands occupied 99,210 ha (245,148 ac) within the study area representing 52.1% of all uplands.

Upland forest represented 3.4% of land cover in the 1940-50s, 11.5% in 1972 and 9.6% in 1982. The relatively low composition in the 1940-50s and corresponding net increase during the study period may be due to mapping artifacts; upland forests were mapped within the upland-rural category during the 1940-50s and were more discernible during later mapping periods due to further fragmentation and partitioning of these canopied habitats. Physiognomic changes to the structure of these habitats through modification of fire regimes (fire suppression and physical exclusion) and hydrologic patterns may also account for the 6.2% net increase in

mapped upland forest. This characteristic conversion of native habitats to low intensity rural land uses and agriculture, and ultimately to high intensity urban and industrial uses, is responsible for the virtual elimination of native coastal upland habitats adjacent to Tampa Bay.

Planned coastal upland habitat restoration in the Tampa Bay watershed is non-existent, although uplands are increasingly being incorporated as components of habitat mosaics and as major portions of large wetland restoration projects (e.g., Cockroach Bay and Wolf Branch Creek restoration sites). Additional opportunities for large-scale upland restoration (hundreds to thousands of hectares) and management exist via various land acquisition programs for the bay. Continued cooperative efforts should be directed in a holistic approach to incorporate coastal uplands into the habitat restoration mosaic for Tampa Bay.

The Future

Land Acquisition

Increased recognition of the importance of public land acquisition for preservation, restoration and management has prompted various agencies and governments to accelerate efforts to acquire parcels around the bay. Important land acquisition and management programs for the bay include:

- The state's Preservation 2000 Trust Fund and related programs of the Conservation and Recreation Lands (CARL) Trust Fund as well as the Save Our Rivers (SOR) Trust Fund;
- SWFWMD Water Management Lands Trust Fund;
- Hillsborough County Environmental Lands Acquisition and Protection Program (ELAPP);
- Pinellas County Real Estate Department;
- A potential Manatee County program;
- Various municipal efforts.

Future restoration of the bay will depend not only on availability of parcels, but also on funds to restore and manage the parcels. SWFWMD alone has 34 parcels approved in its 1997 Five Year Acquisition Plan totaling 4,943 ha (12,214 ac). These tracts include both coastal intertidal wetlands and adjacent lands as well as nearby freshwater and upland parcels, all in keeping with the idea of ecosystem restoration and, as feasible, to provide wildlife corridors both north and south along the bay as well as east and west from inland to bayfront areas. With the potential of the non-renewal of the Preservation 2000 program, local acquisition programs are prioritizing the most important tracts to pursue for acquisition prior to the year 2000.

Management of publicly owned tracts is becoming increasingly problematic. In general, addition of management staff has not been in direct proportion to land acquisition. In almost all cases, land management (and post-restoration operation and maintenance duties) is the responsibility of the land owner. Proper management of land tracts and restored parcels is recognized as imperative for the long-term success of viable, productive ecosystems. Improved cooperation among governmental entities may offer creative avenues for effective management of tracts, and it is hoped that additional managers will become available to assume the work load.

The possibility exists that significant additional coastal areas could become available for acquisition under the right socio-politico-economic conditions. Specifically, high intensity, recurrent hurricane damage could result in areas becoming infeasible to redevelop due to unavailability of funds (i.e., loss or cost of insurance, reconstruction costs, etc.). Accordingly, these tracts then may be available for acquisition, restoration and management. The potential acreage could meet or exceed previous wetland impacts, providing an opportunity to fully restore historic estuarine wetland coverage. The potential for this scenario may warrant drafting of position papers and/or plans by regional land acquisition programs and management entities, addressing a path of action should the situation arise.

Funding

No dedicated funding sources have ever existed for the restoration of Tampa Bay. While discussions continue concerning dedicated funding options, annual restoration funds have and currently are being secured from SWFWMD Basin and Governing Boards, FDEP PRTE/EMRTF, local governments and granting programs. Potential funds may also come from post-"New Water Source Initiative" funds from SWFWMD, mitigation funds and mitigation banks, a permanent funding source for SWIM from the Solid Waste Management Trust Fund, granting programs and the private sector.

Partly due to a change in the philosophy of enforcement of environmental regulations (a greater emphasis is now being placed on long-term problem avoidance and in-kind settlements), fewer fines are being levied and less money is finding its way into the EMRTF. There is question whether the use of EMRTF dollars will continue to be used by the FDEP for pollution recovery projects as was the case with the FPRP. If the FDEP continues this type of program, it is likely to be redesigned to mirror the present day Conservation and Recreation Lands program. It also is likely that legislative approval of projects will be necessary as the legislature seems reluctant to relinquish control of the EMRTF dollars.

Also enacted during the 1996 legislative session was the Florida Department of Transportation (FDOT) Mitigation Act. This act provides for the FDEP and Water Management Districts (WMDs) to perform regional, long-range planning and implementation of mitigation for FDOT wetland impacts. The FDOT will provide \$75,000 to the EMRTF for every acre of wetland impact from FDOT road projects. In turn, this funding will be used by the WMDs to accomplish mitigation projects. These projects may include restoration, creation, preservation, and/or enhancement of wetlands, surface waters or uplands. Any mitigation dollars remaining after project completion may be kept by the WMDs for other non-mitigation (restoration) work. By the close of 1996, the WMDs, in consultation with FDEP, the U.S. Army Corps of Engineers and other appropriate agencies, submitted regional mitigation plans, subject to legislative approval. Currently, WMD (inclusive of SWFWMD) plans are under review, and details of the resolution and implementation of the FDOT mitigation program are pending.

Restoration Strategy and Management

The Tampa Bay National Estuary Program (TBNEP) is a key restoration and management program for the bay. Adopted during April 1997, the TBNEP Comprehensive Conservation and Management Plan (CCMP) has been a collaborative effort of regional governments, agencies, and public and private entities. The CCMP establishes carefully crafted long-term plans for re-establishing and maintaining a viable, productive Tampa Bay ecosystem through cooperative implementation of the plan by the plan's authors. The CCMP was developed using a process known as "normative forecasting" (defining goals of a future reality and the steps needed to achieve that reality). One critically important component of the CCMP deals with habitat restoration strategies for the bay.

As a stage of the maturation of the restoration process for the bay and as an extension of the SWIM program's "habitat mosaic" approach to restoration, the CCMP defines a restoration strategy of restoring lost habitats in direct proportion to their 1950 historical percentages ("restoring the balance"), inclusive of emphasis on oligohaline and freshwater wetlands. TBNEP's goal is to restore the bay's wetland ecosystem to 1950 proportions by restoring approximately 809 ha (2,000 acres) of wetlands over the next 100 years (1997-2096, $\bar{x}=8.09$ ha/yr [20 ac/yr]). As practicable, restoration programs for the bay will strive to follow the "restoring the balance" strategy, inclusive of coastal uplands and freshwater wetlands. With wetland restoration costs averaging about \$30,000 (constructed by public employees) to \$50,000 (private construction) per acre, total restoration costs for the 100 year/2,000 acre plan range from \$60 million to \$100 million, respectively. While seemingly high, this would average only \$600,000 to \$1 million per year for the 100 years (not adjusted for inflation); in perspective, this appears to be an attainable and affordable goal.

Last, but not least, it is critically important to continue education efforts of the public and public officials on the importance and value of restoring, preserving and properly managing our bay's ecosystem. Long term vision and perpetual implementation are absolutely necessary to ensure the ecological integrity of the Tampa Bay estuarine ecosystem. While great strides have been accomplished by thousands of dedicated individuals over the last thirty years, great challenges await the Tampa Bay environmental community as we continue to expand human populations and their concomitant impacts to the estuary and other coastal habitats.

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NOTE: For more detailed information on restoration efforts for Tampa Bay, readers are encouraged to contact authors of this summary.

SEAGRASS IN TAMPA BAY: HISTORIC TRENDS AND FUTURE EXPECTATIONS

J.O.R. Johansson
T. Ries

ABSTRACT

Historical (pre-1930s) seagrass meadows in Tampa Bay are believed to have covered 31000 ha of the shallow bay bottom. Interpretation of vertical aerial photographs from the 1950s and 1982 yielded about 16500 ha and 8800 ha of seagrass, respectively, suggesting a 72% loss from the earliest estimate and a 47% loss since the mid-1900s. Baywide seagrass monitoring has been conducted by the Surface Water Improvement and Management (SWIM) program of the Southwest Florida Water Management District every two years since 1988. Results from this study show that the trend of seagrass loss has been reversed. The 1994 cover was estimated at near 10800 ha, indicating an increase of almost 23% since 1982. The City of Tampa, studying Hillsborough Bay, has also reported expanding seagrass meadows. In this bay segment, seagrass cover has increased from near zero in 1984 to about 40 ha in 1996. The seagrass expansion apparently started in response to water quality improvements which occurred more than a decade ago and which in turn followed a large reduction in nitrogen loading from primarily domestic and industrial point-sources. Although this nutrient reduction occurred almost two decades ago it most likely still contributes to the current seagrass expansion. The Tampa Bay National Estuary Program has adopted goals to protect existing Tampa Bay seagrass meadows and to restore, over the long-term, about 5000 ha of additional seagrass primarily through the control of nitrogen loading to the bay. Tampa Bay seagrass meadows in areas popular to boaters are impacted by propeller scarring. Studies have been funded to determine the extent of propeller impacts and to evaluate management options for the protection of the impacted areas.

INTRODUCTION

Seagrass is an important natural resource present in many shallow estuaries and coastal areas of the world, including Tampa Bay. This habitat supports coastal food chains through high levels of primary and secondary production, and it serves as nursery habitat for numerous animal species, including many of recreational and commercial importance. Seagrass also reduces impacts from waves and currents, helps stabilize sediments, and further, seagrass is an integral part of the shallow water nutrient cycling process.

Seagrass is an important indicator of estuarine health primarily because of its sensitivity to changes in submarine light availability. Seagrass losses caused by light reductions generally result from a build-up of algae populations (i.e. phytoplankton, epiphytic algae and macroalgae) following excessive inputs of manmade nutrients (eutrophication) or by increases in non-algae associated turbidity often resulting from dredging activities.

Seagrass has been selected as an integral component in many estuarine management efforts, because of its ecological importance to shallow marine systems and its sensitivity to degraded water quality. These efforts generally aim to restore eutrophic estuaries to a more natural balance between its primary producers by reducing nutrient inputs. This is attempted for Tampa Bay as well, where the Tampa Bay National Estuary Program (TBNEP) has adopted a seagrass restoration and protection goal to be reached through the reduction of external nitrogen loadings to the bay (see Wade and Janicki 1995).

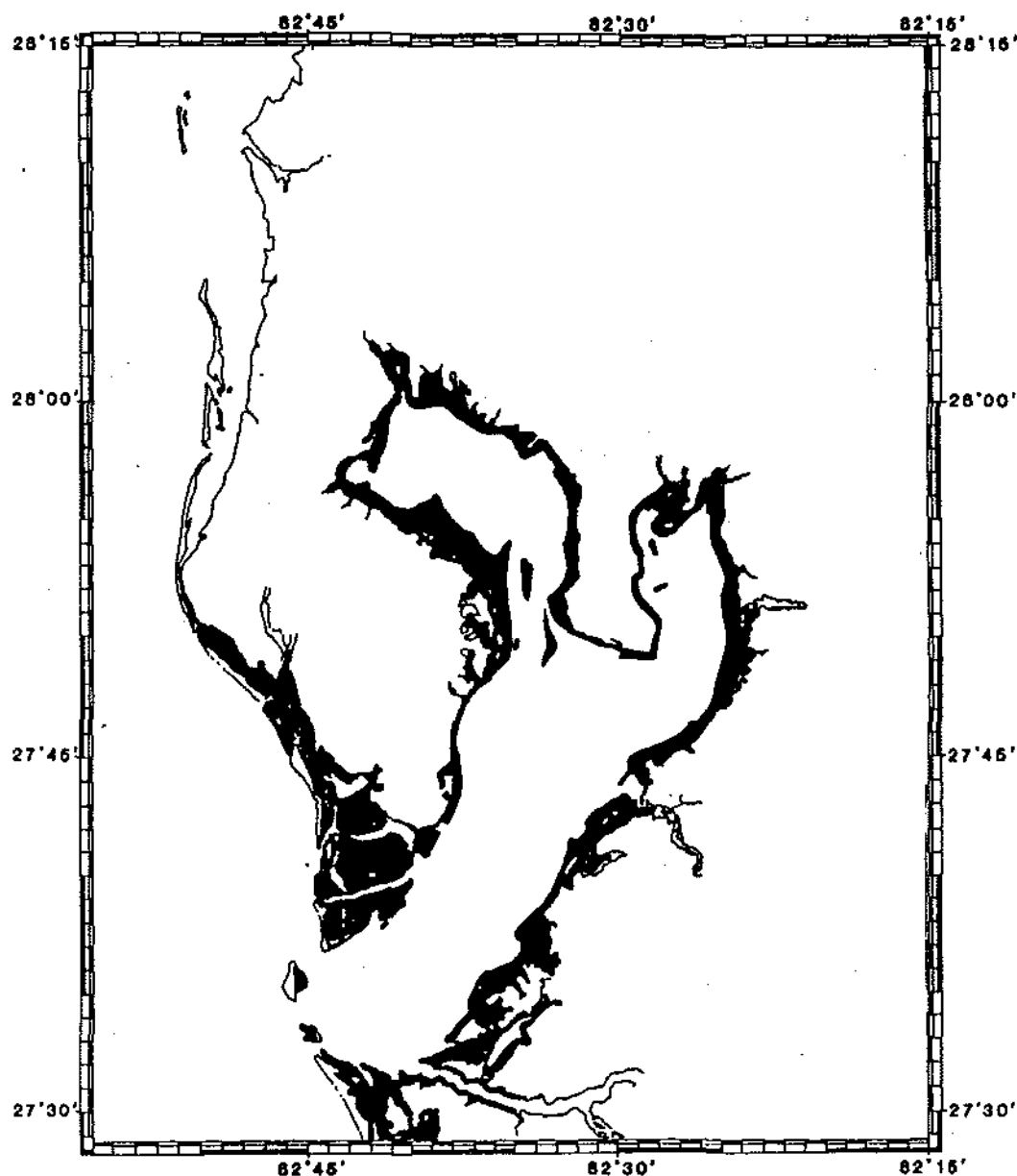


Figure 1. Estimated extent of seagrass meadows in Tampa Bay, 1897. Source: Lewis et al. 1985.

In this report we discuss the major changes that have occurred in seagrass abundance and some of the causes which most probably have contributed to those changes. We also present a summary discussion of the ongoing seagrass monitoring programs conducted by the SWIM program of Southwest Florida Water Management District (SWFWMD) and the City of Tampa (COT). More detailed discussions of these programs can be found in BEMER (1996) and Avery (this volume). Our report addresses the important role seagrass plays in the Comprehensive Conservation & Management Plan (CCMP) now being finalized by the TBNEP. This plan is discussed in much greater detail by several other contributors to this symposium. Finally, we

also include a short discussion on the issue of propeller scarring of Tampa Bay seagrass meadows.

HISTORIC TRENDS

In 1982 at the first BASIS meeting, Lewis et. al. (1985) presented a most comprehensive paper on Tampa Bay seagrass. This paper included the estimate that approximately 31000 ha of seagrass was present in Tampa Bay during the late 1800s (Fig. 1). The estimate was based mainly on bathymetric information rather than on actual seagrass distribution, and therefore it can perhaps best be described as the potential Tampa Bay seagrass coverage at a time when man's influence on the bay was very limited.

At the second BASIS meeting in 1991, Lewis et. al. (1991) presented the distribution of Tampa Bay seagrass cover in 1950 and 1982. These estimates were based on state-of-the art analysis of aerial photographs. The 1950 Tampa Bay seagrass cover was estimated to have been approximately 16500 ha (Fig. 2). Seagrass coverage had apparently decreased in all segments of the bay by 1950, when compared to the estimate for the late 1800s; however, major losses had occurred in the upper portions of the bay (i.e. Hillsborough Bay and Old Tampa Bay). Large reductions were also noted in Boca Ciega Bay as a result of extensive residential dredge-and-fill activities. Tampa Bay continued to lose seagrass after the 1950s, because by 1982 only some 8800 ha remained. During this 30-year period, additional large reductions had occurred primarily in the upper portions of the bay and virtually all seagrass had been lost from Hillsborough Bay by 1982 (Fig. 3).

The cause of these large seagrass losses, perhaps as much as 70% of the historic Tampa Bay seagrass cover, is undoubtedly related to man's impact on the bay. One major impact was eutrophication or the excessive loading of nutrients to the bay, which is directly related to the growth of the bay area population. Eutrophication as indicated by water column chlorophyll-*a* concentrations (Fig. 4) appears to have peaked in the late 1970s and early 1980s (Johansson 1991; Boler 1995). Another leading cause of large seagrass losses was various dredging operations and shoreline developments. These included in-bay shell dredging, port construction, ship channel expansion, causeway construction and residential dredge-and-fill projects. Impacts from these activities appear to have culminated during the 1950s, 1960s and 1970s.

Researchers generally agree that eutrophication and dredging operations were the major reasons for the large seagrass loss, although it is unclear which of these impacts was most serious. Also, more detailed questions remain about the process of seagrass loss. For example, did dredging operations cause losses mainly through direct physical destruction of the seagrass meadows or through more indirect impacts such as increased turbidity of the water column or increased sediment deposition on the meadows? Details also remain unclear about the effects of eutrophication. Tampa Bay seagrass losses attributed to eutrophication are generally assumed to have resulted from a decrease in light availability, which in turn was caused by an increase in phytoplankton and epiphytic biomass. However, it is also known that the increased nutrient loading stimulated the growth of large amounts of unattached macroalgae, specifically in Hillsborough Bay (FWPCA 1969; Kelly 1994) and Old Tampa Bay

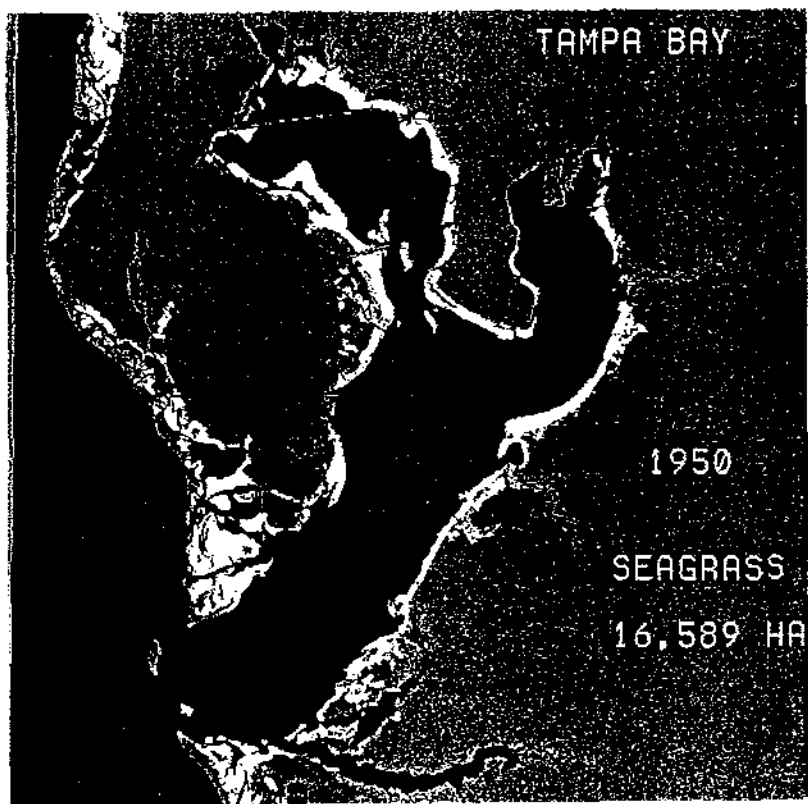


Figure 2. Seagrass coverage in Tampa Bay, 1950. Source: Lewis et al. 1991.



Figure 3. Seagrass coverage in Tampa Bay, 1982. Source: Lewis et al. 1991.

(Johansson, pers. obs.). Dense mats of macroalgae often accumulated in the shallow areas and could have created an environment unsuitable for seagrass colonization. The discussion of seagrass and macroalgae in Hillsborough Bay is continued by Avery (this volume).

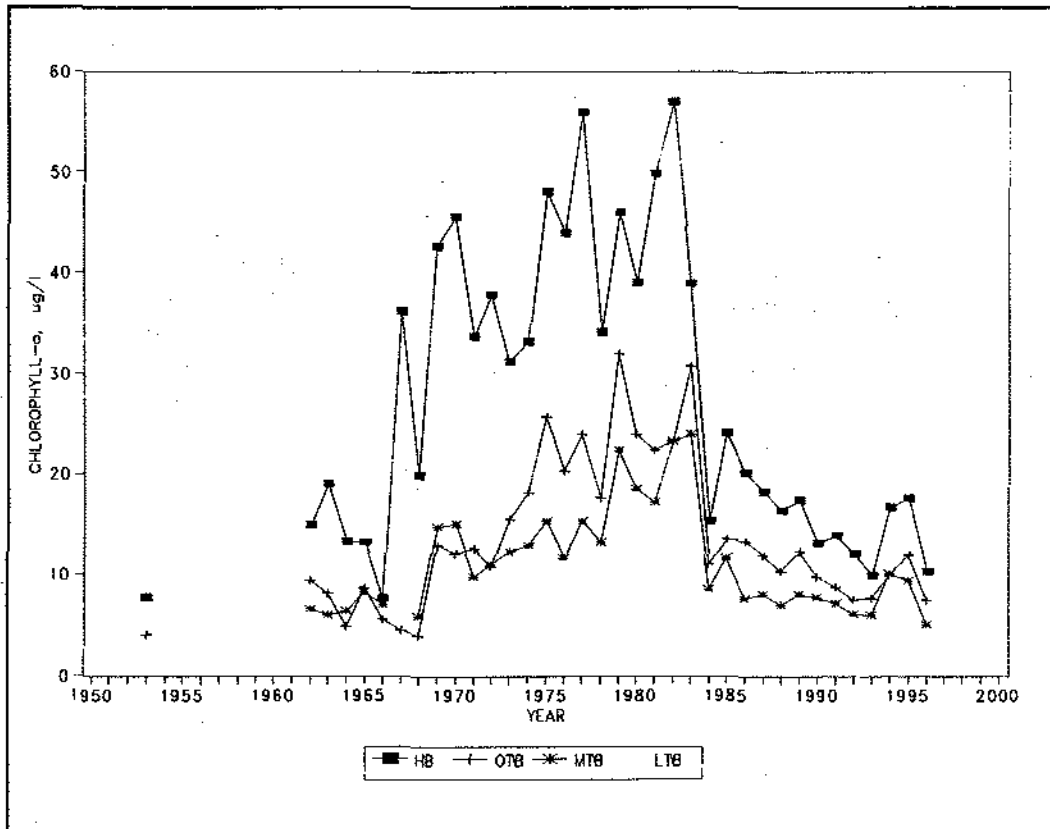


Figure 4. Annual average chlorophyll-a concentrations for the major subdivisions of Tampa Bay, 1953–1996. HB—Hillsborough Bay; OTB—Old Tampa Bay; MTB—Middle Tampa Bay; LTB—Lower Tampa Bay.

A large reduction in nitrogen loading to Tampa Bay occurred during the late 1970s and early 1980s (Johansson 1991; Johansson and Lewis 1992; Zarbock et al. 1994). This reduction was primarily caused by better treatment of discharges from domestic and industrial point-sources. A large decrease in phytoplankton biomass soon followed the nitrogen reduction. By 1984, chlorophyll concentrations were about half of the levels found only a few years earlier (see Figure 4). At approximately the same time that the low chlorophyll concentrations were recorded, sparse recolonization by *Halodule wrightii* (shoal grass) in the Kitchen area of Hillsborough Bay was first observed by Robin Lewis (pers. comm.).

TAMPA BAY SEAGRASS MONITORING PROGRAMS

The return of seagrass to barren areas in Tampa Bay, which historically had seagrass cover, was one of the first easily observed signs indicating that the bay truly had made the turn towards improved water quality conditions after many years of serious eutrophication. Recognizing the importance of closely following the progress of

seagrass growth in the bay, the SWIM program of SWFWMD and the COT created two independent seagrass monitoring programs. The COT program, which monitors seagrass primarily in Hillsborough Bay, was started in 1986 and the SWFWMD program, which conducts baywide monitoring, was started in 1988.

The City of Tampa Program

The COT program uses high and low altitude aerial photography and ground measurements to generate total Hillsborough Bay seagrass coverage data. Details of the monitoring program have been modified several times in response to the rapid seagrass expansion but the basic survey program has remained intact. The aerial and ground surveys are conducted in September or October in order to minimize seasonal variations in seagrass coverage. Only two seagrass species, *H. wrightii* and *Ruppia maritima*, are presently found in Hillsborough Bay. Although the COT program records the presence of *R. maritima*, only *H. wrightii* coverage is included in the COT seagrass estimates. *R. maritima* is considered to be ephemeral and it is uncertain if, or how, its highly variable year-to-year growth pattern is related to water quality. In 1984, Hillsborough Bay seagrass coverage (estimated from aerial photographs) was limited to a few isolated patches, comprising less than 0.02 ha. Since 1984, each successive survey has shown a substantial increase in *H. wrightii* seagrass cover (Fig. 5). The 1996 Hillsborough Bay estimate is slightly more than 40 ha. The progress of the Hillsborough Bay seagrass growth occurs at a near logarithmic rate. However, the current 1996 coverage accounts for only 4% of the near 1000 ha estimated to have been present in the 1950s (Lewis et al. 1991). Additional information about the COT monitoring program is presented by Avery (this volume).

The detailed seagrass information collected by the COT in Hillsborough Bay can be used to search for potential relationships between seagrass expansion and water quality trends. Year-to-year variations in Hillsborough Bay chlorophyll-*a* concentrations, which indicate changes in the eutrophic state of the bay and also the amount of nitrogen being discharged to the bay, are not reflected in the trend of Hillsborough Bay seagrass expansion (Fig. 6). Such short-term relationships between the relatively slow process of seagrass areal expansion and more variable water quality parameters should not be expected. Instead, the recent expansion of seagrass in Hillsborough Bay, and in other sections of Tampa Bay as well, most probably resulted from the large decrease in eutrophic state that occurred in the early 1980s and which is reflected in the Tampa Bay chlorophyll-*a* record (see Figure 4). Further, the seagrass may still be expanding in response to this change that occurred almost two decades ago. Eutrophic conditions have continued to improve since the early 1980s, although at a slower rate than the rapid change seen earlier. This improvement should also have had a favorable effect on the rate of seagrass expansion in Hillsborough Bay, and in other sections of Tampa Bay as well.

The SWFWMD Program

The SWIM program conducted their first baywide aerial photography survey and field monitoring in 1988. This survey was the first comprehensive baywide mapping of seagrass since 1982 when the Florida Department of Environmental Regulation (DER) sponsored a mapping project (Haddad 1989). The SWIM seagrass program has been modified since the start but basically, high altitude true color photography is

conducted every two years, usually during the winter. The photographs are groundtruthed by inspecting some 60 randomly selected sites twice a year in areas of the bay which are less than 2 m deep. Seagrass species composition cannot be determined from the photographs and is noted in the field. Therefore, the seagrass information obtained from the photographs is limited to areal distribution and two classifications of density, continuous and patchy. The seagrass distribution and density information is digitized and entered into a GIS database. Maps are then produced which show the Tampa Bay seagrass distribution and density information together with the 1 m and 2 m depth contour lines. More detailed information about the SWIM seagrass monitoring program, including changes in methodology since the start of the program, can be found in BEMER (1996).

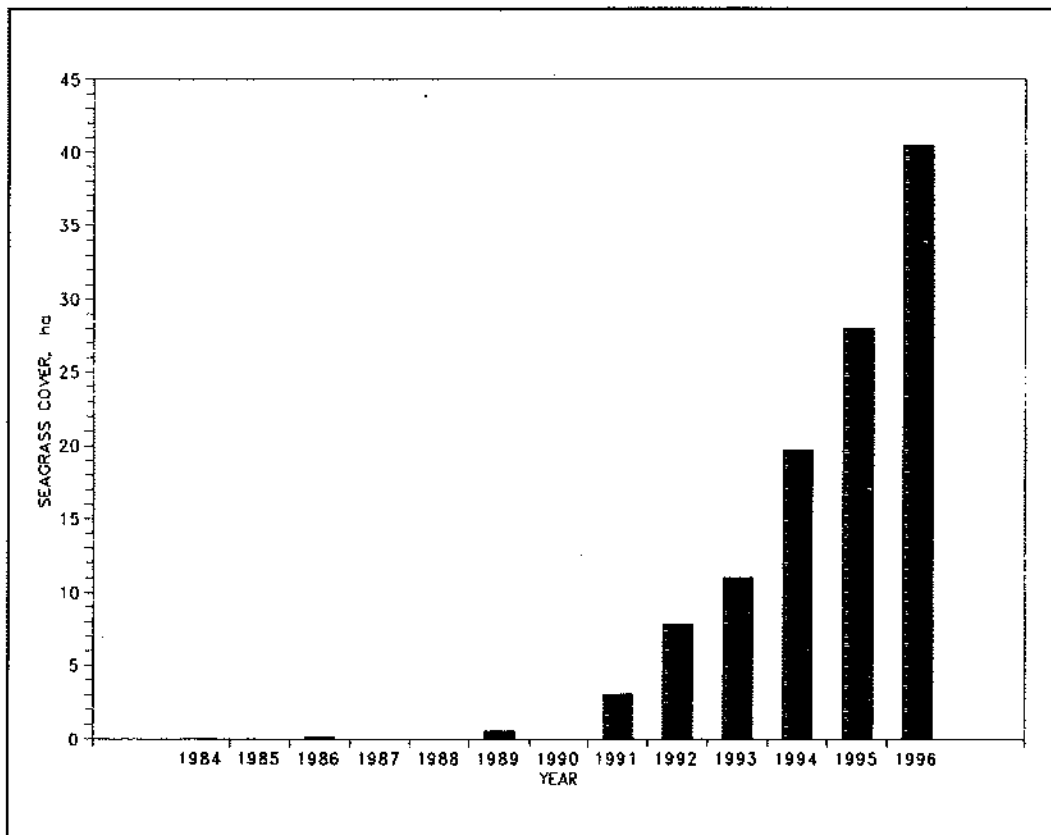


Figure 5. Hillsborough Bay seagrass cover measured by COT, 1984–1996. No surveys were conducted in 1985, 1987, 1988 and 1990.

The SWIM program has now completed baywide seagrass surveys for the years 1988, 1990, 1992 and 1994. Like the results of the COT monitoring program, the SWIM program has also shown that Tampa Bay seagrass coverage is increasing. Over the six-year period 1988 through 1994, the baywide seagrass area has increased from 9590 ha to 10780 ha, which is a 12% increase (Table 1). Anna Maria Sound is the only bay segment surveyed by the SWIM program which shows a loss of seagrass cover since 1988. This loss is most probably an artifact caused by a change in survey area definition between 1988 and 1990. Since 1990, this area has had a 15% increase in

seagrass cover. Old Tampa Bay and Boca Ciega Bay have seen the greatest increase in the number of hectares revegetated since 1988, while Hillsborough Bay, by far, has had the greatest percentage increase in seagrass cover. Although the SWIM program shows the same trend of rapidly expanding seagrass growth in Hillsborough Bay as that found by the COT, there are differences in the areal estimates of the two programs. In 1988 the SWIM program reported 6 ha in this bay segment, while the COT program in 1989 reported less than 1 ha. In 1994, the SWIM program found 61 ha but the COT program reported only 20 ha. These discrepancies are probably due to differences in seagrass survey techniques and the methods used to calculate coverage. The lower COT estimates for Hillsborough Bay may be, at least in part, the result of including only *H. wrightii* in the coverage estimates. The SWIM program estimate for this bay segment also includes the ephemeral seagrass *R. maritima*.

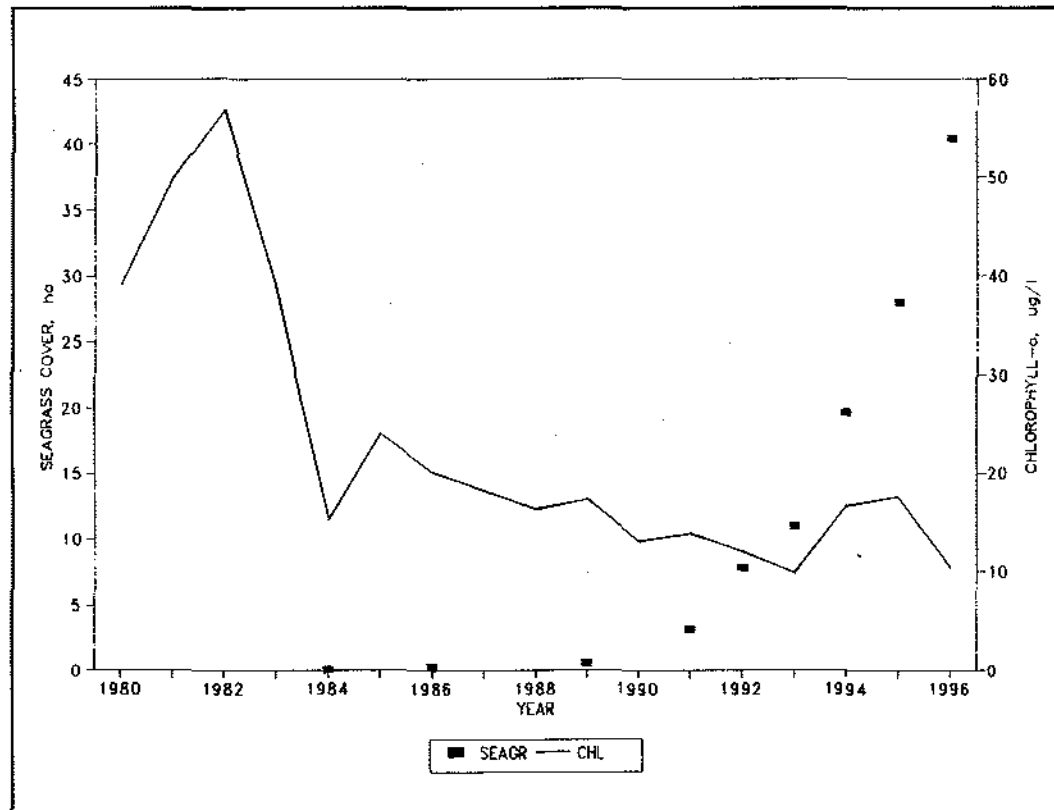


Figure 6. Hillsborough Bay annual average chlorophyll-a concentration measured by EPC and seagrass cover measured by COT.

Although all bay segments surveyed by the SWIM program, except Anna Maria Sound, show a net increase in seagrass coverage over the six-year monitoring period, the most recent survey in 1994 detected some thinning of the seagrass meadows in all segments except Hillsborough Bay. It is not clear at this time why this thinning has occurred; however, this apparent change needs close attention and if the thinning persists, an expanded seagrass monitoring effort should be conducted in the affected areas.

Table 1. Tampa Bay seagrass coverage (hectares), 1988–1994. OTB—Old Tampa Bay; HB—Hillsborough Bay; MTB—Middle Tampa Bay; LTB—Lower Tampa Bay; BCB—Boca Ciega Bay; TCB—Terra Ceia Bay; MR—Manatee River; AMS—Anna Maria Sound.

SEGMENT	YEAR				CHANGE 1988–1994	PERCENT
	1988	1990	1992	1994		
OTB	2121	2341	2471	2475	354	17
HB	6	20	21	61	55	881
MTB	2024	2081	2059	2273	249	12
LTB	1918	2218	2236	2195	277	14
BCB	2410	2667	2724	2818	408	17
TCB	357	368	369	367	11	3
MR	110	117	117	118	7	7
AMS	644	406	464	468	-176	-27
TOTAL	9590	10219	10461	10775	1185	

SUMMARY OF TAMPA BAY SEAGRASS TRENDS

The late 1800s estimate of Tampa Bay seagrass coverage reported by Lewis et al. (1985), as discussed earlier, describes the potential coverage at a time when man's influence on the bay was very limited (Fig. 7). The second bar in this graph is the estimated cover from the 1950s as it was reported by Lewis et al. (1991) at the second BASIS meeting. The TBNEP has adopted the 1950 coverage as the long-term management goal for Tampa Bay seagrass restoration and protection.

Severe seagrass losses continued through the 1960s and 1970s, apparently as a result of increasing eutrophication and extensive dredging activities. The 1982 baywide estimate, also presented at the second BASIS meeting, indicates a near 50% decrease of seagrass coverage between the 1950 and 1982 estimates.

The remaining four Tampa Bay seagrass estimates, starting in 1988, are from the SWFWMD monitoring program. Results from this program show a limited but continuous increase in Tampa Bay seagrass cover. The 1994 coverage was estimated at approximately 10800 ha, indicating a near 23% increase in Tampa Bay seagrass cover since 1982.

Propeller Scarring

During the evaluation of Tampa Bay seagrass meadows it has become evident that propeller scarring of seagrass beds may pose a serious threat to the seagrass meadows in areas popular with boaters. It was pointed out by Robin Lewis many years ago that this was a serious problem in Cockroach Bay (R. Lewis, pers. comm.). His concerns that propeller scarring could be a threat to the Tampa Bay seagrass habitat have recently been substantiated by a statewide study conducted by the Florida Department of Environmental Protection (DEP) (Sargent et al. 1995). This study found that Hillsborough, Manatee and Pinellas Counties ranked among the top ten Florida counties with most damage. The DEP study proposes that management programs to help reduce propeller scarring of seagrass should be based on education, channel marking, increased enforcement and limited motor-usage zones. Additional studies, ongoing and proposed, will evaluate and derive local management options to help

reduce propeller scarring impacts in Tampa Bay (Ehringer 1994; Dawes et al. 1995; Sargent et al. 1996).

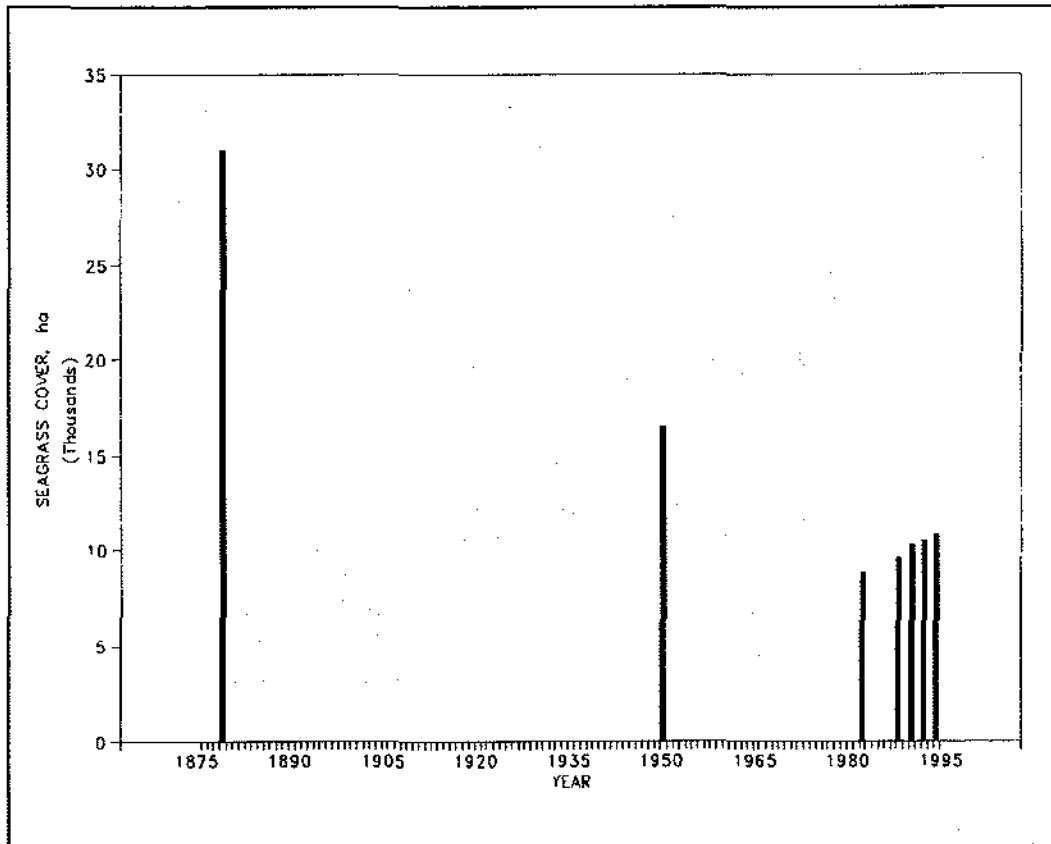


Figure 7. Long-term trend of Tampa Bay seagrass coverage, 1897–1994.

CONCLUSION

In the paper presented by Lewis et. al. (1991) at the second BASIS meeting, the authors asked whether the areal expansion of Tampa Bay seagrass meadows noted in 1988 was caused by real bay improvements, specifically the substantial reduction in anthropogenic nitrogen loading to Hillsborough Bay which occurred in the late 1970s and early 1980s, or was this expansion a result of natural causes related to a three-year period of relatively low rainfall immediately prior to 1988? It was cautioned that increased inputs of both nutrients and tannin from a saturated watershed may have the potential to reverse the water quality improvements seen prior to 1991.

Five years of additional information are now available since the question was asked and during this period there have been several years of normal and above-normal rainfall. As expected, increases in rainfall and accompanied increases in nutrient loading appear to reduce the water quality of the bay, specifically by increasing chlorophyll-*a* concentrations. However, the recent chlorophyll-*a* record suggests that water quality impacts resulting from periods of higher than normal rainfall (e.g., 1994 and 1995) may be of short duration. In addition, the recent annual Tampa Bay chlorophyll-*a* concentrations have remained much below those recorded during the

period of high eutrophication in the late 1970s and early 1980s. And finally, Tampa Bay seagrass meadows have continued to expand in all major bay segments since 1988.

It now appears that we can afford to be optimistic and accept the conclusion that the large nitrogen reductions during the late 1970s and early 1980s have allowed Tampa Bay to start on its way to recovery after many years of serious eutrophication. However, this is not the time to step back or to be complacent. We must continue our efforts to protect the bay. Watchful monitoring of the seagrass meadows, and other important indicators of bay conditions, play a critical role in the future preservation of Tampa Bay.

ACKNOWLEDGMENTS

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DISTRIBUTION AND ABUNDANCE OF MACROALGAE AND SEAGRASS IN HILLSBOROUGH BAY, FLORIDA, FROM 1986 TO 1995

W. Avery

ABSTRACT

Data collected since 1986 on macroalgae and seagrass in Hillsborough Bay indicate a general trend of decreasing drift macroalgae biomass and increasing seagrass coverage. Drift macroalgae biomass of 930 grams dry weight/square meter (gdw/m²) and 80 gdw/m² was reported for 1987 and 1994, respectively. Coverage by the attached alga, *Caulerpa prolifera*, increased from 5 ha in 1986 to 280 ha in 1988 before declining to less than 0.2 ha by 1995. Coverage by the shoal grass, *Halodule wrightii*, increased from less than 0.2 ha in 1986 to over 28 ha in 1995 while coverage by widgeon grass, *Ruppia maritima*, has fluctuated between 0.2 ha and 2.2 ha. Improving water quality has resulted in a better light climate for seagrass in Tampa Bay. This trend has generally been cited as the primary reason for the re-establishment and expansion of seagrass meadows. However, the moderation of drift macroalgae biomass in Hillsborough Bay, in addition to improved water quality, may have contributed to seagrass reestablishment on the shallow flats in this segment of Tampa Bay.

INTRODUCTION

In the past decade, seagrass acreage in Tampa Bay has begun to increase as a result of concerted management actions intended to improve water quality and restore seagrass coverage to the level found in 1950 (TBNEP 1996). This trend follows decades of anthropogenic impacts (Simon 1974) which deteriorated water quality to the point where the decline and loss of seagrass became widespread. Perhaps the most noticeable change has occurred in Hillsborough Bay, where seagrass recolonization is occurring on nearly all shallow subtidal flats.

Eutrophication and dredge and fill operations have been cited as the primary reasons for the decline in Tampa Bay's water quality. Prior to the late 1970s, excess nutrient loading to Hillsborough Bay resulted in an increasingly eutrophic system as indicated by an elevated phytoplankton standing crop (Johansson et. al. 1985) and high macroalgae biomass (FWPCA 1969). Dredge operations altered existing seagrass habitat (Lewis 1977) and resuspended sediments into the water column. The high algal biomass and sediment resuspension combined to attenuate the light available for seagrass beds.

Information regarding historical distribution of seagrass in Tampa Bay, specifically Hillsborough Bay, is sparse. Phillips (1962) described seagrass distribution in Tampa Bay and, in Hillsborough Bay, found *Syringodium filiforme*, *Halodule wrightii* and *R. maritima*. He found only *R. maritima* north of a line from Ballast Point to the Alafia River (Fig. 1) while all three species occurred south of this line. However, all *S. filiforme* coverage was confined to the southeastern portion of Hillsborough Bay. Lewis and Phillips (1980) prepared seagrass maps of Hillsborough County for the years 1876, 1939, 1948 and 1980 and noted the decline of coverage in several portions of Tampa Bay. By the early 1980s, only a few patches of *Ruppia maritima* remained in Hillsborough Bay (Lewis et. al. 1985). However, as water quality in Tampa Bay began to improve following large reductions of nutrient loadings, some minor seagrass recolonization began to occur (Johansson and Lewis 1990).

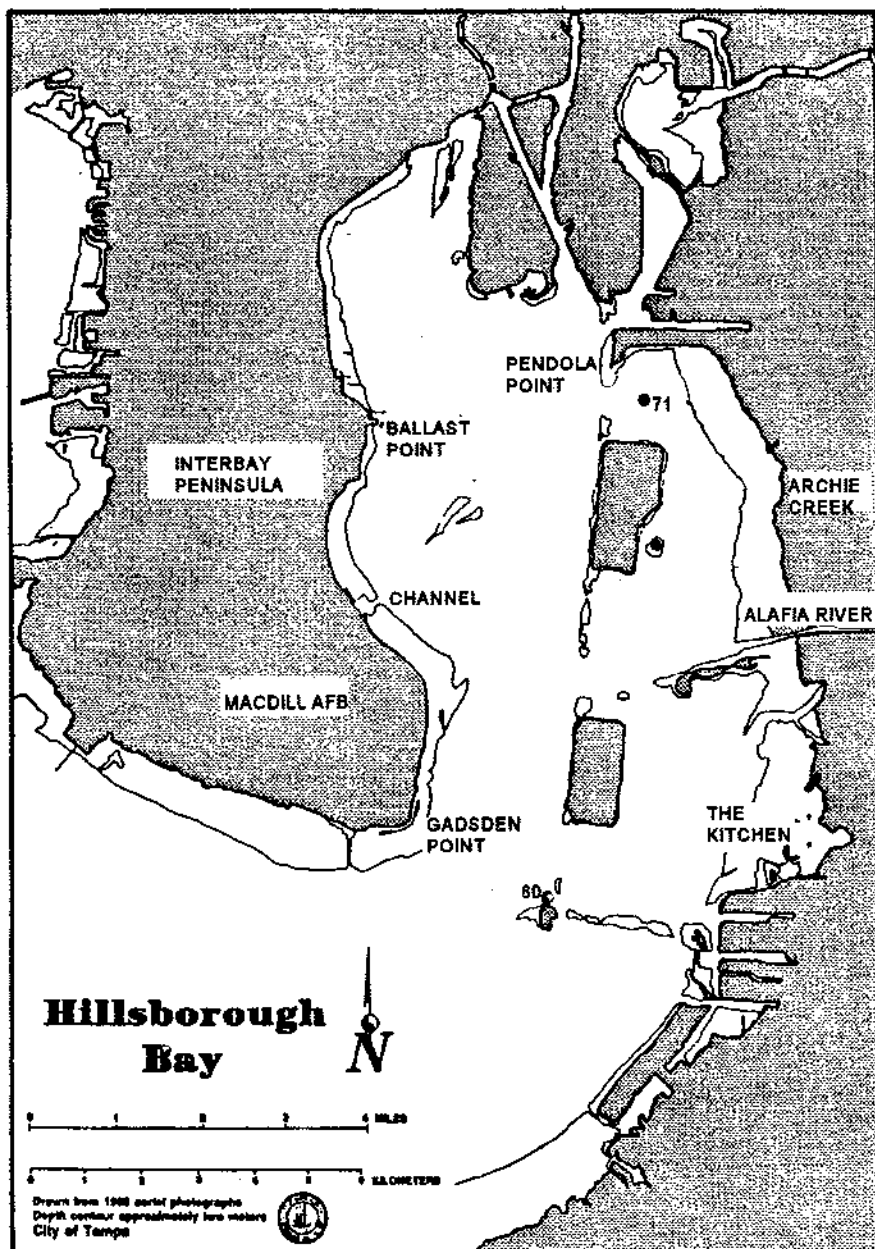


Figure 1. Location of key landmarks and HCEPC stations 71 and 80 in Hillsborough Bay.

The City of Tampa (COT) conducts a variety of programs to evaluate the ecological status of Hillsborough Bay. The COT began monitoring drift macroalgae in 1983 (Kelly 1995). This program commenced following an 18-month study of drift macroalgae in Hillsborough Bay by Mangrove Systems, Inc. In 1986, the COT started a seagrass monitoring program in response to minor recolonization by *H. wrightii* in eastern Middle Tampa Bay.

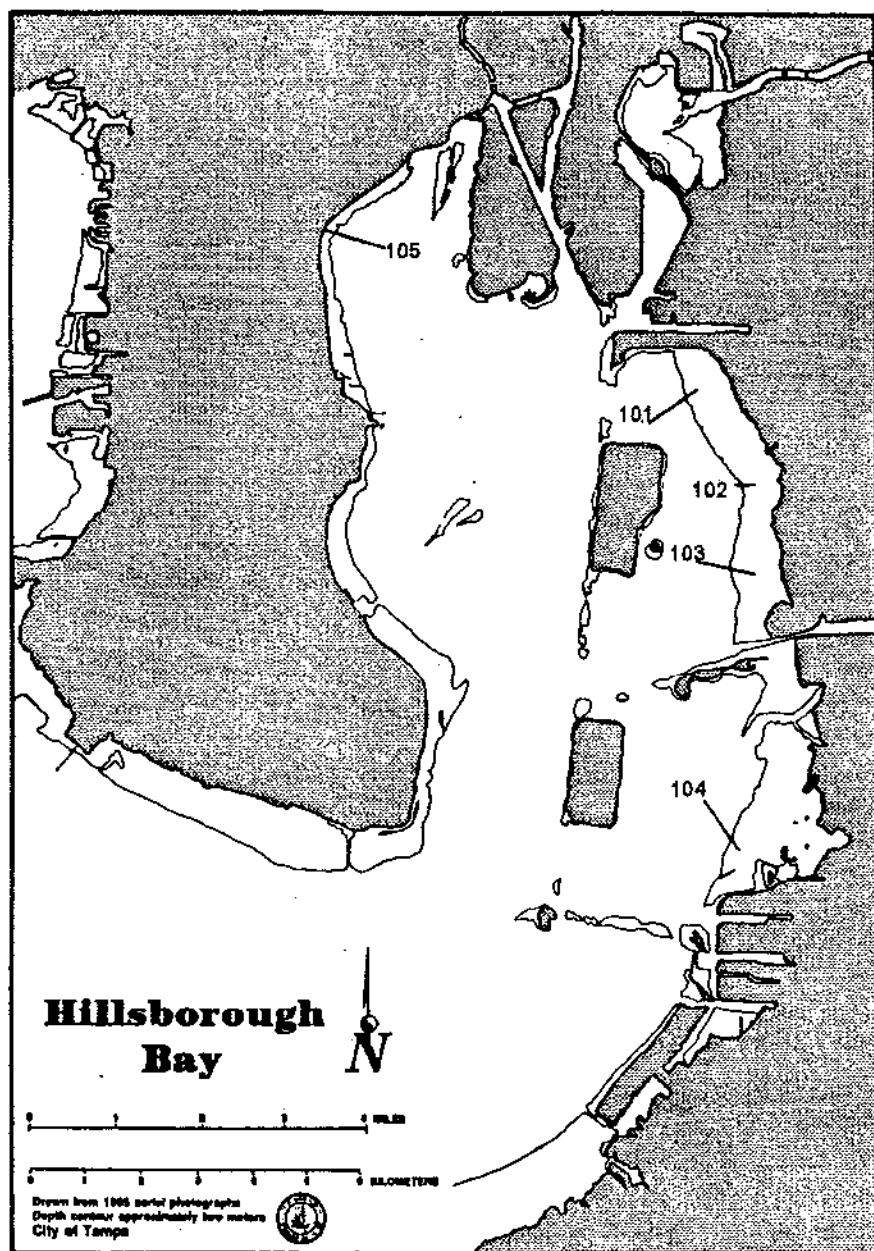


Figure 2. Location of the five COT macroalgae transects in Hillsborough Bay.

METHODS

Macroalgae Sampling

The COT has collected data on drift macroalgae species composition and biomass in Hillsborough Bay since 1983. However, the number, location and length of transects were modified in 1985. Since 1986, five transects, ranging between 250 to 950 meters in length, have been sampled monthly for macroalgae (Fig. 2). An otter trawl with an width of two meters was used for the macroalgae collection. After each trawl, the macroalgae was weighed, the percent species composition estimated, and a

subsample taken for laboratory analysis. Laboratory analyses included detailed species composition and the percent dry weight per species. Laboratory results were extrapolated to yield grams dry weight per square meter over a transect for each species.

Seagrass and Attached Macroalgae

Between 1986 and 1995, Hillsborough Bay was surveyed seven times to determine the distribution and abundance of seagrass. With the exception of the first survey, which was initiated in the spring of 1986, surveys have been conducted in the fall before *H. wrightii* areal coverage was reduced due to senescence. In the initial survey, all intertidal and shallow subtidal areas were visited to assess seagrass coverage. Low level (<500 ft) photographic overflights aided in the location of seagrass. Each patch encountered was measured and mapped. Coverage estimates in subsequent surveys have been generated from groundtruth efforts and aerial photographs.

The COT has modified its seagrass program several times due to expanding seagrass coverage. A description of the original program design is in the first COT seagrass report (1988). Modifications to the program in subsequent surveys are described in annual COT reports entitled *Seagrass and Caulerpa Monitoring in Hillsborough Bay* (1990-96).

Data on the attached alga, *Caulerpa prolifera*, was collected seasonally through 1994. Six transects, ranging from 60 to 300 meters in length, were established to monitor the alga's growth patterns. Further discussion on the study design and seasonal results may be found in the previously mentioned COT reports.

RESULTS AND DISCUSSION

Macroalgae

Eighteen species of macroalgae were recorded in Hillsborough Bay between 1986 and 1995 (Table 1). The potential morphological variations in the genus *Gracilaria* make specific identification difficult and, in this instance, all variants will be reported as *Gracilaria* spp. All species reported were drift alga except *C. prolifera*. This attached alga is reported as a minor species on the five transects; however, discussion later in this section addresses *C. prolifera* as a dominant species in Hillsborough Bay between 1986 and 1988.

Generally, the dominant macroalgae collected by trawl were *Gracilaria* spp., *Spyridia filamentosa*, *Ulva lactuca* and *Agardhiella tenera*. Transect 101 had the lowest biomass of all transects (Fig. 3). *Gracilaria* spp. has been the primary species found along this transect. Transect 102, situated just south of transect 101, contained the highest biomass of the five transects. Macroalgae at transect 102 was dominated by a *Gracilaria* spp. peak (630 gdw/m²) in October 1987 and a codominant *Gracilaria* spp. (265 gdw/m²) and *S. filamentosa* (225 gdw/m²) peak in May 1995 (Fig. 4). These data tend to mask the results of the other sampling dates and are omitted from subsequent figures. Figure 5 illustrates biomass trends without these two points. *Gracilaria* spp. was the dominant alga through 1989 with a few peaks of *U. lactuca*, *S. filamentosa*, and *Chaetomorpha* spp. Following 1989, trawl collections were composed primarily of *S. filamentosa*. At transects 103 and 104 (Figs. 6 and 7), macroalgae was generally

comprised of *Gracilaria* spp. and *U. lactuca* through early 1990. Low biomass was documented after 1990 except for a spring peak of *S. filimentosa* along transect 103 in 1992. Macroalgal biomass on transect 105 (Fig. 8) in northwestern Hillsborough Bay was dominated by *Gracilaria* spp. and *A. tenera* through the spring of 1991. On several sampling dates subsequent to 1991, either *Gracilaria* spp., *S. filimentosa*, *U. lactuca* or *A. tenera* was the primary species collected; however, biomass was reduced.

Table 1. List of macroalgae species found and biomass ranking from each transect. The percent frequency that each species was found (N=119) is in parenthesis. — indicates this species did not occur at this transect.

SPECIES	TRANSECT				
	101	102	103	104	105
<i>Gracilaria</i> spp.	1 (56)	1 (89)	1 (57)	1 (53)	1 (44)
<i>Spyridia filimentosa</i>	2 (41)	2 (56)	4 (32)	3 (15)	4 (32)
<i>Ulva lactuca</i>	4 (31)	3 (59)	2 (37)	2 (34)	3 (66)
<i>Agardhiella tenera</i>	3 (29)	6 (30)	5 (19)	5 (25)	2 (54)
<i>Chaetomorpha crassa</i>	7 (21)	4 (29)	7 (16)	10 (8)	7 (11)
<i>Centroceros clavulatum</i>	11 (4)	5 (13)	11 (9)	6 (6)	9 (3)
<i>Chaetomorpha gracilis</i>	5 (6)	9 (4)	3 (6)	9 (1)	—
<i>Caulerpa prolifera</i>	8 (21)	7 (28)	8 (6)	12 (1)	8 (14)
<i>Pterocladia americana</i>	10 (8)	8 (17)	6 (14)	8 (3)	6 (3)
<i>Enteromorpha intestinalis</i>	12 (1)	10 (2)	14 (1)	10 (1)	—
<i>Acanthophora spicifera</i>	6 (5)	15 (3)	13 (2)	7 (6)	—
<i>Polysiphonia subtilissima</i>	9 (8)	14 (4)	10 (3)	4 (3)	5 (1)
<i>Chaetomorpha brachygona</i>	15 (1)	12 (1)	9 (1)	11 (2)	—
<i>Chondria tenuissima</i>	—	13 (1)	—	13 (1)	—
<i>Cladophora delicatula</i>	—	11 (2)	12 (3)	—	—
<i>Enteromorpha clathrata</i>	14 (1)	—	—	—	—
<i>Asterocystis ramosa</i>	14 (1)	—	—	—	—
<i>Eucheuma nudum</i>	—	—	—	—	10 (2)

The data suggest there may be some seasonal trends. Generally, the highest biomass occurred between fall and late spring, although this trend is not constant each year at all stations. When the biomass from each transect is totaled for each sampling date (Fig. 9), the seasonal trend (with the 1987 and 1995 values from transect 102 omitted) becomes somewhat more evident.

Since 1990, macroalgae biomass along four of five transects has decreased and the residence time of the macroalgae along the transects is much shorter. However, transect 102 continues to retain a significant macroalgae presence and, in recent years, collections at this site have represented a major portion of macroalgae sampled in Hillsborough Bay (Fig. 9).

Caulerpa prolifera

In the COT initial seagrass survey in the spring of 1986, the attached alga, *Caulerpa prolifera* was found at two locations in western Hillsborough Bay, near Gadsden Point and just north of Ballast Point (Fig. 1). Both locations were shallow dredge sites characterized by a fine grained, organic substrate. The areal coverage by *C. prolifera*

at these two sites was estimated at 3 ha. By the summer, patchy *C. prolifera* coverage had begun to expand onto the shallow, sand-dominated, subtidal flats along southern Interbay Peninsula. This patchy coverage rapidly coalesced into a meadow by December 1986 and vegetated an area from west of Gadsden Point north to a navigation channel accessing eastern MacDill Air Force Base. At times, *C. prolifera* coverage was observed at depths up to three meters below mean low low water (MLLW). Similarly, *C. prolifera* coverage near Ballast Point began to expand onto the flats to the south and rapidly formed a 10 ha meadow by December 1986. *C. prolifera* coverage in western Hillsborough Bay was estimated at 210 ha in January 1987.

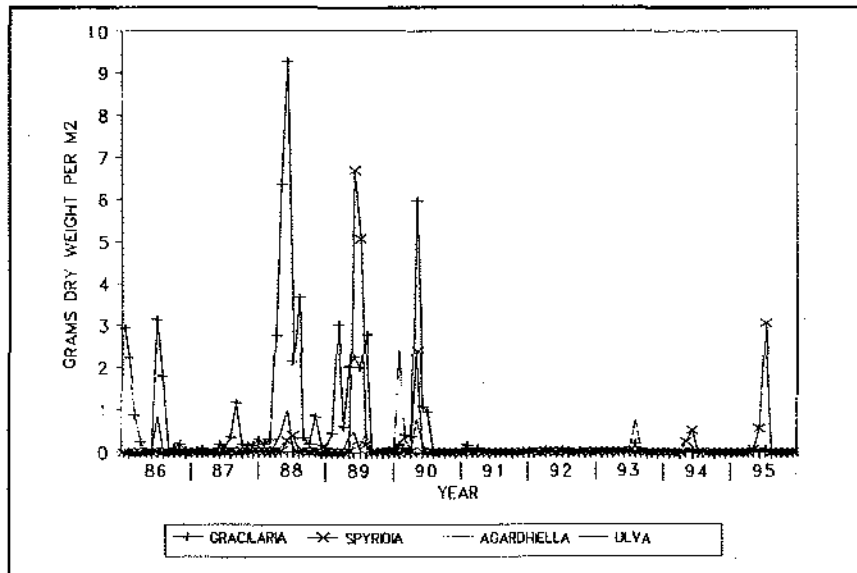


Figure 3. Macroalgae biomass of the four dominant species on transect 101, 1986–1995.

The shallow subtidal flats south of Pendola Point in northeastern Hillsborough Bay were also colonized by *C. prolifera*. Photographic evidence indicates an area of *C. prolifera* of about 9000 m² in the spring of 1986. However, rapid expansion of coverage did not begin until the winter of 1987, nearly eighteen months after the rapid growth in western Hillsborough Bay.

In the spring of 1988, *C. prolifera* covered nearly 280 ha in Hillsborough Bay with over two-thirds of the coverage located in western Hillsborough Bay. However, *C. prolifera* coverage diminished considerably following a 25-year rainfall event which quickly lowered the salinity in parts of western Hillsborough Bay from about 25 ppt to 1–2 ppt. Within a month of the rainfall event, the COT documented a rapid decline in *C. prolifera* coverage in western Hillsborough Bay. In contrast, the coverage south of Pendola Point, nearly 70 ha in the summer of 1988, was not appreciably affected by the rainfall event. The salinity in this portion of Hillsborough Bay decreased to about 15 ppt. *C. prolifera* coverage between Pendola Point and Archie Creek increased to 190 ha by 1990 before declining to a small area of sparse coverage in 1995. Total *C. prolifera* coverage in Hillsborough Bay was estimated to be less than 2000 m² in 1995.

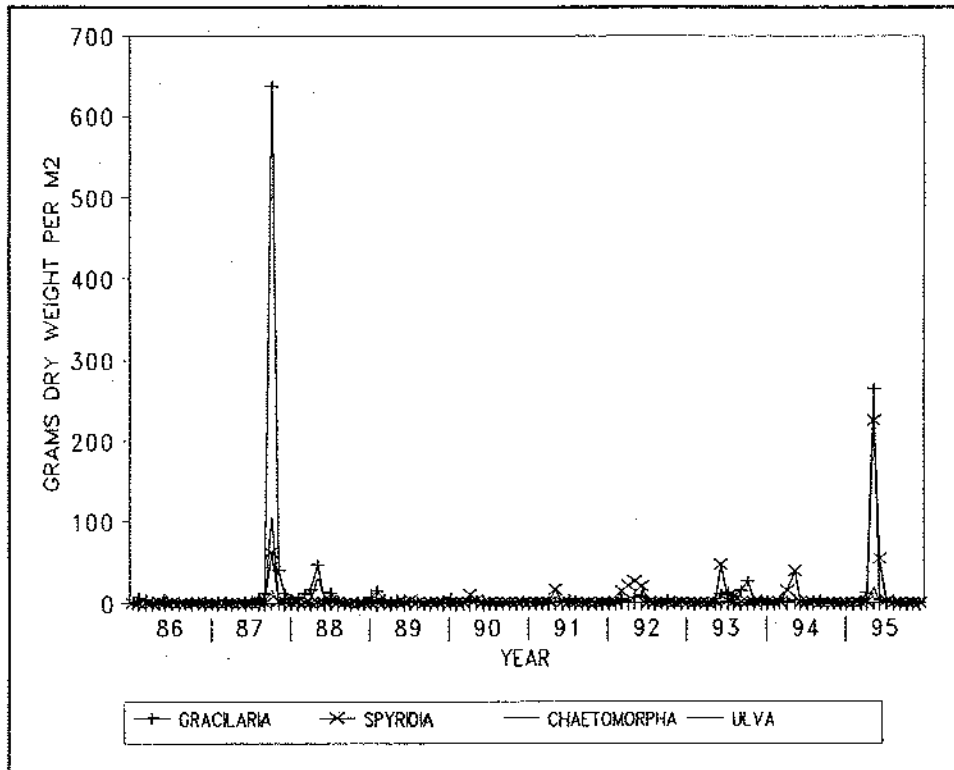


Figure 4. Macroalgae biomass of the four dominant species on transect 102, 1986–1995.

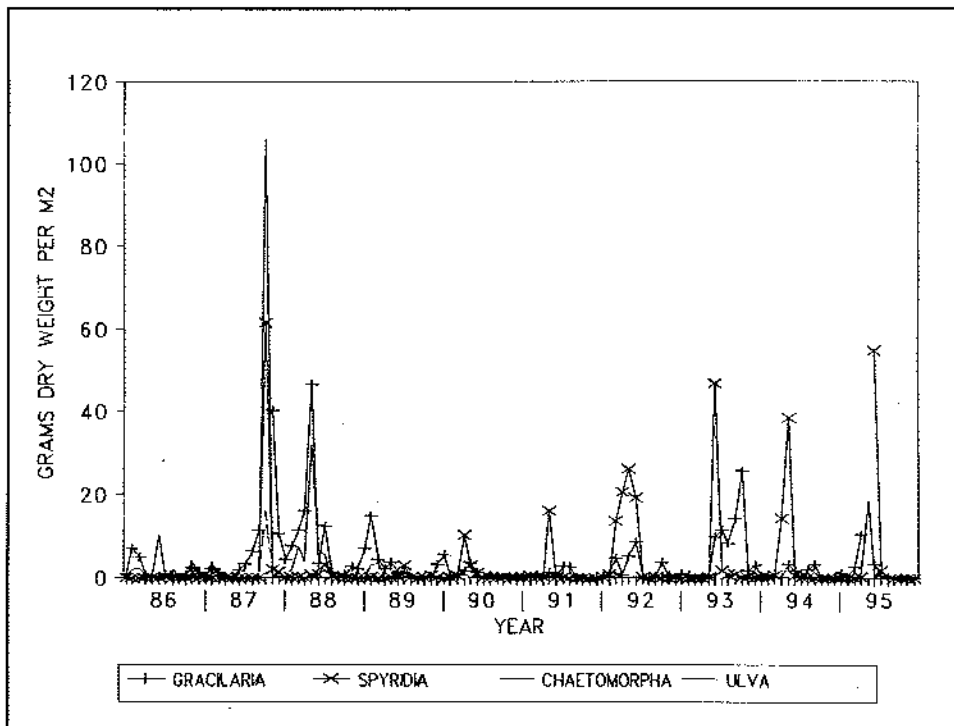


Figure 5. Macroalgae biomass of the four dominant species on transect 102, 1986–1995. The October 1986 *Gracilaria* spp. and May 1995 *Gracilaria* spp./*Spyridia filamentosa* peaks have been omitted.

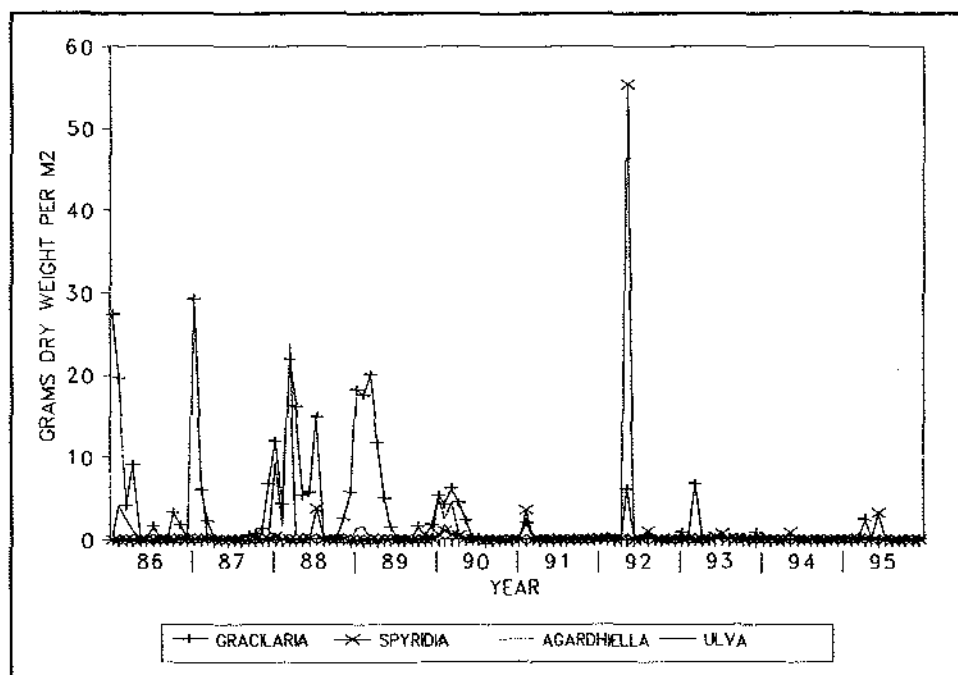


Figure 6. Macroalgae biomass of the four dominant species on transect 103, 1986-1995.

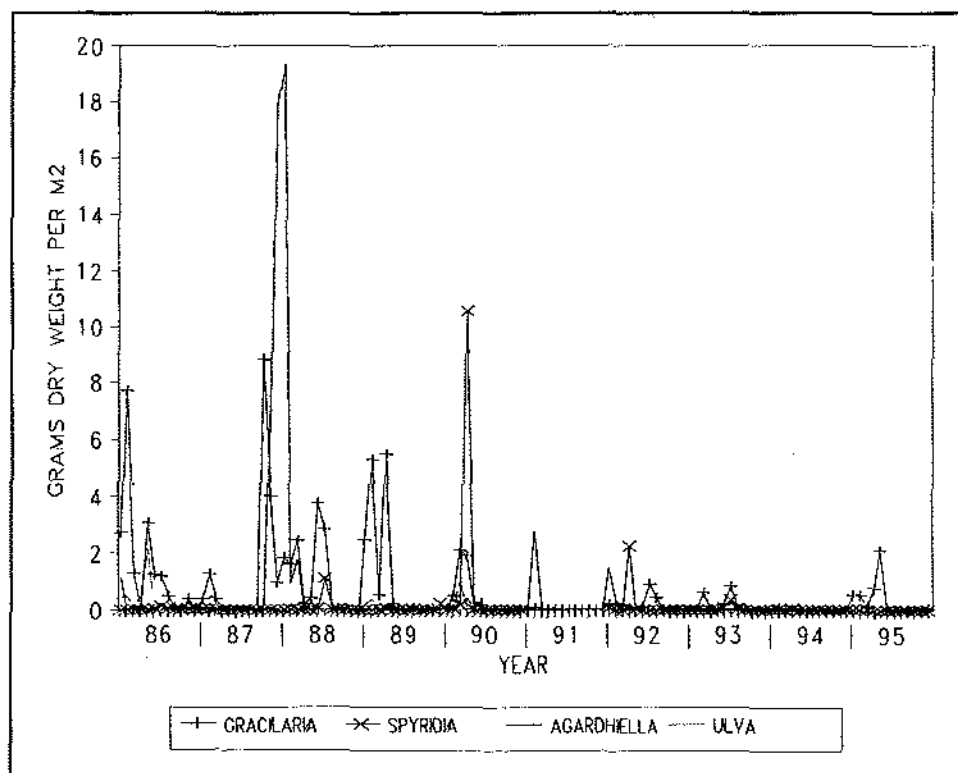


Figure 7. Macroalgae biomass of the four dominant species on transect 104, 1986-1995.

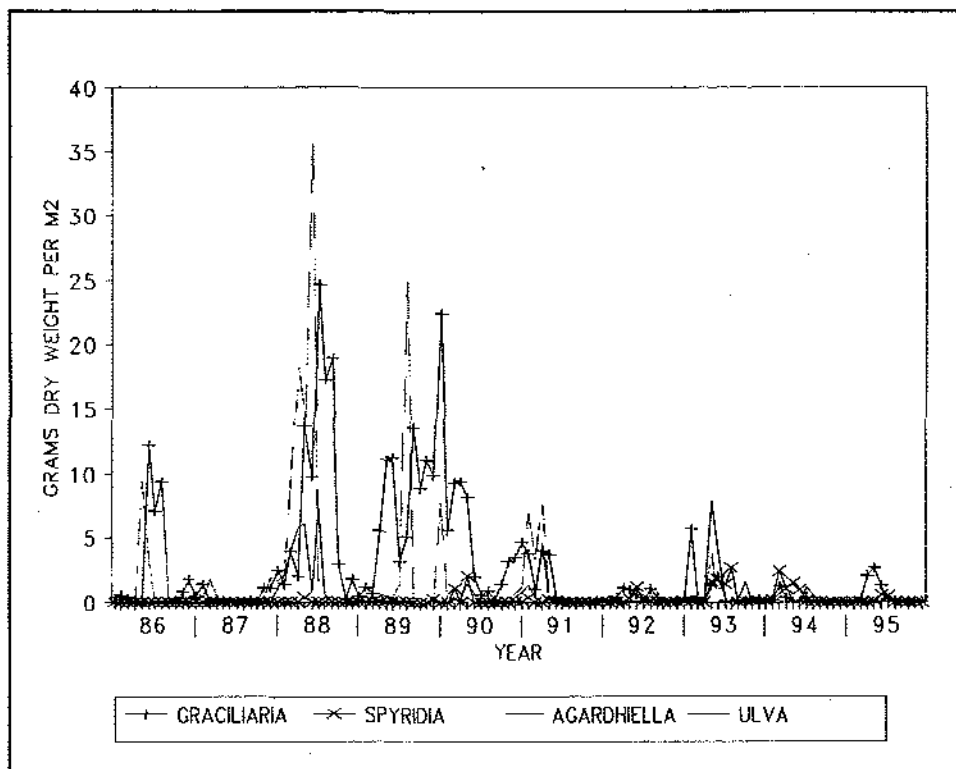


Figure 8. Macroalgae biomass of the four dominant species on transect 105, 1986–1995.

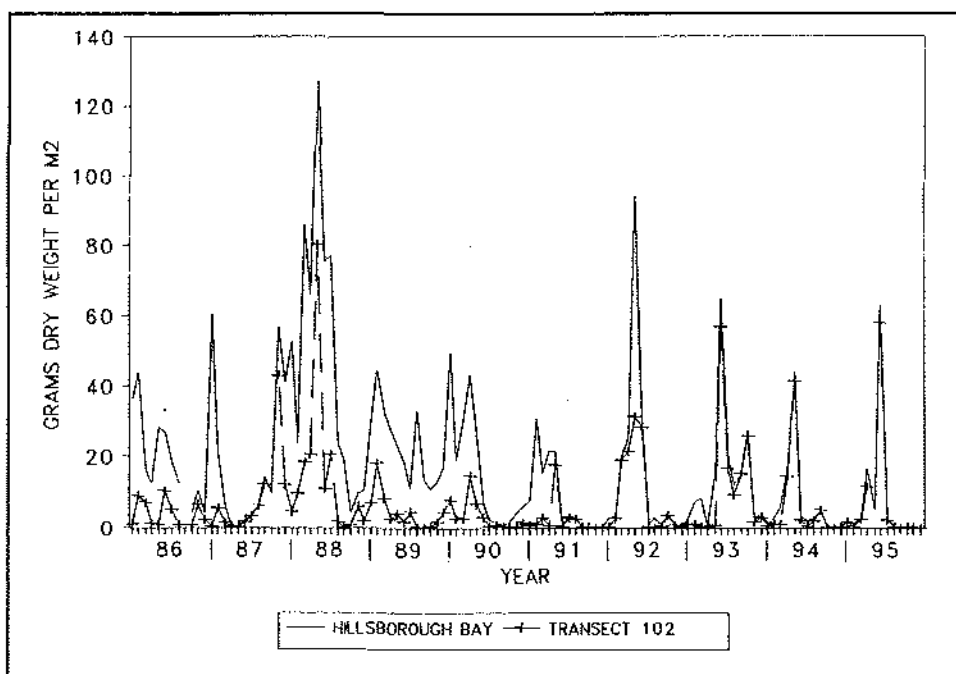


Figure 9. Macroalgae biomass on transect 102 compared to total biomass collected from all transects in Hillsborough Bay, 1986–1995. The October 1987 *Gracilaria* spp. and the May 1995 *Gracilaria* spp./*Spyridia filamentosa* peaks have been omitted.

C. prolifera has functioned in a capacity comparable to seagrass. In lieu of an extensive seagrass environment in Hillsborough Bay, this algae has served as an alternate habitat for many species. Fonseca et al. (1988) demonstrated that seasonal faunal abundance in *C. prolifera* was similar to Tampa Bay seagrass beds in the warmer months with a decline in abundance in the cooler months. Additionally, this alga appears to affect water clarity by stabilizing sediments and increasing sedimentation rates. However, *C. prolifera* has been demonstrated to be an ephemeral species. A rapid salinity reduction was apparently responsible for the decline of the alga in western Hillsborough Bay. The loss of coverage in other portions of Hillsborough Bay remained unexplained.

Seagrass

Ruppia maritima has been a transient species in Hillsborough Bay with coverage ranging from 0.2 ha to just over 2 ha. In some areas, patchy coverage has persisted several years before dissipating while in other areas coverage may be seasonal. The most persistent *R. maritima* coverage appears to be near stormwater culverts and tidal creeks. Coverage has been observed on all the flats of Hillsborough Bay except the northeastern portion near the mouth of the Hillsborough River.

In the initial seagrass survey in 1986, the COT counted 137 patches of *Halodule wrightii* in Hillsborough Bay and estimated coverage at just under 2000 m² (Fig. 10). Patchy coverage was generally confined to an area in southeastern Hillsborough Bay known as the Kitchen and along southern Interbay Peninsula (Fig. 1). Less than a dozen small patches were found in western Hillsborough Bay between Ballast Point and Gadsden Point.

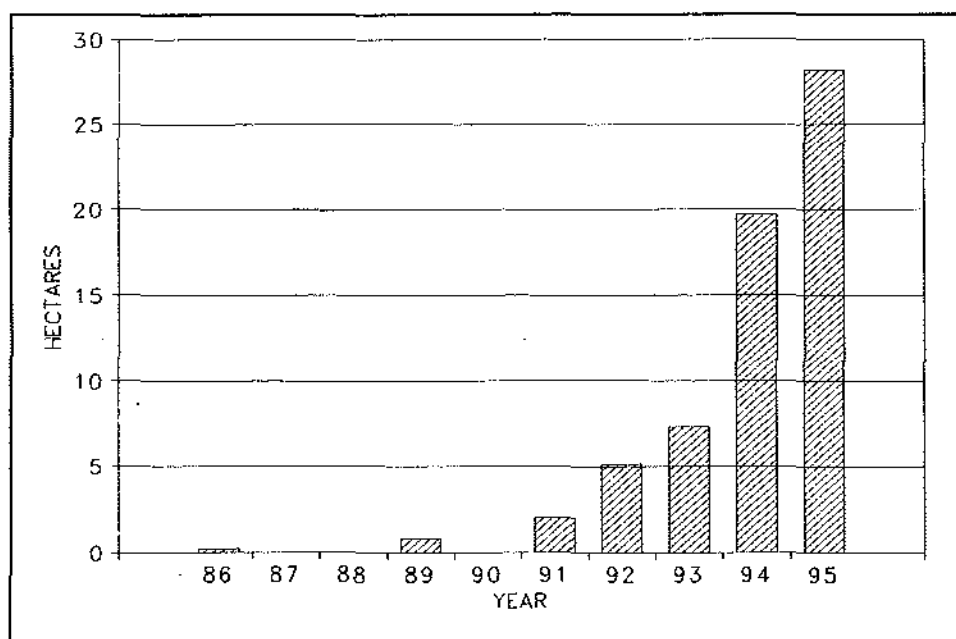


Figure 10. *Halodule wrightii* coverage in Hillsborough Bay, 1986–1995. No surveys were conducted in 1987, 1988 or 1990.

H. wrightii coverage increased in each subsequent survey through 1995 (Fig. 10). Generally, about half of the *H. wrightii* coverage reported in each survey has occurred in the Kitchen. By 1995, *H. wrightii* in the Kitchen had grown into a 17 ha meadow with patchy coverage developing north to Bullfrog Creek. Additionally, patchy coverage was documented north of the Alafia River to western Pendola Point. *H. wrightii* in western Hillsborough Bay increased to about 8 ha and formed a nearly continuous band of coverage from just north of Ballast Point south to Catfish Point. Coverage in western Hillsborough Bay was augmented by a transplanting effort in 1987 (Avery 1991; Fonseca 1995). Coverage has increased just west of Gadsden Point; however, the expected coalescence of patches into small meadows had not occurred by 1995. *H. wrightii* coverage for Hillsborough Bay in 1995 was estimated at just over 28 ha.

Water Clarity

The re-establishment and expansion of seagrass beds in Tampa Bay has generally been attributed to an improvement in water clarity resulting in a better light climate for the seagrass. The light climate for Hillsborough Bay between 1986–1995 may be estimated at Hillsborough County Environmental Protection Commission (HCEPC) stations 71 and 80 (Fig. 1) by converting the Secchi depth annual average to the light attenuation constant k using the relationship $k=1.7/SD$. The constant 1.7 was generated using COT PAR and Secchi depth data from Hillsborough Bay. If the minimum light requirement needed for *H. wrightii* growth is assumed to be 20% of the incident light, the potential depths at which *H. wrightii* may be light limited may be estimated by solving z in the equation $0.2=e^{-kz}$. Due to the senescence of *H. wrightii* during the winter, only the data gathered between March and November of each year was used to produce an annual average. The potential depth for *H. wrightii* growth ranged from about 0.75–1.1 m at station 71 and 1.2–1.8 m at station 80 (Fig. 11). These depths indicate that a major portion of the shallow flats in Hillsborough Bay have had sufficient light for seagrass recolonization for at least a decade.

Potential Factors Affecting Seagrass Coverage

Halodule wrightii recolonization patterns in Hillsborough Bay suggest that factors other than light availability have affected seagrass distribution. In 1986, the light climate was apparently sufficient for recolonization to occur; however, most areas were devoid of seagrass coverage. When coverage was observed, it was limited near shore to a narrow intertidal to shallow subtidal area.

High macroalgae biomass has been shown to impact seagrass beds (COT 1988; den Hartog 1995) and may have impeded seagrass recolonization in Hillsborough Bay during the mid-1980s. Macroalgae mats up to one meter thick have been observed to reside in intertidal and shallow subtidal areas of Hillsborough Bay for months at a time. PAR readings by the COT in a drift algal mat have shown light attenuated to a level below what is needed to sustain seagrass growth. Light attenuation by macroalgae may be exacerbated by sediment resuspension caused by the abrasion of the sediment surface by the shifting algae. Further, the abrasive action may remove existing seagrass coverage or inhibit recolonization. Finally, as the macroalgae decomposes there is a potential for a shift in the chemistry of the surface water at the sediment/water interface and the sediment pore water (Zimmerman and Montgomery

1984). The COT has observed that macroalgae decomposition creates a reduced environment characterized by the production of fine organic sediments, a build-up of H_2S , and pH as low as 7.2. In addition, widespread mortality has been observed in the invertebrate community during macroalgae decomposition.

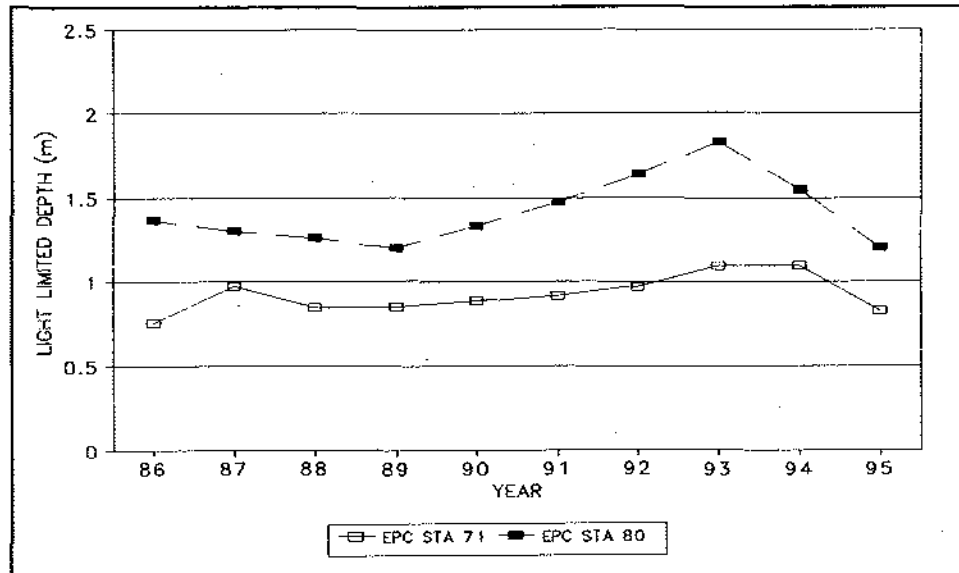


Figure 11. Potential depths at which *Halodule wrightii* may be light limited at HCEPC stations 71 and 80, 1986–1995.

Figure 12 illustrates the macroalgae biomass trend compared to *H. wrightii* areal coverage in Hillsborough Bay. The data indicates that as macroalgae biomass decreased, seagrass coverage increased. In general, as the biomass and residence time of the macroalgae decreased, *H. wrightii* recolonization in several areas of the bay occurred rapidly. When large amounts of macroalgae have periodically covered developing seagrass beds for extended periods (generally over a month), reductions of short shoot density and areal coverage have been noted. Seagrass coverage is developing in many areas where historical nuisance macroalgae biomass has abated.

In addition to macroalgae, other factors may have inhibited seagrass recolonization and expansion. Although recolonization by *H. wrightii* has been observed in most portions of Hillsborough Bay, coverage is generally restricted to a relatively narrow band of the inshore flats with the shallow subtidal zone to seaward remaining unvegetated. Some seaward portions of the subtidal flats may be considered to be a high energy zone as a result of wave action generated by wind and maritime traffic. The turbulence from these waves resuspends sediments and contributes to sediment movement. The COT has seen sandbars shift as much as four meters a month, covering seagrass beds and leaving large areas barren of seagrass.

Data generated at HCEPC stations 71 and 80 indicate that water quality should be sufficient for seagrass recolonization to occur on most of the Hillsborough Bay flats shallower than two meters. However, data from these “deep water” stations may not accurately reflect conditions on the shallow subtidal flats. Each habitat may differ in

depth, benthic floral and faunal composition, and sediment characteristics. More data is needed from the shallow water habitat before data from the deeper stations can be extrapolated to characterize conditions in areas of potential seagrass development.

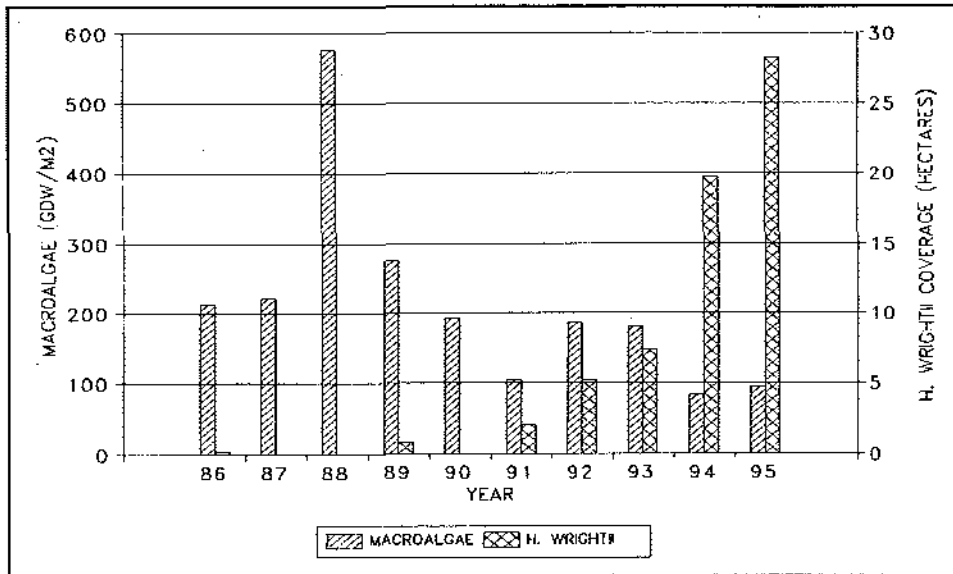


Figure 12. Comparison of macroalgae biomass versus *Halodule wrightii* coverage in Hillsborough Bay, 1986–1995.

SUMMARY

Drift macroalgae biomass in Hillsborough Bay has decreased by an order of magnitude from over 900 gdw/m² in 1987 to 80 gdw/m² in 1994. Also, the residence time of the macroalgae biomass on the shallow subtidal flats decreased after 1990. However, high biomass was documented in northeastern Hillsborough Bay through 1995.

Between 1986 and 1990, the attached alga, *Caulerpa prolifera*, covered extensive portions of the tidal flats in Hillsborough Bay. This alga has shown the ability to rapidly colonize large areas up to three meters in depth. The alga may function in a capacity similar to seagrass; however, it has proven to be an ephemeral species. A sudden influx of freshwater to Hillsborough Bay apparently contributed to a 75% decline in coverage in 1988.

Two seagrasses, *Ruppia maritima* and *Halodule wrightii*, occurred in Hillsborough Bay between 1986 and 1995. *R. maritima* areal coverage fluctuated between 0.2 ha to about 2.2ha. Although found in most areas of the bay, this species seems to prefer areas around stormwater discharges and tidal creeks. *H. wrightii* areal coverage has increased from about 2000 m² in 1986 to over 28 ha in 1995. This species has produced large meadows in eastern and western Hillsborough Bay, apparently as a result of alleviated eutrophic conditions.

Data generated from two HCEPC stations indicate that sufficient light has been available for seagrass recolonization on most of the shallow subtidal flats of Hillsborough Bay for at least a decade, although prior to 1990, only limited seagrass recolonization was observed. Macroalgae biomass may have inhibited seagrass recolonization in Hillsborough Bay through 1990. With the abatement of nuisance macroalgae biomass in most areas after 1990, *H. wrightii* began to rapidly recolonize several sections of the bay with most of the emergent vegetation developing in a narrow band along shore. However, a large portion of the shallow subtidal flats seaward of the developing *H. wrightii* meadows remains virtually unvegetated. These portions of the flats may be impacted by waves generated by maritime traffic and wind, creating an environment not conducive for the initiation of seagrass recolonization.

The water quality on potential seagrass flats must be investigated and compared to data from "deep water" stations (i.e., more than 2 meters deep). Data collected from these deep water stations may not be indicative of the water quality on the flats.

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**Third Prize (tie)
Student Poster Awards**

**CHARACTERISTICS AFFECTING THE MOVEMENT OF
DRIFTING MACROALGAE IN A PATCHY SEAGRASS SHOAL**

Kevin A. Madley
Susan S. Bell

STUDENT POSTER ABSTRACT

For this study, field experiments were performed to examine movement rates and directions of drifting macroalgae on a shallow (<1.5 m) tidal shoal containing beds of *Halodule wrightii*. The goal was to elucidate the characteristics of the seagrass system which were most important in affecting drift algal movement.

In January and October 1995, algal clumps were tagged, released on the edge of seagrass beds, and tracked for two hours. Seagrass canopy height, water depth, and water current velocity proved to be significant factors in the rate of macroalgal movement. Water depth was significant only when the effects of wind velocity were greatest (i.e., when algae was located near the water surface or wind velocities were strongest). Algal transport was greatest in short canopies and combinations of high wind and shallow water. Within the seagrass beds algae traveled parallel to the direction of tidal current, except when relatively high winds occurred. These results suggest that variation in both daily and seasonal transport of drift algae occurs in seagrass beds.

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**Second Prize
Student Poster Awards**

**DOES DRIFT MACROALGAE FACILITATE
SEAGRASS BED HOPPING OF AMPHIPODS?**

Robert A. Brooks
Susan S. Bell

STUDENT POSTER ABSTRACT

Drifting macroalgal clumps are a dynamic above-ground structural component of Tampa Bay seagrass beds, and algal movement may serve as a method for amphipod dispersal. A study was designed to examine the dispersal of phytal dwelling amphipods in *Halodule wrightii* seagrass beds and bare sand patches. Three questions were posed (and answered) through a series of manipulative experiments: 1) do amphipods colonize drift algae located in bare sediment? (yes); 2) do higher numbers of amphipods colonize drift algae in a seagrass bed compared to algae located in sand? (yes); and 3) do amphipods remain, leave or colonize drift macroalgae as it passes through a seagrass bed and exits into bare sediment? (strong tendency to colonize). These results suggest that drift algae is a potential dispersal agent for amphipods across a fragmented landscape.

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ANNUAL LIGHT REGIME OF LIGHT-LIMITED *THALASSIA TESTUDINUM* IN TAMPA BAY, FLORIDA

L. Kellie Dixon
Jay R. Leverone

ABSTRACT

To guide seagrass protection efforts in Tampa Bay, the Surface Water Improvement and Management program of the Southwest Florida Water Management District funded a study of the light requirements of *Thalassia*. Scalar irradiance sensors were continuously deployed at the deep edges (2.0–2.4 m) of four light-limited meadows in Lower Tampa Bay, at canopy height and 0.5 m shallower. Annual irradiance (PAR) in the water column at canopy height ranged from 3600 to 4900 E yr⁻¹. The two sensors allowed calculation of both attenuation coefficients and irradiance at depth as a percentage of the extrapolated immediately subsurface irradiance. The range of median attenuation coefficients (midday, 1000–1400 hours) was 0.73–0.88 m⁻¹. Incorporating rough estimates of the effect of bottom reflectance on the lower sensor, approximately 20.5% of immediately subsurface light reached the canopy height of the deepest seagrasses. Attenuation by epiphytic materials on seagrass blades further reduced plant-available light by 32–36%. The resulting PAR available to the plant was 2200–3100 E yr⁻¹. Physiological responses to lowered light levels (leaf elongation, reduced shoot density) were observed at the station with lowest annual totals, suggesting that measured irradiances bridged an ecological compensation point. Inclusion of the epiphytic component to total attenuation improved agreement among stations. Comparable annual PAR totals were recorded among stations with widely varying water column color. The use of the *water column* PAR percentages measured during this study (20.5%) as light targets for seagrasses throughout the bay incorporates the assumption that epiphytic attenuation is comparable throughout the bay.

INTRODUCTION

The project to determine the light requirements of *Thalassia testudinum* within Tampa Bay was a resource-based management effort sponsored by the Surface Water Improvement and Management Program (SWIM) of the Southwest Florida Water Management District (SWFWMD). The project was one portion of a linkage between watershed management and nutrient loadings control, water clarity (chlorophyll and solids), light attenuation, and seagrass cover within the bay. Light requirements determined during this study were to be coupled with bay segment-specific target depths for seagrasses (selected to restore a desired historical coverage) and used to calculate required water clarity. Empirical relationships of water clarity with chlorophyll and chlorophyll with nitrogen loadings were then to be employed to set nutrient loading targets which would permit desired seagrass restoration.

METHODS

Site selection identified four stable, *Thalassia*-dominated, light-limited grassbeds (Fig. 1) for the determination of annual light regimes. Stations were located at Mullet Key (MUL), Point Pinellas (PIN), Port Manatee (PRT), and in the mouth of the Manatee River (RIV). At the deep edge of the seagrass bed, continuous irradiance measurements (4π, Li-Cor 193SA) of photosynthetically active radiation (PAR) were made at two depths within the water column, to allow calculation of water column attenuation coefficients. Sensors were cleaned approximately every five days. Data loggers stored 15-minute average readings and were downloaded approximately every two weeks, at which time fouling rates were directly measured. Instrument arrays were operated from early December 1993 for a calendar year. During each visit to the sites, manual PAR profile measurements were made (Li-Cor 193S [4π] and 190SA

[air, 2π]). On many occasions, the manual profiles included additional submerged sensors (Li-Cor 192SA [2π]) in both upward and downward facing orientations to determine the degree of upwelling light due to bottom reflectance.

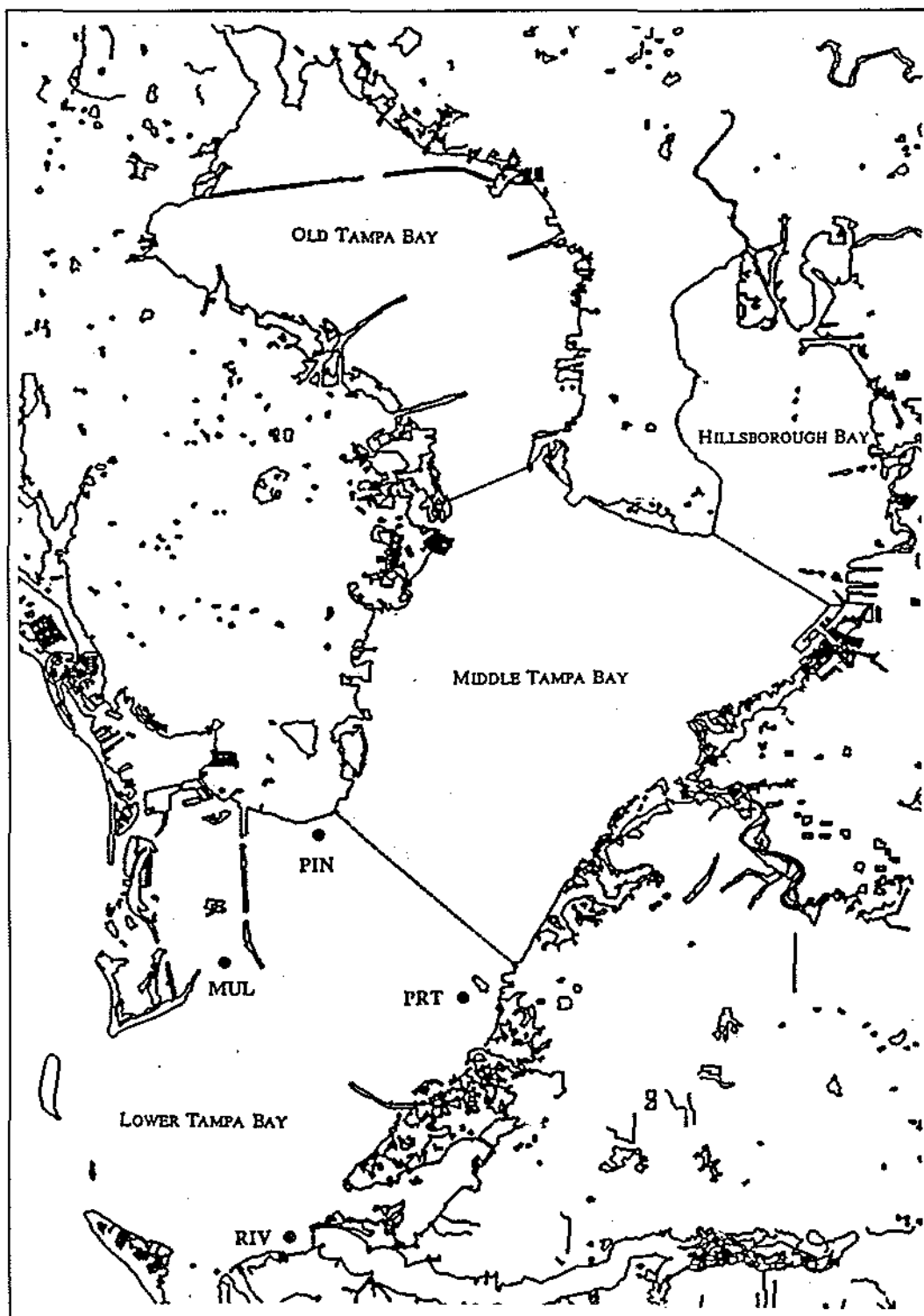


Figure 1. Station locations and designations for Tampa Bay continuous light (PAR) monitoring and seagrass condition measurements.

Calculations of total PAR received by seagrasses and estimates of time above critical light values made use of all available data points from the lower sensor between 0500 and 2100 hours. Seasonal and annual averages of attenuation coefficients and light percentages used data between 1000 and 1400 hours only for maximum correspondence with existing monitoring programs within the Bay. Data reduction of PAR values included correction of sensor values for the attenuation produced by fouling communities. Sensor- and site-specific fouling rates (averaging 2% PAR reduction day⁻¹) were applied to data based on the number of decimal days since cleaning to obtain corrected sensor readings. Absolute levels of light in the water column at the deep edge were computed by integration and summation of the corrected bottom sensor data over the various time periods of interest. Corrected top (E_T) and bottom (E_B) sensor irradiance data (sensors separated by 0.5 m) were used to compute attenuation coefficients (K_0) as follows:

$$K_0 = \frac{-\ln(E_B / E_T)}{0.5}$$

Computed attenuation coefficients were used to solve for the PAR remaining at the bottom of the water column (% PAR_w) as a percentage of the immediately subsurface scalar irradiance, by substituting z (mean water depth at the deep edge) for 0.5 m. (Station depths used were determined from predicted tides and depth observations while on station, and had a typical standard error of 0.02 m.) Implicit in the calculation of light levels at other depths is the assumption that the water column is well-mixed and homogenous from surface to bottom.

$$\% \text{ PAR}_w = (100\%)e^{-K_0 \cdot z}$$

The PAR actually available to the plant (% PAR_p) was calculated by further reducing % PAR_w by measured epiphyte attenuations. Similar adjustments allowed calculation of total PAR received by the *Thalassia* blades.

$$\% \text{ PAR}_p = \% \text{ PAR}_w \cdot (1 - \text{Epiphyte Attenuation} / 100\%)$$

Total attenuation coefficients, K_t , were computed using the mean station water depths (z), as:

$$K_t = \frac{-\ln(\% \text{ PAR}_p)}{z}$$

Total attenuation coefficients, representing water column PAR attenuation over finite depth *plus* attenuation through a comparatively very thin epiphytic layer, cannot be used to extrapolate light climates to other portions of the water column, but are presented for comparison to water column attenuation coefficients.

Bottom reflectance was of concern due to the use of 4π sensors deployed at the bottom of the water column. In the event of substantial bottom reflectance, an attenuation coefficient determined near bottom will appear lower than an attenuation coefficient determined in the upper portion or over the entire water column. Using the artificially low attenuation coefficient to compute the percentage of subsurface

PAR present at depth will generate a higher percentage than if an attenuation coefficient for the entire water column had been used.

Bottom reflectance is a function of bottom type, and character of the light field which reaches the bottom. Bottom reflectance is minimized when the diffuse component of the light field is high, i.e., when particulate load or turbidity is high, attenuation coefficients are high, sun angle is low, wave action is present, or under cloudy or hazy skies. As a result, bottom reflectance is most likely under conditions of shallow water column, sandy bottom, calm surface, midday and high water clarity, and is a highly variable quantity.

Overall estimates of bottom reflectance were obtained from irradiance reflectance (downward-facing 2π sensor:upward-facing 2π sensor percentages) computed at all measurement depths. Irradiance reflectance measurements at surface depths should be minimally impacted by bottom reflectance, while measurements made near the bottom were expected to show increased upwelling:downwelling ratios if bottom reflectance were a significant phenomenon. Irradiance reflectance at surface depths (0.2 m) averaged 5.6%, well within ranges reported by other investigations (summarized in Kirk 1994). Irradiance reflectance at the depths closest to the bottom of the deep stations, on the other hand, averaged 15.8%. The difference between 5.6% and 15.8%, or 10.2%, was taken as an approximation of bottom reflectance.

A simplified model of scalar attenuation in the presence of bottom reflectance was constructed in which observed mean station K_0 was used to attenuate downwelling light, irradiance reflectance (backscatter) was assumed constant at 5% of downwelling light, and bottom reflectance was assumed to be a fixed percentage of the downwelling light reaching the bottom (which was subsequently attenuated in an upward direction using the same coefficient used for downwelling light. The sum of downwelling, upwelling (backscattered), and bottom reflected light was used to develop a scalar profile of irradiance, and attenuation in the absence of bottom reflectance solved by successive approximations. Using a 2.0 m total water column depth, 10% bottom reflectance, the observed K_0 value of 0.87 m^{-1} (from sensors within 0.2 m of the bottom and separated by 0.5 m) is 0.07 m^{-1} lower than an approximate K_0 computed in the absence of bottom reflectance. Resulting calculations of percentages of PAR at depth differed by near 2% (22.5% PAR_w from measurements near bottom, and 20.5% PAR_w if no bottom reflectance was present). Due to the uncertainties associated with correcting for bottom reflectance, the degree of dependence on water clarity, and the highly variable nature of the function, corrections were applied only to annual means of % PAR_w , decreasing % PAR_w by 2%.

Growth and condition measurements of *Thalassia* were performed at the deep edges (-D) and also at a location 0.9 m shallower (-S, and therefore not light-limited), along permanently marked 15 m work lines. On a bimonthly basis, fieldwork determined quadrat counts (40 per station, 25 cm $\times$ 25 cm) of shoot density, above-ground growth rates (15 shoots per station, using the blade marking techniques after Tomasko and Dawes 1989), and rhizome carbohydrate content (10 samples per station). Biomass cores (10 per station, 12.5 cm $\times$ 12.5 cm) were collected on four occasions during the sampling year. Calculations included determination of above-

and below-ground biomass, leaf-, shoot-, and area-based growth rates, leaf areas, turnover times, plastochrone interval (Brouns 1985), tissue apportionment as percentages of total biomass, and rhizome density and weight-to-length ratios.

Epiphytic attenuation was also determined bimonthly (10 shoots per station) by the method of Dixon and Kirkpatrick (1995). Epiphytic materials were scraped from the blades used for above-ground growth determinations and measured PAR attenuation normalized to the blade area scraped. Epiphytic attenuations represent an integrated or area-averaged measurement, i.e., as if the entire epiphyte burden of a single shoot is evenly distributed across both sides of all blade surfaces.

Data from other sources included productivity-irradiance (P/E) relationships (through oxygen evolution) and tissue chlorophyll content performed by Dr. Clinton J. Dawes, University of South Florida, for both the April and June samplings. Light monitoring data were obtained from both the City of Tampa and the Hillsborough County Environmental Protection Commission for the 1994 monitoring year and prior periods.

RESULTS AND DISCUSSION

Water column depths at the deep edges were 2.10, 2.37, 2.15 and 1.98 m for MUL, PIN, PRT and RIV, respectively. Temperature ranges (10.8–33.0°C) and average salinities (28.7–30.6 ppt) at all deep stations were within published ranges for *Thalassia* and were very comparable, although RIV (and to a lesser extent PRT) experienced exfoliation following periods of abruptly lowered salinity (and high color) with the onset of the wet season. Thermal stress (as evidenced by biomass and decreased rhizome carbohydrate content) was apparent at all shallow locations during June.

Expected seasonal patterns of *Thalassia* biomass were evident in all of the biomass parameters, and closely followed seasonal changes in temperature. Seasonal changes often exceeded inter-station differences and were more pronounced at the shallow stations. Gradients of decreasing above-ground biomass, shoot density and leaf area index with increasing depth were quite apparent. Deep stations were also higher in rhizome carbohydrate content and exhibited minimal seasonal fluctuations. *Thalassia* tissues were apportioned to blades, shoots, and combined roots and rhizomes as 23%, 37% and 40%, respectively, for the project as a whole, but seasonal patterns of growth produced a range of 20–35% in blade tissues with a large amount of variation within a given sampling and station.

Growth parameters (leaf relative growth rate, above-ground growth shoot⁻¹) demonstrated no depth-related patterns, but exhibited seasonal maxima during April and June. Areal growth peaked in April, integrating typically higher shoot densities and shoot relative growth rates observed during this month. During the April and June sampling, there was no relationship between growth rates and total PAR or number of hours above critical irradiance values, even though PAR available to the plant was quantified at a shoot level by accounting for epiphytic attenuation.

PIN-D consistently had lower light levels than all other sites. Growth and condition measurements combine to indicate that PIN-D exhibited low-light stress during this study. Shoot density of the deep edge at PIN declined significantly over the course of the project, despite the fact that seasonal patterns in shoot density would predict that October densities would be higher than the December values. Other deep stations in the study either displayed the expected increase in shoot density or were unchanged. Other evidence primarily consisted of increased blade lengths and decreased numbers of blades produced, which in turn affected a number of parameters. Increased blade lengths persisted at PIN-D from April through the October sampling but were particularly evident in August (Fig. 2). Increased blade lengths are one of the typical morphological responses produced by shading (Hall et al. 1991; Goldsborough and Kemp 1990). The longer mean blade lengths at PIN-D were also reflected in the higher growth shoot⁻¹ and leaf area shoot⁻¹ noted for this station in June, August and October. Ratios of blade area to tissue weights indicate that the increased blade area at PIN-D had less structural support. Significantly lower below-ground tissue proportions at PIN-D than at other stations may also reflect cumulative low-light stress. (Dunton [1994] reports an increase in above- to below-ground biomass (A:B) ratios under low-light stress for *Halodule*.)

Blade production year⁻¹ (measured by plastochrone interval and through reconstructive aging analysis) was lower at PIN-D than other deep stations, and the leaf scars enumerated indicated that the low blade production had been going on for some years. The lower below-ground biomass (and higher A:B ratios) seen at PIN-D during all samplings also argues that plant resources have been diverted from typical allocation patterns for some time, as differences between sediments at the deep stations are not sufficient to explain the higher ratios. It is unknown at this time whether the stress experienced by PIN-D can be overcome in subsequent growing seasons or will result in continued declines in the shoot density and losses at the deep edge.

With the knowledge that PAR at one of the deep stations may be at unacceptable levels, the light climate may be examined knowing that the data encompasses a threshold value. Based on other monitoring programs within the Bay, annual average water clarity in Lower Tampa Bay as a whole during the project year (1994) was not significantly different from previous years, and grassbeds were in general presumed to be at a steady state with respect to light. The PAR received at the deep edges of stable beds, therefore, represented ecological compensation points, or the PAR necessary to balance grassbed growth with normal mortality, grazing and repetitive minor stresses.

Annual and monthly averages of water column attenuation coefficients (K_d , 1000–1400 hrs) displayed expected seasonal patterns and did not vary widely between stations, ranging from 0.80 to 0.94 m⁻¹. The range of median values was 0.73–0.88 m⁻¹. Relationships of maximum depth (Table 1) with attenuation coefficient were consistent in that the station with the deepest maximum depth (PIN) recorded the lowest attenuation coefficients overall (clearest water). Water clarity during the growing season (May–September) was substantially less with station

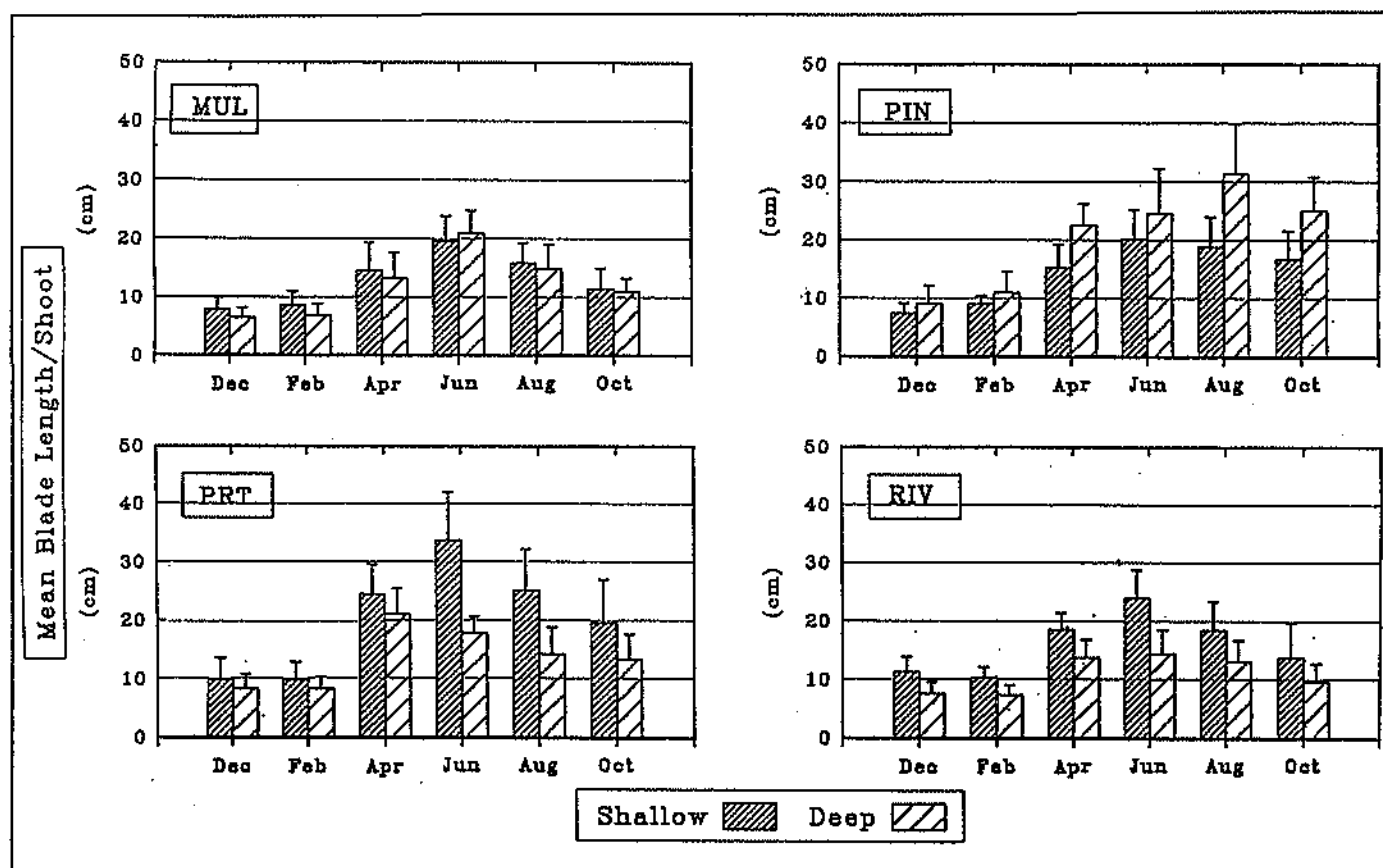


Figure 2. *Thalassia* blade lengths (cm shoot⁻¹) at shallow and deep stations, December 1993 through October 1994. Values are means $\pm$ s.d.; n=15.

averages ranging between 0.89 and 1.17 m^{-1} during this period as typical annual cycles of increased chlorophyll and color were manifested.

Table 1. Water column attenuation coefficients and %PAR_w measured at the maximum depth limits of *Thalassia* between 1000–1400 hours. Total annual water column PAR recorded at canopy height (water column) of the deep edge and after epiphytic attenuation of between 0500–2100 hours.

	MUL	PIN	PRT	RIV	All Stations
ANNUAL ATTENUATION COEFFICIENT (m^{-1})					
Mean of months	0.84	0.80	0.84	0.94	0.86
Mean of all data	0.83	0.80	0.86	0.98	0.87
Median	0.76	0.73	0.78	0.88	
%PAR _w AT MAXIMUM DEPTH (%)					
Mean of months	22.1	20.5	23.5	23.9	22.5
Corrected*	20.1	18.5	21.5	21.9	20.5
Median	20.2	17.7	18.8	17.4	
ANNUAL TOTAL PAR _w WATER COLUMN (E year ⁻¹)	4864	3639	4876	4934	
ANNUAL TOTAL PAR _w AFTER EPIPHYTIC ATTENUATION (E year ⁻¹)	3138	2240	3061	3071	
WATER COLUMN DEPTH AT MAXIMUM DEPTH (m)	2.10	2.37	2.15	1.98	

*Corrected for approximate bottom reflectance.

Annual percentages of PAR present in the water column at the maximum depth limits of *Thalassia* ranged between 20.5% (PIN) and 23.9% (RIV). All four stations (including PIN with losses at the deep edge) averaged 22.5% of subsurface scalar irradiance. Correction for the effects of bottom reflectance reduced estimates of annual %PAR_w to between 18.5% and 21.9%, with a four station average of near 20.5%. *Water column coefficients and percentages represent attenuation by materials in the water column only and can be transferred to other areas as appropriate management targets only if epiphytic growth is comparable.* Inclusion of the PIN station data with significant decreases in shoot density and other shading responses indicate that the 20.5% figure should be viewed as a minimum value with little margin of safety.

The epiphytic growth on *Thalassia* blades was substantial and resulted in an additional 7–67% reduction in light actually available to the seagrass blades, with an average annual reduction of between 32% and 34% at the four stations. Seasonally, epiphytic loads are higher in the winter and appear linked primarily to patterns of *Thalassia* blade growth and the length of time blade material remains available for colonization. Evidence from a more restricted lagoonal environment nearby (Sarasota Bay) indicates annual average epiphytic attenuation can be nearer 50% (Dixon and Kirkpatrick 1995). Epiphytic growth and attenuation in the higher nutrient regimes (HCEPC 1990; Janicki and Wade 1994; Zarbock et al. 1994) of the other portions

of Tampa Bay is unknown, but is expected to be higher than for Lower Tampa Bay based on the numerous reported responses of epiphytes to increased nutrient regimes.

To look at *Thalassia* PAR requirements in the absence of confounding factors such as epiphytes, water column percentages of PAR were further reduced by the station specific epiphyte attenuation measured during the bimonthly samplings in order to compute total attenuation. Annual averages of PAR actually available to the *Thalassia* blades (adjusted for both water column and epiphytic attenuation) were between 13.9% and 14.2% (or between 12.5 and 13.0%, adjusted for bottom reflectance) at MUL, PIN and RIV. At PIN, where low-light stress appears likely, 13% (12.5% less bottom reflectance) was received. *The percentages of subsurface PAR_p (available to the plant) are not appropriate water column management targets, unless epiphytes on Thalassia are completely absent.*

The scatter between the stations is much less when the attenuation due to both water column and epiphytes is considered and relationship of maximum depth limits with *total* attenuation (Fig. 3) improves over relationships with water column attenuation alone. The improvement (and the strength of the relationship) lends support to having defined a functional value for light requirements for *Thalassia* of near 14% of subsurface scalar irradiance. What is remarkable is that the PIN station, showing evidence of low light morphological adaptations, received only about 1% less as an annual average. In addition, monthly PAR percentages reveal that while PIN received lower levels of PAR than the other stations between January and May, MUL, PRT and RIV received lower PAR levels during many of the months of the growing season. Apparently, PAR "deficits" incurred during winter, early spring and into May are sufficient to trigger morphological responses which extend through the fall. Above-ground growth is obviously decoupled in time from PAR received.

When total PAR is examined (not just 1000–1400 hrs), differences between PIN and the remaining stations become more distinct. Annual totals of water column PAR at canopy height of the deep edge at MUL, PRT and RIV ranged between 4,860 and 4,930 $\text{E m}^{-2} \text{ year}^{-1}$ (Table 1). The deep edge at PIN, however, received only 3,640 $\text{E m}^{-2} \text{ year}^{-1}$, or 75% of that received by stations which displayed no shading responses. Daily values of PAR at PIN averaged 10.0 $\text{E m}^{-2} \text{ day}^{-1}$ compared to 13.3–13.4 $\text{E m}^{-2} \text{ day}^{-1}$ at the other three stations. When water column PAR is adjusted for epiphytic attenuation, annual totals of PAR received by the *Thalassia* blades ranged between 3,060 and 3,140 $\text{E m}^{-2} \text{ year}^{-1}$ for MUL, PRT and RIV, while PIN was again near 75% of these levels, or 2,240 $\text{E m}^{-2} \text{ year}^{-1}$. The RIV station, despite higher color and attenuation values during periods of freshwater discharge, was very comparable in annual totals to the MUL and PRT stations.

SUMMARY

The investigation of *Thalassia* light requirements used continuous scalar light measurements at two depths in the water column and periodic seagrass community assessments to define the light climate (and the seagrass response) at the deepest edges of the *Thalassia* beds. Annual or seasonal values of light obtained at a stable deep edge were to be considered as the light "requirement" of the species. The conclusions were tempered by the responses or conditions of the beds as measured over the course of

the project, and by whether water clarity during the project year was representative of typical conditions. Of the four locations sampled, one exhibited a shading response or low-light stress. The amounts of photosynthetically active radiation (PAR) attenuated by the water column and by the epiphytic community on the seagrass blades were each quantified to determine the PAR actually available to the *Thalassia* blades. Average annual water column light (as a percent of immediately subsurface irradiance) was near 20.5% at the deep edge, but is a useful management goal only when epiphytic cover in target areas is comparable to the sites measured in this study. Epiphytic attenuation reduced the PAR received by seagrass blades to near 13%. Total annual PAR, either in the water column or available to the plant, was a much more sensitive indicator of seagrass performance. The station with shading response recorded only about 75% of the light received at the remaining three sites.

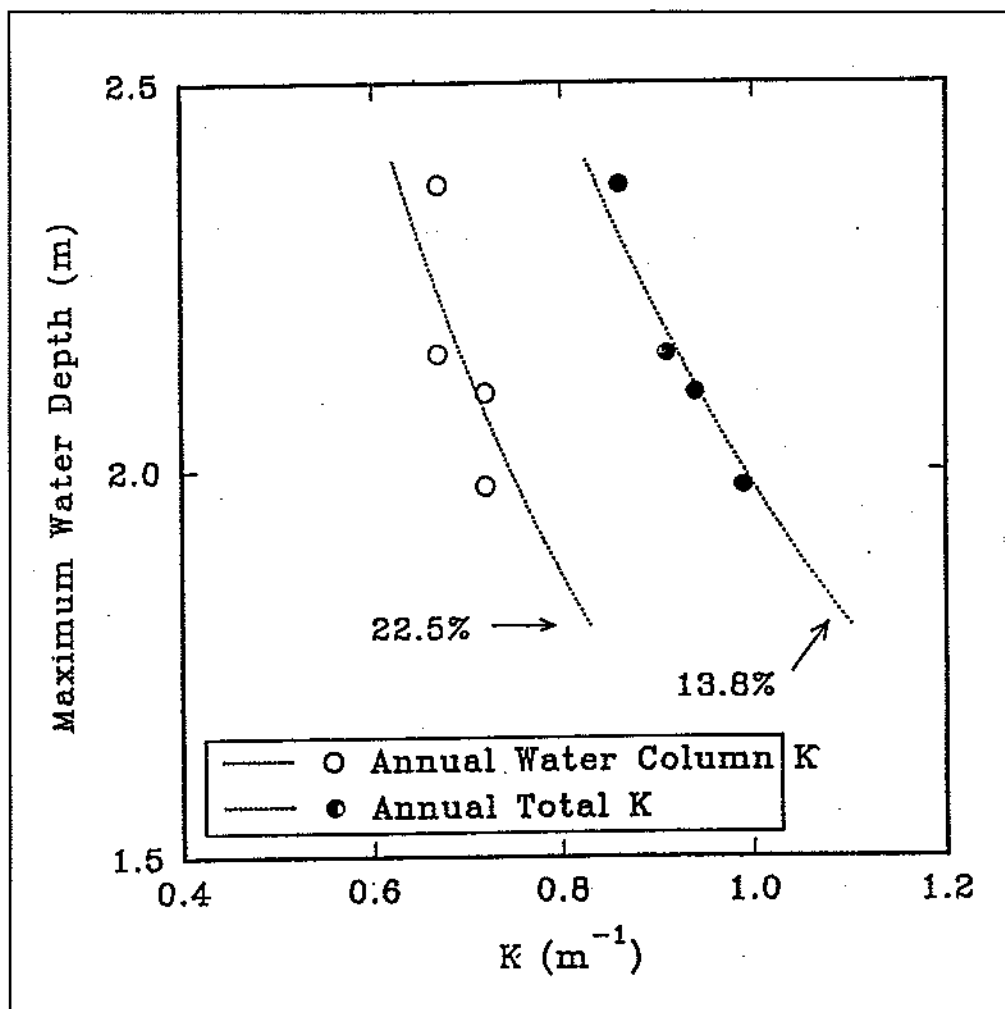


Figure 3. Maximum depth limits of Tampa Bay *Thalassia* as a function of water column and total (including epiphytic attenuation) attenuation coefficients. Coefficients computed from annual averages of %PAR_w and %PAR_p and maximum *Thalassia* depths.

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COST-EFFECTIVE MEASURES APPLIED TO ACHIEVE PERMIT COMPLIANCE AND HABITAT DIVERSITY AT A COUNTY-OWNED MITIGATION SITE

Eric P. Fehrmann

ABSTRACT

Due to contract disputes, a Pinellas County mitigation site received virtually no maintenance for approximately two years. During that time the site had become infested with invasive species and the desirable vegetation was not thriving. The Southwest Florida Water Management District (SWFWMD) issued a letter of non-compliance for this site and the Pinellas County Department of Environmental Management was contacted by the Public Works Engineering Design Section to assist with site remediation.

The site was assessed for hydroperiod, desirable and invasive species herbaceous cover, and tree survival. Several options were discussed and the County decided to design an in-house multi-directional non-destructive approach and was able to gain the support of SWFWMD to try this most cost-effective option first. The County modified the hydroperiod and recontoured areas at the site. Post-construction monitoring revealed that the trees experienced a significant growth spurt as a result of the more favorable hydroperiod and many species of wildlife not previously observed were seen in the area. Invasive species declined markedly with no herbicide use.

Coordination with the Pinellas County Jail enabled inmate volunteers to plant over 500 trees as well as pickerelweed, spatterdock and 6900 maidencane plants at no cost for labor. The site is functioning extremely well at this time and the Department will continue monitoring the site to ensure success.

INTRODUCTION

Studies conducted by contractors on behalf of Pinellas County resulted in the design of a flood control strategy for the Spanish Oaks and Spanish Pines subdivisions located in northern Pinellas (Fig. 1). In late 1985, construction was started on the Curlew Pond #3 flood storage facility to help alleviate flooding in these areas. Storm events such as Hurricane Elena may have helped expedite the project.

Curlew Pond #3 receives water from Curlew Pond #1, Curlew Pond #2 and from the Spanish Pines subdivision. Water eventually outfalls into Curlew Creek. The drainage basin covers approximately 223 hectares. Curlew Pond #3 required extensive excavation to match grades with the two existing ponds. Nearly 400,000 cubic meters of material were excavated to construct the site. Much of the site was situated over green marine clays which resulted in some of the unique hydrological characteristics of the site.

In 1987, after the flood control project was completed, a 1.52-hectare forested mitigation site was required for 0.6 hectare of maple hardwood impact associated with construction of the Jerry Lake Weir. Mitigation was also required for minor impacts associated with sidewalk construction for County Road 1. The permitting agencies agreed that Pond #3 was a suitable site for the mitigation. A total of 3.0 hectares were planted, somewhat more than the area required.

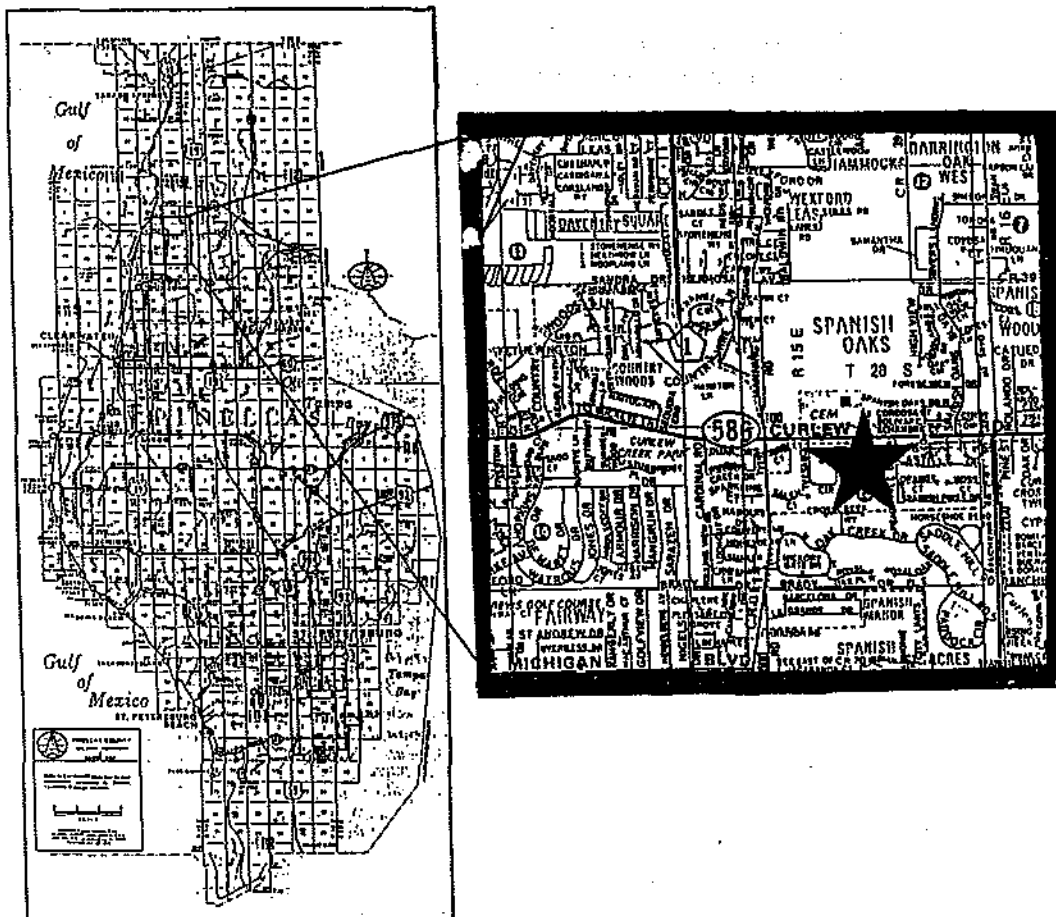


Figure 1. Site location. The study site is located in northern Pinellas County. The area is adjacent to a sand ridge aligned north to south and underlain by green marine clays.

The overall pond site encompasses 5.4 hectares of land. The mitigation site is in the northern 3.0 hectares of the pond. The flood attenuation and storage and the underdrain system are located in the southern 2.4 hectares.

The original flood design was performed by a contractor, but due to unresolvable differences, the contract was terminated and the Design Division of the Pinellas County Engineering Department was asked to design the project. The pond was eventually designed by the Department's Planning and Programming Division.

The pond is located in an area that had an average elevation of 12 meters NGVD. The area was vegetated with a sand hill community that included sand pine, sand live oak and slash pine, and was fairly open under the canopy. The Parks Department removed about 400 sand live oaks which were transported to Howard Park in Tarpon Springs, and about 400 sand pines which were relocated to Sand Key Park in Clearwater.

The pond was excavated about 6 meters into the soil to match drainage pipe inverts from Pond #2. In many areas, the bottom 4 meters was composed of green gumbo

marine clay. An underdrain system was then installed in the southern portion of the site.

The pond was designed with a characteristic horseshoe shape to accommodate a stand of mature live oaks (DBH ≥ 0.5 m). The oak stand is used by a variety of wildlife including hawks, owls and small mammals.

The original pond design did not specify an elevated berm through the center of the site separating the mitigation area from the underdrain, but there was a concern that the underdrain system would draw down the water table in the mitigation area and cause it to dry out. The berm was approximately at the same elevation as the outfall structure, 4.14 meters NGVD. The Pinellas County Construction Division was concerned that water would stage up behind the berm and cause problems in the mitigation area and so an equalizer pipe was installed in the center of the berm. The permitting agencies were worried that the mitigation area would be drawn down, and ordered the pipe removed.

During planting of the mitigation area, the planting consultant warned that the water appeared to be too deep and that the plants and trees would probably not thrive at the site. However, no action was taken at that time due to the previously stated agency concerns.

A muck layer 10 cm to 20 cm deep was placed in the mitigation area as a growing substrate. Approximately 5,000 trees were planted at the site on 3.1-meter centers and consisted of a mixture of cypress, maple, tupelo, laurel oak and sweet bay. Trees were planted in groupings of like species. No herbaceous mitigation was required but pickerelweed, arrowhead, bulrush, needlerush and blue flag iris were planted, also on 3.1-meter centers.

Due to the large amount of unvegetated area and the shallow water conditions, invasive species began to proliferate. The general contractor had hired an environmental contractor to maintain the pond and provide monitoring reports. When the funds allocated by the general contractor had been expended on maintenance (after only 6 months) the subcontractor stopped performing maintenance and submitting mitigation reports because they were no longer receiving payment.

No maintenance was performed for approximately two years as the County attempted to hold the general contractor responsible for maintenance. Unfortunately, there was no legal recourse to make either company responsible to perform the work. (The County has since changed its contract administration policy.)

The pond's non-compliant conditions were observed by the Southwest Florida Water Management District (SWFWMD) in the late summer of 1991 and the Engineering Department received a letter of non-compliance shortly thereafter. The Engineering Design Section contacted the Environmental Support Services Section and requested assistance in assessing the pond and determining the best and most cost-effective option for bringing it into compliance.

MATERIALS AND METHODS

The first site visit was performed in September 1991 at the request of the Engineering Design Section. The assessment team went out to gain an overall perspective of the site and try to make a general assessment of the conditions. The mitigation area was staged up to the berm with water and the team could inspect only the edge of the pond. The trees appeared very stressed and had few leaves. Invasive species seemed to be everywhere and coverage approached 90%. Water levels seemed to be slightly lower in the south side of the pond, but it was also prime cattail habitat and in fact supported a near monoculture of this invasive species. Only three small clumps of willow were present.

The Environmental Support Services Section coordinated with Engineering Design and the Construction Division to devise a better way to assess the pond. It was decided that the best option would be to drain as much water as possible out of the mitigation area by tapping into the main underdrain pipe. This would afford the opportunity to better assess the vegetation within the pond and examine the muck depth for uniformity. At this time the Environmental Support Section authored a 26-point memo outlining Pinellas County's options on pond planting and hydrology modifications.

Karen Gruenhagen of SWFWMD met with County representatives at the site and agreed to let the County drain the pond as part of the plan for bringing it into compliance. In November, the underdrain main pipe was accessed and rim ditch construction started along the western side of the pond to help drain off the standing water.

It took about a 45 days for the pond to drain and dry sufficiently to where one could safely walk on the surface. In early January 1992, members of the Environmental Support Services Section, Engineering Design, Construction and Planning and Programming returned to the site to perform another assessment.

At that time, it was noted that many of the trees had died, probably from excessive inundation. However, a surprising number of trees had survived, and they seemed to be putting out new growth. Almost all the trees were stunted and had grown adventitious roots. Some of the trees were easily uprooted because the muck had not solidified and the trees had not anchored sufficiently. Most of the cypress seemed to have fared better than the other species; many looked like baseball bats—they were short, but very thick at the base. The trees were probably trying to either stabilize or maximize gas exchange by maximizing basal growth and lenticil surface area. At this time, the site appeared to have much more potential for long-term success than previously thought.

Several options to develop a plan to get the mitigation site back into compliance were then discussed:

1. Raze the whole pond and start over. This would be extremely expensive and would sacrifice existing habitat. Also, there was no guarantee that the cattails would not again grow from seed, resulting in the same invasives problem.

2. Raze the south cattail pond, bury the cattails on site, bring in new muck, move the viable trees and herbaceous vegetation from the north pond to the south pond, and plant heavily with new herbaceous species to suppress invasives, then replant the north side and nurture for banking. This option would be very expensive and time-consuming.
3. Use a combination of hand labor and machinery to clear out the invasives from among the trees in the north mitigation site. Selectively herbicide remaining invasives. Recontour the site for better invasive suppression and better habitat value, lower the weir elevation to keep water levels lower, and implement a stringent maintenance program. The Construction Division stated that past hand labor activities proved fruitless on other projects and heavy machinery could not operate in this type of environment. There were also doubts about ensuring a stringent maintenance program if it was to be contracted out.

None of these options appeared satisfactory and discussion continued about some basic conditions at the site.

1. It appeared that no matter how far the outflow weir elevation was reduced, the pond would not totally dry out because of the natural clay lining and the constant groundwater seep from the side slopes into the pond.
2. The permit had no requirement for success for herbaceous species, so as long as the trees could outcompete the invasives, it was assumed they would eventually shade them and kill them off.
3. Almost twice the required amount of mitigation area was planted than was required for the Jerry Lake Weir Project.
4. There was a sizable wildlife population utilizing the pond.
5. Stormwater treatment was still being accomplished.

SWFWMD was invited back to the site to view the pond in its drawn down condition. Karen Gruenhagen met with the same evaluation team at the site in the beginning of February 1992.

By this time the trees had started to flush out and the cattails seemed to be somewhat suppressed by the drier conditions. The team walked the site and pointed out how well most of the surviving trees were doing. It was also interesting to note the growth rings formed from the widely spaced herbaceous plantings. The current habitat value of the site was noted and it was agreed that it would not be environmentally sound to lose the habitat and trees if the site were razed.

Further discussion with SWFWMD obtained approval to allow the site to grow out over the summer to determine if the trees would actually gain height and canopy cover or if they would remain stunted. This was done to help determine whether overinundation or the clay was causing the stress response. Although the recent

growth looked promising, SWFWMD wanted to make sure that the trees were not permanently stunted. SWFWMD requested a long-term plan based on tree growth success.

Based on the discussion, if the trees started to increase in height, SWFWMD would consider allowing the County >10% invasive species coverage on a temporary basis. The County would also have to replant trees that died. To document tree growth, Environmental Support Services tagged and measured selected trees for monitoring of height and DBH.

The underdrain access would have to be sealed again to ensure long-term tree growth and survival. It was known that the weir height needed to be reduced, but it was not known by how much. The assessment team returned in April 1992 to do some survey work to determine if there were large elevation changes in the pond or if the surface was relatively flat.

The elevation of the weir was measured to see if it was installed correctly and the berm was surveyed to determine if it was in fact hindering water flow. The height of adventitious roots on the trees in both the mitigation area and the water treatment area were surveyed to determine standing water depth in each of the areas.

Surprisingly, the pond bottom was fairly level. The elevation of the adventitious roots on the trees were very consistent and measurements were within several centimeters of each other. Even more surprising, the treatment pond's trees had adventitious roots at the same elevation as the mitigation site, indicating that the underdrain system was not drawing down the system as was thought when the pond was first built.

The survey indicated that the weir was constructed at the plan elevation and the berm had a similar elevation as the weir. It was decided that the weir elevation should be reduced by about 15 centimeters to maintain a summer stage-up of water with a bleed-down orifice 16-18 inches below that to maintain a winter drawdown to stimulate growth and suppress invasives. A debris skimmer would be added to the outfall structure.

It was also agreed that a deep winding channel should be cut through the middle of the mitigation area to provide more open water habitat for waterfowl and wading birds. In addition, sediment sumps were designed into the project. The spoil would be used to construct slightly elevated areas where replacement trees would be planted. A temporary outfall was designed by the Engineering Design Division. All survey work was performed by the Environmental Support Services Section and the Engineering Design Division.

Construction on the rim ditch and meandering channel began in June 1992 and took approximately eight weeks to complete. The topsoil (muck) was scraped off the construction area and placed in the planting area and smoothed into a shallow dish shape to help hold water to give the replants a healthy start. The clay underlayer was removed. Once the site stabilized, a plug was installed in the underdrain pipe and a temporary riser was constructed to stage the water up to an elevation approximately

15 centimeters lower than the original weir elevation. A permanent gate valve was installed on the underdrain to facilitate easier draining of the site for future maintenance. A catwalk and staff gauge was also installed. All excavation work was performed by County personnel from the Highway Department.

A planting plan was designed that would replace the trees that had died as well as fill in some of the areas that had not been planted previously. In addition, some herbaceous plants were specified to vegetate the banks and middle of the channel. Over 500 trees were specified with red maple dominating but also including cypress, tupelo, pop ash, laurel oak and sweet bay. Herbaceous plants were mostly pickerelweed, which seemed to be doing well in other areas of the site, and spatterdock.

The assessment group decided to replant the trees in November 1992. To save labor costs, the Environmental Support Section contacted the Pinellas County Jail to determine if trustees could perform the planting. The Jail agreed to supply trustees, a corrections officer and a landscape instructor to oversee the work crew. However, when the planned date arrived there were not enough trustees to form a work crew.

The replanting project was delayed until January 1993. At that time the Jail was able to supply a work crew and the plant material was ready for delivery. As a bonus, 8,000 maidencane plants and a variety of native ferns were available that the County had paid for but could not use at another mitigation site (where a Bald Eagle was nesting in the work area and site preparation was delayed).

The Highway Division excavated holes for tree planting with a small backhoe to save manual labor effort for actual planting. A heavy thunderstorm inundated the work area on the weekend prior to the planting date and planting was delayed another week.

Finally, all parties were able to coordinate and perform the planting. Site conditions were still poor from the rain but progress was swift. The trustee work crew was divided in two with one crew planting maidencane and the other carrying trees into the planting site and installing them. Under the direction of the Environmental Support Section, the trees were planted according to their hydrological requirements as well as in an aesthetically pleasing random manner. Maidencane and ferns were planted in a "floodplain" type area near the outfall structure as well as in the voids between the trees. The work was completed within one week.

RESULTS AND DISCUSSION

The water reached the design elevation within a few days after excavation and the channel filled to the top of bank. Vegetation started colonizing the shore banks immediately but no cattail appeared to be invading the area. Within a short period of time, a varied fish population developed including some larger species. Many reptiles thrived in the new habitat, and a river otter took up residence at the site and was observed in the channel every time the site was visited. Many species of small mammals took advantage of the improved site conditions; wading birds and waterfowl were also observed frequenting the newly created habitat.

Follow-up observations in March of 1993 revealed that all the newly planted trees had sprouted new growth. The water level had returned to the design elevation and tree species appeared compatible with hydrological levels and characteristics. A quarterly monitoring report was performed in March and tree height and DBH were measured but there was minimal growth.

The Environmental Support Services Section performed a baseline assessment of the trees on the site and allowed the site to remain in the staged-up condition through the fall of 1992. Several monitorings for tree growth were performed in the succeeding months and tree growth was impressive. Trees were exhibiting 20-30% growth in height and DBH after only six months. Relative biomass of the trees appeared to have more than doubled. The trees were much healthier and had branched significantly with a high rate of leaf growth. As an interesting aside, the trees within the cattails were as tall or taller than those in the more open areas. This coincides with research performed at other sites with similar conditions. More research needs to be performed to determine if invasive species competition is as much of a problem for tree growth as previously assumed.

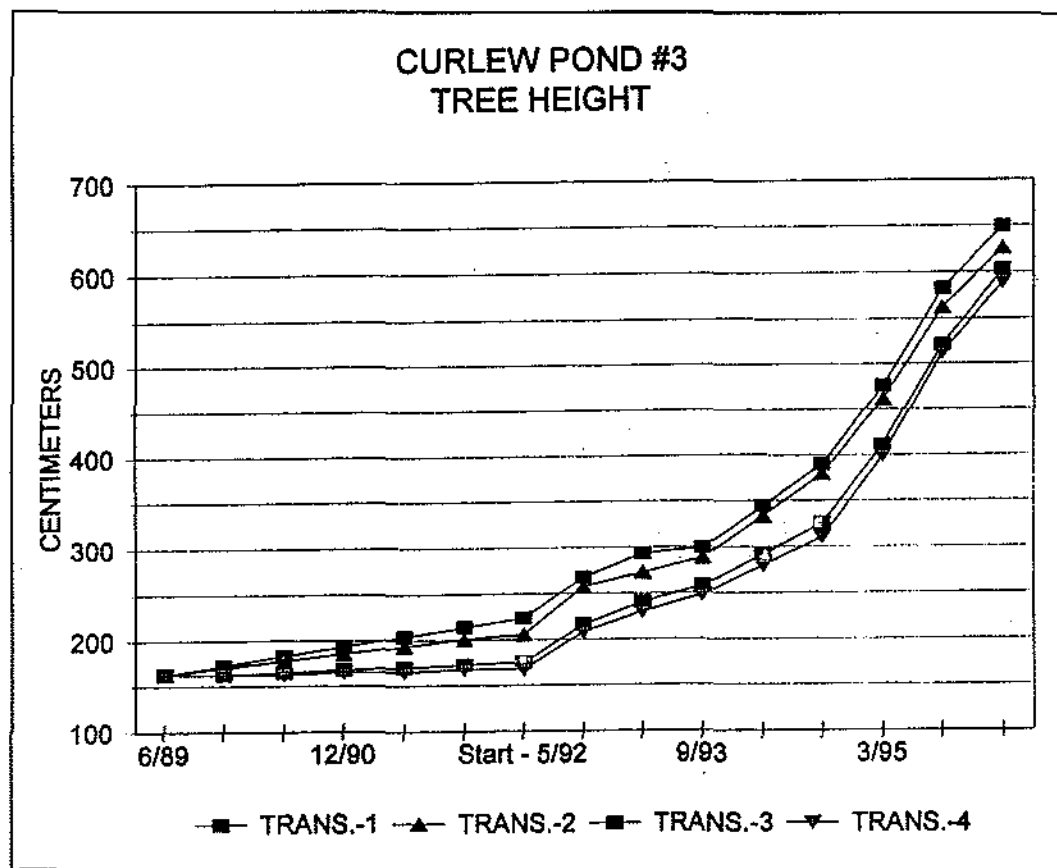


Figure 2. Mean tree height, transects 1-4, Curlew Pond #3.

Over the past three years, the Environmental Support Services Section has continued to monitor the site and tree growth has not only maintained its rate but increased (Fig. 2). The trees have matured and have had several seasons of seed set. Invasive species competition has been minimal; some minor exotic species control has been implemented to ensure that the establishment of Brazilian pepper and Chinese tallow does not occur. Pinellas County was notified in September [1996] that the site has been deemed a success by the permitting agencies.

CONCLUSION

Success of a mitigation project cannot be simply measured and judged using numerical indices or limited variables. A site can be in compliance with permit conditions but not an environmental success. Conversely, a site can be out of compliance but in fact be an environmental success. Success of the mitigation site lies with the establishment of a functioning wetland community including a wide variety of a floral and faunal species. Designers must learn to look beyond permit conditions when creating wetlands and should create systems made up of a variety of habitats that complement each other.

ACKNOWLEDGMENTS

Appreciation is given to Jim Meyer and Steve Robinson of the Pinellas County Environmental Support Services Section and to Kevin Murren, Rudy Garcia and James Richter of the Pinellas County Public Works Department and to Karen Gruenhagen of SWFWMD for their hard work and dedication to make this project a success.

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SUCCESSFUL CREATION OF AN OLIGOHALINE ENVIRONMENT AS WETLAND MITIGATION

Bruce Hasbrouck
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ABSTRACT

Wetland mitigation associated with the replacement of Double Branch Bridge at State Road 580 in Hillsborough County provided an opportunity to increase water quality as well as successful wetland creation. To improve water quality, box culverts were placed under the road to restore historic flows severed during the original roadway construction in 1948. An upland restoration site was included in this project to provide diverse habitat for wildlife.

Coverage within the mitigation area achieved 80% within the first growing season and has been sustained despite extreme flooding during tropical storms as well as freezing temperatures in the winter. A complete maintenance program has been carried out during the last two years and includes monthly maintenance of the uplands and wetlands.

The use of freshwater stormwater pond outfalls into estuarine wetland creation areas increases the function and value of mitigation areas. The design considerations associated with this project can be utilized for numerous projects throughout Tampa Bay for future restoration projects with distinct opportunity for success.

INTRODUCTION

Wetland creation as a form of mitigation has been required by the State of Florida since the enactment of the Warren Henderson Act of 1984. Section 404 of the Clean Water Act established federal regulations requiring the replacement of wetlands impacted during construction activities. In addition to wetland creation regulations, storm water runoff from the impervious pavement of highways must be treated prior to discharge into natural wetland systems. The construction of State Road (SR) 580 during 1994 in Hillsborough County involved wetland impacts to 1.1 hectares of estuarine wetlands. A wetland system was designed and built to perform in conjunction with treated stormwater, thereby replicating an oligohaline environment.

The oligohaline environment is created at the interface of freshwater and tidally influenced saltwater. According to Cowardin et al. (1979), oligohaline is a term "to characterize waters with salinity of 0.5 to 5 ppt, due to ocean salts." The Tampa Bay National Estuary Program (1992) defined oligohaline as 2-10 ppt. The term is roughly equivalent to brackish. Plant communities associated with this habitat are adapted to tolerate diurnal fluctuations in salinity and water elevations. In west central Florida, the oligohaline plant communities include mangrove areas of red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves, and marshes of cordgrass (*Spartina alterniflora*), black needlerush (*Juncus roemerianus*) and other herbaceous plants.

PROJECT DESCRIPTION

The roadway and bridge construction for this portion of SR 580 was permitted by the regulatory agencies in 1993 for 1.1 hectares (ha) of wetland impacts resulting in dredge and fill. An additional 0.27 ha of wetlands was not impacted and was enhanced as part of the mitigation strategy. Construction of the roadway and bridge

occurred during 1994–95. The wetland mitigation area and stormwater pond were constructed in 1994.

The mitigation strategy for the project included wetland creation, wetland enhancement and water quality enhancement. The total area of mitigation involved 3.74 ha of wetlands, intertidal mud flats and open water. An additional 0.13 ha of upland restoration was provided for a mature stand of laurel oaks (*Quercus laurifolia*). Table 1 identifies the species, quantities, and elevation of the plantings within the project area. Figure 1 shows the site layout and planting plan.

Table 1. Installed plants.

ELEVATION (m)	PLANT TYPE	QUANTITY
0.3–0.45	<i>Spartina alterniflora</i>	4,660
0.45–0.6	<i>Juncus roemerianus</i>	3,912
0.6–0.9	<i>Spartina bakeri</i>	627
	<i>Spartina patens</i>	627
	<i>Salicornia</i> spp.	627
	<i>Paspalum</i> spp.	627
0.9–1.5	<i>Zamia pumila</i>	500
	<i>Muhlenbergia</i> sp.	667

Wetland Creation

Wetland creation of estuarine wetlands totaled 1.2 ha of tidal marsh. *Spartina alterniflora* was planted in 0.41 ha of intertidal zone from elevation 0.3 m to 0.45 m (National Geodetic Vertical Datum [NGVD]). *Juncus roemerianus* was planted in 0.33 ha of intertidal zone from elevation 0.45 m to 0.6 m NGVD. A high marsh mixture of *S. bakeri*, *S. patens*, *Salicornia* spp. and *Paspalum* spp. was planted in 0.21 ha of the wetland creation area from elevation 0.6 m to 1.0 m NGVD. An additional 0.25 ha of channel was excavated to an elevation of -0.3 m NGVD. This design feature created a channel to assure an open water connection thereby reducing the formation of a saltern.

No mangroves were installed with the anticipation of recruitment. Therefore, the appropriate species would colonize at the appropriate elevations. All three species of mangroves exist in upper Tampa Bay and provide an ample seed source.

Upland Enhancement/Preservation

Upland enhancement, including the preservation of more than twenty mature laurel oaks, included 0.13 ha of *Zamia pumila* and *Muhlenbergia* sp. The largest trees were 1.0 m diameter-breast-height (dbh). An adjacent area of Brazilian pepper (*Schinus terebinthifolius*) was cleared.

Water Quality Enhancements

When SR 580 was constructed in the late 1940s, Double Branch Creek was re-routed along a shorter path, disconnecting the creek branch at a point approximately 250 m

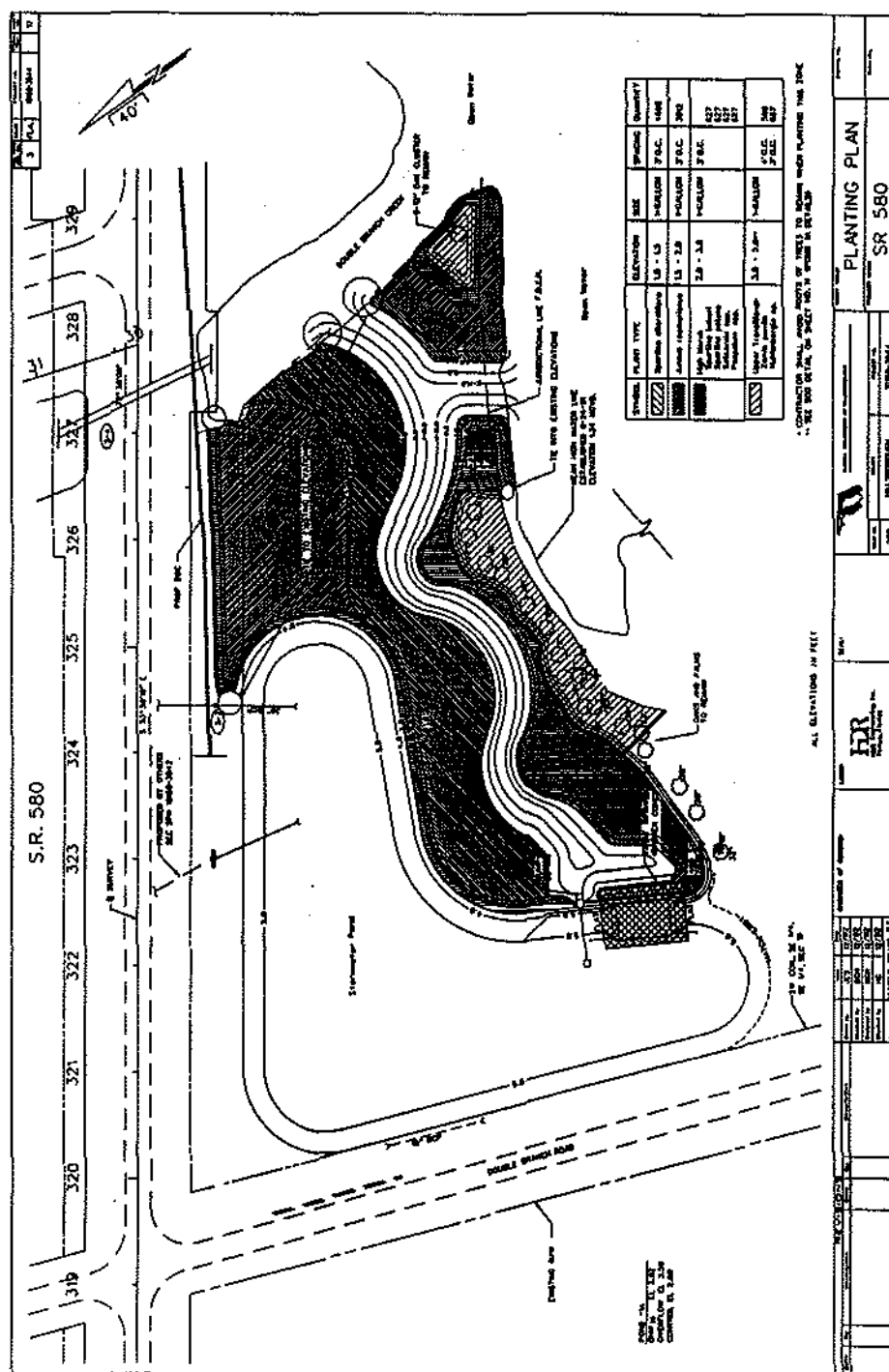


Figure 1. Site planting plan.

west of the present bridge and totally obstructing flow. That blockage affected 2.29 ha of tidal waters. Debris and sedimentation had become a problem as well as lower dissolved oxygen levels.

During roadway construction, double 1.3 × 1.3 m box culverts were installed at the location of the original creek alignment. The adjacent open water channels were dredged to remove accumulated silts. It is interesting to note that analysis of sediment samples did not reveal any elevated levels of EPA priority pollutants.

Wetland Enhancement

Subsequent to the roadway construction, development occurred along the banks of Double Branch Creek during the 1950s. Encroachment of two driveways left a 0.63 ha estuarine area with a small 0.4 m diameter corrugated metal pipe providing the tidal connection to the Creek. Over the years the pipe had collapsed and left very little connection.

The roadway construction impacted 0.36 ha of this marsh. The remaining 0.27 ha was enhanced by the removal of one of the driveways and creation of a small channel. All *Schinus* within FDOT right-of-way was removed.

Stormwater Management

The engine that drives the oligohaline system is the stormwater management facility. A portion of the stormwater runoff from the bridge, western approaches and an adjacent project is collected in a curb and gutter system, transferred via underground culverts and discharged into a 1.21 ha stormwater pond. Biological treatment of the stormwater is accomplished through wetland plants. Almost 1.0 ha of the pond was planted with *Scirpus robustus*, *S. validus*, *Sagittaria lancifolia*, and *Spartina bakeri*. The control structure was designed to discharge the treated stormwater at a metered rate to allow one-half of the volume of a mean-annual rain event in 60 hrs. A emergency spill-way was constructed at elevation 1.07 m to allow discharge of a 25-year rain event without causing flooding of the roadway.

METHODOLOGY

Wetland Creation Site

Three monitoring transects were established on December 13, 1994 for representative sampling of the wetland creation area. A pair of one-meter square quadrats were placed every 15 meters along the transect and permanently marked with PVC pipe (odd number quadrats' PVC in southeast corner, even number quadrats' PVC in northeast corner). Transect 1 (northeast to southwest) contains 24 quadrats, Transect 2 (northwest to southeast) contains 12 quadrats, and Transect 3 (east to west) contains six quadrats, for a total of 42 quadrats.

Herbaceous cover and species composition (planted and recruited) within each quadrat was assessed, recorded and averaged to determine the herbaceous cover within the created site. Permit success criteria require an 85% cover of desirable estuarine vegetation in planted zones with at least 0.10 hectare of the site dominated by mangroves.

Saltmarsh Enhancement Site

One monitoring transect (Transect 4) was established for representative sampling of the wetland enhancement area. The transect (~200 m) runs west-to-east with a pair of one-meter quadrats located every 30 meters. A single PVC pipe (per pair of quadrats) is located in the southeast corner of the northern quadrat and the northeast corner of the southern quadrat. Channel quadrats are located on adjacent bank slopes with PVC pipe in the northeast corner of the northern quadrat and the southeast corner of the southern quadrat. There are 14 total quadrats. Herbaceous cover and recruiting species composition within each quadrat was assessed, recorded and averaged to determine the herbaceous cover within the enhancement site. Permit success criteria specify that the site becomes 25% covered by desirable estuarine vegetation.

Upland Enhancement Area

Four upland enhancement survivorship plots (P1, P2, P3, P4) were established for representative sampling of the upland enhancement areas. Each plot measures 2 m × 5 m with PVC pipe permanently located in each corner. Planted upland species (*Zamia pumila* and *Muhlenbergia* sp.) are counted in each plot for survivorship determination. Permit success criteria specify an 85% survivorship rate for these species within the upland enhancement area.

RESULTS

Wetland Creation Site

Cover by the planted species increased by 75% within 18 months from the time of planting. Recruited mangroves did have a decrease in cover as result of a freeze in winter 1996. The freeze affected the white mangroves the most. Tables 2 and 3 provide the results of five separate monitoring events. Figure 2 presents these data graphically.

Table 2. Transects 1 and 2 within the wetland creation site.

	1st QUARTERLY	2nd QUARTERLY	3rd QUARTERLY	4th QUARTERLY	1st SEMI- ANNUAL
Average cover	41	56	68	84	88
Planted species cover	38	52	57	68	79
Recruited species cover	3	4	11	16	9
<i>Juncus roemerianus</i>	10	14	13.5	17	22
<i>Spartina alterniflora</i>	10	15	15	16	18

Recruits include *Laguncularia racemosa*, *Avicennia germinans*, *Iva* sp., *Bacopa* sp., *Sesuvium* sp. Recruited species decreased from 4th quarterly to 1st semiannual because of the freeze. Many of the white mangroves were frozen back. Nuisance species are below 1%.

Upland Enhancement Area

The upland oak hammock buffer of the mitigation area was enhanced with planting of *Zamia pumila* and *Muhlenbergia* sp. The plantings are growing beneath the canopy of established live and laurel oaks and cabbage palm understory. Ground cover includes *Serenoa repens*, *Andropogon* sp., *Vitis* sp., *Habenaria* sp., silk grass, *Woodwardia* sp., *Smilax* sp., *Sisyrinchium*, *Asimina* sp. and *Hypericum* sp., as well as St. Augustine grass and Bahia grass.

Table 3. Transect 3 within the wetland creation site.

	1st QUARTERLY	2nd QUARTERLY	3rd QUARTERLY	4th QUARTERLY	1st SEMI- ANNUAL
Average cover	19	39	53	73	80
Planted species cover	17	36	47	63	71
Recruited species cover	2	3	6	10	9
<i>Juncus roemerianus</i>	10	22	30	41	57
<i>Spartina alterniflora</i>	7	14	17	21	14
<i>Laguncularia racemosa</i>	2	3	6	11	7

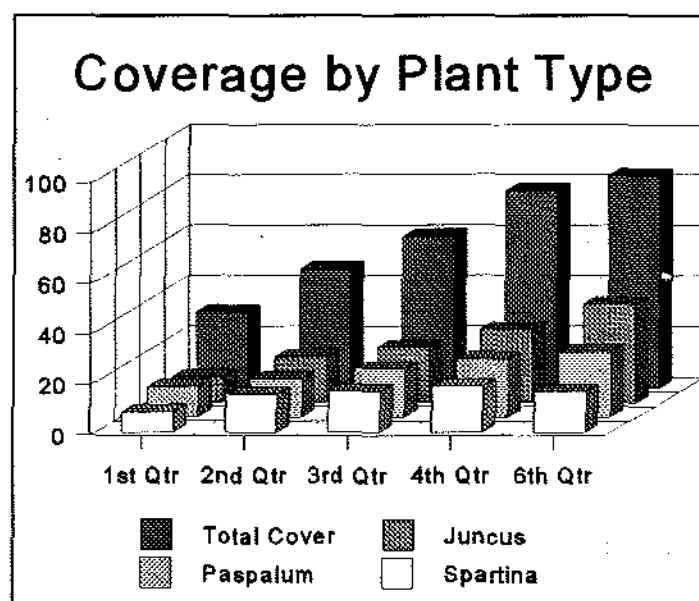


Figure 2. Wetland creation site, coverage by plant type.

Saltmarsh Enhancement Area

The saltmarsh enhancement area increased steadily (12%, 26%, 32%, 51%, 36%) in recruited species until the winter freezes of 1995. Recruited species include *Laguncularia racemosa*, *Avicennia germinans* and *Rhizophora mangle*, as well as *Distichlis spicata*, *Sesuvium*, *Bacopa* sp., *Batis maritima* and *Iva imbricata*. Nuisance species were less than 1%.

DISCUSSION

The wetland creation has been successful in terms of vegetative cover. All of the installed plants have flourished and continue to increase in cover. Recruited mangroves exhibit continued growth and increased cover of epiphytes.

Utilization of the site by juvenile fisheries indicates the site is suitable as nursery areas. Sampling of the channel built through the mitigation area with a 4-meter seine yielded numerous species including redfish (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), spotted trout (*Cynoscion nebulosus*), snook (*Centropomus undecimalis*), bay anchovy (*Anchoa mitchilli*) and southern four-spot flounder (*Paralichthys oblongus*).

(see Figures 3 and 4). Most of the fish sampled by the seine were less than 10 cm long. Casual observations of much larger snook indicate the site is used as feeding grounds for more mature individuals.



Figure 3. Juvenile snook.



Figure 4. Juvenile trout.

The wetland enhancement areas show an increase in species diversity and general health of the existing plants. Prior to construction, the enhancement areas were severely stressed as a result of decreased flushing. Through the use of open swales and the removal of culverts, the monitoring results indicate an increase in the function and value of the existing wetlands which were enhanced by the project.

Water quality enhancement was provided through the installation of a box culvert underneath SR 580. Increased circulation through the old connection was established and has, at a minimum, decreased the amount of flotsam present in each of the old "dead-ends". With the renewed patterns of circulation, the mitigation site is provided an opportunity for additional flushing.

The upland enhancement area has required more maintenance than other areas. As the site was a former residence, several nuisance species have required continual effort to eliminate them from the site.

SALINITY MONITORING

The intent of the design included a freshwater discharge from the stormwater pond into the tidally influenced waters of the mitigation area. Diurnal fluctuations of water levels within estuarine systems contain varying levels of salt. This is a function of the varying amount of freshwater discharge from Double Branch Creek as well as Gulf of Mexico water from lower Tampa Bay flowing into upper Old Tampa Bay during high tides.

Methods

Water samples were collected during October 1996 and analyzed with a salinity refractometer. Samples were taken at the surface and 0.3 m depth utilizing a LaMotte sampler. Background samples were collected at the new bridge crossing Double Branch Creek. Other samples were collected at the outfall from the stormwater pond, the constructed creek through the mitigation area, and the canal at the mouth of the mitigation area.

Results

Figures 5 and 6 show the diurnal fluctuation of the salinities for the surface at a depth of 0.3 m respectively. Figure 7 shows the salinity of the samples after a tropical storm passed north of Tampa Bay just before midnight on the 7th of October.

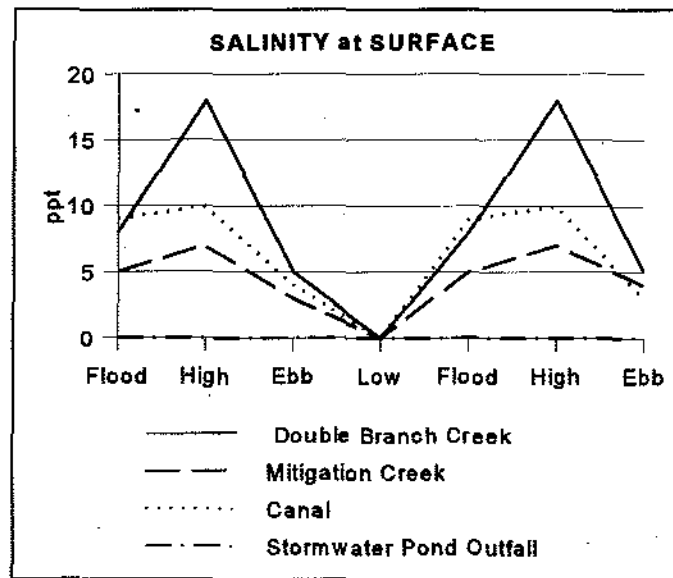


Figure 5. Diurnal fluctuation of salinity at surface.

DISCUSSION

Lewis and Estevez (1988) identified that vertical differences in salinity of Tampa Bay are usually slight. The reduced temperature range, as well as the shallow water, of Upper Tampa Bay contributes to this reduced vertical stratification. Within Chesapeake Bay, the vertical difference in salinity is marked (Thomann et al. 1994). During the spring, upper Chesapeake Bay has a difference of 8 ppt with the surface and bottom salinities averaging 10 and 18 ppt respectively. The Double Branch

mitigation site is shallow and well mixed and therefore exhibits no variation in salinity during most tides. During high tide, Double Branch Creek did exhibit a stratification with a difference in salinity of 10 ppt.

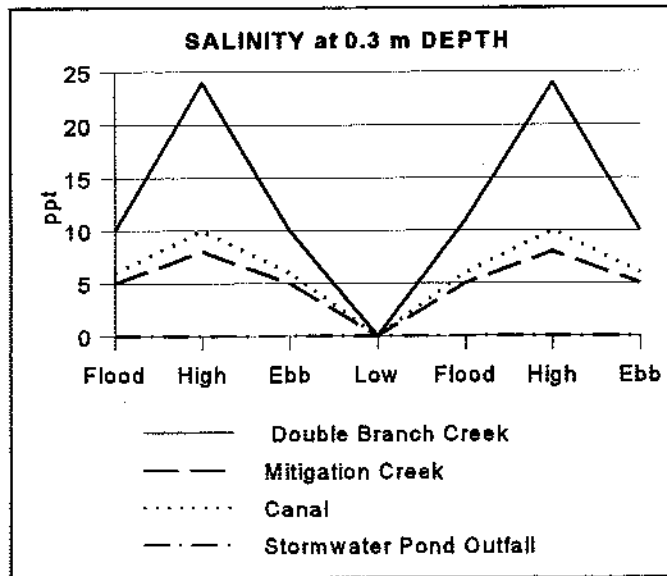


Figure 6. Diurnal fluctuation of salinity at 0.3 m depth.

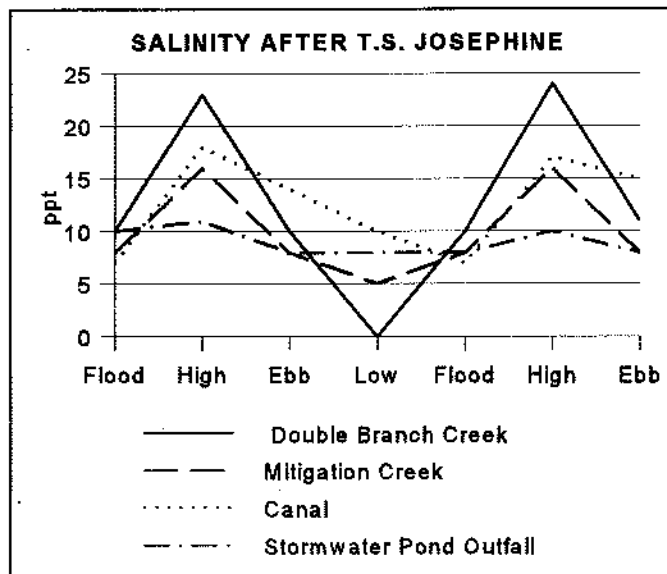


Figure 7. Diurnal fluctuation of salinity after passage of tropical storm Josephine, 7 October.

As designed, the stormwater pond discharges treated fresh water into the mitigation site. Even during very high tides, the salinity at the outfall is 0 to 1 ppt. As the creek progresses through the site, the salinities vary from 0 to 10 ppt. During low tides, the entire mitigation creek system is basically fresh water.

On October 7, 1996, the winds associated with tropical storm Josephine drove tidal waters in Tampa Bay to an elevation of 1.83 m. The predicted high tide for the day was 0.6 m. Figure 8 illustrates the differences between predicted and actual water levels. Shortly after noon, the water breached the emergency spillway of the stormwater pond and flooded the pond with salt water. The elevated water levels persisted for 24 hours and did not recede until afternoon the following day. Very little rain (less than 3 cm) fell during the storm. The pond was designed to accommodate stormwater runoff from portions of an adjacent project which was not on-line during the storm. As a result, the stormwater input was not enough to flush the pond.

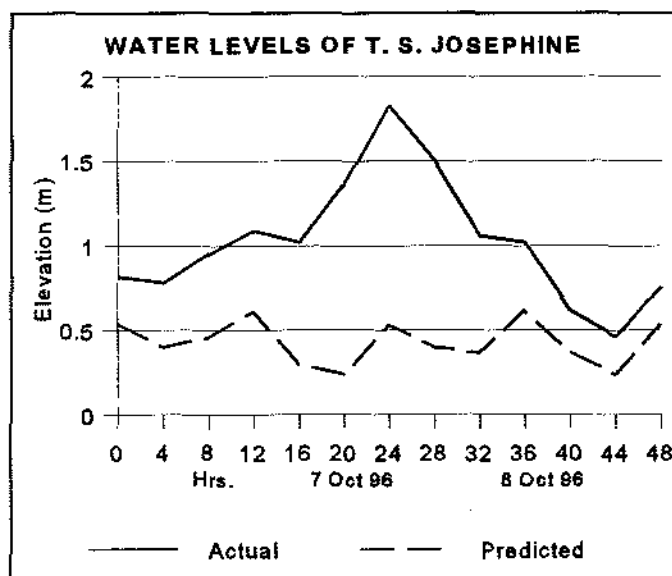


Figure 8. Difference between actual and predicted water levels associated with passage of T.S. Josephine, October 1996.

During the following two weeks, water sampling revealed that the stormwater pond was actually working in reverse than designed. Instead of discharging fresh water into a saltwater system, the pond was discharging water with a salinity of 10 ppt. Figure 7 denotes the changed conditions from previous sampling shown in Figure 5. Casual observation did not detect any significant change to juvenile fisheries or vegetation in the mitigation area. *Sagittaria lancifolia* within the stormwater pond started to die after one week of saltwater intrusion. It is interesting to note that *S. lancifolia* at the edges of the pond persisted as a freshwater lens at the surface was in contact with those particular plants.

The site was designed to allow for complete exposure of the vegetated flats during low tide. Shallow slopes, less than 100:1, were envisioned to reduce the chances of salterns. Vegetation-free, hypersaline areas have been described by many authors in Odum et al. (1982). The terms salterns, salt flats and salinas have been used to describe areas which have shallow standing water with occasional tidal inundation and high evaporation rates resulting in salinities above 100 ppt and water temperatures as high as 45°C. The design elevations and the open water channel prevent the formation of salterns.

Stormwater management of runoff from SR 580 is the engine that drives the machine. Not only does the stormwater pond provide treatment, the continual discharge of fresh water creates a mixing zone within the mitigation area and maintains low salinities near the discharge point. Wetland plants within the pond provide biological filtration of excess nutrients, bind suspended sediments and increase dissolved oxygen in the water column.

CONCLUSION

The wetland mitigation for the impacts associated with the construction of the bridge over Double Branch Creek has been successful. Water quality has been enhanced, the wetland creation site has substantial coverage of desirable plant species, nuisance plant species have been kept at a minimum, and wildlife, including juvenile fish, are utilizing the site.

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VARIATIONS IN DISCHARGES, NUTRIENT CONCENTRATIONS AND NUTRIENT LOADS FROM THE ALAFIA RIVER, HILLSBOROUGH RIVER AND THE TAMPA BYPASS CANAL

Y.E. Stoker

ABSTRACT

Hillsborough Bay receives more surface water inflow than any other segment of Tampa Bay and is nutrient enriched. The U.S. Geological Survey measured discharge, water quality, and phosphorus and nitrogen loads from the Alafia River, Hillsborough River, and Tampa Bypass Canal, the major sources of fresh water to Hillsborough Bay, and evaluated long-term trends in these data.

A long-term, decreasing trend in annual mean discharge was detected for discharges from selected sites in the Alafia River (1933-92) and Hillsborough River (1939-92) basins. In addition, temporal changes have been detected in low-flow and high-flow characteristics in the Alafia and Hillsborough Rivers.

Over the past 30 years, changes have occurred in water quality characteristics. Phosphorus concentrations have declined in the Alafia River since peaking in the 1960s and nitrogen concentrations have been declining since about 1981. However, increases are occurring in nitrite plus nitrate nitrogen concentrations in Lithia Springs, which flows into the Alafia River. Specific conductance of water discharging from Sulphur Springs to the Hillsborough River has increased from 124 to more than 2,000 microsiemens per centimeter.

Nitrogen and phosphorus loads for the period April 1, 1991, through March 31, 1992, were evaluated. The greatest annual loads of nitrogen and phosphorus from the major tributaries to Hillsborough Bay were from the Alafia River. Annual phosphorus load from the Alafia River was 894 tons, more than six times greater than the phosphorus load from the Hillsborough River. Annual nitrogen load was 630 tons, two times greater than loads from the Hillsborough River, and more than six times greater than loads from the Tampa Bypass Canal.

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MINIMUM FLOW REGULATIONS FOR MAJOR TRIBUTARIES TO TAMPA BAY

M.S. Flannery

ABSTRACT

The Southwest Florida Water Management District has adopted a schedule for establishing minimum flow regulations for the Manatee, Braden, Little Manatee, Alafia, and Hillsborough Rivers and the Tampa Bypass Canal. These regulations will pertain to flows in these watercourses as they are affected by existing or potential water withdrawals. Minimum flows will be established for the Hillsborough River/Tampa Bypass Canal system by 1997; for the Manatee, Braden and Little Manatee Rivers by 1999; and for the Alafia River by 2001. Minimum flows will be based technically on hydrologic, ecological and water use information collected for each watercourse by studies required by the District. These tributaries represent a wide range of ecological characteristics due to structural modifications to their watersheds and quantities of water use.

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MANATEE RIVER SALINITY RESPONSE TO RESERVOIR RELEASES

Michael G. Heyl
John A. Zimmerman

ABSTRACT

The Draft (1996) Tampa Bay National Estuary Program (TBNEP) Comprehensive Conservation and Management Plan identified a need to establish and maintain seasonal freshwater flows downstream of dams. The activities necessary to complete the action item were identified as: a) quantification of the existing flows downstream of impoundments; b) establishment of target "living resources" and their environmental requirements (including low-salinity habitat) where sufficient information exists; and c) establishment of the flows required to achieve the necessary low-salinity habitat and the impact on public water supply of providing those flows. In response to the need to complete those activities, Manatee County developed and calibrated an upstream reservoir routing model and coupled the discharge results to a calibrated hydrodynamic water quality model of the Manatee River from the reservoir to Tampa Bay. Salinity values were predicted at 30-minute intervals at 31 locations for a period of a year under three assumed minimum reservoir release rates. The resultant salinity profiles were compared to a "no-reservoir" scenario. A variety of alternative water supply sources were evaluated which could provide the additional freshwater releases without jeopardizing the existing water supply. Planning level costs were established for each alternative.

HISTORY

In the early 1980s when Manatee County applied to the Southwest Florida Water Management District (SWFWMD) for a water use renewal permit, the District added a requirement that the County evaluate the downstream impacts resulting from decreased freshwater releases from the reservoir. SWFWMD further stipulated that sufficient flow be maintained to ensure that the daily average conductivity at Rye Road (approximately 2.5 miles downstream from Lake Manatee) remain below 1,000 $\mu\text{mhos/cm}$. In response to that requirement and in addition to vegetation and biological monitoring, the County conducted weekly sampling for salinity and other water quality parameters at 32 stations for 22 months. These data were used as input to an empirical model and a steady-state mass transport model to predict riverine response to releases from the Lake Manatee reservoir located 25 miles upstream from Tampa Bay. The results of these two modeling approaches were in substantial agreement and indicated that a 0.425 cfs constant release was sufficient to maintain the 1,000 $\mu\text{mhos/cm}$ water downstream. Once approved by SWFWMD, this value of minimum release was subsequently used by the County for long-range water supply planning. In 1991, when the County again applied for a permit renewal, SWFWMD stipulated that another evaluation of the minimum release and downstream impacts be completed using the same input data, and that a dynamic range of isohalines be included. The present study is the result of those requirements and includes a dynamic water quality model coupled with a reservoir routing model to address both the environmental and water supply impacts of increased minimum flow releases.

RESERVOIR ROUTING MODEL

A reservoir routing model, similar to the Army Corps of Engineering HEC-3 and HEC-5 models, was developed for the Lake Manatee watershed. Stage/storage curves were developed for the existing and proposed reservoirs, and coupled with 50 years of gaged streamflow. Mean monthly withdrawals, rainfall, lake evaporation, and bank storage were simulated. Water in excess of the reservoir(s) storage was balanced as a

downstream discharge. The model was verified ($r^2=0.94$) with observed lake levels for a 70-month period (Camp Dresser McKee 1992). In order to achieve a successful calibration, it was necessary to make additional adjustments for reject groundwater irrigation volumes introduced between the stream gage site and the reservoir. After verification, the model was used to evaluate the safe yield (at 95% reliability) of a variety of alternative water supplies and minimum release rates. The simulated release volumes representing 50 years of inflow were then used as input for the downstream salinity model.

WATER QUALITY MODEL

The portion of Manatee River between Tampa Bay and Lake Manatee was represented in a DYNHYD/TOXIWASP water quality model. Nonpoint source flows were simulated at 21 junctions along the river representing the smaller contributing tributaries and creeks and were derived from use/land cover reported by Dames & Moore (1990). Monthly estimates of nonpoint source flows were derived from monthly rainfall and a runoff coefficient (0.95) for the impervious area, plus the pervious area contribution, which was assumed to be proportional to the gaged watershed above Lake Manatee. Tidal forcing functions were incorporated at the Tampa Bay boundary, and releases from both the Ever's reservoir and Lake Manatee reservoir were imposed at the upstream junctions of the model.

The downstream hydrodynamic model was calibrated and verified using diurnal *in situ* velocity measurements collected in May and September 1983 respectively to represent a dry and a wet condition when reservoir release rates differed by three orders of magnitude. The overall agreement between observed and modeled velocity for both sets resulted in $r^2=0.74$ ($n=33$). Salinity calibration was achieved for monthly average salinities using the data collected during 1982. Figure 1 illustrates a typical water quality calibration at the same location (e.g., I-75 crossing) as the hydrodynamic verification. Figure 2 shows the results of the water quality calibration for all segments and all salinity data ($r^2=0.95$, $n=158$) collected during 1982. Following calibration, the DYNHYD/TOXIWASP model was used to evaluate the salinity regime in the absence of Lake Manatee and in the presence of Lake Manatee with various assumed minimum release rates.

ISOHALINE DEPENDENCE ON MINIMUM RESERVOIR RELEASES

The impact of the existing (0.425 cfs), a 5.0 cfs and a 10.0 cfs minimum release from the reservoir was evaluated for median background conditions (rainfall and streamflow below the reservoir) and for the 80th percentile dry background conditions. These results were compared with a "no reservoir" scenario. The difference between the assumed release rates is minimal at Tampa Bay, and maximize near Devil's Elbow (6.4 miles downstream of reservoir) after which near-zero and zero salinities are encountered. From approximately Ft. Hamer (8.6 miles downstream from reservoir) to 1.8 miles above Devil's Elbow, the maximum salinity difference between the existing release and the 10 cfs scenario is 2-4 ppt, while the maximum difference between the 0.425 cfs minimum release and the "no reservoir" scenario occurs at Devil's Elbow and is around 7 ppt in December. Figure 3 illustrates the pattern at the confluence of the Manatee River, Mill Creek and Gamble Creek (7.2 miles downstream of reservoir).

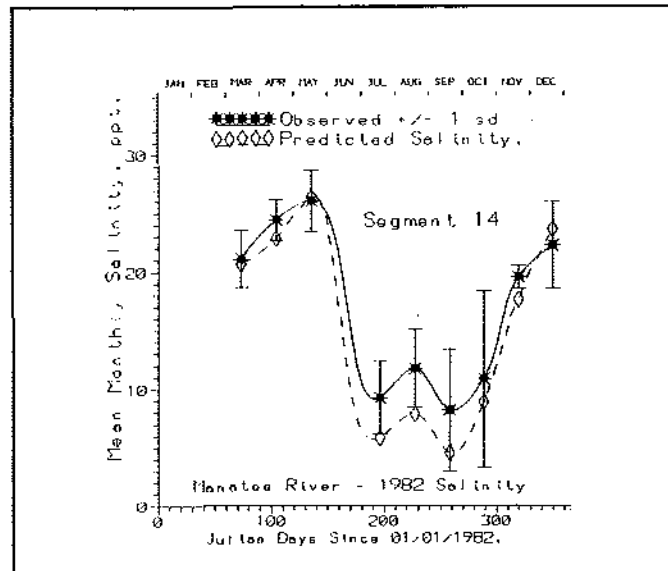


Figure 1. Typical water quality calibration at the same location as the hydrodynamic verification.

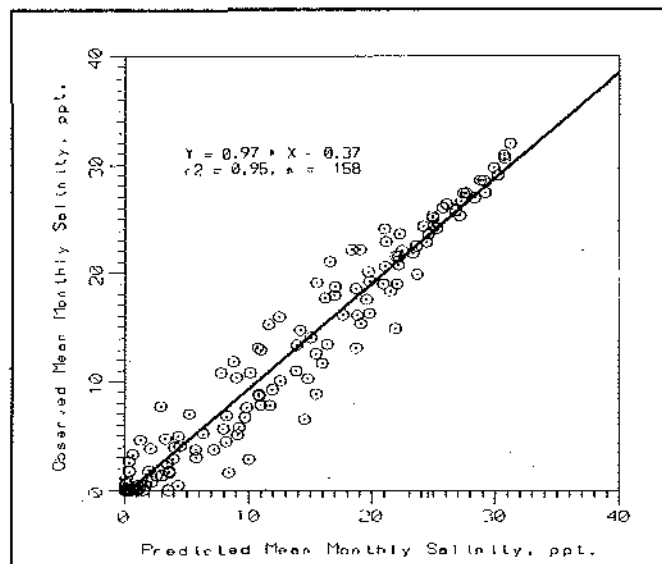


Figure 2. Results of water quality calibration for all segments and all salinity data collected during 1982.

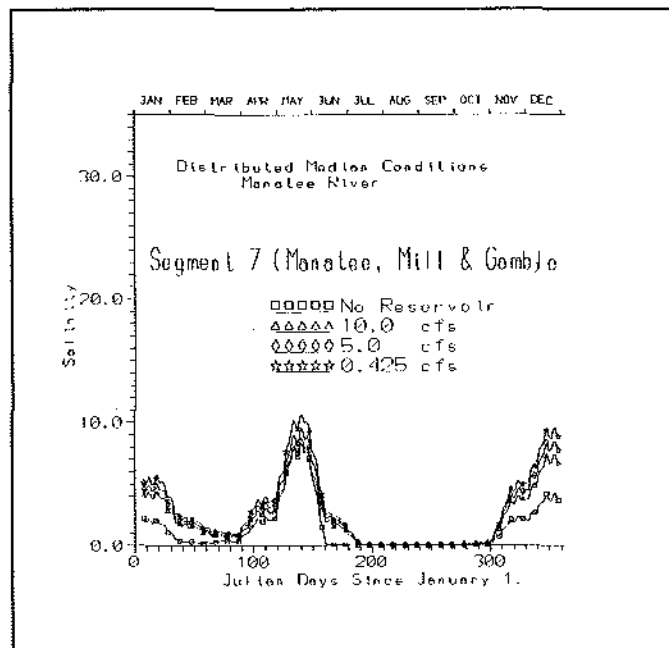


Figure 3. Pattern at confluence of Manatee River, Mill Creek and Gamble Creek.

SIMULATION OF RELEASE EVENTS

In order to evaluate the impact of a sudden release event from Lake Manatee on the downstream salinity structure, a series of two-day releases was simulated at 500, 1,000, and 2,000 cfs as shown in Figure 4. Releases were simulated at the end of June, and were preceded by a minimum release rate of 0.425 cfs and followed by a constant rate of 32 cfs corresponding to the mean July value. Just prior to the simulated releases, the background flows were increased to represent the increase from mean June to mean July conditions. The hydrology utilized for this study is insufficient to account for the timing and volumes of runoff below the reservoir during a single event. The background conditions are believed to be an underestimate of the true conditions during a major storm, and consequently the baseline is also an underestimate of the true conditions. Nevertheless, the results give a good first approximation of changes in isohaline position during moderate to large discharge events.

ALTERNATIVE SUPPLIES

Using the routing model, a series of in-stream and off-stream reservoirs was evaluated for safe yield and the effect on seasonal release rates. Minimum release rates of 0.425, 5.0 and 10.0 cfs were evaluated. As expected, the loss of safe yield was nearly in direct proportion to the rate of release, representing a 0.3–6.5 mgd loss. The estimated cost of each alternative supply option was evaluated with standard pricing conditions for land acquisition, clearing and grubbing, excavation, control structures, etc., but mitigation costs were not included. The safe yields obtainable with in-stream reservoirs at the current minimum release ranged from 33.2 mgd (existing) to 51.2 for the combination of Lake Manatee, Gilley Creek and the North/East Fork impoundments of the Manatee River. Various combinations of excavation, and raising

the existing structures were also evaluated, but were not cost effective. The cost was normalized to both \$/1,000 gallons of new yield, and \$/1,000 gallons of total yield. Thus, the cost of adding Gilley Creek reservoir (additional yield of 9.2 mgd) is \$0.31/1,000 gallons of new water, or \$0.07/1,000 gallons for the system (Lake Manatee + Gilley).

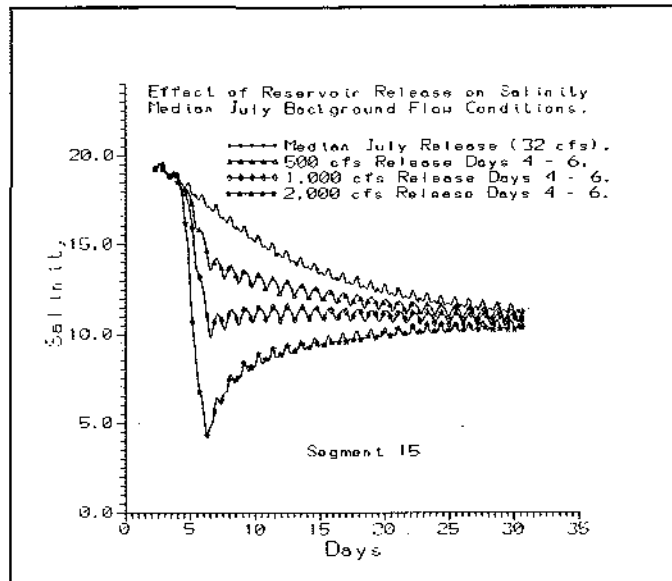


Figure 4. Effect of reservoir release on salinity, median July background flow conditions.

A series of off-stream reservoirs ranging from 2,350 to 26,500 acre-feet was also evaluated. The capital costs to provide off-line storage solely for the purpose of providing downstream environmental water ranged from \$14.6 to \$39.10 million for the 5.0 and 10.0 cfs scenarios respectively. When distributed over the existing water supply, this directly adds \$0.15–0.40/1,000 gallons, or about \$1.8–4.8 million per year with no increase in potable water supply. The cost of providing increased minimum flows from alternative supply on-line and off-line facilities is summarized in Table 1.

ISOHALINE CHANGE OF ALTERNATIVE SUPPLIES

The safe yield of the various in-stream and off-stream facilities was determined with the routing model. An output of safe yield determination is the spillway discharge for each month of the 50 years simulated. The predicted discharge was then used as input to the salinity model (DYNHYD/TOXIWASP) and the impacts to downstream salinity determined. While there is a wide variety of discharge scenarios which can be abstracted from the 50-year prediction, caution must be exercised when comparing the impact of output on the riverine salinity structure. In the present evaluation and at the request of the SWFWMD, the series of consecutive median monthly discharges resulted in an annual discharge which was abnormally dry (70th percentile) when compared to median of ranked annual discharges. By contrast, when the mean monthly discharges were compared to the mean annual discharge, the result was at approximately the 40th percentile.

Table 1. Representative alternate supplies and water costs. Key to scenarios: 1—Lake Manatee; 2—off-line storage @ acre-feet; 3—Gilley Creek Reservoir; 4—North/East Fork Reservoir.

SCENARIO	MINIMUM RELEASE (cfs)	YIELD (mgd)	CAPITAL (\$ million)	TOTAL YIELD (\$/1000 gal)
1 + 2@2,350 ac-ft	5.0	33.2	\$14.6	\$0.15
1 + 2@6,300 ac-ft	10.0	33.2	\$39.1	\$0.40
1 + 2@19,180 ac-ft	5.0	45.2	\$102.6	\$0.79
1 + 3	0.425	42.4	\$8.6	\$0.07
1 + 3	5.0	39.6	\$8.6	\$0.08
1 + 3 + 4	0.425	51.2	\$22.2	\$0.15
1 + 3 + 4	5.0	48.3	\$22.2	\$0.16
1 + 3 + 4	10.0	45.2	\$22.2	\$0.17

Figures 5 and 6 are based on the latter output and depict the resulting salinity at the confluence with the Braden River (17 miles downstream from the reservoir) and at the confluence of Mill and Gamble Creeks with the Manatee River (7.2 miles downstream). The illustrated results are based on mean monthly discharge rates for: a) Lake Manatee with an existing minimum release (0.425 cfs); b) Lake Manatee plus the Gilley reservoir and the North and East Fork reservoir with a 5.0 cfs minimum release; and c) the three-reservoir system with a 10.0 cfs release. At Tampa Bay, there is no difference (<0.25 ppt) among the scenarios. The maximum difference in salinity among the three scenarios is 1.43 ppt predicted to occur 11 miles downstream in June.

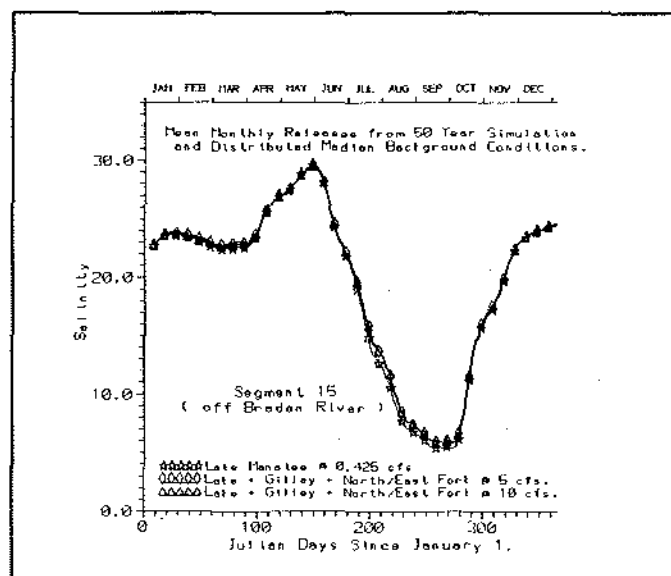


Figure 5. Mean monthly releases from 50-year simulation and distributed median background conditions, Segment 15.

Determining the ecological significance of such differences in salinity is the subject of continued research. Following the examples of Estevez (1994) and Browder (1981), the degree of overlap between stationary habitat and dynamic habitat can be

determined for a variety of river characteristics. For example, the number of minor creeks, length of wetted shoreline (edge effect), and the cumulative volume of water surface have been related to a range of isohalines in the Manatee River. By integrating the various analytical models to predict the dynamic salinity overlap with stationary habitat, the optimal environmental conditions can be related to the cost of providing the fresh water. Work completed for this project suggests that existing models can be cost-effectively coupled to address the issues raised by the Tampa Bay NEP regarding freshwater inflows in the Manatee River.

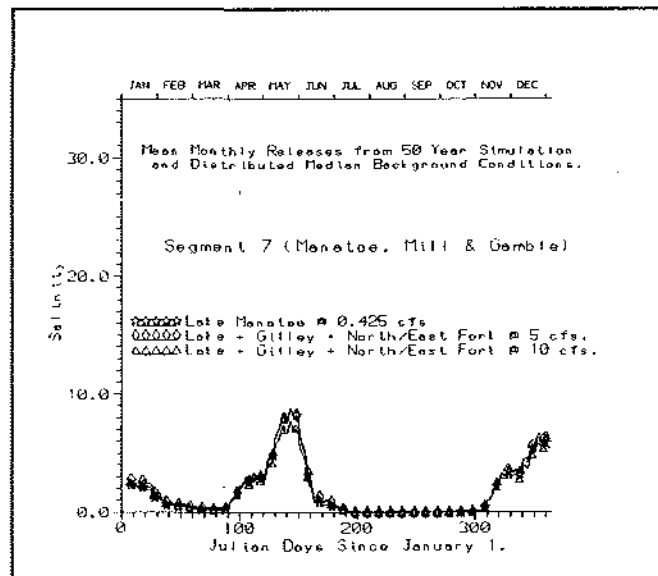


Figure 6. Mean monthly release from 50-year simulation and distributed median background conditions, Segment 7.

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ADDRESSES: (MI) Camp, Dresser & McKee, Inc., 201 Montgomery Ave., Sarasota, FL 34210; (JZ) Manatee County Public Works, PO Box 2501, Bradenton, FL 34206.

1. The first part of the document is a list of names and addresses of the members of the committee. The names are listed in alphabetical order, and the addresses are listed below each name. The list includes the names of the members of the committee, the names of the members of the sub-committee, and the names of the members of the advisory committee.

2. The second part of the document is a list of the names and addresses of the members of the committee. The names are listed in alphabetical order, and the addresses are listed below each name. The list includes the names of the members of the committee, the names of the members of the sub-committee, and the names of the members of the advisory committee.

3. The third part of the document is a list of the names and addresses of the members of the committee. The names are listed in alphabetical order, and the addresses are listed below each name. The list includes the names of the members of the committee, the names of the members of the sub-committee, and the names of the members of the advisory committee.

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A LANDSCAPE-LEVEL METHOD TO ASSESS ESTUARINE IMPACTS OF FRESHWATER INFLOW ALTERATIONS

Ernest D. Estevez
Michael J. Marshall

ABSTRACT

Few systematic methods exist for assessing estuarine impacts of historic or proposed freshwater inflow alterations. A method was developed to evaluate estuarine impacts of watershed and reservoir management policies affecting stream flow. The method applies existing theory stating that fishery production is regulated by space/time overlaps of dynamic and structural habitat features.

The method as presented uses salinity as a dynamic habitat feature, but will work using other physical or chemical features. Salinity is represented by monthly and annual mean and median values, and coefficients of variation. The method uses river attributes as structural habitat features. Habitat features were compiled from existing sources of information. The method compares how an ensemble of critical salinities overlaps each habitat feature, and determines the difference between management scenarios (e.g., with or without river regulation) in linear, areal and volumetric terms.

In the Manatee River (Manatee County, Florida) the method determined that current reservoir operations cause the largest salinity/habitat dislocations in oligohaline reaches; marsh and mangrove areas, and numbers of creeks occurring in ≤ 2 ppt, were reduced greatly (50–100%); and natural shoreline length and river area were reduced 27–48%. Mesohaline submerged aquatic vegetation area was reduced, and the pattern of loss suggests that variance as well as mean salinity affects seagrasses.

Overlap analysis amplifies non-linear changes in flow, salinity, and habitat relationships in oligohaline areas, associated with river regulation. The method can be used for impact assessments or to screen alternative proposals for river modification. Species-specific salinity requirements can also be evaluated with the method. The method can be generalized as a PC-resident shell with GIS links.

INTRODUCTION

Although several methods exist for determining minimum or optimum flows in running streams, comparatively few systematic methods have been proposed or used for inflow optimization to estuaries. Like rivers, estuaries are by definition dependent on freshwater flows and, like rivers, flow deprivation causes negligible to severe changes in the ecological structure and function of estuaries. By the same token, flow enhancements or changes in the timing of flows can harm estuarine as well as riverine ecosystems. There are, at present, no uniform or transferable methods for determining the minimum flows of fresh water to estuaries. Nor are there standard methods for assessing the impacts of flow alterations proposed either for development or ecosystem restoration.

This paper reviews what is known of fresh water's role in estuaries, impacts of flow alteration, and past attempts at optimization. Then, a new method for estuarine inflow optimization is introduced and results of its applications to a local river are presented. (As used here, optimization refers to the determination of minimum or other regulatory flows, environmental impact assessment, and the design of restoration or mitigation programs.)

The Role of Freshwater in Estuaries

Fresh water delivers materials and energy to coastal areas, fueling primary and secondary productivity. Inflows also create weak to strong estuarine gradients in physical, chemical and biological conditions. Such gradients occur along and across estuaries, from the surface to the bottom, and through time. Gradients structure ecological features of estuaries and maintain spatial heterogeneity. Gradients change at rates set by the geometry of the estuary, amounts of inflow, and tidal characteristics. In this way, gradients also serve as time-givers for ecological processes in estuaries.

Estuarine Impacts of Flow Alteration

At the present time, there are no comprehensive literature reviews of ecological impacts in estuaries resulting from altered freshwater inflow or salinity. Part of the reason for this situation is the diversity that exists in the ways that inflows can be altered. Such alterations include increases or decreases in the quantity of inflow, changes in the short-to-long period temporal variations of inflow, and changes to inflow location. A number of case studies are available for specific types of inflow/salinity alteration, estuaries, and ecological components. Existing reviews have been organized phylogenetically (Gunter et al. 1973) or by estuary (Halim 1990; Mahmud 1985).

Despite such reviews, direct impacts of inflow alteration have often been ignored, even in texts on estuarine ecology and management. For too long, scientists and managers have mistakenly believed that, because estuaries are high-variation ecosystems, estuarine biota can tolerate any kind or level of salinity alteration. Another common assertion is that estuarine ecosystems will adapt to changes in freshwater inflow, or salinity, however frequent or severe the changes. The majority of scientific evidence available for estuaries indicates that impacts of severe inflow alterations occur rapidly (within a few years), making significant ecological differences more difficult to identify because the system later develops eurytopic characteristics.

Earlier Efforts in Optimization

The majority of prior efforts have concerned regulated rivers and the question of minimal discharges. As such, these methods have not been used to answer another common question in estuary management—how much water can be diverted from a natural river without causing downstream harm. Three basic approaches have been attempted. A landscape approach by Van Beek et al. (1982) most resembles the present method, by determining the acreage of Louisiana marshes and oysters covered by favorable salinities under existing and proposed flow scenarios. Starfield et al. (1989) employed a rule-based model, actually an artificial-intelligence (AI) shell, for optimization questions for a South African estuary. A noteworthy outcome of the AI model was the inference that SAV (submerged aquatic vegetation) biomass was sensitive to the rate of salinity change rather than the salinity level, *per se*.

Complex modeling efforts were made in numerous estuaries. Most emphasize circulation, salinity, residence times or water quality. Beginning in the early 1970s, federal and state agencies involved with regulation of coastal rivers along the Texas coast undertook numerous studies of estuaries, for the purpose of determining

freshwater inflow requirements. The culmination of this work is summarized in Longley (1994). This collection of works revealed numerous significant relationships between inflow, salinity, and biogeochemical attributes of Texas estuaries, and combined the most informative relationships into a multi-objective optimization technique. Although built from ad hoc discoveries not directly transferable to other estuaries, the methods of technique development go further than previous efforts in accounting for ecological resources.

A LANDSCAPE-LEVEL METHOD TO ASSESS ESTUARINE IMPACTS OF FRESHWATER INFLOW ALTERATIONS

Theoretical Basis

The hypothesis by Browder and Moore (1981)—that production of a fishery species is regulated by the overlap of its stationary and dynamic habitat requirements—forms the starting point of the method. At the species level, work by Browder and Moore was paralleled by Dovel (1981), who opined that striped bass production in the Hudson River was a function of overlaps between favorable temperature and salinity patterns with structural habitat. Edwards (1991) mapped the Browder and Moore model onto a tidal Florida river (the Manatee) to illustrate how microhabitat requirements may further constrain habitat overlaps. Figures 2A, 2B and 6 from Edwards (1991) map the overlap concept into a tidal river setting.

Although data limitations presently prevent the application of Browder and Moore's (1981) hypothesis at the species level for most marine or estuarine fisheries, the hypothesis may still be used at the habitat or community levels. The present method assesses changes in the overlap of stationary and dynamic habitat attributes across tidal river gradients. As the scale of such gradients is on the order of hundreds to thousands of square kilometers, it may be referred to as a landscape (or seascape) method.

Florida's microtidal coastline is deceptive. Tides move far into coastal rivers, especially during periods of low river flow. Tidal backwater effects extend even farther inland. Salinity varies along a river according to the interplay of river flow, river geometry and tidal influence. A given site along a river consequently experiences a range of salinities. Most river sites will have zero salinity for some period of time, while the river is fresh to its mouth. River sites also have maximum salinities that are determined by bed elevation and tide range. Over sufficient periods of time, each site also has a characteristic mean salinity. Of equal significance, though, is the fact that each site along a river also has a characteristic salinity variance. Vertical stratification occurs in Florida's largest coastal rivers but is absent in most others, except during periods of very high river flow. Then, a site has a characteristic surface and a different bottom salinity mean and variance.

Salinity, and other river variables, are dynamic features because they change through time. Color, transparency, dissolved oxygen, detrital load, and other conditions like salinity that regulate biological productivity should therefore be seen as probability functions, with unique values for specific river locations and structural habitats (marshes, mangroves, oysters, etc.). Changes in river flow, river geometry, or tide

must therefore be manifest as changes in the coincidence (overlap) of structural and dynamic habitat features.

How the Method Works

1. Existing or new information is used to describe stationary habitat features of a tidal river. These may include physical or living attributes. River area and volume are physical attributes. Others may include sediment type, shoreline length or tributary locations. Some features may be described as counts, as in number of tributaries, or in linear terms, such as shoreline length. Others may be areal or volumetric, as is surface area of intertidal flats, or mean-tide volume of the river.
2. By the same token, living attributes may be described as counts or in linear, areal or volumetric terms. Examples include number of oyster reefs, length of brackish marsh shoreline or area of SAV. Living and physical attributes are determined for each kilometer or mile of river length from the river mouth to head of tide, or an arbitrary boundary.
3. A reference salinity regime for the river is described in terms of distance above the river mouth. The reference salinity regime may reflect "pre-project" conditions, "hindcast-to-natural" conditions, or other situation. Care is taken to state how salinity is defined, as in "mean surface salinity at high tide," or, "March to May depth-integrated salinity minimum." Different definitions will be employed depending upon the nature of analysis being undertaken. At least one definition should include a measure of salinity variance, such as standard deviation or coefficient of variation.
4. Quantities of habitat coinciding with particular reference salinities or salinity ranges are determined. An initial assessment would include the quantity of each habitat attribute upstream and downstream of several "standard" salinities (0, 5, 10, 15, 20, 25, 30 parts per thousand). Different salinity standards will be employed depending upon the nature of analysis being undertaken, but at least one set should employ a description of salinity variation.
5. An alternative salinity regime is described in terms of distance above the river mouth. The alternative salinity regime may reflect existing conditions or conditions resulting from a proposed project to change the amount, timing, or location of river inflows. Salinity is described using the same units and definitions decided in Step 3.
6. Quantities of habitat coinciding with particular alternative salinities or salinity ranges are determined, as in Step 4.
7. Differences in the quantity of each habitat feature are determined by comparing values obtained for the reference salinity regime (Step 4) to values obtained for the alternative salinity regime (Step 6).

Options

Habitat attributes for individual species for which management is sought could be used instead of landscape-level attributes. A salinity interval (for example, 6 to 12 parts per thousand) can be used in addition to reference salinities; habitat quantities falling within the interval are calculated for the reference and alternative salinity regimes. Differences in habitat quantity can be expressed as percentages of habitat available under the reference salinity regime. Variables other than salinity can be used as dynamic habitat features, if data and project rationale allow.

Gross physical changes, such as an existing or proposed in-stream barrier such as a dam, will affect tabulations of habitat quantity, and habitat differences between reference and alternative scenarios. To illustrate: *miles of river* above a given salinity will be large without a dam built near head of tide, but can be very small with the dam. *Area of tidal marsh* above the same salinity may differ much less between scenarios, because the dam location is upstream of all tidal marsh. Comparisons must be made with judgments appropriate to the purpose of the analysis.

METHOD DEMONSTRATION IN THE TIDAL MANATEE RIVER

The Manatee River

The Manatee River, a tidal tributary of Tampa Bay (Florida west coast), is impounded by a dam near head of tide. The dam is opened infrequently, releasing large (to 5,000 cfs) pulses of water, but most often the dam retains all discharge except for a small regulatory release. Most (65%) of Tampa Bay's oligohaline wetlands occur in the Manatee and its tidal tributary, the Braden River, raising a management question of how the river and estuary are managed.

The study area is the portion of the Manatee River between the dam at Lake Manatee, and Tampa Bay. The dam is approximately 22 river miles upstream from Tampa Bay. The river below the dam is a meandering coastal plain stream affected almost entirely by tidal action. For the first 5 to 6 river miles below the dam, the river is a deeply incised stream. No wetlands adjoin the river in the first few miles immediately below the dam, although maidencane and willow grow up the sides of collapsed banks, and on ephemeral point-bars. This river reach contains no submerged aquatic vegetation.

Approximately 6 river miles downstream of the dam the banks widen, levees and point bars become more frequent, and the river deepens. Small patches of wetland (leatherfern, spatterdock, sawgrass and panicum grass) occur as narrow bands along the river bank. A major tributary enters from the north near river mile 7 before the river enters a reach of braided channels, with islands comprised of remnant uplands surrounded by fringing wetlands. Wetlands are primarily mixed marshes dominated by black needlerush. Mangroves grow in marshes along the western end of the braided channel area. No SAV occurs in this river reach although periphyton mats can be extensive on intertidal and shallow subtidal shoals.

Islands and braided channels end about 11 river miles below the dam. For the next 4 to 5 miles (to the Braden River) the Manatee River is a wide and shallow upper-estuary embayment. Natural sandy beaches and shallow shoals are common, and water depths begin to increase with downstream distance. From the Braden River

west to Tampa Bay the river is a wide, tidal river with urbanized shorelines. Known seagrass beds occur only west of the Interstate 75 bridge (river mile 12.5).

Habitat Attributes

Information on habitat attributes in the Manatee River was taken from reports, maps, charts, and aerial photographs. Attributes include:

- **Shallows:** River areas not deeper than 2.0 ft on navigation charts; also sand bars and shoals visible on aerial photographs; also mapped SAV beds.
- **Sandy Shorelines:** Natural estuarine and riverine beaches of gentle slope, where adjacent shallow (<2 ft) water occurs.
- **Creeks:** Named and un-named streams, creeks, and rivers entering the Manatee River; also river openings of waterways within marsh and mangrove islands; also ditches and canals with creek-like features.
- **Marshes:** Intertidal non-forested wetlands, including fern marshes, growing as river islands or fringing wetlands; also areas associated with creek mouths; also mixed wetlands dominated by marshes.
- **Mangroves:** Intertidal forested wetlands growing as river islands or fringing wetlands; also areas associated with creek mouths; also mixed wetlands dominated by mangroves.
- **Open Waters:** Standing and flowing waters within or connected to the main channel of the river; also canal systems connected to the river. River volume was calculated by multiplying the area of each segment by a mean depth value adapted from Camp Dresser and McKee (1994).

Attributes were delineated on mylar base maps produced as overlays of aerial photographs of the Manatee River between the dam and Tampa Bay. Base map scales were either 1:200 or 1:500, depending on sources of aerial photographs and processing methods. Base maps accounted for image overlap in photographs. The positions of section lines, model segment boundaries, and prominent landmarks were recorded. The center line of the river was scribed and measured on each base map. In the braided channel reach of the river, the channel used by boaters was used to map and measure river mileage. River mileages and other spatial attribute data were measured using a SummaGraphics "Summa-Sketch" digitizing pad coupled to a statistical analysis software package running on a personal computer. Data were compiled and analyzed with a database application, Fox Pro, and plotted by river mile, as illustrated in Figure 1.

Attribute data for tributaries were not considered, except that each was counted as a creek. The basis for excluding tributaries was two-fold. First, the major systems (Braden River and Gamble Creek) each have their own salinity structures but these are poorly known. Second, the distribution and abundance of main-stem habitat attributes (and, therefore, analyses depending thereupon) are markedly skewed when tributary data are added. The Braden River, for example, contains approximately 208 acres of marsh and 265 acres of open water, for a wetland density of 44.1%. The tidal Manatee River, where the Braden River discharges, contains 40 acres of wetland and 1,675 acres of open water (2.3% wetland density). Adding the Braden River data to

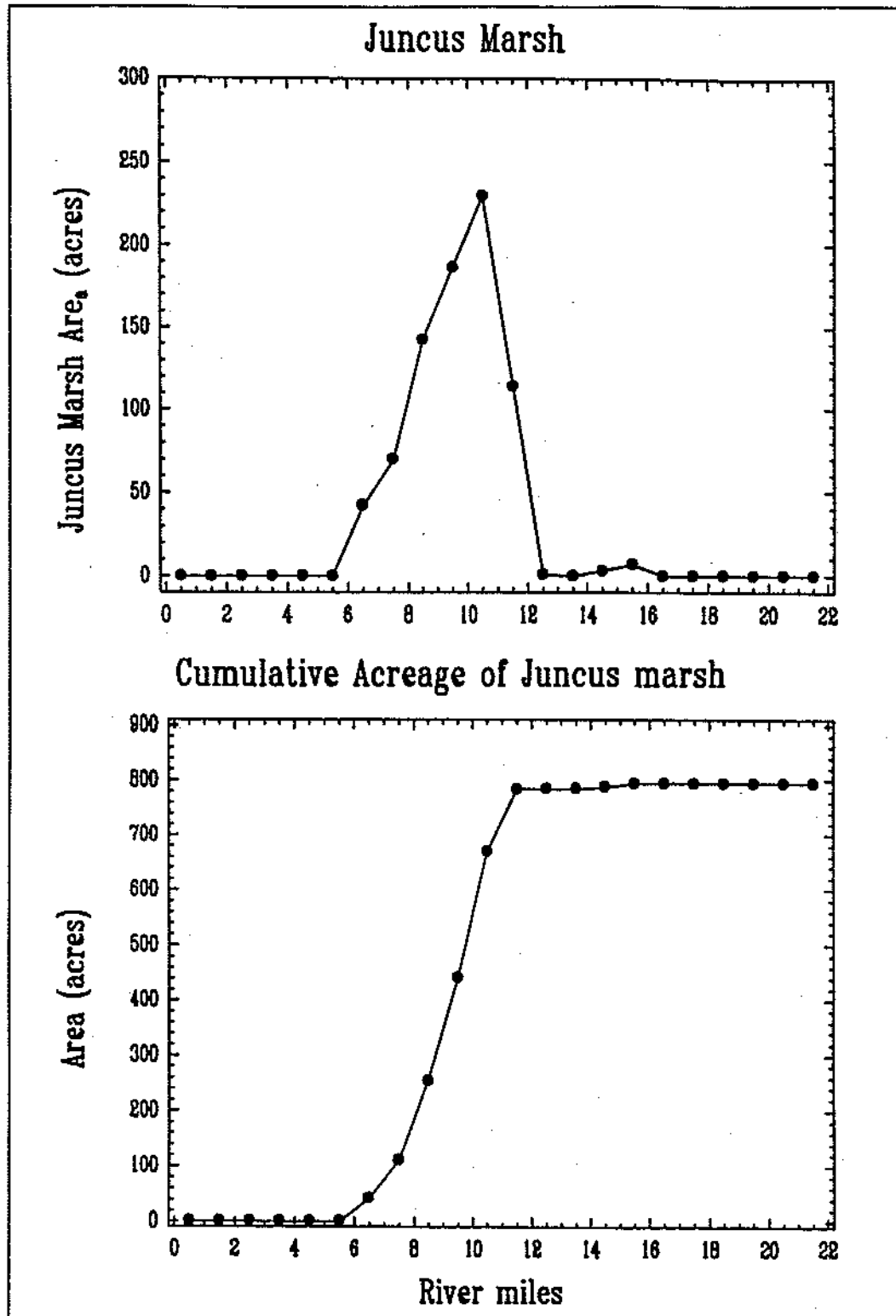


Figure 1. Upper: area of Manatee River marsh as a function of distance downstream from the dam. Most marsh occurs in the braided-channel reach of the river. Similar graphs were made for other structural habitat features of the river. Note that data density is greater than the number of segments used for salinity modeling. Lower: same data presented as an accumulation curve. Accumulation curves were used for salinity overlap analysis.

the Manatee River would artificially inflate habitat data compiled along the long axis of the Manatee River, and potentially mislead analyses based on salinity distributions.

Flow Scenarios and Salinity

Salinity was modeled by Dames & Moore, Inc. using a modified Nonpoint Source Loading Analysis Model (NPSLAM) approach described in Tampa Bay National Estuary Program Technical Publication No. 09-94. Salinity was estimated by regression analysis, using equations developed by regressing average monthly salinities from previous studies with estimated monthly flows using NPSLAM and reservoir release records. Salinity was calculated for the mid-points of eight segments following the main stem of the river, listed in Table 1, in which the dam is located at river mile 0.0. Salinities were calculated on a monthly basis at each segment, for each of three management scenarios:

- Pre-Alteration: No dam; land cover and land use from 1938 aerial photographs;
- Post-Alteration Without Dam: No dam, modern land use and land cover;
- Post-Alteration With Dam: Dam plus modern land use and land cover.

Table 1. River mile definition of main stem segments, Manatee River.

SEGMENT	BEGINS (river miles, where dam = 0.0)	ENDS	MIDPOINT	LENGTH
1	19.14	21.97	20.56	2.83
2	15.69	19.14	17.42	3.45
3A	11.43	15.69	13.56	4.26
4	9.21	11.43	10.32	2.22
5	8.00	9.21	8.61	1.21
6C	7.00	8.00	7.50	1.00
7	5.41	7.00	6.20	1.59
8	2.49	5.41	3.95	2.92
9	0.00	2.49	1.25	2.49

Outputs were generated for a wet year (1983), a dry year (1990), and average conditions from 1982 to 1992. Figures 2, 3, and 4 depict salinities by river mile for each management scenario, where 12 monthly values per segment were averaged. Salinity was plotted at the mid-point of each segment and salinities between the plotted values were computed by linear interpolation. Figure 5 depicts salinity coefficients of variation for wet and dry years together, where monthly values were used to produce means and standard deviations.

Reference Salinities

Assessing the overlap of habitat attributes and salinity invited several possibilities insofar as the selection of salinity values was concerned. In choosing salinities it was useful to review the origin and limitations of salinity outputs produced in this study. First, modeled salinities are depth-averaged. Second, each value applied through the entire length of a given segment, in some cases over a distance of 3 or more river miles. By the same token, each value applied over the whole width of the river, including adjoining distributaries but excluding tidal wetlands. Third, each value

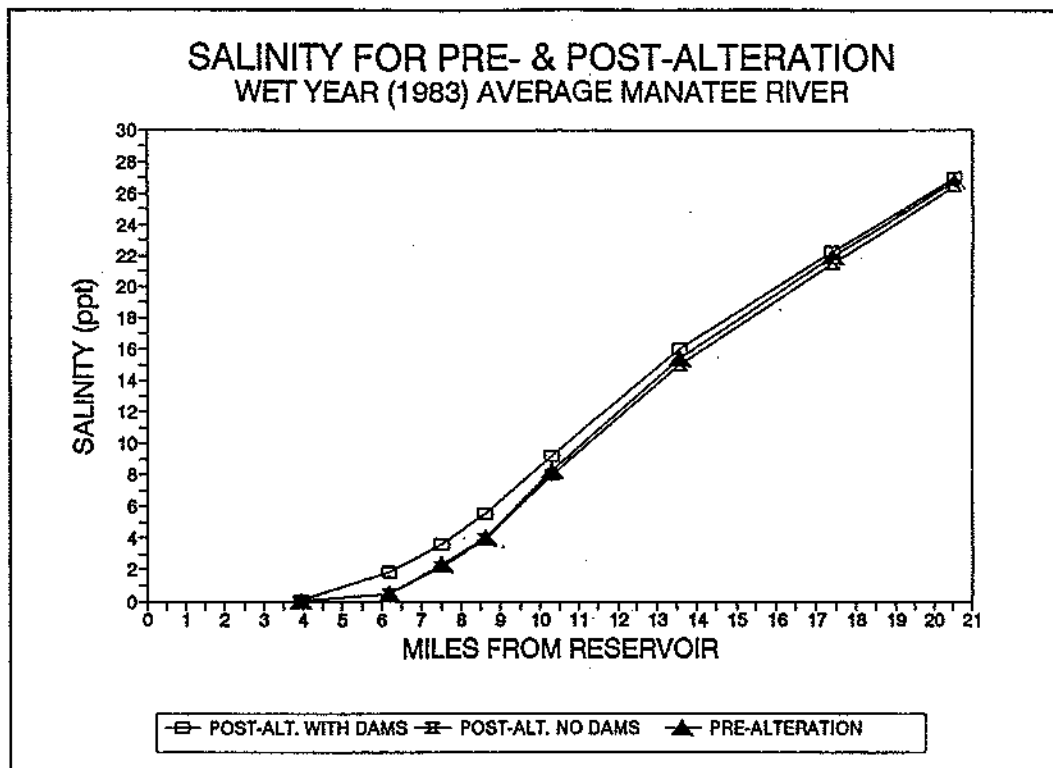


Figure 2. Salinity structure of the Manatee River for 1983, a relatively wet year. Data are mean values of 12 monthly modeled outputs per scenario. Scenarios are described in the text. Note the similarity of pre-alteration and post-alteration no-dam scenarios.

represented a mean salinity over a 29–31 day period of time, for which no measures of variance were available. In light of the above limitations, overlap was evaluated in terms of specific salinity values (“reference salinities”) and specific pairs of salinity values (“salinity bands”). Each is defined and explained below.

A. Transition from fresh to salt water: Tidal freshwater by definition has a salinity less than 0.5 ppt (Odum et al. 1984). Values of 0.5 ppt or 1.0 ppt could not be interpolated with precision from salinity graphs. Following Estevez et al. (1991), a salinity value of 2.0 ppt was chosen to approximate the limit of tidal freshwater areas because of its spatial correspondence (during high tides) to a transition from alluvial to tidal soils in tidal rivers of peninsular Florida.

B. Oligohaline water: Coastal Environmental Services, Inc. (1992) identified “oligohaline” areas in Tampa Bay tributaries for the TBNEP, defined as river reaches with salinities always less than 10 ppt. This system allows for comparison of all tributaries to the Bay, and for the detection of changes through time in the area or location of oligohaline water within a given river.

C. Salinity Coefficient of Variation=50%: This salinity attribute describes variation rather than a constant isohaline. Salinity variation seems meaningfully related to SAV biomass (Montague et al. 1989; Fears 1993) although very little data are available relating SAV diversity or productivity to patterns or degree of salinity variation. In

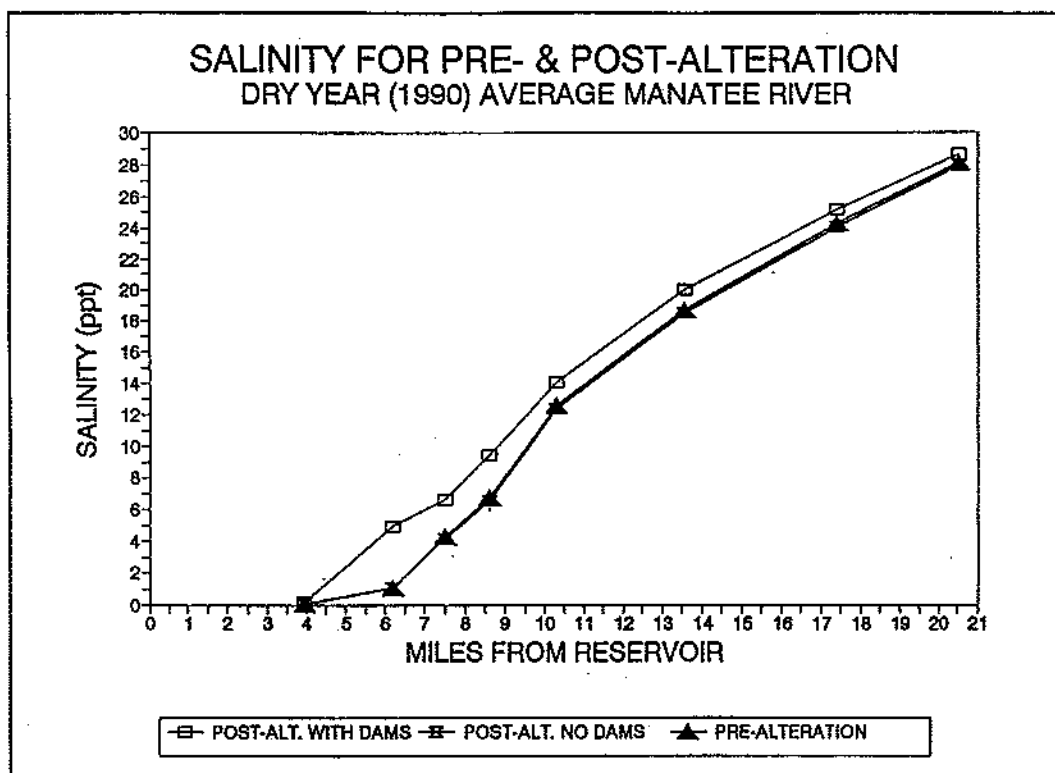


Figure 3. Salinity structure of the Manatee River for 1990, a relatively dry year. Data are mean values of 12 monthly modeled outputs per scenario.

this assessment, a salinity coefficient of variation equal to 50% is used. A CV(50) signifies that the standard deviation is half the value of the corresponding mean. Upriver limits of SAV in the tidal Sebastian and Loxahatchee Rivers correspond to CV values less than or equal to 50% (Estevez and Marshall 1993).

D. NOS Principal Components: The National Ocean Survey (NOS) recently reported on a multi-variate analysis of salinity zones used by fishes and invertebrates in Atlantic coastal plain estuaries. Bulger et al. (1990) identified five overlapping salinity ranges as principal components accounting for the distribution and abundance of estuarine species by life stage. Similar work is in progress for Gulf of Mexico species which may be expected to produce similar results. The Atlantic coast salinity zones were used here as approximators of locally relevant salinity zones. The zones, or bands, are: Freshwater to 4 ppt; 2 to 15 ppt; 11 to 19 ppt; 15 to 28 ppt, and 23 ppt to marine salinities. Calculations made with reference salinities of 2 and 10 ppt suggest the types of compression to be expected for the first two NOS salinity bands, so these were not separately calculated. However, in order to examine the behavior of a salinity band under different watershed management scenarios, the highest band occurring in the Manatee River (11–19 ppt) was analyzed.

Overlap Assessment

For each analysis, the river-mile position of a specific salinity, salinity band, or salinity coefficient of variation was determined. The river-mile position of each salinity was determined for the with-dam and without-dam scenarios. In this report, only the

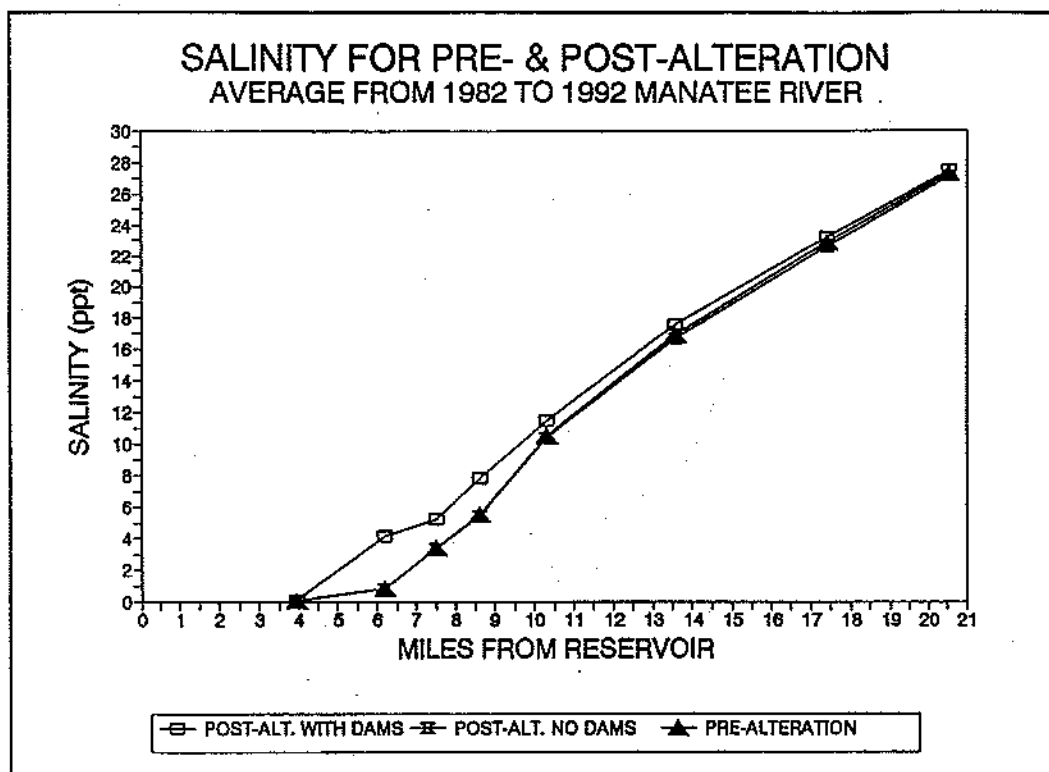


Figure 4. Salinity structure of the Manatee River for the 1982-1992 decade. Data are mean values of 120 monthly modeled outputs per scenario.

"post-alteration with dam" scenario is assessed. Next, each graph of habitat attributes was entered using the river miles corresponding to the location of with-dam and without dam salinities. The amount (area, volume, number) of an attribute upstream of the given salinity was determined from the graph, and the difference between scenarios was calculated in absolute and relative (percent) units. For salinity band analysis, this process was repeated for each end-member of the band and the amount of habitat between them was calculated. As appropriate, amount of habitat downstream of a particular salinity was also calculated by the same method.

RESULTS

It is worth noting that the river mile system employed in this study differs from other systems because of differences in base maps, thalweg definition, and measurement technique. Within this project, river miles for model segments and salinity outputs agreed with river miles for habitat attributes.

Habitat attributes are not dispersed uniformly throughout the length of the tidal river. From the dam to Gamble Creek (mile 7) all attributes are relatively limited. From Gamble Creek to approximately Interstate 75, shoreline, surface area, and wetland attributes increase dramatically and reach river-wide maxima. Downstream of I-75, only river volume, and area of SAV plus potential SAV, increase or reach their respective maximum values.

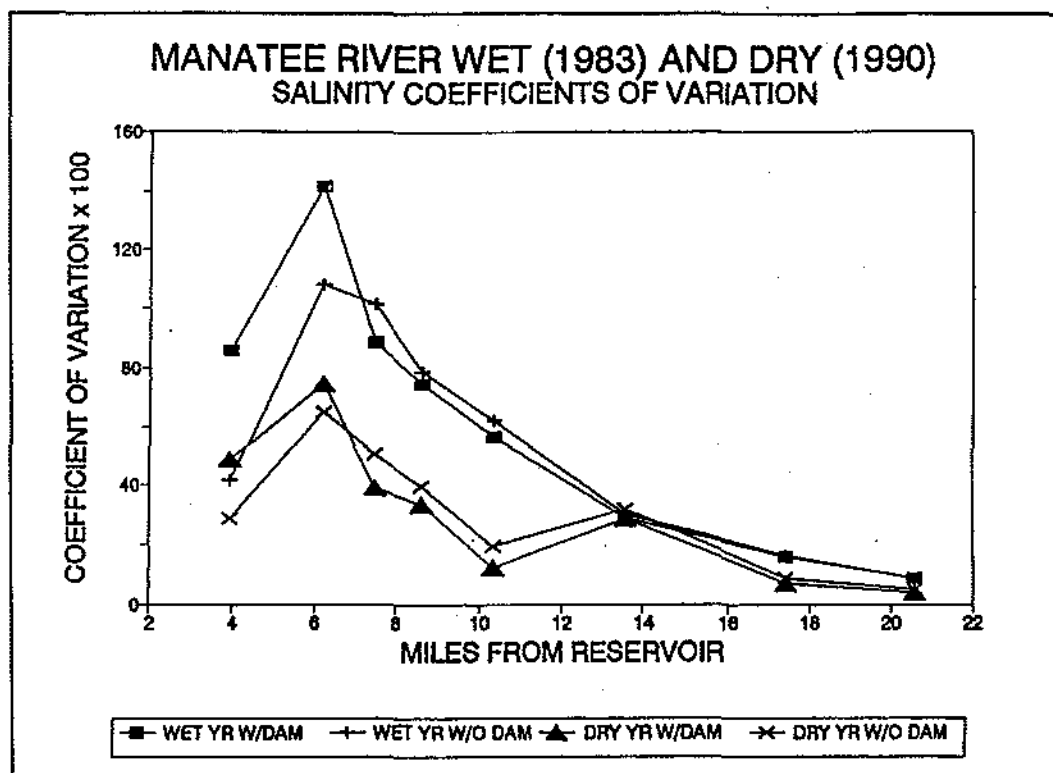


Figure 5. Salinity structure of the Manatee River for wet (1983) and dry (1990) years, expressed as coefficients of variation. Only dam and no-dam scenarios are shown. Submerged aquatic vegetation occurs downstream of I-75 (river mile >12.5).

Salinity differences between pre-alteration and post-alteration no-dam scenarios were negligible for all months and water years, and are not discussed further. The similarity of these two scenarios indicates that land cover and land use changes in the watershed have not affected the salinity structure of the tidal river to any significant degree. Both scenarios are different than the post-alteration-with-dams scenario. Although the significance of these differences cannot be tested statistically because values are model outputs¹, salinities modeled under the latter scenario always are greater than salinities modeled under the scenarios lacking dams. Salinity differences are greater for the tidal Manatee River upstream of the Braden River, rather than downstream, suggesting that effects of the Manatee River dam are greater than the effect of the Braden River dam on Evers Reservoir (Ward Lake).

The overall pattern of difference between scenarios is that the post-alteration-with-dams salinity structure of the tidal river is shifted upstream. Table 2 summarizes monthly and yearly salinity shifts in the river mile locations of reference salinities (2 and 10 ppt) and selected end-members of salinity bands (4, 15, 19, 23 and 28 ppt), for average conditions from 1982 to 1992. Shifts are reported as upstream changes

¹ For which error terms are unavailable.

from salinity locations determined in the post-alteration-no-dam scenario². Salinities of 2 and 4 ppt shifted upstream more than one mile. Higher salinities shifted less than one-half mile and, in general, there was a non-linear relationship between reference salinity and associated shift.

Table 2. Change in river mile location of reference salinities, calculated as difference between post-alteration-without-dams and post-alteration-with-dams scenarios. Minima and maxima were taken from monthly outputs. All changes are upstream shifts except as marked by plus signs (+).

SALINITY, ppt	N	MIN	SHIFT, miles		MEAN	% CHANGE
			MAX			
2	12	0.80	2.00		1.80	-26.5%
4	12	0.75	2.10		1.75	-22.0%
10	12	0.25	1.20		0.50	-5.0%
15	12	<+.25	0.75		0.45	-3.5%
19	12	<+.25	0.90		0.30	-2.0%
23	11	<+.25	0.80		0.28	-1.6%
28	8	0.10	0.50		nc	nc

nc—not calculated.

Because the dam is an instream barrier it can be used to gauge compression of river reaches with salinity values less than a reference value. For average conditions and monthly data, the river reach with salinity <2 ppt was shortened by 26.5%, and the river reach with salinity <4 ppt was shortened by 22.0%. Compression of other reference salinities was 5.0% or less. These compression values are conservative for two reasons. First, average water year results were used rather than dry year results. Second, a literal comparison of isohalines would add the length of the river upstream of the dam to the post-alteration-without-dams scenario, resulting in compression values approaching 90%.

Neither the presence of dams nor type of water year greatly affects the down-river (river miles >14) pattern of salinity variation, in terms of salinity coefficients of variation (Figure 5). *Patterns* of salinity variation close to Tampa Bay seem dominated by tidal exchange rather than river flow, whereas water year and model scenarios have greater effects than tides do in upriver reaches.

The method of Table 2 compared river mile locations of certain salinity values produced by different scenarios. The same method can be applied to evaluate the overlap of habitat attributes and salinities, using river miles as their common factor.

A. Transition from fresh to salt water (2 ppt): Table 3 summarizes changes in the amount of five different habitat attributes affected by a salinity of 2 ppt or less, when the river-mile location of the 2 ppt isohaline varies according to three water year types and two management scenarios. Two attributes, wetland area and number of creeks, were reduced greatly (60% to 100% of no-dam scenarios). Shoreline length and river area were reduced less (32% to 48%), and SAV plus potential SAV was

²Four segments in June had slight (<0.25 mile) downstream shifts. This anomaly may be the result of model sensitivity, segment geometry, and interpolation of values between segment mid-points.

unaffected. Volume was not calculated because of measurement imprecision in the low range of acre-feet involved.

Table 3. Reference salinity 2.0 ppt for post-alteration scenarios vs. habitat attributes.

	WATER YEAR TYPE	NO DAMS	WITH DAMS	DIFFERENCE	PERCENT
A. NATURAL SHORELINE LENGTH, UPSTREAM MILES	Avg. 1982-92 Wet 1983 Dry 1990	21.0 26.5 20.0	11.0 18.0 10.5	10.0 8.5 9.5	-47.6 -32.1 -47.5
B. RIVER AREA, UPSTREAM ACRES	Avg. 1982-92 Wet 1983 Dry 1990	150 225 130	90 130 75	60 95 55	-40.0 -42.2 -42.3
C. RIVER VOLUME, UPSTREAM ACRE-FEET		(not calculated for 2 ppt)			
D. WETLAND AREA, UPSTREAM ACRES	Avg. 1982-92 Wet 1983 Dry 1990	55 100 50	0 35 0	55 65 50	-100.0 -65.0 -100.0
E. SAV & POTENTIAL SAV AREA, UPSTREAM ACRES	Avg. 1982-92 Wet 1983 Dry 1990	7 7 7	7 7 7	0 0 0	0 0 0
F. CREEKS, UPSTREAM NUMBER	Avg. 1982-92 Wet 1983 Dry 1990	21 35 19	3 14 3	18 21 16	-85.7 -60.0 -84.2

B. Oligohaline water (10 ppt): Table 4 summarizes changes in the amount of six different habitat attributes affected by a salinity of 10 ppt or less, when the river-mile location of the 10 ppt isohaline varies according to three water year types and two management scenarios. Because the 10 ppt isohaline occurs farther downstream than the 2 ppt isohaline, and generally coincides with a river reach in which habitat attributes are changing greatly, several non-linear combinations of water year and scenario result. Compressions of wetland area and creek number are less than 33%. River volume is compressed by about one-fifth. Compression of river area is slightly less at the 10 ppt level (30% to 33% loss) than at the 2 ppt level (40% to 42% loss).

C. Salinity Coefficient of Variation=50%: The area of SAV and potential SAV downstream of CV(50) does not differ between wet and dry years or between scenarios without-dams and with-dams, for a given year. Following Mangrove Systems, Inc. (1983), actual SAV extends from river mile 13 (below the dam) to Tampa Bay. In this regard it is interesting to note that down-river trends in CV for wet and dry years converge near river mile 13. Wet and dry year values of CV diverge upstream of river mile 13, where shallow shoals are barren of SAV.

Reference salinity analysis utilized the extent of habitat attributes upstream of specific isohalines. In the Manatee River, the upstream limits are set by the Lake Manatee dam. In lower river reaches, both the downstream and upstream limits of salinity bands are able to change, resulting in different patterns of overlap between salinity and habitat attributes.

Table 4. Reference salinity 10.0 ppt for post-alteration scenarios vs. habitat attributes.

	WATER YEAR TYPE	NO DAMS	WITH DAMS	DIFFERENCE	PERCENT
A. NATURAL SHORELINE LENGTH, UPSTREAM MILES	Avg. 1982-92	60	50	10	-16.7
	Wet 1983	75	70	5	-6.7
	Dry 1990	50	40	10	-20.0
B. RIVER AREA, UPSTREAM ACRES	Avg. 1982-92	900	600	300	-33.3
	Wet 1983	1400	950	450	-32.1
	Dry 1990	600	420	180	-30.0
C. RIVER VOLUME, UPSTREAM ACRE-FEET	Avg. 1982-92	900	700	200	-22.2
	Wet 1983	1160	1050	110	-9.5
	Dry 1990	700	550	150	-21.4
D. WETLAND AREA, UPSTREAM ACRES	Avg. 1982-92	610	460	150	-24.6
	Wet 1983	800	720	80	-10.0
	Dry 1990	460	310	150	-32.6
E. SAV & POTENTIAL SAV AREA, UPSTREAM ACRES	Avg. 1982-92	7	7	0	0
	Wet 1983	7	7	0	0
	Dry 1990	7	7	0	0
F. CREEKS, UPSTREAM NUMBER	Avg. 1982-92	111	93	18	-16.2
	Wet 1983	123	122	1	-0.8
	Dry 1990	93	69	24	-25.8

The National Ocean Service's estuarine classification employs five overlapping salinity bands. Habitat overlap of one band, 11 ppt to 19 ppt, was evaluated for the Manatee River. The overlap behavior of lower NOS salinity bands was suggested by the 2 ppt and 10 ppt reference salinity analyses. Higher NOS salinity bands exceed the modeled salinities of the Manatee River and cannot be evaluated. The 11-19 ppt NOS band is similar to the "mesohaline zone" of Texas estuaries (5 to 18 ppt) found by Zimmerman and Minello (1993) to be most productive for juvenile fishery species with wetland affinities. In the Manatee River, the 11-19 ppt salinity band covers a river reach not already considered.

Habitat attributes increased or decreased depending on water year type (Table 5). When the unconstrained 11-19 ppt salinity band changed position in the river because of inflow differences, certain attributes (most notably, wetland area and creek number) increased by 75-120%. It is also noteworthy that shoreline length and river area actually increased during some inflow conditions but decreased during others. Creek number increased during average and dry year flow conditions but was unaffected by wet year flows. Conversely, SAV and potential SAV area declined during average and dry year flow conditions but was unaffected by wet year flows. Such variation differs markedly from attribute changes measured upstream of low (2 and 10 ppt) salinities, where all changes were losses (Tables 3, 4). This difference is due to the fact that attributes end naturally, upstream of saline waters, or end because the dam at Lake Manatee truncates the river.

Table 5. Salinity band 11-19 ppt for post-alteration scenarios vs. habitat attributes.

	WATER YEAR TYPE	NO DAMS	WITH DAMS	DIFFERENCE	PERCENT
A. NATURAL SHORELINE LENGTH, BANDED MILES	Avg. 1982-92	27	37	10	+37.0
	Wet 1983	22	22	0	0
	Dry 1990	34	42	8	+23.5
B. RIVER AREA, BANDED ACRES	Avg. 1982-92	2100	2175	75	+3.6
	Wet 1983	1950	1900	50	-2.6
	Dry 1990	1850	1750	100	-5.4
C. RIVER VOLUME, BANDED ACRE-FEET	Avg. 1982-92	2450	2325	125	-5.1
	Wet 1983	2700	2500	200	-7.4
	Dry 1990	2000	1625	375	-18.8
D. WETLAND AREA, BANDED ACRES	Avg. 1982-92	135	260	125	+92.6
	Wet 1983	40	70	30	+75.0
	Dry 1990	280	490	210	+75.0
E. SAV & POTENTIAL SAV AREA, BANDED ACRES	Avg. 1982-92	74	64	10	-13.5
	Wet 1983	77	77	0	0
	Dry 1990	52	31	21	-40.4
F. CREEKS, BANDED NUMBER	Avg. 1982-92	10	22	12	+120.0
	Wet 1983	10	10	0	0
	Dry 1990	24	51	27	+112.5

DISCUSSION

Manatee River Demonstration

River isohalines consistently agreed between the pre-alteration scenario and post-alteration-without-dams scenario, signifying that salinity differences were caused most by the addition of dams. Among post-development scenarios, upstream shifts in the locations of seven reference salinity values marked the most notable difference associated with dams. The largest upstream shifts (>1.5 miles) occurred among the lowest salinities (2 and 4 ppt) and salinities > 10 ppt shifted upstream by 5% or less.

The effect of water year (average, wet, dry) on habitat attributes was approximately as great as the effect of dams for salinities of 2 ppt and 10 ppt (Tables 3, 4). At 2 and 10 ppt, habitat attributes decreased less in wet year runs than in dry year runs, compared to average year runs. In fact, dry year losses tended to follow average year losses for most attributes, suggesting that an analysis based on median salinities could be useful. The tendency for average conditions to follow dry year conditions may be caused by natural decreases in habitat attributes in low-salinity areas, truncation of the river by the Lake Manatee dam, or both. It is clear, however, that the effects of dams or water years are much less for unconstrained salinity bands, compared to effects calculated between the dam and salinities of interest.

The effects of dams on down-river patterns of variation, expressed as coefficients of variation, were much greater for the wet year (1993) than the dry year (1990) within the first 5 miles of river below the dam. Values of CV at river mile 4 increased by 100% in the wet year scenario. The river-mile position of maximum CV (mile 6 in all scenarios) was unaffected. This results agree with other findings that upstream salinity alterations are proportionately greater than downstream changes.

The area and volume of low salinity waters describe the availability of plankton habitat. Using waters with salinity <10 ppt as an index, the with-dam scenario reduces river area by 30–33% and reduces river volume by 10–22%, compared to the without-dam scenario. In average years, area is reduced by one-third and volume is reduced by one-fifth, implying proportional reductions in stocks of phytoplankton and faunal plankton, respectively. Actual reductions in faunal plankton may be larger, approaching a third, because the oligohaline river is usually well-mixed. In the same sense, habitat of “mesohaline” (11–19 ppt) plankton stocks also decreases in area and volume, but not as much as in lower-salinity areas.

The habitat of subtidal, soft-bottom benthic fauna changes in terms of river area. Low-salinity and mesohaline benthic habitat areas decrease to the same degree described for plankton habitat. Compression of these benthic areas is consistent with the conclusion of Culter (1984) that an oligohaline to mesohaline fauna between Ft. Hamer and the Braden River would be intruded by a polyhaline fauna farther downstream, if flows were reduced sufficiently.

Mats of filamentous algae (periphyton) occur on low-salinity shoals, point-bars and intertidal banks of the Manatee River (E.D. Estevez, personal observation) but beds of vascular SAV apparently do not (King Engineering Associates 1994). No change in the area of low salinity algae habitat occurs between scenarios with-dams and without-dams. Farther downstream, the with-dam scenario accounts for a 0–40% decrease in the area of SAV and potential SAV falling within the 11–19 ppt salinity band. Fauna inhabiting SAV or unvegetated shallows, such as spotted seatrout (Killam et al. 1992), within 11–19 ppt would decrease by the same amount.

Following Mangrove Systems, Inc. (1983), present-day SAV in the Manatee River occurs only west of Interstate 75, and the majority of SAV is west of Wares Creek (mile 17.5). Approximately 43% of potential SAV habitat in the Manatee River occurs upstream of Wares Creek, but is unvegetated. More would be included if river bottom shallower than 6 feet was included. As is the case for other tributaries to Tampa Bay, the middle and upper Manatee River supports no vascular SAV at all (King Engineering Associates 1994). How this condition should exist, when the tidal Myakka River (Sarasota County, Florida) supports dense beds of tape grass (*Vallisneria neotropicalis*) and widgeon grass (*Ruppia maritima*), is a mystery.

Wetlands considered in this study include mangrove forests and marshes. With-dam salinity conditions eliminate the area of low-salinity (<2 ppt) wetlands during average and dry years, compared to the without-dam scenario. In relative terms, the effect is less severe for salinities <10 ppt, but the absolute acreage lost (150 acres) is three times greater in the latter case. On balance, “mesohaline” (11–19 ppt) wetland area increases by 75–93% in the with-dam scenario. These patterns of change are mirrored by changes in the length of natural shoreline, recognized by the National Wetland Inventory as a wetland type.

Conclusions for the General Method

The overlap method worked well with existing information in the form of reports and graphic data. Even for relatively unstudied systems, it should be possible to

accumulate enough data on stationary habitat features, from charts and aerial photographs, to apply the method. Rapid assessments of conceptual changes to river flows can be made using the method as a screening tool.

Results from the Manatee River demonstration were not intuitive, but consistent with physical processes. Neither habitats nor salinity regimes were dispersed uniformly along the river. Changes to river flow affected both differently in different river reaches. Overlap analysis amplified the ecological effect of relatively small salinity changes in oligohaline river reaches, leading to conclusions different than any based solely on changes to salinity. Upper estuaries and tidal rivers have multiple, non-linear aspects and features (Browder 1991), and the coupling of these analytically provides for a simple, powerful method for detecting or predicting ecological changes resulting from altered freshwater inflows or salinity regimes.

Habitat features and calculated changes in their overlap with critical salinities provide indirect insight to consequences for fauna. Changes in shoreline length are relatable to the availability of juvenile fish habitat (Edwards 1991). Changes in river area can be taken as estimators of potential benthic infaunal community response (Culter 1984), while changes in river volume may suggest phytoplankton or ichthyoplankton consequences of altered salinity regimes (Peebles et al. 1991).

Recent work in California estuaries provides a robust demonstration that salinity regimes are meaningful habitat indicators for estuarine species. Jassby et al. (1995) reported significant relationships between the downstream location of the 2 ppt isohaline, and numerous biological variables associated with the food chain for striped bass, *Morone saxatilis*, in the San Francisco Bay and Sacramento-San Joaquin Delta Estuary. Isohaline location was variously described by season, lagged interval, or running means, signifying that overlap analyses should seek to scale salinity descriptions so as to capture ecological processes known for a given estuary. The California work also suggests that species-level habitat requirements could be employed in overlap studies of Florida's altered estuaries.

The analytical technique developed for this study is transferable to any tidal river setting. Refinements could include the use of GIS and site-specific determinations of reference salinities. For the technique in general, overlap analysis should be performed in a variety of coastal plain rivers and estuaries to determine its transferability to other settings. Other types of inflow alteration should be assessed by the technique. Given favorable results, the technique could be generalized as a PC-resident shell, and links with geographic information systems should be explored.

ACKNOWLEDGMENTS

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ALTERNATIVE WATER SUPPLY DEVELOPMENT FOR INDUSTRY, AGRICULTURE AND PUBLIC SUPPLY IN MANATEE COUNTY, FLORIDA

Charles A. Hunsicker

"When the well's dry, we know the worth of water."—Benjamin Franklin

THE MARS PROJECT

The Manatee Agricultural Reuse Supply (MARS) project has been developed in response to the New Water Source Initiative (NWSI) of the Southwest Florida Water Management District (SWFWMD). The MARS project was also designed to fully demonstrate the effectiveness of the Alternative Sources recommendations in the Draft Southern Water Use Caution Area (SWUCA) Management Plan.

Area's Groundwater Under Siege

The NWSI and the SWUCA Plan were established to address recent severe groundwater level declines occurring in the Upper Floridan aquifer system throughout the SWUCA, an eight-county area shown in Figure 1. The stressed state of groundwater in the SWUCA and its deleterious impact upon the region is clearly evident. Since the 1930s, groundwater levels in central Manatee County and portions of east central Hillsborough and central Polk Counties have declined by up to 50 feet (Fig. 2).

Our groundwater aquifers are not the only resource threatened by continuing withdrawals—surface water resources are also threatened. Numerous lakes throughout the SWUCA, particularly along the Highlands Ridge, have been dramatically lowered because of groundwater pumping.

Groundwater in the region is used primarily for agricultural irrigation. Irrigated citrus acreage has increased from 115,000 acres to 250,000 since 1966, and associated water use was estimated to increase from 150 mgd to approximately 330 mgd. The estimated increase in tomato acreage during this period was from 5,000 acres to over 15,000 acres, with water use estimated to increase from 15 mgd to over 45 mgd.

Meanwhile, as groundwater used for irrigation continues to rise, estimated industrial and mining water use has declined from 233 mgd in 1977 to 162 mgd in 1990, according to the draft management plan. The reduction primarily comes from increased recycling of previous wastewater as implemented by phosphate mines during the late 1970s. Recycling or reuse of reclaimed domestic wastewater, irrigation tailwater, and stormwater can reduce groundwater demands in much the same way for agricultural irrigation.

The Southwest Florida Water Management District Needs and Sources Plan (1992) projected total groundwater use in the Southern Water Use Caution Area could increase to approximately 1,300 million gallons per day (mgd) by 2020, up from the 1990 total of 798 mgd. The SWUCA draft management plan stated, "if realized, this projected increase in water use would cause further water level declines in the Upper Floridan aquifer system across the entire SWUCA."

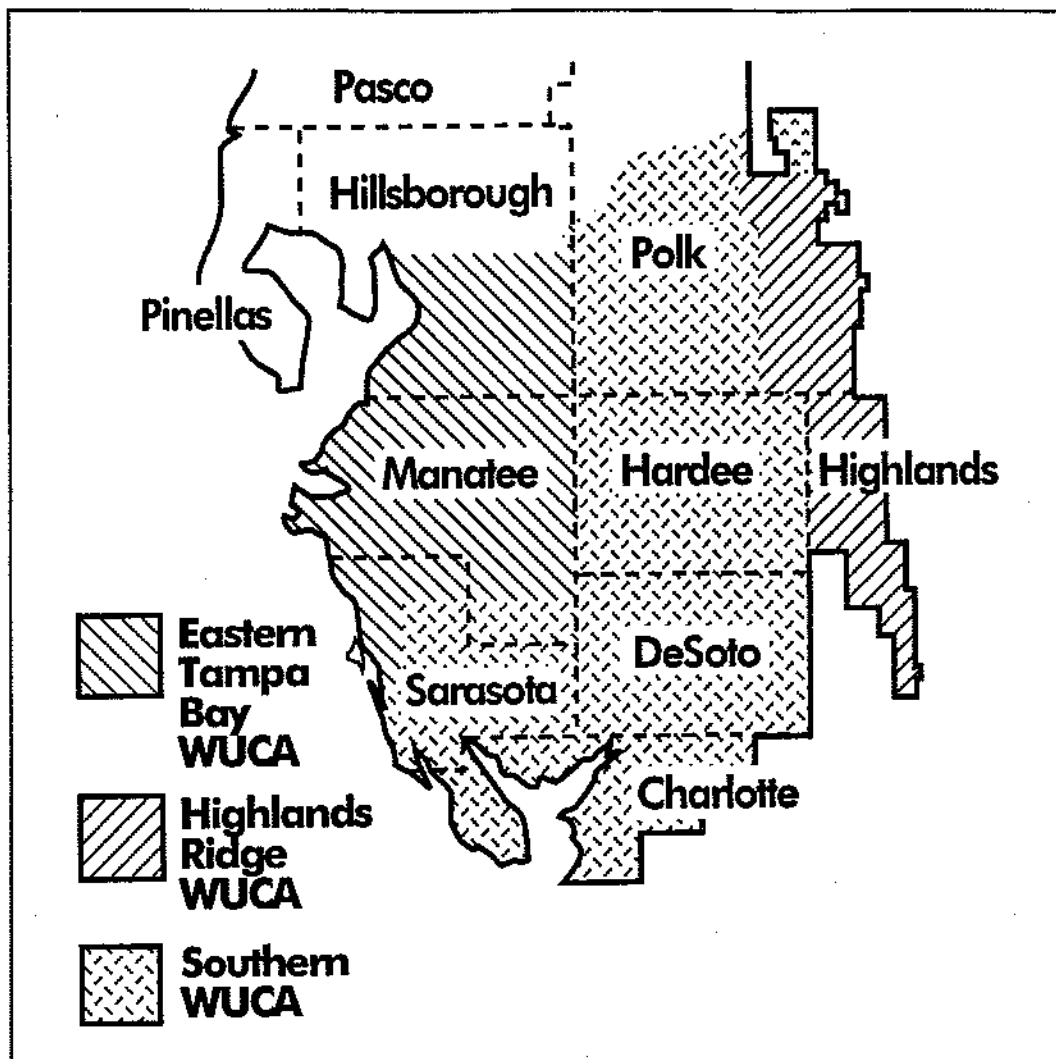


Figure 1. Location of the Southern Water Use Caution Area (SWUCA). Source: Southwest Florida Water Management District.

The SWUCA plan described the potential changes that can occur with the saltwater interface under current pumping conditions and those predicted for 2020 demands. For the coastal counties within the Eastern Tampa Bay Water Use Caution Area (Manatee, Hillsborough, Sarasota) the studies show that movement of the saltwater interface over the next 50 years could affect water quality in wells as much as three miles farther inland under current pumping conditions. The extent of intrusion during the same period is projected to increase to as much as seven miles inland if pumpage increases to levels projected for 2020 (Fig. 3).

Remedial action to reduce groundwater withdrawals through alternative water supplies is critical, especially in an area so dependent on groundwater. More than 98% of the non-public water supply in the SWUCA is derived from groundwater sources. Many of the public water supplies in the SWUCA, including Manatee County, use surface water reservoirs.

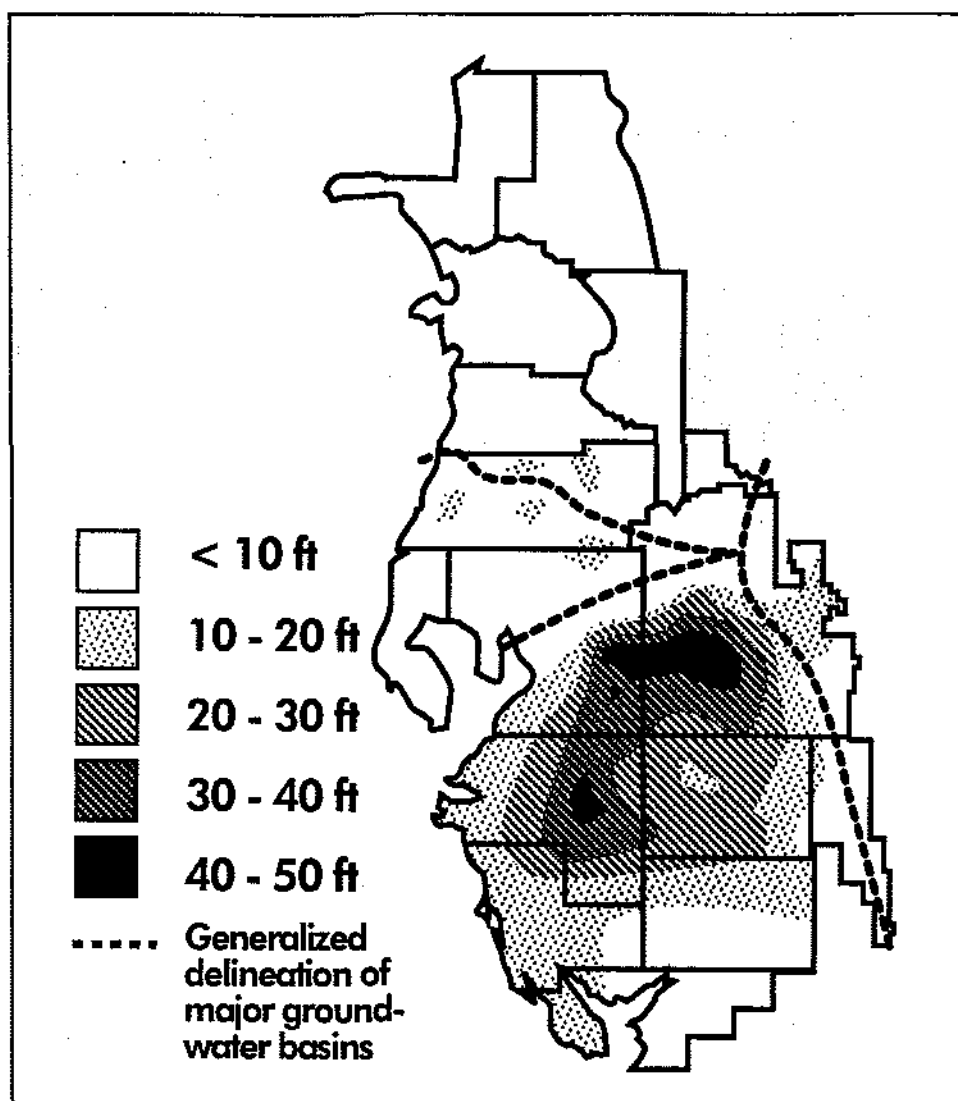


Figure 2. Decline in the Florida aquifer potentiometric supply from predevelopment to 1991.
Source: Southwest Florida Water Management District.

The SWUCA Management Plan: a Search for Alternative Water Supplies

In response to serious concerns about declining groundwater levels, saltwater intrusion, and lake level declines, the SWFWMD developed the Southern Water Use Caution Area Management Plan. The plan's objective is to stabilize the saltwater interface and lake level declines within the SWUCA. To accomplish this, the plan recommends limiting groundwater withdrawals to 700 mgd in the SWUCA, 150 mgd in the eastern Tampa Bay area and 550 mgd in the remaining SWUCA (Fig. 4). Groundwater use in the SWUCA was estimated at 798 mgd in 1990.

The District has proposed a number of incentives to encourage the development of alternative sources, including future groundwater credits and economic assistance such as the Basin Cooperative funding programs and now the New Water Source Initiative, the District's \$10 million fund dedicated to supporting conservation and alternative supply projects.

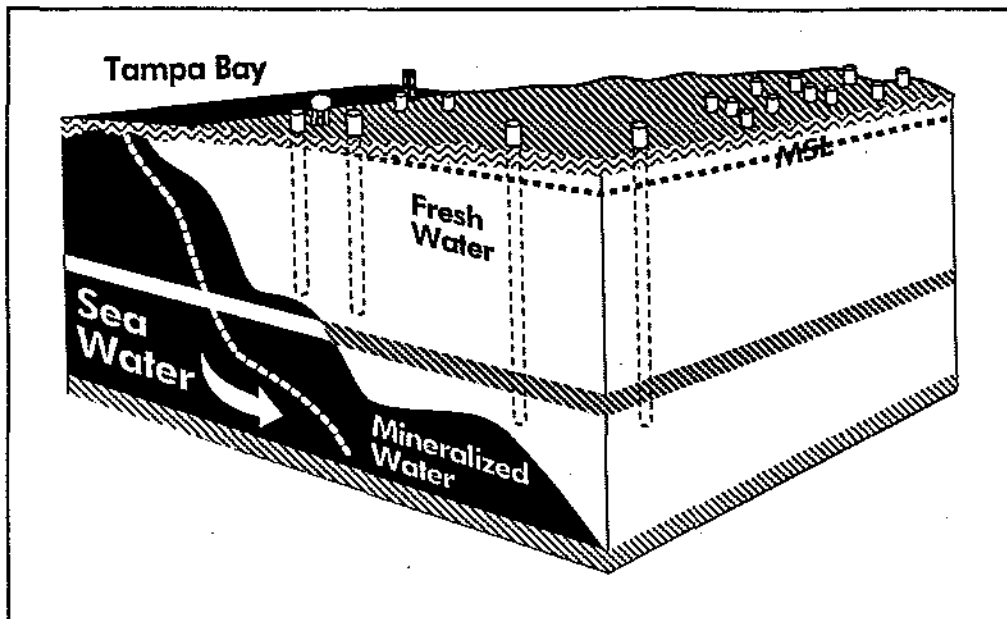


Figure 3. Schematic diagram of saline water interface in the eastern Tampa Bay area. Source: Southwest Florida Water Management District.

The first recommendation in the SWUCA plan for stabilizing groundwater withdrawals is the development of alternative sources. The plan states: "An important component of the plan is the development of alternative sources of water to substitute for the use of groundwater and to extend the use of surface water sources." New alternative water sources will play a major role in meeting the current and future water demands within the SWUCA. The primary objective of developing new water sources is to offset the current and future water needs in the SWUCA.

Manatee County, The Logical Alternative For Alternative Water Sources

The regional drawdown map (Fig. 2) provides an excellent means to identify priority target areas for alternative sources. As indicated by the extent and severity of drawdowns, it is clear that Manatee County is an area of priority concern.

The development of alternative water sources in Manatee County will have a region-wide impact and benefit the entire SWUCA. Water, of course, does not recognize political boundaries. Manatee County's deep groundwater sources share an entire groundwater basin called the Southern West-Central Florida Groundwater Basin. The basin comprises nearly the entire SWUCA (Fig. 5). The SWUCA plan states that "depressed groundwater levels resulting from pumpage within the entire Southern Basin contributes to several problems:

- The saltwater intrusion problem in the coastal region of the basin;
- Reduced well efficiencies as a result of pumps being required to lift groundwater from lower depths;
- Reductions in spring flow and stream flow;
- Wetlands impacts; and
- Lowered lake levels in Highlands and Polk Counties."

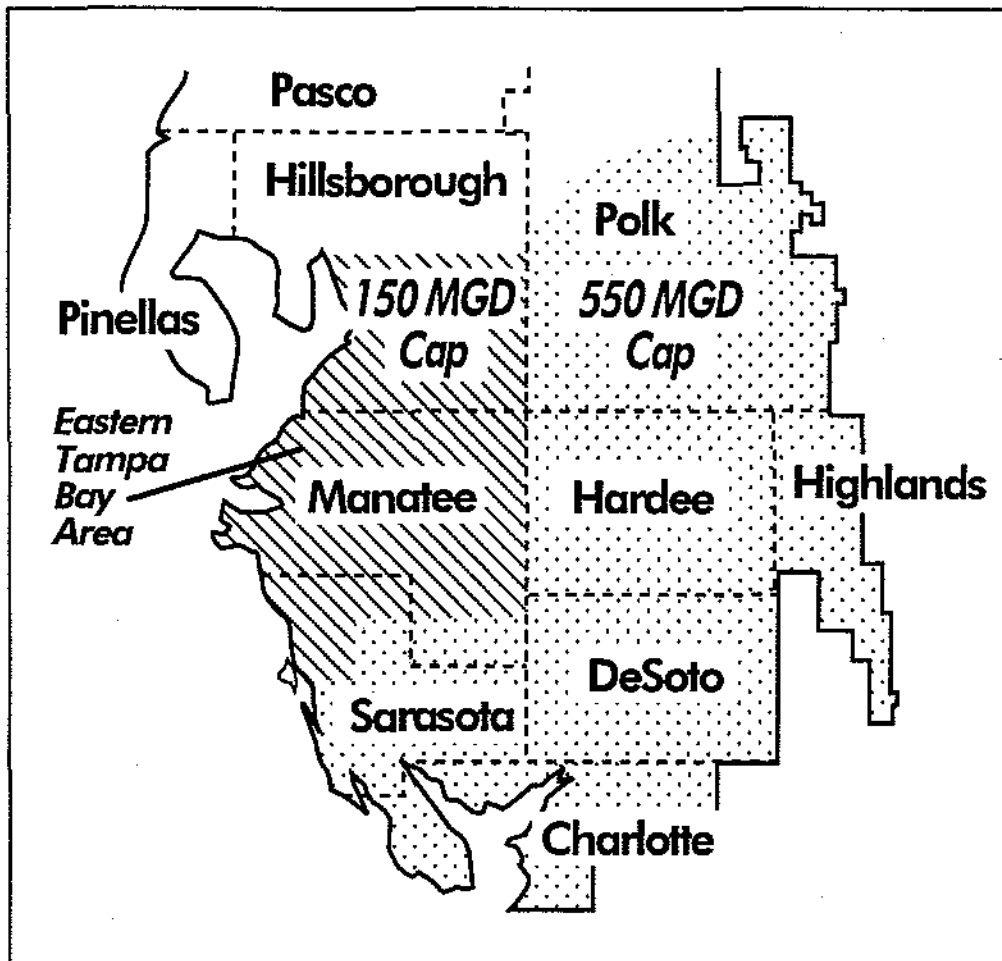


Figure 4. Capped quantities by area. Source: Southwest Florida Water Management District.

Full implementation of the MARS Project would substantially accomplish the first objective of the SWUCA Management Plan and help mitigate all of the above problems in Manatee County and the entire SWUCA.

Geographically, Manatee County is one of the largest agricultural regions in the state, ranking 7th of all 67 Florida counties in total cash receipts. About 87% of all groundwater pumpage in the county is used for agricultural irrigation. Manatee County, consequently, is ideally positioned with a large and ready existing demand for alternative water supplies.

Manatee County, through the MARS project, is capable of providing a significant amount of alternative water supply. This is possible because of the highly developed state of the county's wastewater systems. Expeditionary planning and development will be necessary for the MARS project and the NWSI to be effective over the short term.

Reuse, Manatee County's Alternative Water Source

Reuse of reclaimed water involves taking what was once considered to be wastewater, giving it a high degree of treatment, and using the resulting high-quality reclaimed

water for a new, beneficial use. Extensive treatment and disinfection ensure that public health and environmental quality are protected.

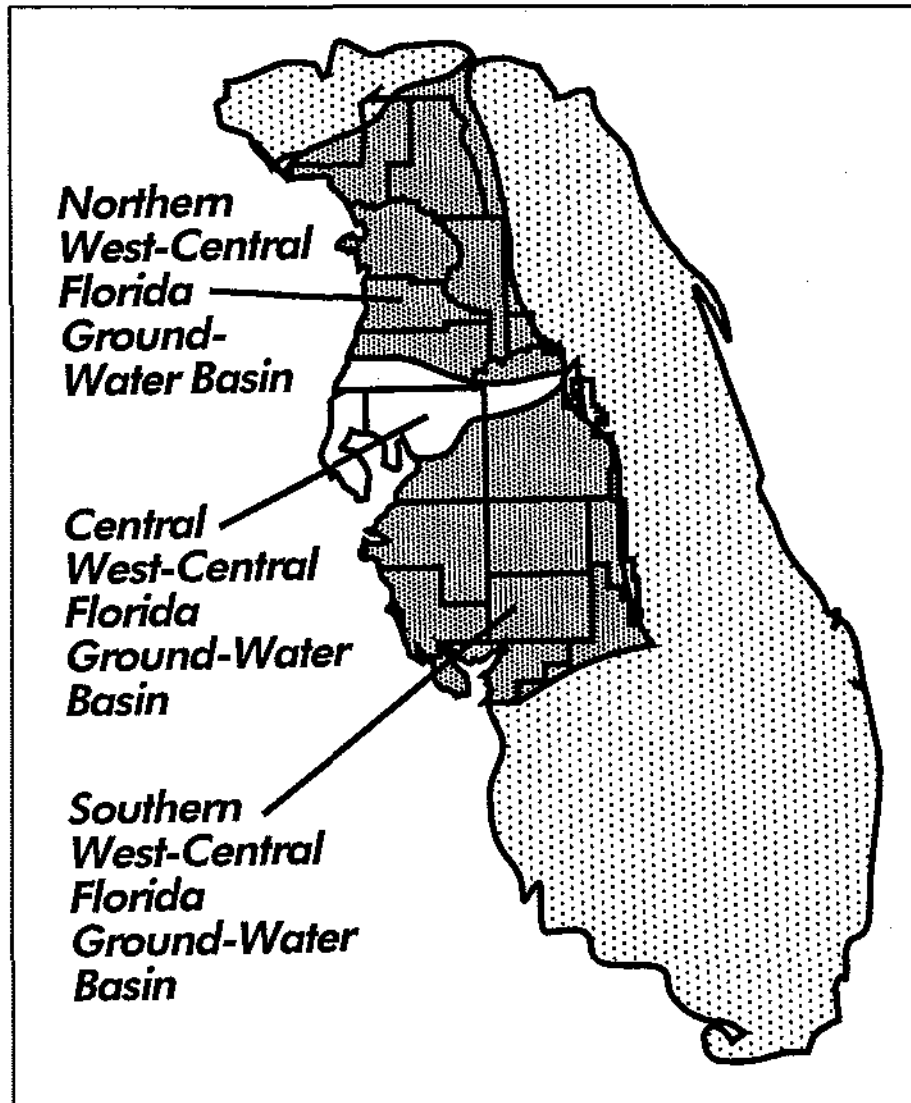


Figure 5. Location of Floridan aquifer groundwater basins in the Southwest Florida Water Management District. Source: Southwest Florida Water Management District.

With limited opportunities to discharge reclaimed water into surface waters, reuse of reclaimed water is now an integral part of many water management programs, including Manatee County's. Reuse will greatly help the state and SWFWMD meet the water supply and wastewater management needs of a growing population. The State of Florida, SWFWMD, EPA, and the National Estuary Program all promote and support the reuse of reclaimed water as major water management objectives.

Reuse simply makes sense for the SWUCA and Manatee County. It:

- Reduces demands on the highly stressed but invaluable groundwater resource.
- Eliminates surface water discharges that may detrimentally impact surface water aquatic systems.
- Postpones costly investment for development of new water sources and supplies.
- Recharges groundwater and prevents salt water intrusion.
- Allows multiple uses of land for agriculture and reuse of urban reclaimed water.
- Can provide aesthetic value.

Manatee County...A Leader in the Reuse of Reclaimed Water

Manatee County's Regional Wastewater Treatment System was designed and built and is operated on the principle of reclaiming wastewater for beneficial reuse. The county receives multiple benefits including improved surface water quality by eliminating wastewater discharges, a high quality source for irrigation, reduced groundwater withdrawals, reduced demand on the public drinking water supply, and a nutrient-rich soil conditioner for agriculture.

Indeed, the Sarasota Bay National Estuary Program states in its *Framework For Action*, "Meanwhile, concerted action on wastewater treatment by local governments led to noticeable improvements in the bay. In 1990, both the City of Sarasota and Manatee County significantly improved wastewater treatment operations, resulting in a 43% reduction in nitrogen loads to the central bay and a 25% reduction in baywide nitrogen loads. These actions improved water quality in the northern and central parts of the bay and increased fishery habitat by at least 20%."

Manatee County Public Works Department operates three regional treatment facilities providing reclaimed water to large agricultural and recreational water users near the plants. Traditionally, these users fully consumed the available supply of reclaimed wastewater. However, in the late 1980s a reclaimed surplus developed in the urban Southwest service area as a result of diminishing agricultural use and a growing urban base. This surplus was and is disposed of through deep well injection.

In 1990, the Public Works Department and SWFWMD completed the *Effluent Reuse Feasibility Study and Master Plan for Urban Reuse*. This study and master plan provided the blueprint for an urban reuse system in the southwest service area, which is the cornerstone of the county's Urban Water Conservation Program. However, not all of the wastewater produced at the Southwest Treatment Plant can be utilized in an urban system as planned. Therefore an expected surplus of up to 8 mgd is available for alternative uses such as agricultural irrigation or industrial cooling. The master plan also recognized a continuing commitment of the North and Southeast Regional Wastewater Treatment Plants to agricultural reuse.

With the North and Southeast WWTPs committed to agricultural reuse and a surplus of water available at the Southwest WWTP, these three sites were chosen as cornerstones in the development of a new water source initiative for agricultural reuse supply in Manatee County, the MARS project.

The MARS Project, Manatee Agricultural Reuse Supply

The Manatee Agricultural Reuse Supply project is designed to maximize the reuse of reclaimed wastewater, demonstrate the reuse of stormwater, and utilize surface water storage for agricultural irrigation in eastern Manatee County.

The SWUCA plan states "alternative supplies would be addressed by requiring reuse of treated wastewater where feasible, encouraging use of surface water, stormwater, and the surficial aquifer, and exploring the feasibility of artificially recharging the confined aquifers." Significantly, MARS incorporates four of these alternative water sources in its plan: wastewater reuse, stormwater reuse, and surface water use and reclaimed water aquifer storage and recovery.

The MARS project will interconnect the three regional treatment plants, construct a stormwater reuse facility, and provide 16.25 mgd of reclaimed water for agricultural use. To significantly reduce groundwater withdrawals, it was determined that additional water is needed to supplement flows from the North and Southeast treatment plants. Potential sources that were considered include the City of Bradenton Wastewater Treatment Plant and the proposed Frog Creek Stormwater Reuse Facility.

The City of Bradenton, which discharged approximately 4.8 mgd of reclaimed water to the Manatee River in 1994 has, to date, declined to participate in the project and is reviewing its option to either continue with urban reuse or connect to the County system. The City of Palmetto, which discharged approximately 0.6 mgd to Terra Ceia Bay in 1994, plans to connect to the MARS system.

The MARS project has been divided into three phases to allow for better administrative control of design and construction. Phase I is subdivided into two parts. Part 1 of Phase I is the design and construction of the Frog Creek Stormwater Reuse Facility. The facility will have 800 acre-feet of storage with a reuse yield of 1.6 mgd. The project will include a diversion structure, high service pumps, filters, chlorination, and a 16" transmission connection to the North Wastewater Facility. The site is located at a previous borrow pit, east of US 41 at the intersection with I-275. Part 2 of Phase I is the construction of a 24" reuse transmission line from an existing line at McClure Farms along Moccasin Wallow Road east through Parrish and along SR 62 to farms approximately 1.5 miles east of Saffold Road. The extension is approximately 12.15 miles in length and traverses an agricultural area. In Phase II, a 24" transmission line will be constructed to interconnect the North and Southeast Reuse Systems. The transmission line is approximately 9.8 miles in length and will enable transfer of flows between the two systems. In Phase III, a 24" transmission line will be constructed to interconnect the Southeast and Southwest Reuse Systems. The transmission line is approximately 6.8 miles in length.

Total project costs are estimated at \$14,024,724. The project received a Federal Grant from the Environmental Protection Agency for \$4,145,000. The District will fund up to 50% of the remaining eligible cost up to a maximum of \$4,668,470. Funding for this project is being provided over FY 95 through FY 98. Manatee County will provide the remaining project costs of \$5,211,254.

All phases are under design. Preparations are under way to apply for a permit from the District and Florida Department of Environmental Protection (FDEP) for the Frog Creek Stormwater Reuse Facility. Potential agricultural customers are being contacted and agreements are being negotiated to receive reuse water. Discussions are ongoing with Florida Power & Light for possible supply of reclaimed water at the Parrish Facility. The proposed layout of the MARS system is shown in Figure 6.

Reclaimed Water Aquifer Storage and Recovery

To be fully successful, the MARS project must accommodate wet weather flows, crucial to any successful reuse project, by making wet weather water available for potential reservoir augmentation at FPL's Lake Parrish and in the Tatum Sawgrass restoration area. The SWUCA plan states: "A main objective of the development of these systems is to find wet weather uses for reclaimed water, such as aquifer recharge, reservoir augmentation or minimum flow augmentation."

At Manatee County's Southwest Regional Wastewater Facility, approximately 330 million gallons of storage is needed to fully utilize the future plant flow of 18 mgd. Current storage at the site is limited to approximately 170 million gallons. Failure to develop a cost-effective means to temporarily store reclaimed water will mean a continued dependence on the wasteful practice of deepwell injection of reclaimed water during the wet season.

Manatee County has proposed the development of a reclaimed water aquifer and storage (RASR) system. The RASR system would tie into the MARS project. Success of the project would make an additional 8 mgd of reclaimed water available annually by reducing the use of deep well injection and increasing wet weather storage capacity. Currently there are no permitted reclaimed ASR systems in the state of Florida; as such, the Manatee County project would be in the forefront of the effort to develop this type of system.

RASR Project Description

The project consists of permitting, design, construction and cycle testing of a reclaimed water Aquifer Storage and Recovery (RASR) well and associated monitor wells at the Manatee County Southwest Regional Wastewater Treatment Facility. This project is intended to answer the question of whether RASR can be employed in this area of Manatee County.

The first work element of the project will be a feasibility study to evaluate several issues pertaining to RASR. The feasibility study will evaluate permitting requirements that must be considered in storing and recovering reclaimed water in subsurface aquifers of various water qualities. Some or all of the following permits will need to be obtained: a Class V Injection Well Construction Permit, Manatee County Well Construction Permit, FDEP Water Quality Criteria Exemption, FDEP Class V injection Well Operation Permit and SWFWMD Water Use Permit Modification. The study will also address potential Aquifer Exemptions or Water Quality Exemptions that may be required for the RASR system. The feasibility study report will be used to support permitting and subsequent design and construction tasks.

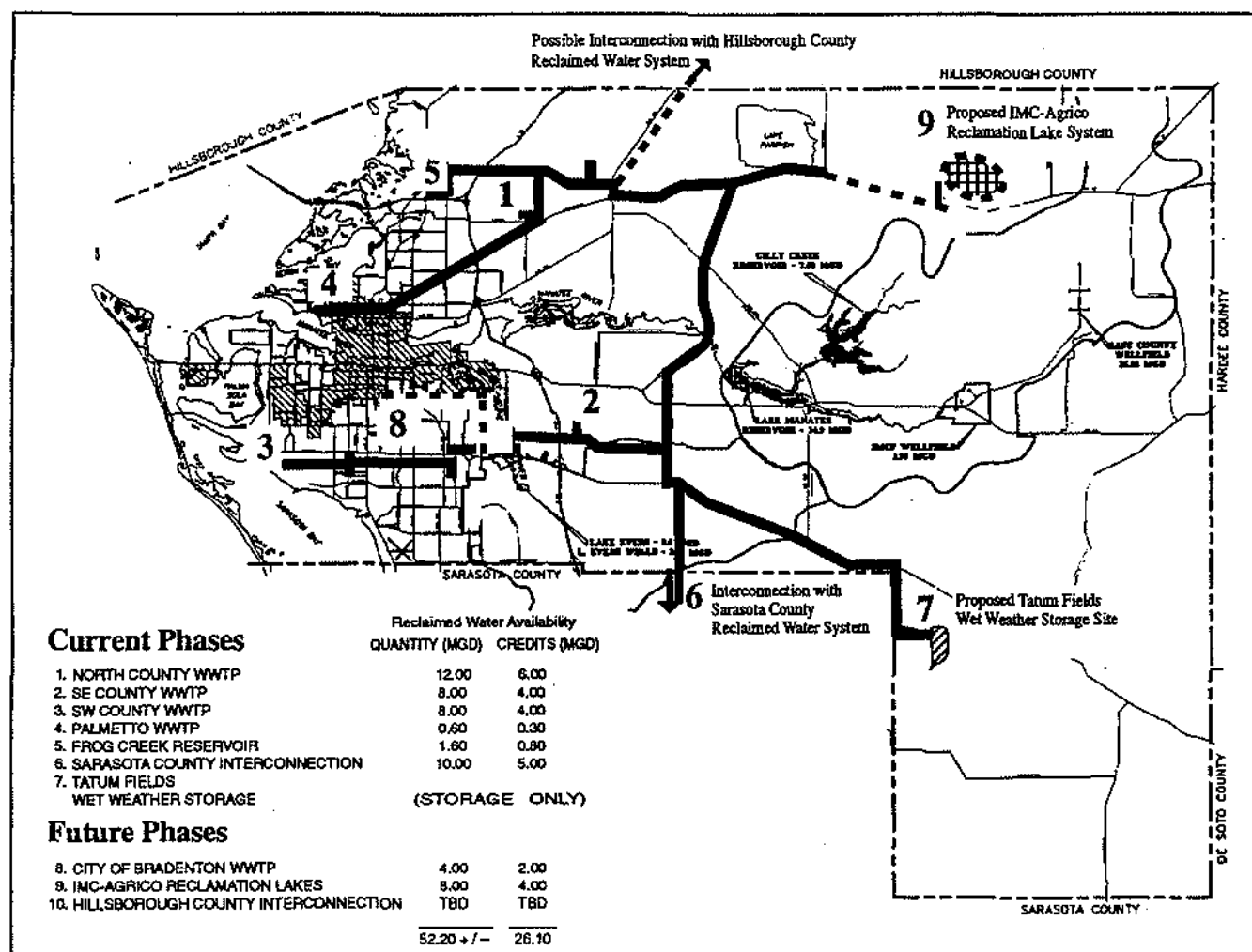


Figure 6. New water source initiative alternative source implementation options, Manatee County.

Geophysical logging, specific capacity tests, and visual inspection of drilling cuttings will be used to determine a favorable storage zone at the site. Once the storage zone has been determined and the necessary wells have been installed, a series of cycle tests will be performed to assess the storage zone's capacity to store reclaimed water. The purpose of these tests is to determine what percentage of the stored water can be recovered before either water quality deteriorates or aquifer drawdowns become great enough to require shutting down the recovery system. An additional purpose of the testing is to ensure that the stored water doesn't migrate an appreciable distances prior to recovery. More than one cycle test is generally necessary to determine if the percentage of recovered water increases as residual water from previous cycles accumulates.

Details of the well drilling and cycle testing program have not been finalized at this time. Final plans will be contingent on FDEP requirements. However, it is anticipated that at a minimum of one monitoring well in the storage zone, one in the aquifer below the confining unit of the storage zone, and one in the aquifer above the confining unit of the storage zone will be necessary. The scope of work includes the design and construction of the necessary piping, recovery pumps, electrical systems, and wellhead valve assemblies. A 30" reclaimed water supply main is located nearby and will be utilized to supply the necessary water for injection.

Project Benefits:

- Demonstrate the feasibility of reclaimed water ASR in the state of Florida;
- Provide the means to fully utilize reclaimed water throughout the year;
- Allow storage of excess wet season reclaimed water for use during the dry season;
- Increase utilization of reclaimed water at the Southwest WWTP from an annual rate of 4 mgd to 12 mgd.

The MARS Project, The Right Alternative

The Manatee Agricultural Reuse Supply project is, without question, the right alternative for the development of alternative water sources in the Southern Water Use Caution Area. Here's why:

- Reuse of reclaimed water will reduce demand for groundwater, reduce surface water pollution, preserve potable water supplies, and prevent salt water intrusion.
- Manatee County is a recognized leader in reuse and has demonstrated success in previous projects supported by the Manasota Basin Board and SWFWMD.
- Manatee's geography and agricultural base is ideal for reuse.
- In addition to reuse of reclaimed water, the MARS Project also demonstrates the viability of stormwater reuse projects to reduce pollution loads on our bays, improve flood control and make alternative water available for beneficial reuse.
- The MARS Project will incorporate alternative source considerations into future reclamation plans for the IMCF NE Manatee Tract making additional surface water available for beneficial use by 2020.
- The impact of the MARS Project will be regional in scope. The District is working with Manatee and Sarasota Counties to consider an interconnection between reclaimed water distribution systems being developed in both counties.
- The MARS Project will reduce existing groundwater withdrawals in the Eastern Tampa Bay Water Use Caution Area.

Hunsicker

- The MARS Project can be effectively implemented in a relatively short period of time. Future phases to extend reclaimed water lines to additional agricultural acreage and incorporate additional surface water impoundments are under study (see Fig. 6).

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ESTIMATED NITROGEN FLUXES AND NITROGEN-CHLOROPHYLL RELATIONSHIPS IN TAMPA BAY, 1985-1994

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ABSTRACT

Cultural eutrophication driven by anthropogenic nutrient loadings has been identified as a priority problem affecting the water quality of Tampa Bay. Bay management programs therefore wish to control future nutrient loads, an effort that will be complicated by the continuing population growth projected for the watershed in coming decades. The eutrophication management effort is "resource-based," seeking to maintain water clarity in the bay that is adequate to support seagrasses at target acreage levels. Among the factors affecting water clarity, anthropogenic nitrogen loadings and corresponding increases in phytoplankton density appear most amenable to management.

A two-pronged (mechanistic and empirical) water quality modeling approach has been used to develop nitrogen budgets for the bay to support the eutrophication management effort. The two models are driven by the same estimated hydrologic and nitrogen loadings to provide maximum comparability.

Although external loadings are the ultimate source of the nitrogen present in Tampa Bay, the mechanistic water quality model suggests that under current conditions annual nitrogen fluxes associated with estuarine regeneration, recycling and transport processes are larger than annual external loadings. Phytoplankton bioassay data, analyses of measured primary production rates and nitrogen standing stocks, and water quality trends observed in the bay following recent reductions in point source loadings, appear to corroborate the model-based flux estimates. Taken together, the available information suggests that watershed management practices which cause small year-to-year reductions in external nutrient loadings (relative to the size of the existing internal fluxes) may not have immediately detectable effects on bay water quality. If sustained over a number of years, however, management efforts which continue to produce small annual reductions in external loadings should provide water quality improvements by reducing the sizes of the internal nitrogen pools available to support phytoplankton growth.

BACKGROUND

Cultural eutrophication—an unnatural increase in the water body's trophic state driven by anthropogenic nutrient loads—has been identified as a priority problem affecting the water quality of Tampa Bay (Federal Water Pollution Control Administration 1969, Johansson 1991, TBNEP 1996). The Tampa Bay National Estuary Program and other bay management initiatives are therefore attempting to develop strategies for controlling future nutrient loadings, in order to protect water quality despite the increasing population growth, urbanization and other forms of development that are projected to occur in the watershed in coming decades (TBNEP 1996). The eutrophication management effort is "resource-based," seeking to achieve and maintain adequate water clarity to allow seagrass meadows to expand to the acreage levels observed in the bay during the early 1950s (Janicki and Wade 1995; Greening, Morrison et al., this volume).

Reductions in water clarity, as a result of elevated concentrations of phytoplankton and other turbidity sources, have contributed to losses of estuarine seagrass meadows on a worldwide basis (e.g., Giesen et al. 1990, Batiuck et al. 1992, Dennison et al. 1993, Morris and Tomasko 1993, Dixon and Leverone 1995). Over the long term, plants that do not receive adequate sunlight to allow the rate of photosynthetic production to exceed respiration will cease growing and eventually die, leading to reduced seagrass acreage in estuaries where anthropogenic nutrient loadings cause significant reductions in water clarity. In addition to reduced light availability due to increased phytoplankton growth, other water quality-related factors (e.g., shading by epiphytes and drift macroalgae, direct nitrogen toxicity) have been suggested as possible contributing factors in some estuarine seagrass declines.

Recent research indicates that *Thalassia testudinum*, the seagrass species for which water quality goals and nitrogen loading targets are being set in Tampa Bay, requires an annual average of 20–25% of subsurface irradiance for long-term survival in the bay (Dixon and Leverone 1995). In order to restore and maintain seagrass meadows at target depths in different bay segments, these results indicate that water quality in each segment should be sufficient to allow 20–25% of the sunlight which penetrates the water surface to reach the target depth. Light penetration through the water column of Tampa Bay is primarily affected by three factors: phytoplankton density, non-phytoplankton turbidity, and water color (Janicki and Wade 1995). Among these factors, phytoplankton cell density (as measured by chlorophyll-*a* concentration) appears most amenable to management. Water color, which is caused by the presence of dissolved organic compounds in the rivers and streams that flow into the bay, is a natural source of light attenuation to which bay organisms are presumably adapted. Non-phytoplankton turbidity, which is caused by a number of factors including natural estuarine physicochemical processes and natural and anthropogenically induced resuspension of bay sediments, does not appear susceptible to management using current technologies. Chlorophyll-*a* concentrations, however, can be managed by altering the loadings of nutrients (particularly nitrogen) that are discharged to the bay as a result of human activities in the watershed (Johansson 1991, Janicki and Wade 1995, TBNEP 1996).

A 1991 water quality modeling workshop sponsored by the TBNEP recommended implementation of a multi-pronged (empirical and mechanistic) modeling approach to provide technical support for the water quality management process (TBNEP 1996). In accordance with that recommendation, the TBNEP has funded the development of an empirical, regression-based water quality model (Janicki and Wade 1995, 1996) and the Southwest Florida Water Management District's Surface Water Improvement and Management (SWIM) program has funded the application of a mechanistic model (Martin et al. 1996) to Tampa Bay. To ensure comparability, the two models simulate the same ten-year time period (1985–1994) and are driven by the same estimated hydrologic and nutrient loadings (Zarbock et al. 1994, Janicki and Wade 1995, Zarbock et al. 1996). The intent of this approach is that two complementary water quality models, which are based on the same hydrologic and nutrient loadings but very different technical assumptions and mathematical modeling approaches, will be available to serve as cross-checks for one another during the development of water quality and nutrient loading targets.

As summarized by Greening, Morrison et al. (this volume), the following steps are being used by the TBNEP and other resource management programs to develop seagrass-based targets for light attenuation, chlorophyll-*a* concentrations, and nitrogen loadings to Tampa Bay:

- 1) Identify acreage and depth targets for seagrasses in each bay segment;
- 2) Identify the light requirements of target seagrass species (e.g., 20–25% of subsurface irradiance for *Thalassia testudinum*);
- 3) Estimate levels of water column transparency (e.g., light attenuation coefficient, Secchi disk depth) necessary to ensure that adequate sunlight reaches target depths;
- 4) Estimate chlorophyll-*a* concentration targets that are consistent with water column transparency targets; and
- 5) Estimate nitrogen loading targets that are consistent with chlorophyll-*a* targets.

This report describes the empirical and mechanistic models used in steps (4) and (5) of the target-setting process, and the nitrogen loading estimates used by the models to simulate the spatial and temporal dynamics of bay water quality.

NITROGEN LOADING ESTIMATES

Estimated monthly nitrogen loadings were developed for the period 1985–1994 by Zarbock et al. (1994, 1996) and Janicki and Wade (1995, 1996), based on the following categories of potential sources:

- general nonpoint sources (stormwater runoff and base flow),
- point sources (domestic and industrial facilities, springs),
- atmospheric deposition falling directly on the bay surface,
- groundwater inputs (with the exception of spring discharges),
- losses of fertilizer products during handling at shiploading facilities, and
- reported spills resulting from other (primarily industrial) human activities.

For comparative purposes, loading estimates were also developed for a “benchmark” less-impacted period (c. 1940) in the recent past, for a potentially more-impacted period (c. 2010) in the near future, and for a “worst-case” period of severe anthropogenic impacts which occurred in the late 1970s prior to the implementation of more stringent treatment levels at a number of municipal wastewater treatment plants and industrial (e.g., fertilizer processing) facilities (Johansson 1991; Zarbock et al. 1994, 1996; Janicki and Wade 1995, 1996).

Annual loading estimates for total nitrogen (TN) during each of these periods are summarized in Figure 1 for four major Tampa Bay segments (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay and Lower Tampa Bay). The estimated annual loadings show a very large (>400%) increase between the benchmark and worst case periods, a substantial (62%) decline between the worst case and present-day periods, and a projected 7% increase between the present-day and 2010 periods. The latter increase in predicted load is driven primarily by the anticipated growth rate of the human population within the Tampa Bay watershed and airshed (Zarbock et al. 1996).

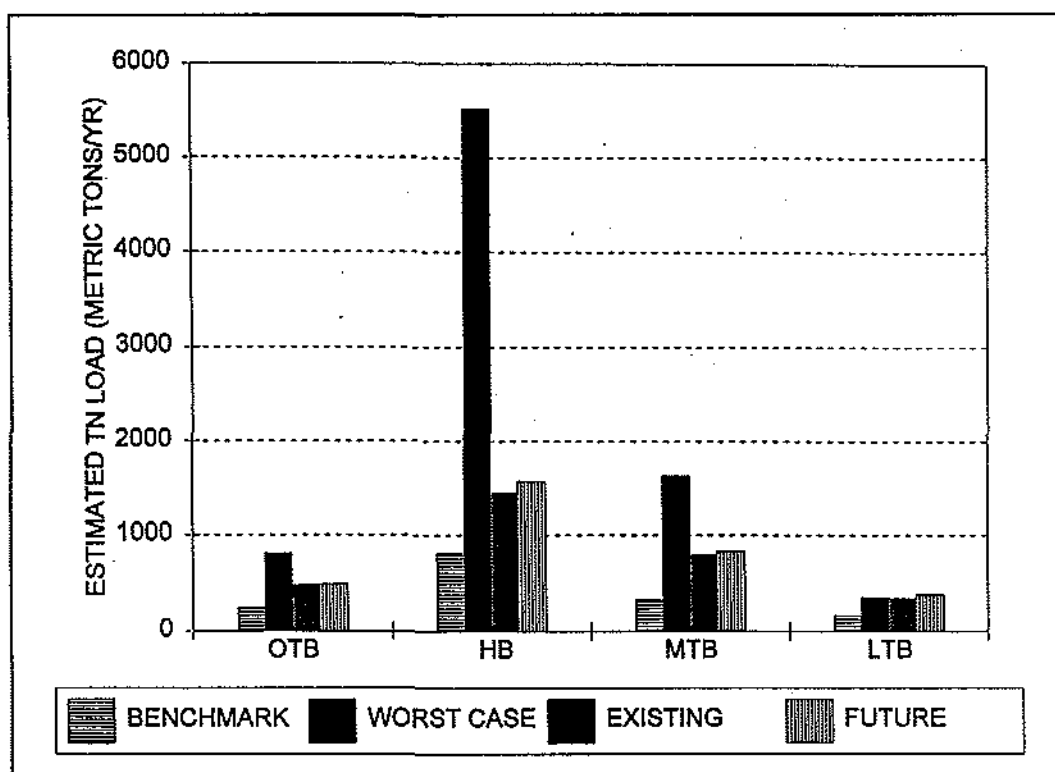


Figure 1. Estimated total nitrogen (TN) loadings to Tampa Bay segments under "benchmark" (c. 1940), "worst case" (c. 1979), "present day" (1985-1994) and projected future (2010) conditions. Source: Zarbock et al. 1994, 1996.

CHLOROPHYLL-*a* AND WATER CLARITY TRENDS

The Environmental Protection Commission (EPC) of Hillsborough County has collected monthly data describing chlorophyll-*a* concentrations and water clarity (Secchi disk depth) levels at 52 sites in Tampa Bay since 1974 (Boler 1995). Annual average values of these parameters are shown for the four largest bay segments in Figure 2.

Throughout the period 1974-1995, chlorophyll-*a* concentrations have been highest in Hillsborough Bay (HB), intermediate in Old Tampa Bay (OTB) and Middle Tampa Bay (MTB), and lowest in Lower Tampa Bay (LTB)(Fig. 2). Particularly high concentrations were observed in HB during the period 1974-1982, and marked reductions occurred in the three upper bay segments (HB, OTB, and MTB) between the early 1980s and early 1990s. These reductions in chlorophyll-*a* concentration, which are thought to have been due primarily to reduced nitrogen loadings from domestic and industrial point source discharges (Johansson 1991, Boler 1995), appear to have begun one year earlier in HB (1983) than in OTB and MTB (1984). Apparent concentration trends in LTB, a bay segment whose water quality is influenced to a particularly large degree by tidal exchange with the Gulf of Mexico, are more difficult to discern, although there is some indication of a weak increasing chlorophyll-*a* trend during the period 1974-1983, a reduction during 1984, and fluctuations around an average value of approximately 5 $\mu\text{g/L}$ during the period 1984-1995.

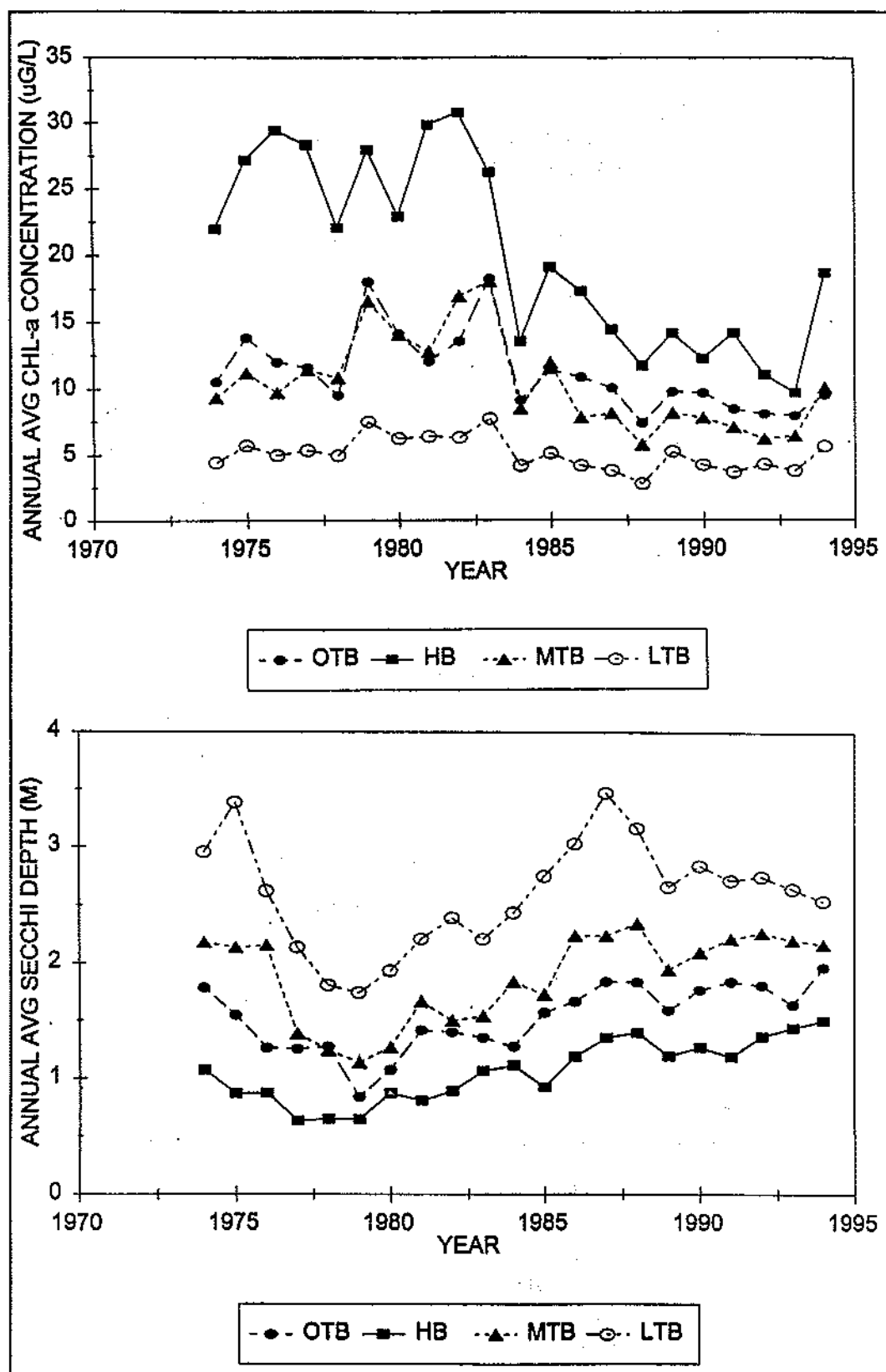


Figure 2. Time series of annual chlorophyll-*a* concentrations (top) and Secchi disk depths (bottom) in four major bay segments (OTB, HB, MTB, LTB), 1974–1995. Source: Boler 1995.

In general, trends in water clarity (Secchi disk depth) observed in these bay segments since 1974 have tended to mirror trends in chlorophyll-*a* concentrations, declining from 1974 through 1979 and increasing from 1980 through 1995 (Fig. 2). Plotting the annual average Secchi disk depths versus the annual average chlorophyll-*a* concentrations produces evidence of a curvilinear inverse relationship which can be linearized by log-transforming the chlorophyll-*a* concentration values (Fig. 3).

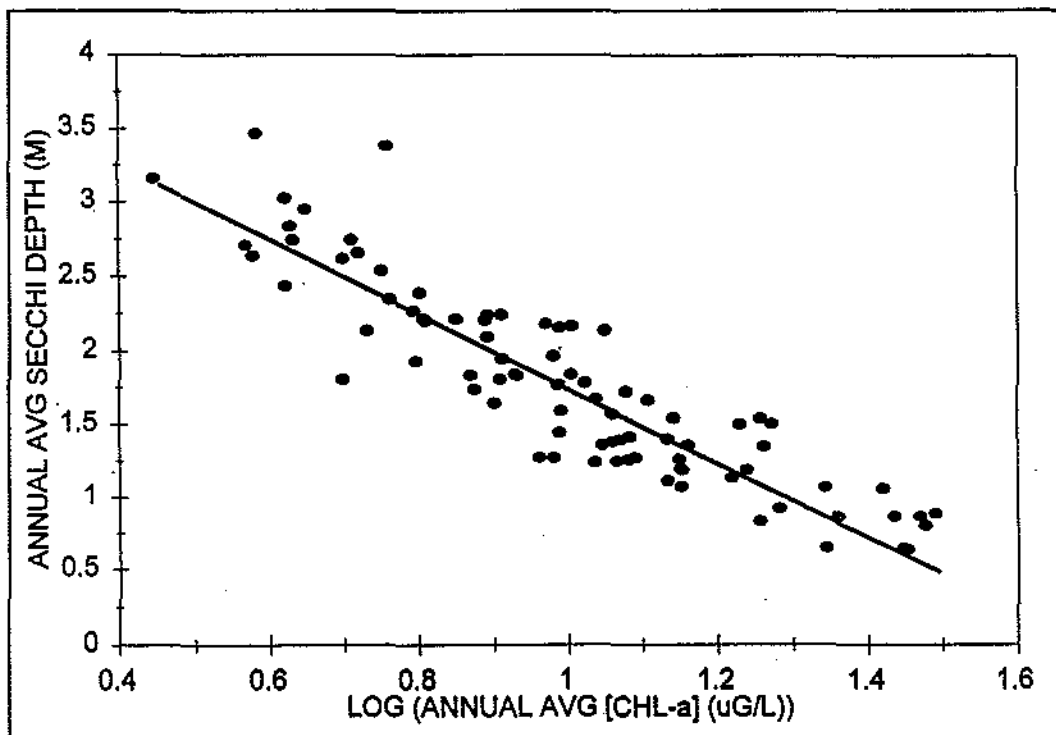


Figure 3. Relationship between annual average Secchi disk depth and annual average chlorophyll-*a* concentration in four major bay segments (OTB, HB, MTB, LTB) during the period 1974–1995. Regression line: Secchi depth = $4.2 - 2.4(\log[\text{Chl-a}])$, $R^2 = 0.82$. Source: Boler 1995.

RELATIONSHIP BETWEEN WATER CLARITY AND CHLOROPHYLL-*a* CONCENTRATION

Janicki and Wade (1996) used regression analysis to relate monthly EPC water clarity measurements to monthly chlorophyll-*a* concentrations in the four largest bay segments (HB, OTB, MTB, and LTB). Least squares regression methods were used to estimate parameters for the equation:

$$\ln(C_{t,s}) = \alpha_{t,s} + \beta_s [\ln(Z_{t,s})]$$

where $C_{t,s}$ = average chlorophyll-*a* concentration at month t and bay segment s ,
 $Z_{t,s}$ = the depth to which 20.5% of subsurface irradiance penetrates at month t and bay segment s , and
 $\alpha_{t,s}$, β_s = regression parameters.

An R^2 value of 0.67 was obtained for this model, using monthly (EPC) data from HB, OTB, MTB, and LTB (Janicki and Wade 1996). The intercept term of the regression was allowed to vary between months to avoid potentially confounding effects of seasonality in the independent and dependent variables.

RELATIONSHIPS BETWEEN CHLOROPHYLL-*a* CONCENTRATION AND NITROGEN LOADING Empirical Model

For the period 1985–1994, Janicki and Wade (1995, 1996) also used regression analysis to relate monthly EPC chlorophyll-*a* measurements to the monthly nitrogen loading estimates developed by Zarbock et al. (1994). A series of steady-state equations was used to model the intersegmental transport of water and nitrogen, where net transport rates were estimated based on observed salinity data and freshwater inflow estimates (Janicki and Wade 1996). The nonconservative behavior of nitrogen was accounted for in the intersegmental transport rates through a comparison of observed EPC nitrogen concentrations and nitrogen concentrations predicted based on the steady-state equations alone.

The estimated overall nitrogen loads (i.e., nitrogen loads from external sources and internal estuarine processes) to individual bay segments were related to observed chlorophyll concentrations using the regression model:

$$C_{t,s} = \alpha_{t,s} + \beta_s L_{t,s}$$

where $C_{t,s}$ = average chlorophyll-*a* concentration at month t in bay segment s ,
 $L_{t,s}$ = overall nitrogen load at month t to bay segment s , and
 $\alpha_{t,s}$, β_s = regression parameters.

An overall R^2 value of 0.69 was obtained using this relationship.

Mechanistic Model

For the period 1985–1994, Martin et al. (1996) used the U.S. EPA's "water analysis simulation program" (WASP) model to relate monthly (EPC) chlorophyll-*a* measurements to the monthly nitrogen loading estimates developed by Zarbock et al. (1994, 1996). WASP is a dynamic, compartment-based ("box") modeling program which incorporates time-varying processes such as point and non-point source nutrient loadings, boundary exchanges, advection, dispersion, phytoplankton growth and respiration, microbial nutrient transformations, particle settling, and benthic nutrient releases to simulate water quality responses to changing nutrient loads (Ambrose and Martin 1990, Martin et al. 1990). The model is based on the principle of mass conservation, and divides the water body under study into a set of comparably-sized "boxes" or segments within which water quality conditions are relatively homogeneous. Masses of water, nutrients, and other constituents of interest which enter a segment either exit the segment by physical transport and chemical or biological transformation or accumulate within the segment. For water bodies represented by a series of segments, transport can occur between segments or across the system's boundaries. Through detailed bookkeeping of the simulated movement of constituents between segments and accumulation within segments, the model

computes predicted concentrations and fluxes of the water quality constituents of interest.

The eutrophication component of the model simulates the transport and transformations of up to eight state variables representing four interacting systems (phytoplankton kinetics, phosphorus cycle, nitrogen cycle, and dissolved oxygen balance) by solving a general mass balance equation for each state variable. The eutrophication state variables and interactions included in the model are summarized in Figure 4.

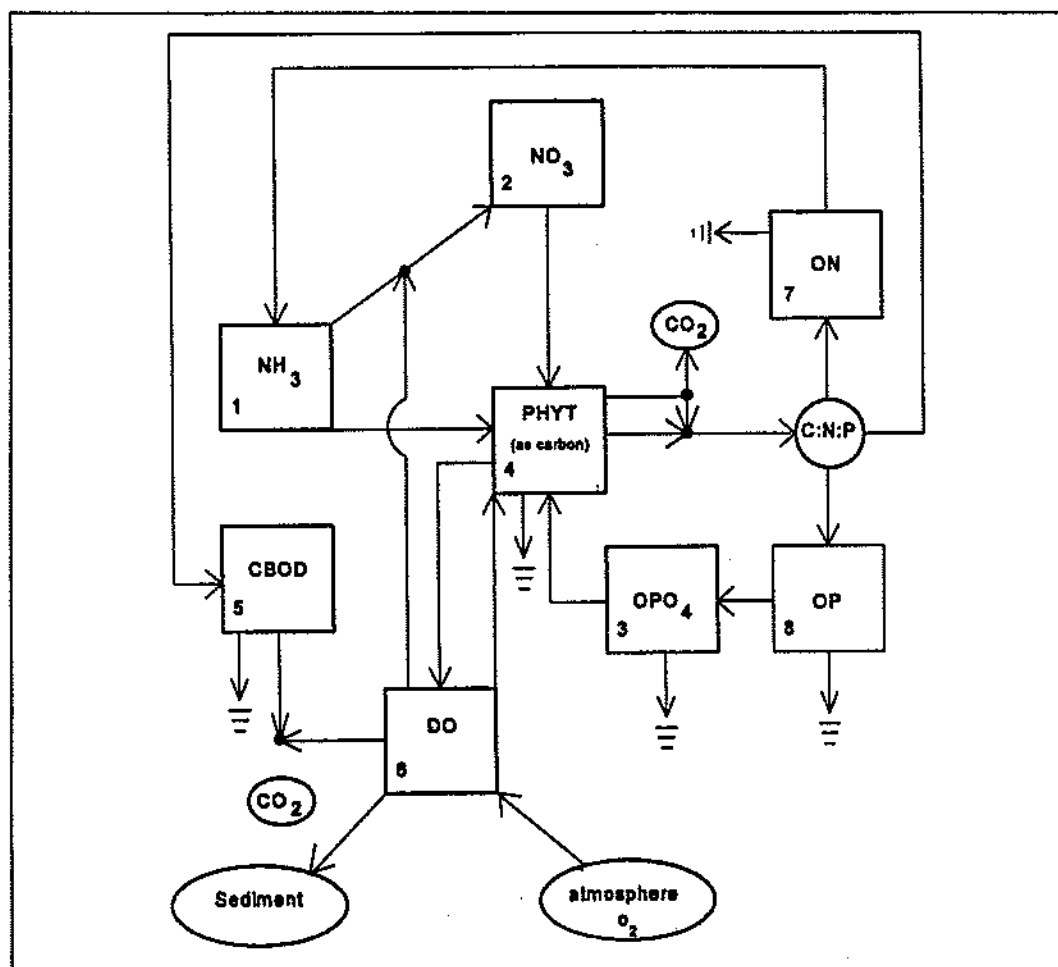


Figure 4. WASP model state variables and simulated interactions. Source: Martin et al. 1996.

Phytoplankton growth is simulated in the WASP model using a postulated maximal growth rate and computed "multipliers" which may range in value from zero (no algal growth) to one (maximal algal growth) depending on the simulated availability of light (photosynthetically active radiation) and the macronutrients nitrogen and phosphorus. The computed multipliers for these factors, from a representative subset of model segments in OTB, HB, MTB, and LTB, are shown in Figure 5. The computed multipliers indicate that light availability is the primary factor limiting phytoplankton growth rates in the Tampa Bay model.

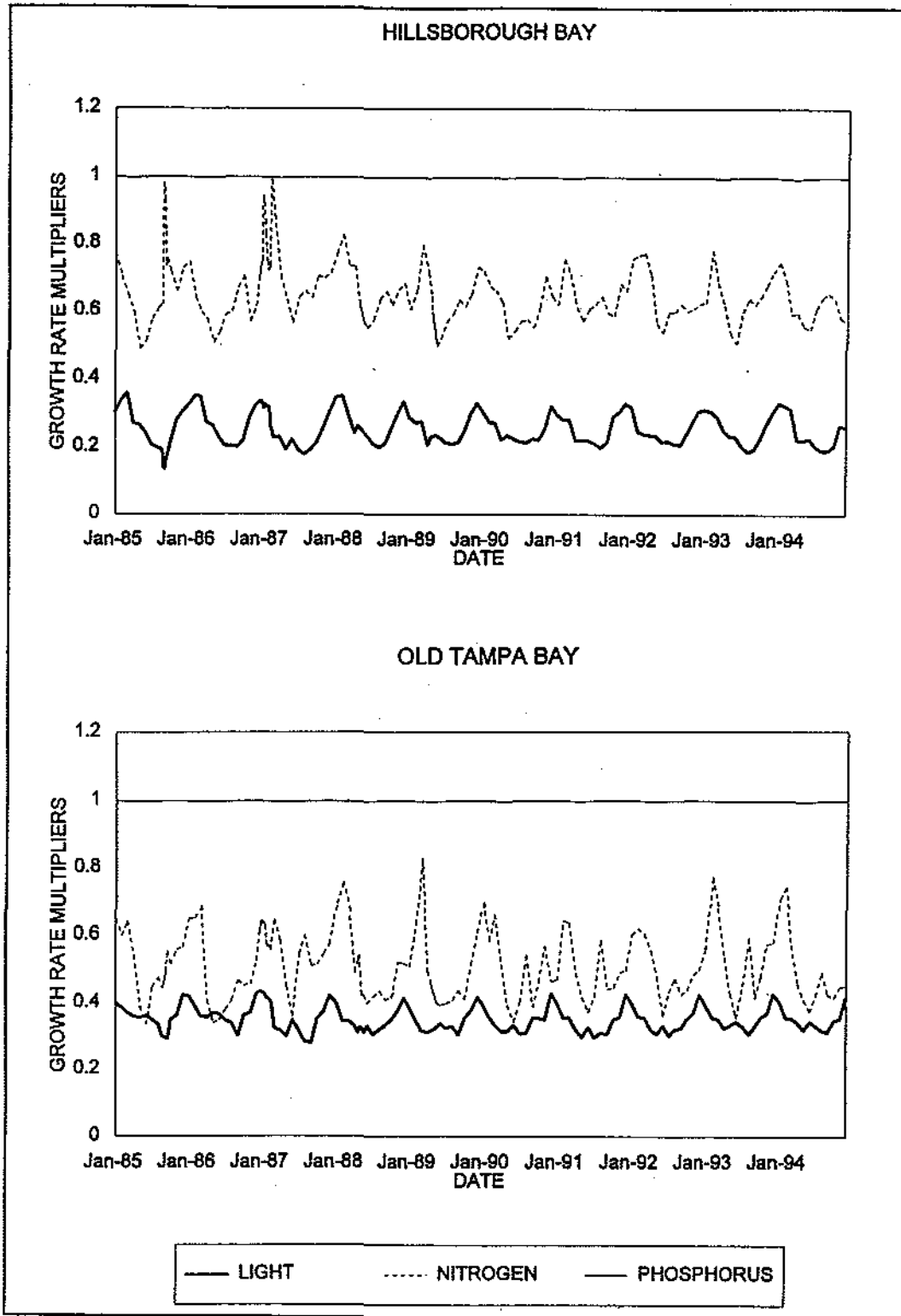


Figure 5. Predicted algal growth multipliers for macronutrients (N, P) and light in selected Tampa Bay model segments. Source: Martin et al. 1996.

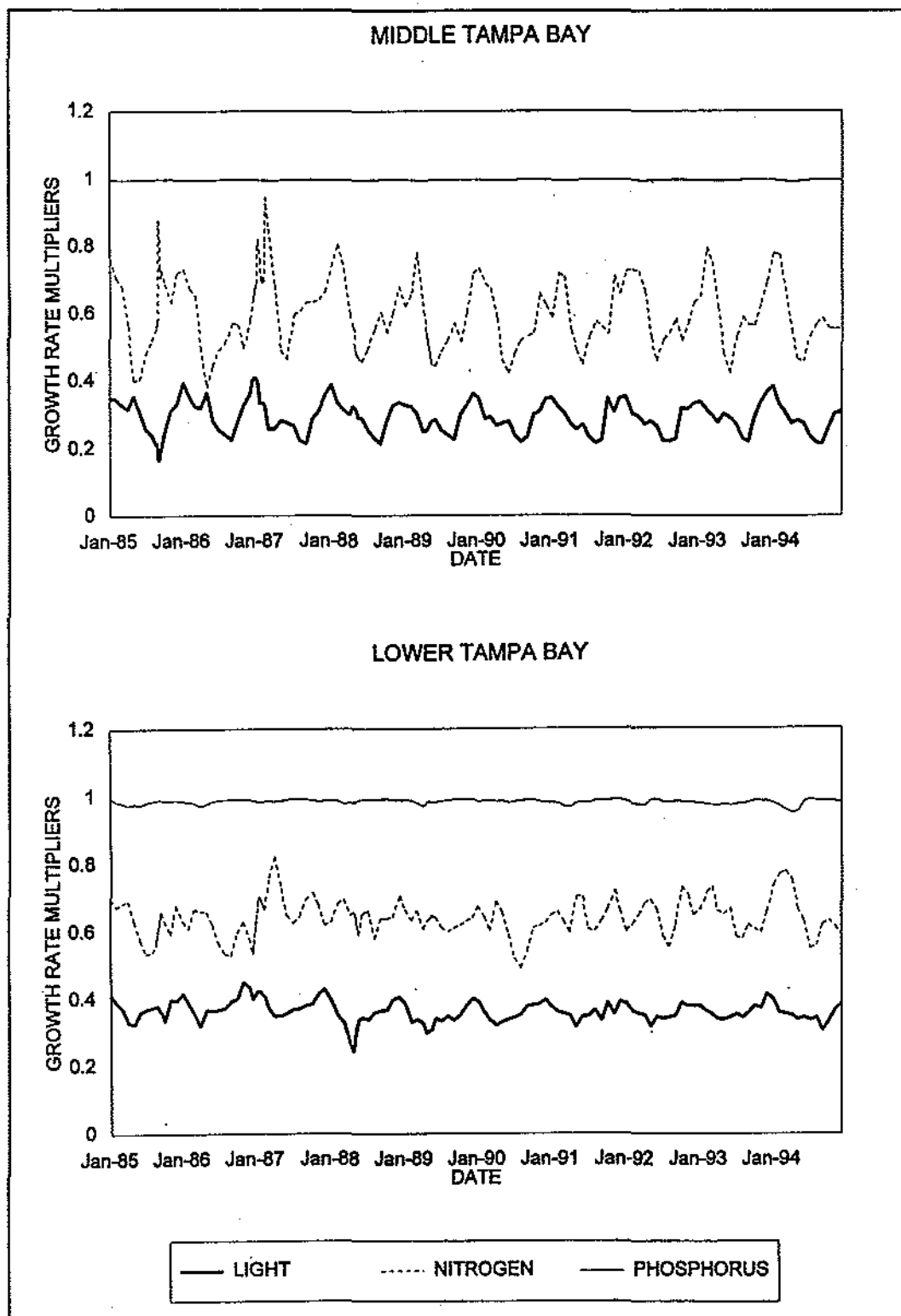


Figure 5 continued. Predicted algal growth multipliers for macronutrients (N, P) and light in selected Tampa Bay model segments. Source: Martin et al. 1996.

Although light appears to be the chief limiting factor in this model application (Fig. 5), the model also predicts a positive relationship between nitrogen loading and chlorophyll-*a* concentration within the bay (see Figure 6 below). Simulated increases in inorganic nitrogen loadings, such as those that occurred in Tampa Bay as a result of ammonia spills during 1985 and 1987, also produced substantial increases in model-predicted phytoplankton growth rates and chlorophyll-*a* concentrations (Martin et al. 1996). These responses indicate that nitrogen availability plays an important role in determining phytoplankton growth rates within the model (Martin et al. 1996). Phosphorus is present in sufficiently high concentrations in all modeled bay segments that its availability does not appear to limit phytoplankton growth.

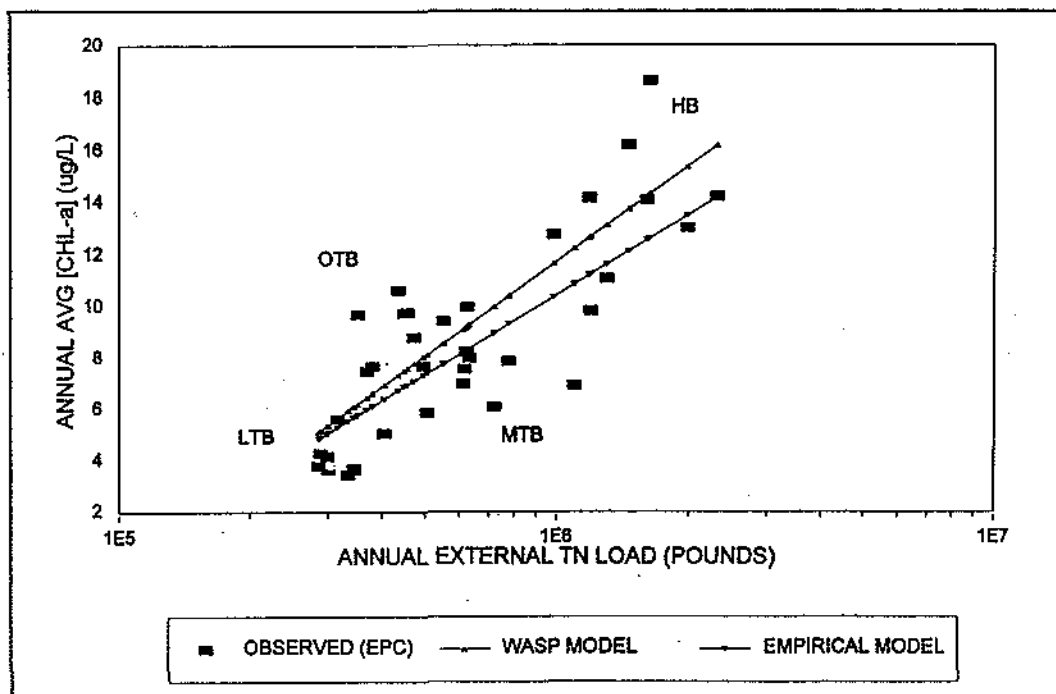


Figure 6. Observed and model-predicted relationships between annual TN loading and annual average chlorophyll-*a* concentration in major Tampa Bay segments, 1986–1994 (1985 omitted due to gaps in measured chlorophyll-*a* values). Regression equations: (empirical model) chlorophyll-*a* = $-51.67 + 4.49(\log \text{ TN load})$, $R^2=0.66$; (WASP model) chlorophyll-*a* = $-61.74 + 5.32(\log \text{ TN load})$, $R^2=0.61$. Sources: Boler 1995; Janicki and Wade 1996; Martin et al. 1996.

Comparison of Model Predictions:

Chlorophyll-*a* Concentration vs Total Nitrogen Load

Observed and model-predicted relationships between annual average chlorophyll-*a* concentrations and estimated annual nitrogen loadings for the four largest bay segments are shown in Figure 6. At the annual time scale Hillsborough Bay received the largest estimated TN loadings and produced the highest observed chlorophyll-*a* concentrations, while Lower Tampa Bay was the site of lowest external loadings and chlorophyll-*a* concentrations. Old Tampa Bay and Middle Tampa Bay exhibit intermediate values of both parameters. Relationships predicted by the empirical and WASP models were summarized by regressing predicted (average annual) chlorophyll-*a* concentrations against predicted annual nitrogen loadings. In general, both models

appear successful in describing the relationship between estimated total nitrogen loadings and chlorophyll-*a* concentrations observed in the major bay segments during the 1985–1994 period of interest (Fig. 6).

SIMULATED NITROGEN FLUXES

The detailed bookkeeping performed by the WASP model as part of its mass balance calculations also allows the user to estimate the simulated fluxes (in units of mass/time) of nitrogen forms and other water quality constituents within and between model compartments. These flux estimates can be used provide insights regarding interactions that exist between external nutrient loadings, advective and dispersive transport, and internal regeneration and recycling (e.g., through algal and microbial food webs) in the Tampa Bay model. To the extent that the model resembles the actual bay, such insights may prove helpful to resource managers in the development of water quality management targets and strategies.

Total Nitrogen

Simulated annual fluxes of total nitrogen for the four largest bay segments (HB, OTB, MTB, and LTB), averaged over the period 1985–1994, are shown in Figure 7. Major sources of total nitrogen for the water column include the annual external load from the watershed, and microbial and benthic processes which recycle nitrogen within the water column and between the water column and the underlying sediments. The major loss term for the water column is advective and dispersive transport, which moves nitrogen (in the form of algal cells and particulate and dissolved nitrogen) between bay segments and between the bay and the Gulf of Mexico. When summed over the four segments, the estimated annual loss of total nitrogen via advective and dispersive transport (15,400 metric tons/year) is about 4.5 times larger than the estimated annual load (3,400 metric tons/year) received from the watershed, suggesting that the overall mass of nitrogen in the bay may be relaxing to a lower level following several decades of unusually large external loadings.

Phytoplankton growth and respiration processes represent a small loss term for each bay segment, which is the (net) difference between the inorganic nitrogen removed from the water column by growing algal cells and the (primarily) organic nitrogen returned to the water column as a result of cell respiration and death. The fact that the estimated net flux due to phytoplankton growth and respiration processes is negative presumably reflects a permanent loss of some phytoplankton-associated nitrogen from the water column each year as a result of transport from the system or deep burial in the sediments.

Summation of these fluxes produces a relatively small (1,500 metric tons/year) net loss term, indicating that, on average, the mass of total nitrogen in the modeled water column of the largest bay segments declined by this amount annually during the period 1985–1994.

Inorganic Nitrogen

The total nitrogen fluxes shown in Figure 7 include several nitrogen (e.g., organic nitrogen) forms which are not readily available to phytoplankton to support cell growth and associated changes in water-column chlorophyll-*a* concentrations. Because

phytoplankton cells preferentially remove dissolved inorganic nitrogen (e.g., nitrate, ammonia) from the water column to support growth, fluxes of inorganic nitrogen may be more relevant than total nitrogen fluxes for Tampa Bay management efforts.

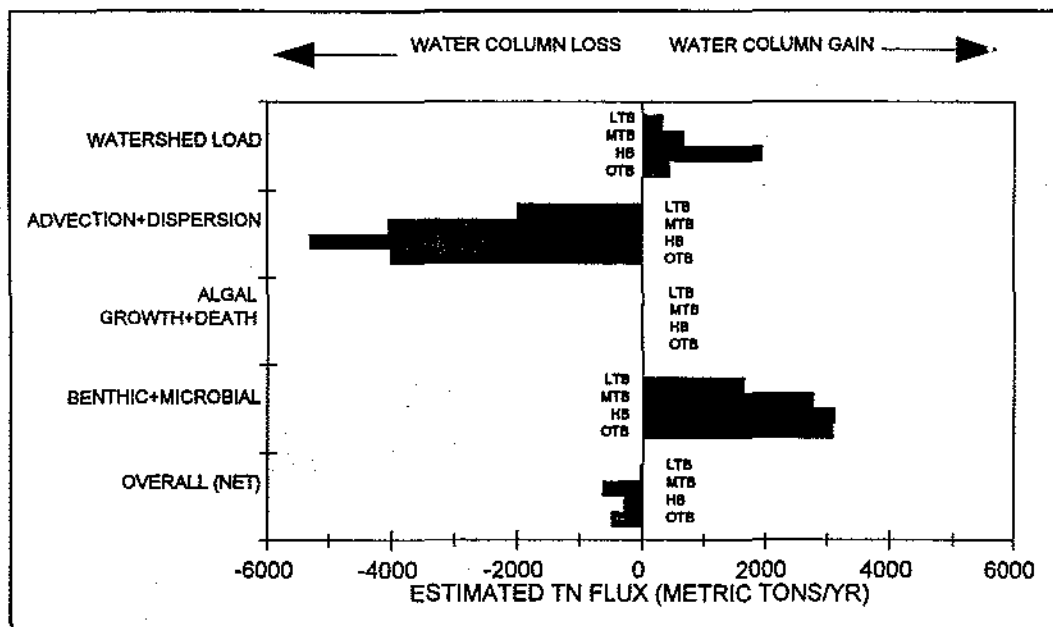


Figure 7. Annual fluxes of total nitrogen estimated by the WASP model. Source: Martin et al. 1996.

Simulated annual fluxes of dissolved inorganic nitrogen for the four largest bay segments, averaged over the period 1985–1994, are shown in Figure 8. Benthic and microbial processes which transform organic nitrogen to inorganic nitrogen and release it to the water column represent the major water column source term (58,900 metric tons/yr). Among these processes, microbial mineralization of organic nitrogen to ammonia, and benthic ammonia releases, contribute the highest flux rates. Estimated fluxes due to nitrification are an order of magnitude smaller than those associated with ammonia production, a model result which may explain the large ammonia:nitrate ratios typically observed in the water column of Tampa Bay. Estimated external loadings of inorganic nitrogen from the watershed represent a relatively minor source term (2,300 metric tons/yr).

Phytoplankton uptake represents the major loss term for inorganic nitrogen from the water column (60,300 metric tons/yr), while advective and dispersive transport cause minor losses (2,300 metric tons/yr). Simulated losses via denitrification are small (20 metric tons/yr).

Although external loadings from the watershed and airshed represent the bay's ultimate source of nitrogen, the comparable magnitudes of the microbial/benthic source term (58,900 metric tons/yr) and the phytoplankton-uptake loss term (60,300 metric tons/yr) suggest that microbial and benthic processes are providing most of the inorganic nitrogen fueling phytoplankton growth on an annual basis.

Summation of the estimated fluxes produces a small net loss term (1,300 metric tons/year), the model's estimate of the annual change in the mass of inorganic nitrogen present in the water column of the four largest bay segments during the period 1985–1994.

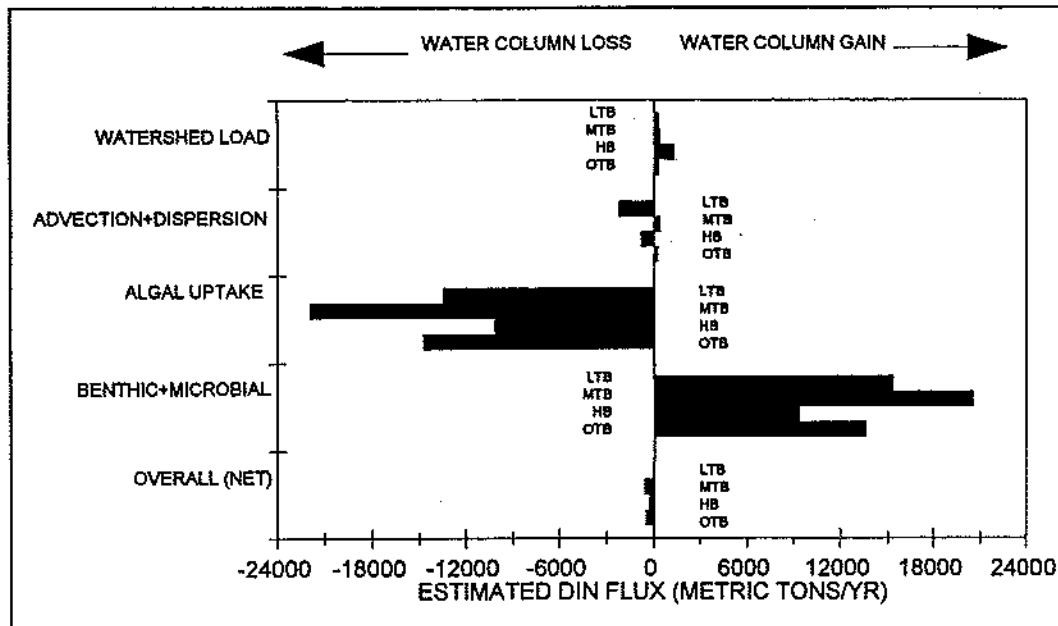


Figure 8. Annual fluxes of inorganic nitrogen estimated by the WASP model. Source: Martin et al. 1996.

BIOASSAY RESULTS

Rodriguez (1991) examined potential nitrogen limitation in Tampa Bay and the 12 ppt salinity zone of the Little Manatee River by performing monthly nitrogen addition bioassays using water samples from the two systems. Her results demonstrated linear relationships between the final yield of chlorophyll-*a*, particulate carbon, and particulate nitrogen over a range of inorganic nitrogen additions. Additional examination of Rodriguez's (1991) data, including corrections for chlorophyll-*a* generated using ambient inorganic nitrogen present in the water samples, produced highly significant linear relationships between annual average chlorophyll-*a* yields and nitrogen additions (Vargo 1996) (Fig. 9). Yield per unit nitrogen addition was greater in the Little Manatee River than in the Tampa Bay bioassays, primarily because of higher yields during the wet season, but the difference is not significant. Yields observed in the monthly bioassays varied seasonally at both locations (Fig. 10). Chlorophyll yield during the summer wet season was lower than during the winter dry season in the Tampa Bay bioassays, while the opposite was true for the Little Manatee River samples. Yields ranged from 0.08 to 2.9 $\mu\text{g Chl}/\mu\text{M}$ nitrogen added, with median values of 1.0 and 1.96 $\mu\text{g Chl}/\mu\text{M}$ nitrogen for the Tampa Bay and Little Manatee River samples, respectively. These values are comparable to estimates from a variety of other systems (e.g., Thomas 1970, Graneli 1978, Gowan et al. 1992). Rodriguez's (1991) results provide experimental support for the model-based hypothesis that nitrogen is the primary limiting nutrient in Tampa Bay (and the 12 ppt salinity zone of the Little Manatee River), as well as

demonstrating a direct relationship between inorganic nitrogen inputs and changes in chlorophyll-*a* concentration.

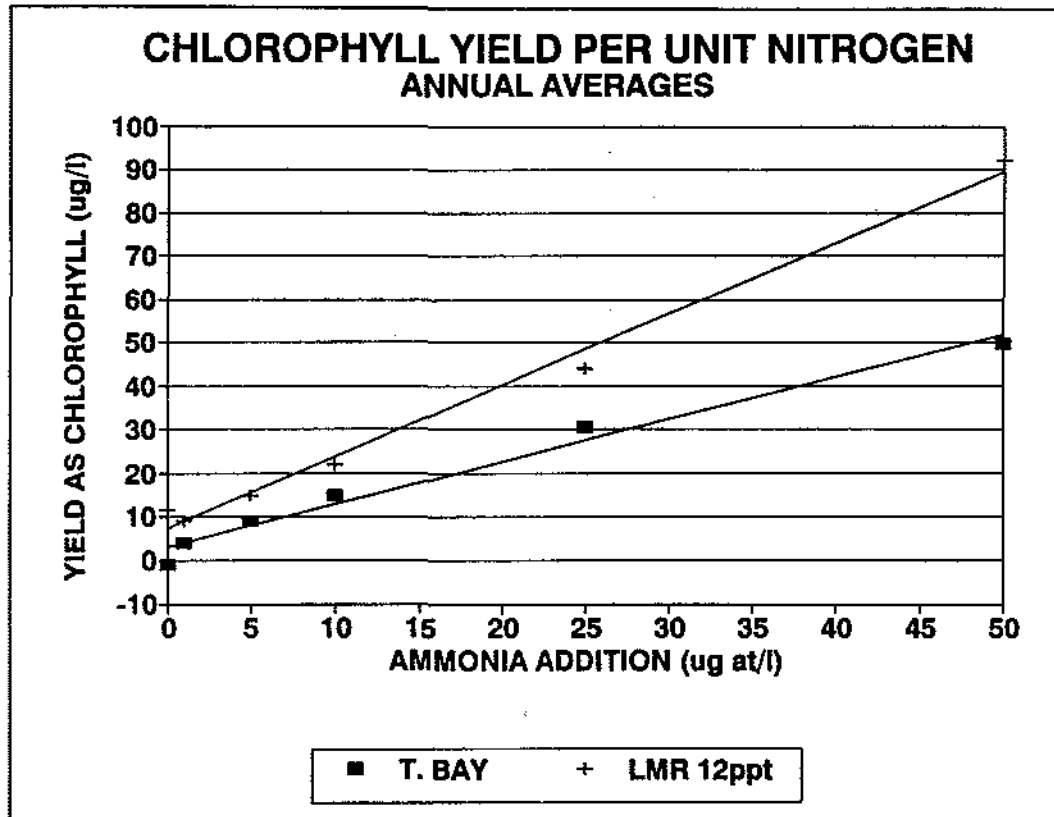


Figure 9. Relationships between the annual average chlorophyll yields and added ammonia concentration determined in laboratory bioassays using natural water samples. Regression equations: (Tampa Bay) $\text{Yield} = 3.09 + 0.98(N)$, $R^2 = 0.98$; (Little Manatee River) $\text{Yield} = 7.41 + 1.64(N)$, $R^2 = 0.99$. Source: Rodriguez 1991; Vargo 1996.

A second element in conceptualizing the response of Tampa Bay phytoplankton populations to external nitrogen loadings is an understanding of the relative proportions of available nitrogen contributed by external loadings and estuarine regeneration and recycling processes. One method of estimating these values, based on WASP model output, is shown in Figure 8. As an independent assessment, Vargo (1996) used a conversion factor [$\text{DIN} = 0.47(\text{TN})$] to convert the estimated annual total nitrogen (TN) loadings reported by Morrison (1992) to dissolved inorganic nitrogen (DIN) loadings. These estimated dissolved inorganic nitrogen loadings were then compared to the nitrogen masses estimated to be necessary to support measured nitrogen uptake (Vargo et al. 1993), primary production (Johansson et al. 1985), and dissolved inorganic nitrogen standing stocks (based on EPC monitoring data). As shown in Table 1, the estimated dissolved inorganic nitrogen loads appear to provide a relatively low and highly variable fraction (0.9% to 17%) of the nitrogen required to support the phytoplankton populations observed in the water column of Tampa Bay. The remaining nitrogen required to support water column phytoplankton production appears to be supplied by the regeneration of inorganic nitrogen through

microbial and benthic processes within the estuary. At a conceptual level, results of the bioassay experiments and associated analyses by Rodriguez (1991) and Vargo (1996) thus tend to corroborate the model-based flux estimates shown in Figure 8.

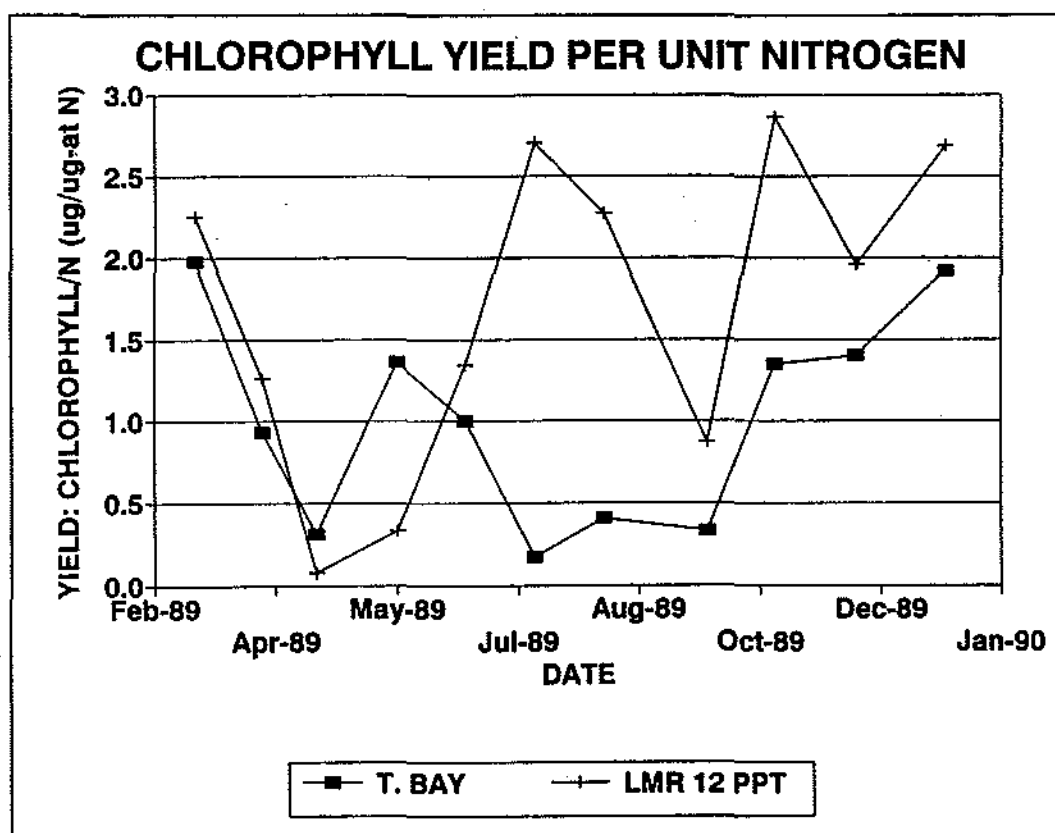


Figure 10. Monthly values of chlorophyll-*a* yield (μg) per unit nitrogen (μM) for bioassay samples from Tampa Bay (TB) and the 12-ppt salinity zone of the Little Manatee River (LMR). Source: Rodriguez 1991.

RESOURCE MANAGEMENT IMPLICATIONS

The fact that estimated annual nitrogen loads during the period 1985–1994 (Fig. 1) have remained substantially larger than the estimated “benchmark” (ca. 1940) values, despite the very large load reductions that occurred between 1979 and 1985 (Johansson 1991), reflects the magnitude of human population growth that has taken place in the watershed and airshed since the benchmark period. Annual nitrogen loads are projected to increase an additional ~7% bay-wide between the 1985–1994 period and the year 2010 (Fig. 1), a trend which, if continued over time, will make a substantial amount of additional nitrogen available to support increased chlorophyll-*a* concentrations (Fig. 6) and reduced water clarity levels (Fig. 3) in the bay in future years.

Results from the mechanistic water quality model (Fig. 8) and empirical studies (Table 1) suggest that the mechanisms underlying observed relationships between nitrogen loading rates and chlorophyll-*a* concentrations in the bay are relatively complex. Only a small proportion of the phytoplankton standing stock (as estimated by chlorophyll-*a*

concentration) observed in the bay at any given time appears to be supported by loadings of "new" nitrogen recently delivered from the watershed. A much larger proportion is apparently supported by the regeneration of inorganic nitrogen within the bay, through microbial and benthic pathways, from pools of recycled organic nitrogen. Taken together, the modeled flux rates and bioassay results imply that short-term changes in external nitrogen loads, particularly if they are small relative to the size of the internal nitrogen pools and occur following a prolonged period of elevated loadings, may not produce immediately detectable changes in chlorophyll-*a* concentrations. An example of this situation appears to have occurred in the bay during the period 1980–1983. Although the City of Tampa's municipal wastewater treatment plant at Hookers Point upgraded to advanced wastewater treatment nitrogen discharge standards in 1979, producing a marked reduction in annual nitrogen loadings to Hillsborough Bay (Johansson 1991), reductions in chlorophyll-*a* concentrations were not observed until 1983 in Hillsborough Bay and 1984 in other bay segments (Fig. 2). As noted by Johansson (1991), the observed lag between nitrogen load reduction and chlorophyll-*a* response appeared to represent the time period necessary for the bay's internal processes to equilibrate to the new level of nitrogen input following several decades of quite elevated anthropogenic loads.

Table 1. Nitrogen requirements and nitrogen loadings for three regions of Tampa Bay. Loadings calculated as total nitrogen (TN) or dissolved inorganic nitrogen (DIN = 0.47[TN]).

SEGMENT	PROCESS	METRIC TONS/YEAR				
		N REQUIRED ^a	N LOADINGS ^b TN DIN	STANDING STOCK ^c DIN	PERCENT REQUIREMENT MET ^c TN DIN	
HB	N uptake ^a	8520	983 462		11.5	5.4
			3060 1440		35.7	16.9
	1° prod. ^d	8200			11.9	5.6
				1780	37.3	17.5
						26-81
MTB	1° prod.	8600	550 260		6.4	3.0
			2530 1190		29.4	13.8
LTB	N uptake	21210	450 210		2.1	0.9
			2470 1160		11.6	5.4
	1° prod.	6900			6.5	3.0
		12700			3.5	9.1
				2610		8-44

^aCalculated from C:N ratio of 5.7:1 by weight for primary production values (Vargo 1996). N uptake rates from Vargo et al. 1993.

^bEstimated loadings from Morrison (1992), representing high and low flow years.

^cFrom Vargo 1996.

^dRange of primary production values from Johansson et al. 1985.

Unlike short-term fluctuations in external nitrogen loads, sustained directional (increasing or decreasing) loading changes which are sufficient to alter the sizes of the internal nitrogen pools should produce changes in bay water quality that are observable over time. External loads from the watershed and airshed represent the ultimate source of the nitrogen present in the internal pools, and the water quality improvements observed in the bay during the 1980s (Fig. 2) have demonstrated the system's long-term responsiveness to sustained directional loading changes.

Unfortunately, neither the empirical nor mechanistic water quality models addressed here are capable of simulating long-term changes in some internal flux rates (e.g., sediment nutrient release rates) that would be expected to occur in response to long-term changes in external loadings. This problem is not unique to the Tampa Bay modeling effort, and while efforts to model estuarine sediment/water column interactions have been initiated and improved in recent years, accurate prediction of long-term interactions, and the availability of data to test the accuracy of model predictions, remain problematic. Because of this limitation, it should not be assumed that the available Tampa Bay models will provide unbiased predictions of water quality conditions (e.g., chlorophyll-*a* concentrations, Secchi disk depths) in the bay following long-term increases or decreases in nitrogen loadings. In fact, because both models are calibrated to current (1985-1994) conditions, when nitrogen concentrations in the bay appear to be relaxing to lower levels following several decades of elevated external loads, their predictions concerning future water quality conditions may contain some inherent bias. Because neither model actively simulates changes in sediment nutrient exchange rates, both must assume that today's rates (for which the models are calibrated) will continue into the future. In reality, however, a prolonged period of increasing external loads would presumably cause (after some time lag) an increase in sediment release rates, while a prolonged period of declining external loads would eventually cause sediment release rates to fall. As a result, both models may tend to underestimate the water quality benefits that would occur as a result of long-term load reductions as well as the negative water quality impacts that would occur as a result of long-term load increases. This is a potentially important issue from a water quality management perspective, and should be kept in mind when interpreting any long-term predictions generated by the models. Relatively frequent model recalibration (e.g., on a three- to five-year cycle) would be helpful to reduce the likelihood that an inherent model limitation might contribute to an incorrect watershed management decision.

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CONTRIBUTION OF ATMOSPHERIC DEPOSITION TO NITROGEN AND TOXIC MATERIALS LOADINGS TO TAMPA BAY

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ABSTRACT

Coastal waters around the United States receive large quantities of nutrients and toxic materials from various sources—including the air. As recently as 1991, scientists and resource managers assumed that atmospheric deposition had minimal effect on water quality in Tampa Bay. However, recently completed nitrogen loading estimates now suggest that up to 27% of the nitrogen entering the bay comes from wetfall and dryfall directly deposited to the bay's surface alone, making this source second only to stormwater as the largest bay nitrogen loading source. The occurrence of heavy metals, pesticides, PAHs and PCBs in bulk deposition samples appears to be linked to localized activities rather than long range transport, while patterns of bulk nitrogen deposition indicate both localized and non-local sources.

The relationship between emissions sources and deposition in the Tampa Bay area is the subject of ongoing studies being conducted through a joint effort between EPA's Great Waters Program, the Tampa Bay National Estuary Program, Florida DEP Air Management Department, and the Air Quality divisions of Hillsborough and Pinellas counties. Questions to be addressed with results from ongoing studies include: 1) how much of the nitrogen and toxic materials emitted annually from sources within the Tampa Bay watershed are subsequently deposited in the bay or its watershed? 2) what are the relative contributions of remote vs. local air pollution sources of NO_x and toxic materials to deposition in the watershed? and 3) what are the relative contributions of mobile and stationary sources of NO_x and toxic materials to deposition in the watershed?

BACKGROUND

The relative importance of atmospheric deposition to the environmental condition of Tampa Bay has only recently been recognized. In 1991, bay scientists and managers participating in a Tampa Bay National Estuary Program (TBNEP) workshop to define priority issues affecting the bay's environment described atmospheric deposition as "unknown, but thought to be of minor importance" (Ramsay and Boynton 1992).

Since 1991, new information now indicates that atmospheric deposition is a major source of both nitrogen and some pollutants, particularly metals, to Tampa Bay and its watershed. As in many new areas of research, however, more questions have been raised than answered. An update of findings since 1991, and a description of ongoing work on atmospheric deposition follows.

Nitrogen Deposition

As an element of the resource-based management approach adopted by TBNEP partners at the initiation of the Tampa Bay program (Greening et al. 1997), a nitrogen loading budget which included atmospheric deposition was developed in 1994 and updated in 1996 (Zarbock et al. 1994, 1996a). For these loading estimates, only nutrients delivered to the open water of the estuary were accounted for as atmospheric input.

Precipitation volume (rainfall amount times the open water area of the bay) and nutrient concentration data as recorded at the National Atmospheric Deposition Program site located at Verna Wellfield were used to estimate nitrogen loads delivered to the surface of the bay as wetfall or rainfall (Zarbock et al. 1994). Dryfall loads (airborne pollutants) were estimated using wetfall estimates multiplied by a regionally-derived estimate of a ratio of 2.04 (wetfall to dryfall) as calculated by the Florida Acid Deposition Study (Environmental Science and Engineering 1987).

Results of the nitrogen loading budget estimate that up to 29% of the nitrogen entering the bay comes from wetfall and dryfall directly deposited to the Bay's surface, making this source second to only stormwater as the largest bay nitrogen loading source (Fig. 1; Zarbock et al. 1994, 1996a). If analyses include atmospheric deposition to the surrounding watershed, which enters the bay as stormwater, EPA-sponsored studies indicate that as much as 67% of the total nitrogen load delivered to the bay originates from atmospheric deposition (Patwardhan and Donigian 1995). About 1,100 tons of nitrogen are deposited on the open bay each year, and an estimated 6,600 tons fall on the watershed (Zarbock et al. 1994).

Major sources of atmospheric nutrients include stationary sources such as power plants, other industries and incinerators, and mobile sources, mainly automobiles but including trucks, buses and boats. Nationwide, combined manmade emissions from motor vehicles and power plants contributed almost 70% of the total nitrogen oxides (NO_x) that were deposited in 1984. Industrial sources provided another 15%. The remaining 15% was generated from natural sources (Fisher et al. 1988). In the Tampa Bay region, stationary sources (primarily power plants) contribute an estimated 70% of the manmade NO_x emissions as compared to 30% from motor vehicles (Florida Department of Environmental Protection 1994).

Toxic Materials Deposition

Atmospheric deposition of toxic contaminants is also estimated to be substantial for some materials. Using literature values collected locally (when available) and from other parts of the country, Frithsen et al. (1995) estimated deposition rates of potentially toxic metals (including cadmium, copper, lead, zinc and mercury), pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

Results of the Frithsen et al. (1995) study indicate that atmospheric deposition is a major contributor of cadmium (46% of all sources), chromium (13% of all sources), copper (18% of all sources), iron (11% of all sources) and lead (12% of all sources). Atmospheric deposition was not found to be a large contributor to other metals of concern; however, the only known source of PCBs was estimated to be atmospheric deposition (Frithsen et al. 1995).

In 1995–1996, Dixon et al. (1996) collected bulk atmospheric deposition data at seven locations for a one-year period throughout the watershed. One objective of the study was to evaluate the spatial distribution of atmospheric deposition of nitrogen, metals and other contaminants to a standardized surface. Integrated weekly samples were collected and analyzed for copper, lead, zinc, aluminum, inorganic and organic

nitrogen, and total phosphorus. Pesticides, PAHs and PCBs were analyzed at five of the seven stations for a 12-week period. Figure 2 shows the distribution of stations throughout the watershed.

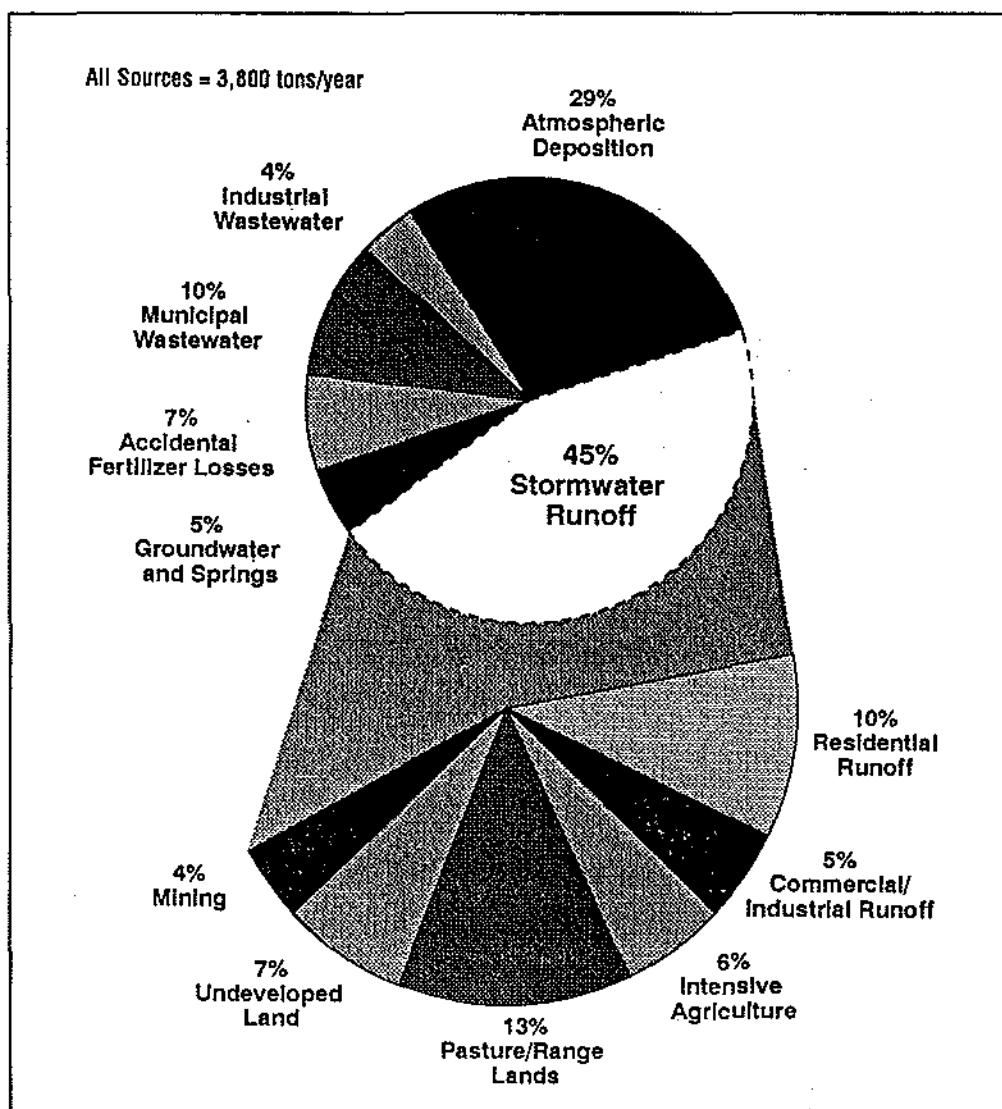


Figure 1. Sources of total nitrogen to Tampa Bay, 1992-1994 (Zarbock et al. 1996).

Weekly deposition rates were significantly different among stations for some parameters, and annual loads of total nitrogen varied by a factor of 1.4 across the watershed. Annual direct deposition of total nitrogen to the bay was estimated by the bulk deposition study to be 32%; for phosphorus, estimates of direct atmospheric loads were 5% of bay totals. The urbanized stations received many of the highest loadings of copper, lead and zinc, indicating localized anthropogenic sources. Loadings estimated from the bulk deposition study indicated that atmospherically derived copper, lead and zinc consisted of 11%, 3% and 8%, respectively, of total bay loads (Dixon et al. 1996).

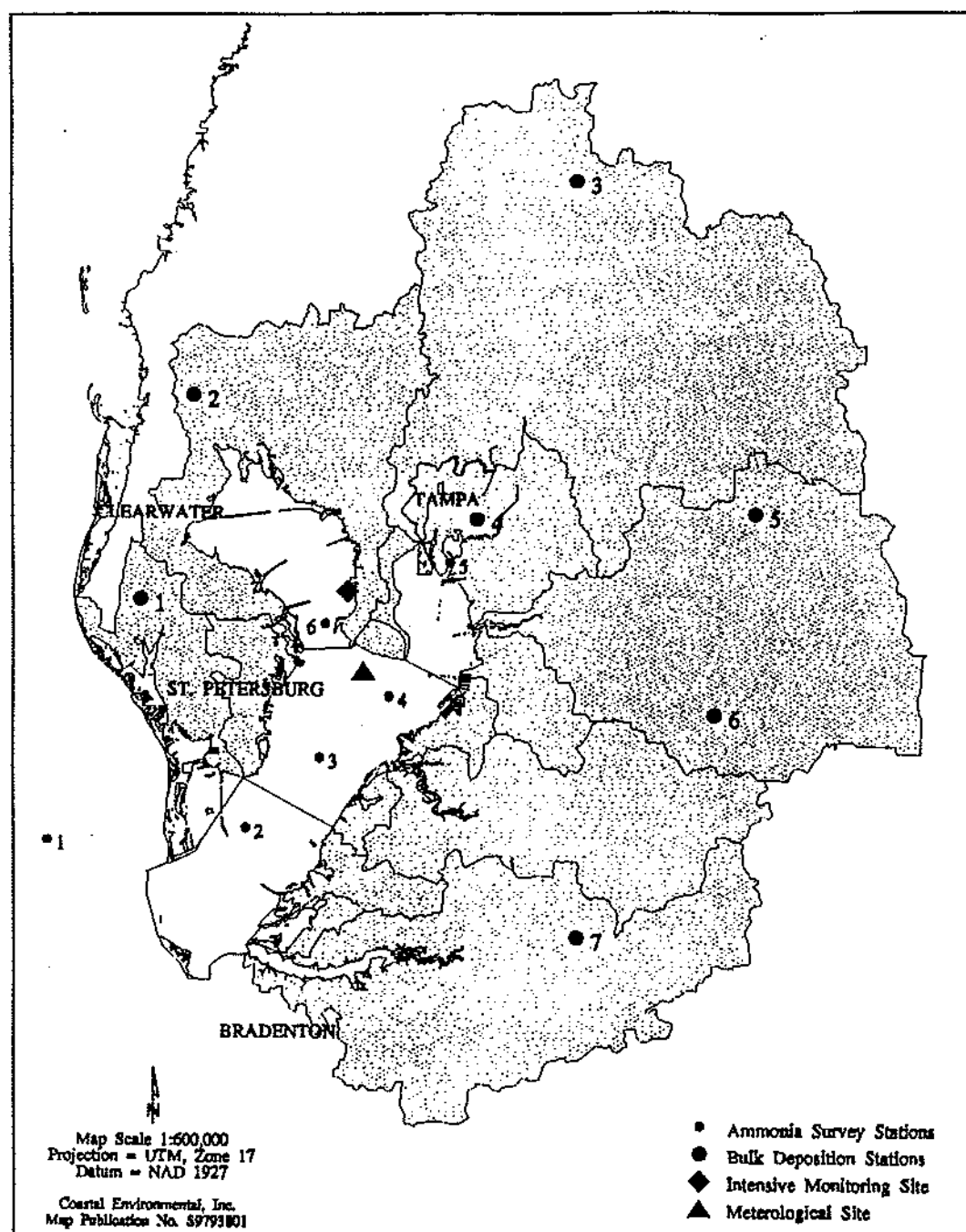


Figure 2. Location of bulk deposition collection sites, ammonia survey stations (1-6), the intensive site at the Gandy Causeway, and the meteorological monitoring site in Tampa Bay (Dixon et al. 1996; Greening and Squires 1997).

The occurrence of pesticides in the bulk samples was linked to localized activities (primarily agricultural) rather than long-range transport. Chlordane and dieldrin, the most abundant pesticides in the 1970s, were not detected during this 12-week sampling period. Total DDT (DDT plus DDD and DDE) loadings were about 20% of those reported in the 1970s. Endosulfans were the most abundant pesticides in this study. Annualized chlorinated pesticide atmospheric loading to Tampa Bay was about

one-third of previous estimates; however, the winter and spring growing season was not sampled. Overall, the occurrence of heavy metals, pesticides, PAHs and PCBs in bulk deposition samples appears to be linked to localized activities rather than long-range transport, while patterns of bulk nitrogen deposition indicate both localized and non-local sources (Dixon et al. 1996).

INITIATION OF THE TAMPA BAY ATMOSPHERIC DEPOSITION STUDY

To further address issues defined in the nitrogen and toxic materials input budgets, TBNEP, in collaboration with the counties of Hillsborough, Pinellas and Manatee and the Florida Department of Environmental Protection, requested that the Tampa Bay area be included as an EPA Great Waters Program—a program designed specifically to examine the impacts of air quality on water quality in the nation's waterbodies. Specific issues to be addressed in Tampa Bay are: 1) to estimate extent of water quality impacts from atmospheric deposition both directly to the bay's surface and via stormwater runoff; and 2) to identify sources of atmospheric nitrogen and toxic materials deposited in the bay and its watershed. The request was approved by the EPA Great Waters Program, and the Tampa Bay Atmospheric Deposition Study (TBADS) was initiated in spring 1995.

In July 1995, TBADS participants reviewed the existing technical knowledge of atmospheric deposition in the Tampa Bay watershed and developed specific objectives (phrased as questions) for TBADS. Questions/objectives were developed for nitrogen and toxic materials deposition as follows:

Nitrogen Deposition

Rationale: Seagrass light requirement/chlorophyll/nitrogen loading relationships show the need for "holding the line" or slight reduction of controllable sources of nitrogen. Need for management over time will increase as population levels increase. Atmospheric deposition contributes a significant amount of total nitrogen loading to Tampa Bay (Greening, Morrison et. al., this volume).

The TBADS participants identified the following specific questions concerning atmospheric deposition of nitrogen as important to be considered during the 3-year study:

1. What is the relative contribution of various nitrogen species to nitrogen loading from deposition?
2. What is the relative contribution from wet vs. dry deposition?
3. What is the relationship between NO_x and ammonia, organic nitrogen, and nitric acid?
4. What fraction of nitrogen loading in stormwater delivered to the bay is derived from atmospheric deposition? Specifically, determine estimated watershed transfer coefficients and retention rates of nitrogen originating as deposition in the watershed.
5. What are the specific sources of nitrogen species of concern? What are the relative importance of stationary, mobile and natural sources, and what role does internal recycling of nitrogen play in the bay's nitrogen budget?

6. What are the locations of sources affecting the watershed? Determine relative importance of local vs. regional sources.

Toxic Contaminants Deposition

Rationale: Literature reviews and data indicate that atmospheric deposition of some contaminants may be important sources to sediment contamination in defined "hot spot" areas of the bay (Frithsen et al. 1995; Zarbock et al. 1996b).

The TBADS workshop participants identified the need to more fully understand the relative importance of toxic contaminants in Tampa Bay prior to more detailed work on atmospheric deposition of contaminants. Specific questions which remained to be addressed included the following:

1. At what scale are sediment contamination problems evident?
2. Is there a surface area gradient of contamination?

If identified sediment contamination problems can be linked to specific types of contaminants, then characterize:

3. What fraction of toxic loading of contaminants of concern in stormwater is derived from atmospheric deposition?
4. What is the relative contribution of internal recycling?

ONGOING TBADS PROJECT ELEMENTS

As of December 1996, five elements of the recommended TBADS project have been initiated:

- Intensive monitoring of wet and dry deposition;
- Continuous monitoring of meteorologic data located at a within-bay station;
- Regional air mass movement modeling;
- Survey of atmospheric ammonia throughout the bay;
- Impacts of atmospheric deposition on stormwater quality.

A map depicting the intensive site, meteorologic site and ammonia deposition survey site locations is shown in Figure 2. The TBADS projects are cooperatively conducted by the following participants:

Tampa Bay National Estuary Program
USEPA Office of Air Great Waters Program
Florida Department of Environmental Protection, Air Management
Environmental Protection Commission of Hillsborough County Air Quality
Pinellas County Air Quality
Manatee County Air Quality
Florida Department of Transportation
Southwest Florida Water Management District
Hillsborough County Engineering Department
Pinellas County Department of Environmental Management
Manatee County Environmental Management

Initiation of Intensive Wet and Dry Deposition Station

Research has indicated that atmospheric deposition is an important nitrogen loading source through two primary mechanisms, wet deposition (primarily rainfall and dew)

and dry deposition (including aerosols and particulates). The components and processes of deposition, and the methods used to measure and/or estimate wet and dry atmospheric deposition are summarized below.

Wet Deposition

Components of wet deposition (Reuss and Johnson 1983) include strong acids (sulfuric, nitric), mineral acids (hydrochloric and phosphoric acids), organic acids (formic, acetic and carbonic acids), and cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+ and NH_4^+). Wet deposition is essentially the process of precipitation scavenging or the mechanisms that combine pollutants with water elements, followed by deposition of the resultant pollutant-laden form of precipitation to the ground. The water elements, or precipitation, may be in the form of rain, snow, ice and cloud droplets.

Estimates of nitrogen in wet deposition are relatively straightforward and simply involve the periodic (daily, weekly, monthly, etc.) collection of precipitation samples and the subsequent measurement of NH_4^+ and NO_3^- in those samples.

Dry Deposition

Elements of dry deposition include gaseous components of sulfur oxides (SO_x), nitrogen oxides (NO_x) and ammonia (NH_3), and particulate components of salts of any of the acid anions or basic cations. Dry deposition is the process by which particles, gases or aerosols settle, adsorb or attach onto surfaces. Dry depositional processes are highly dependent on aerodynamic factors, the surface-boundary layer, dewfall, surface effects and deposition to water surfaces. The rate of dry deposition will likely be much different in a pasture relative to a highly urbanized area with the latter's abundance of flat vertical surfaces available for attachment by particles and gases.

For the TBADS, dry deposition will be predicted by measuring concentrations of atmospheric nitrogen in the form of particles, aerosols and gases, and then multiplying those concentrations by the deposition velocity that is appropriate for the surface under consideration. Deposition velocities are determined by studies and models of the uptake of atmospheric nitrogen by particular types of surfaces.

Site Selection

Following examination of various site locations around the bay under selection criteria, a site located on Tampa Bay's Interbay Peninsula (known as the "Gandy Site") was recommended by local participants in TBADS and approved by NOAA/Great Waters participants. The Gandy Site currently houses an approved Hillsborough County air quality station, and therefore already has passed site selection criteria for state air quality standards. The Gandy Site has electricity and telephone hookups, a building on site for equipment housing, and is visited daily by County air quality staff.

Ongoing collections of wet atmospheric deposition and fine particulates to determine dry deposition to the surface of Tampa Bay have been conducted from the site since August 1996. The site is operated and serviced by air sections from the Environmental Protection Commission of Hillsborough County (EPCHC) and Pinellas County

Department of Environmental Management (PCDEM). The existing instrument array, in conjunction with meteorological measurements discussed below, will allow for the collection of samples that will enable estimates of both wet and dry atmospheric deposition to be made.

Wet Deposition Sampling

The collection of wet deposition is conducted daily at the Gandy Bridge site according to detailed protocols developed by the National Atmospheric Deposition Program Atmospheric Integrated Research Monitoring Network (NADP/AIRMoN), wet deposition component. Wet instrumentation/equipment includes a standard wet/dry bucket collector whereby the wet bucket opens, and the dry bucket closes, during periods of rainfall. No samples are analyzed from the dry bucket. Daily rain samples of 40 ml or more are collected, preserved and transported to an analytical laboratory for subsequent analyses. A rain gauge records the volume of rainfall and the time period rainfall occurs each day at the intensive site. Samples will be analyzed by the Central Analytical Laboratory of the Illinois State Water Survey utilizing the same analytical methods currently used on wet deposition samples for the NADP/AIRMoN program. Analytical results will include rainwater pH, specific conductance and concentrations (weight per unit volume of sample) of the following analytes: ammonium, calcium, chloride, magnesium, nitrate, orthophosphate, potassium, sodium and sulfate.

Fine Particulate Collection

Dry atmospheric particles are being sampled using specialized collectors of fine particulates in the atmosphere. The sampling instrumentation is a dual flow-through system consisting of annular denuders that scrub gaseous nitrate, sulfate and ammonia. After passing through the denuders, air flow passes into filter packs which trap particulate components of nitrate, sulfate, and ammonia on nylon filters. Dry samples will be collected for one 24-hour period every six days throughout the year. The denuders and filter packs will remain sealed and shipped to an analytical laboratory for analysis. The laboratory will provide results in terms of total weight of gaseous nitrate, sulfate and ammonia, as well as particulate nitrate, sulfate and ammonia.

The concentration of analytes collected with the fine particulate sampling apparatus alone will not allow for an estimation of dry deposition to be calculated. Dry deposition rates to the surface of Tampa Bay will be estimated using a bulk range exchange model provided by NOAA's Air Resources Laboratory. The model ("Buoy Model") utilizes meteorological data collected near the water surface of Tampa Bay and calculates the air/water transfer rate of hydroscopic compounds (HNO_3 , NH_3 , SO_2) for which transfer can be considered one-dimensional (i.e., downward).

Meteorological Monitoring

Meteorological data is provided from a meteorological instrument array established in Middle Tampa Bay (Fig. 2). Those data will serve as Buoy Model input parameters, and include day, hour, wind speed, air temperature, surface water temperature and percent relative humidity. Model output of a heat transfer coefficient enables the calculation of a deposition velocity for a given time step as follows:

$$V_d = (Dh)(U)$$

where: V_d = deposition velocity
 Dh = heat transfer coefficient
 U = wind velocity.

Calculation of Dry Deposition

The dry deposition flux to the surface water of Tampa Bay will then be calculated given the analyte concentration per unit volume of air (as derived from the fine particulate sampling) and the deposition velocity as follows:

$$F = (V_d)(C_a)$$

where: F = dry deposition flux
 V_d = deposition velocity
 C_a = atmospheric concentration of chemical analyte.

Total Atmospheric Deposition

The atmospheric deposition load of nitrogen (wet+dry deposition), as estimated from data collected from the intensive and meteorological monitoring sites, will serve as the total estimate of atmospheric deposition delivered to the surface of Tampa Bay.

The TBADS workshop participants recommended a minimum sampling period of 18 months to two years, once calibration is complete. Sampling was initiated in August 1996, and adequate funding is available to extend the intensive site monitoring through August 1998.

Meteorological Model

The Cooperative Institute for Tropical Meteorology at Florida State University will apply an existing air transport model developed by Penn State (the Penn State/NCAR Mesoscale Model Version 5 (MM5)) to investigate air transport at a coarse grid for the southeastern U.S., while maintaining a much higher resolution grid over the Tampa Bay area watershed. The resolution of the grids over Tampa Bay (2-4 km) will allow estimation of air movements both within the watershed and between the Tampa Bay watershed and its much larger airshed. The modeling approach has been recently used to investigate the role of sea breeze circulation in the Florida panhandle, and appears well suited for developing air mass movement estimates in the Tampa Bay area.

Model application is directed by Drs. Chris Herbster, Paul Ruscher and John Winchester of the FSU Meteorology Department under an existing project from NOAA. Model results and interpretation are expected by mid-1997. Results of the modeling will provide estimates of air mass movements and transport of NO_x .

Urban and Residential Stormwater Runoff Sampling

The TBADS has been working with the Florida Department of Transportation and local governments' stormwater departments to locate bulk atmospheric deposition collection sites at up to ten existing stormwater sampling locations throughout the watershed. Many of the sites will be co-located with stormwater NPDES collection

sites operated by the local governments. The addition of bulk deposition data will provide indications of the spatial heterogeneity of deposition throughout the watershed. Results will be closely coordinated with results obtained from the intensive Gandy Site, and will also provide data to estimate the contribution of atmospheric deposition to stormwater water quality. Sampling is scheduled to be initiated in early 1997.

Funding for these additional atmospheric deposition sites (equipment and sample analyses) will be jointly provided by the Florida Department of Transportation (as an element of their NPDES permit requirements) and TBNEP. Sample collection will be provided by Hillsborough, Pinellas, Pasco and Polk counties and the City of Tampa's Stormwater Departments. TBADS sample collection and analysis protocols will be used.

Ammonia Contributions from Shoreline Sources

The objective of the initial survey of ammonia concentration, conducted on board the *RV Anderson* July 15-23, 1996, was to obtain information of the spatial distribution of gaseous ammonia (NH_3) and particulate ammonium (NH_4^+) over open bay waters of Tampa Bay. Drs. Pai-yei Whung and Zu-Li (University of Miami) used two sampling techniques—denuder and filter pack—to measure ambient concentrations of ammonia and ammonium at five locations throughout the bay and at one “background” station approximately 30 miles offshore in the Gulf (Fig. 2).

Preliminary data indicate that the mean gaseous ammonia concentration at the “background” offshore site was near the detection limit. The highest averaged ammonia concentration was observed at Station #5, located in East Bay; concentrations measured at this station were approximately 15 times higher than at the offshore station. Station #4, located just south of the Interbay Peninsula, also showed higher concentrations of gaseous ammonia and the highest particulate ammonia concentration of the six stations.

Phase 2 of the project, scheduled for early 1997, will focus on the apparent “hot spot” of atmospheric ammonia concentrations in the East Bay area. Results of this project will help estimate the relative contribution of suspected ammonia sources directly to the surface of Tampa Bay.

Intensive Stormwater Sampling

This project, to be initiated in early 1997, is designed to measure stormwater runoff contaminant and nitrogen concentration and loads from gaged subbasins. Results of the loading estimates and atmospheric deposition from the intensive site will be used to estimate the relative contribution of atmospheric loading to stormwater runoff from each of the land use types gaged in the project. Subbasins will be located in close proximity to the intensive site; therefore, land use types will be primarily residential.

Information gained from this project will be useful not only to Tampa Bay and Florida, but to watersheds nationwide. The transfer coefficients to estimate the effect of atmospheric deposition on surface water quality via stormwater remains largely unknown.

Examination of Sediment Quality

Two ongoing TBNEP projects to determine whether atmospheric deposition of toxic materials (metals, PAHs, PCBs) appears to be a problem are scheduled to be completed by early 1997. A recently completed sediment quality assessment project examined the spatial extent of sediment contamination and correlations with benthic community structure and laboratory toxicity studies. Results from this work indicate the presence of several "hot spots" of sediment contamination (particularly in the more urban areas of the bay), but that much of the bay is uncontaminated (Zarbock et al. 1996c). The other ongoing TBNEP project is conducting risk assessments of specific contaminant concentrations found in Tampa Bay sediments (using benthic organisms, fishes, birds and human health as endpoints). Results from the risk assessment indicated that certain chlorinated pesticides (DDTs, heptachlor and lindane), polychlorinated biphenyls (PCBs), high molecular weight polycyclic aromatic hydrocarbons (HPAHs) and specific metals (chromium, copper, mercury, nickel and silver) are priority contaminants of concern for specific areas in Tampa Bay (upper Hillsborough Bay and McKay Bay, Boca Ciega Bay and Bayboro Harbor) (McConnell et al. 1996).

USE OF RESULTS OF THE TAMPA BAY ATMOSPHERIC DEPOSITION STUDY

All elements of the TBADS project are directly applicable to specific questions identified by the initial working group in 1995. Specifically, results of each element will be used as follows:

- Intensive site:
 - Identify relative contributions from wet and dry deposition;
 - Assess temporal variability in deposition rates;
 - Revise nutrient loading model as appropriate.
- Air Mass Movement Model:
 - Importance of local vs. remote sources of emissions
- Atmospheric ammonia:
 - Importance of direct deposition of ammonia to bay water quality
- Stormwater projects:
 - Assess contribution of atmospheric deposition to stormwater quality

Findings of ongoing TBADS work will be used to develop an action plan that includes cost-benefit analyses of options to manage atmospheric deposition (TBNEP 1996).

IMPLICATIONS FOR MANAGEMENT

Within the last five years, Tampa Bay resource managers and scientists have come from identifying relative impacts of atmospheric deposition as "unknown, but probably minor" to an understanding that deposition may be one of the most important issues facing maintenance of the long-term health of Tampa Bay. A primary implication for resource managers is that atmospheric deposition is a regional issue rather than a watershed issue, and one which will require regional, statewide or national management decisions and actions.

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SEDIMENT CONTAMINATION IN TAMPA BAY— SOURCES, RISKS AND MANAGEMENT

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ABSTRACT

The extent and severity of sediment contamination, and the potential for risks to living resources and human health from degraded estuarine sediments, have been subjects of research in Tampa Bay for over 20 years. Initial field studies focused on sediment characterization and the development of screening mechanisms to identify impacted sediments, and on the relationships among contaminated sediments, sediment physical properties and depositional environments. More recently, data obtained from field sampling programs have been used to evaluate sediment contamination using the "sediment quality triad" method. The triad method was used to develop a weight of evidence to identify areas with the highest potential risk to living resources by examining synoptically collected sediment chemistry, sediment toxicity and benthic samples, and it provided a thorough assessment of the potential effects of contamination. Other work has focused on identifying the chemicals of highest potential concern and the potential sources of those chemicals to Tampa Bay, and on developing estimates of loadings from these sources. Urban and agricultural runoff, point sources and atmospheric deposition have been identified as the most significant contributors to sediment contamination in Tampa Bay. Subsequent to sediment characterization and source identification, risk analysis techniques have been used to quantify the potential for impacts to living resources and humans. In the context of water resource protection, "risk" refers to potential impacts to ecological resources, indications of potential human health effects, impairment of designated uses of a waterbody, or a combination of these effects resulting from water or sediment contamination. It is anticipated that the scientific information gained through these studies will be transformed to sound, technically defensible management guidelines and regulations to protect and enhance the ecological health of the bay.

INTRODUCTION

For more than 20 years, research has been conducted to determine the extent and severity of sediment contamination in Tampa Bay, and to evaluate the potential for risks to living resources and human health. Early field studies focused on sediment chemistry and the development of screening mechanisms to identify impacted sediments. These studies were also directed toward establishing relationships among contaminated sediments, sediment physical characteristics and depositional environments. A common finding of these investigations was that potentially significant contamination of sediments was occurring, or had occurred in the past, in portions of Tampa Bay. The most significant sediment contamination was found in Hillsborough Bay, Boca Ciega Bay and western Middle Tampa Bay, all of which adjoin highly urbanized portions of the watershed (Fig. 1). Subsequent work sponsored by the Tampa Bay National Estuary Program (TBNEP) evaluated potential sources of contaminant inputs to the bay and provided estimates of loadings of "contaminants of concern" (COCs) from major sources. COCs are contaminants that are present, or that may be expected to be present, in sediments, that may pose a threat to living resources or human health. COCs for Tampa Bay, as determined through sediment chemistry and toxicity testing and risk assessments, include metals (cadmium, copper, chromium, copper, lead, mercury, nickel, silver and zinc), organochlorine pesticides (chlordane, dieldrin, DDT, DDE, endosulfan, endrin, mirex and

lindane), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

Recent field investigations have broadened the information base for evaluating sediment contamination. During the early 1990s, the National Oceanic and Atmospheric Administration (NOAA) and others conducted sediment sampling to support sediment quality assessment using the "sediment quality triad" (SQT) method (Long and Chapman 1985). The SQT method examines concurrently sampled sediment chemistry, sediment toxicity and benthic invertebrate community data to assess the potential effects of contamination. Using the results of the sediment characterization, source identification and SQT analysis, risk assessment techniques have been employed to assess the potential risk posed by contaminated sediments to living resources and public health in Tampa Bay.

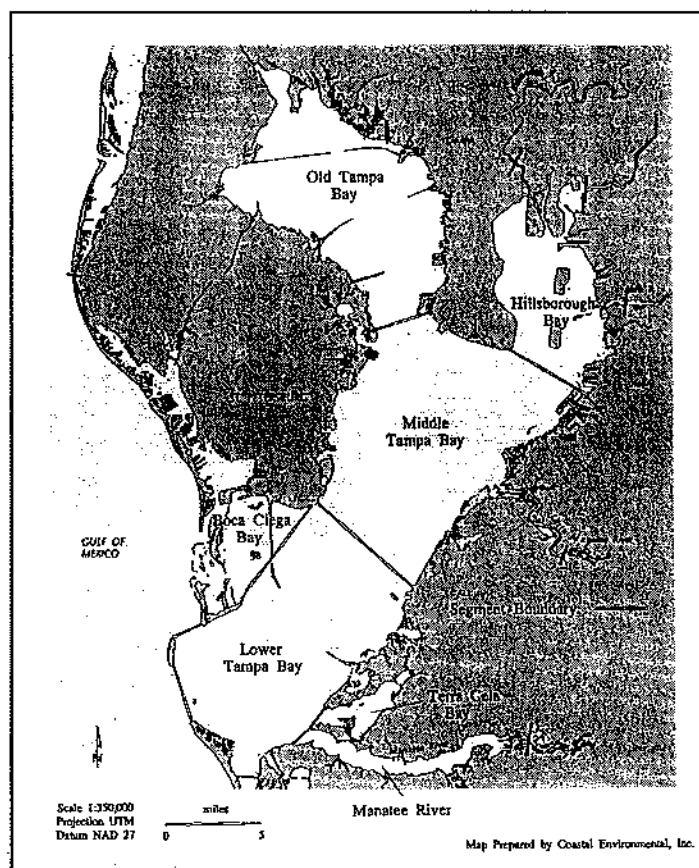


Figure 1. Tampa Bay segments.

From a management perspective, sediment contamination has been recognized as a potential threat to the bay by the Southwest Florida Water Management District in their Surface Water Improvement and Management (SWIM) Plan for Tampa Bay (SWFWMD 1992), as well as by the Tampa Bay National Estuary Program (TBNEP 1996). It is anticipated that the scientific information gained through these studies will be transformed to a technically defensible management plan, as illustrated in Figure 2. For example, future management efforts can be focused on appropriate

source control of those chemicals that represent the most significant risk. To assist in the management of contaminated sediments, the state of Florida has developed Sediment Quality Assessment Guidelines (SQAGs) for many toxicants found in Florida's coastal sediments (MacDonald et al. 1996). The empirically derived SQAGs are advisory only and have no regulatory mandate. The SQAGs are intended to define three ranges of contaminant concentrations that are rarely, occasionally or frequently associated with adverse biological effects (MacDonald et al. 1996) as follows:

PEL, probable effects level—the concentration above which biological effects are likely;

TEL, threshold effects level—the concentration below which biological effects are not expected.

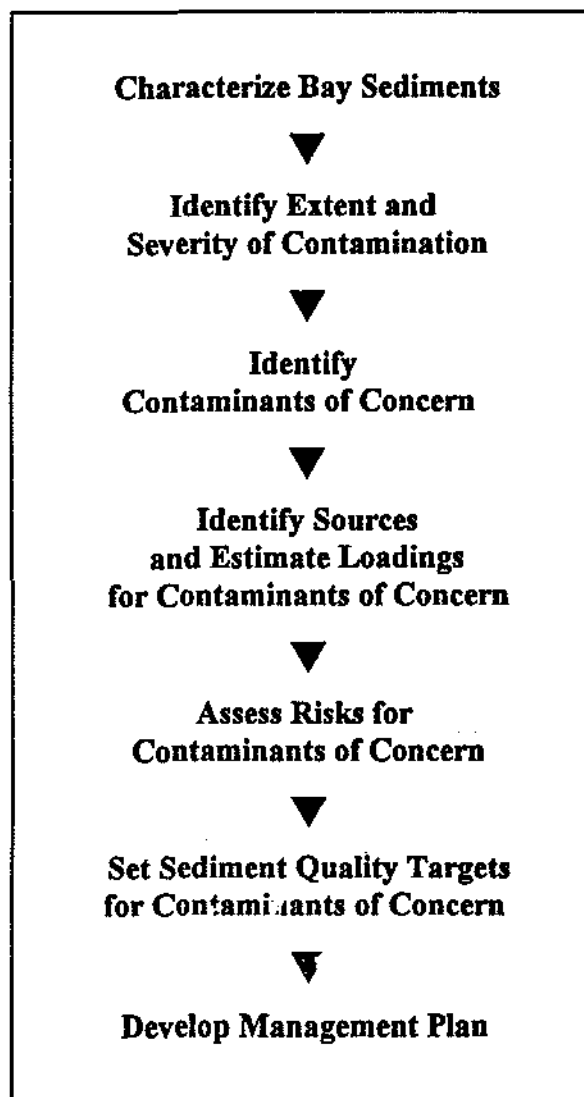


Figure 2. Development of a sediment contamination management plan.

Concentrations of contaminants that fall between PEL and TEL levels may or may not cause biological effects. Contaminant levels in bay sediments may be compared to these effects levels to identify sites that are most likely to be impacted by contamination and that have the greatest potential for impacting living resources.

CHARACTERIZING SEDIMENT CONTAMINATION

Sediment Chemistry

Early investigations of Tampa Bay's sediments focused primarily on determining sediment chemistry and physical properties. Work at the University of South Florida (Brooks and Doyle 1992) showed that relationships exist between sediment contaminant levels and the percentage of fine-grained particles in the sediments. Many chemicals readily bind to fine-grained sediments through physical or chemical processes, and are often found at higher concentrations in areas where sediments are comprised primarily of fine-grained particles. It was also demonstrated that sediment contaminants can often be found at elevated concentrations in nearshore areas that are either close to inputs (such as nonpoint or point sources) or in low energy coastal areas where quiescent waters allow suspended sediments and accompanying contaminants to settle. Sediment characterization work by the Florida Department of Environmental Protection (Seal et al. 1994) provided data for comparing sediment quality in Tampa Bay to that in other estuaries statewide. In addition, a screening method was developed to determine if observed metals concentrations were of "natural" origin or were associated with anthropogenic activities, by comparing the ratios of different metals to aluminum concentrations (Schropp and Windom 1988).

More recently, work by NOAA has expanded the knowledge base of Tampa Bay sediment contamination and has provided insights into the toxicity of the bay's sediments. NOAA sampled eight sites in Tampa Bay for metals and organics as a part of the National Trends and Status (NS&T) Program Mussel Watch (Long et al. 1991). At those sites, a total of six PEL or TEL exceedances for metals were observed. All established TELs or PELs for organic COCs were exceeded at one or more sites, with concentrations of tPCB and tDDT exceeding the SQAGs most frequently.

A more thorough sediment sampling program was completed in Tampa Bay by NOAA in 1992 (Long et al. 1994). The concentrations of both metals and organic compounds were determined in sediments. Additionally, toxicity testing was conducted on whole sediments, solvent extracts and pore water. Several of the 165 samples collected near known or probable contaminant sources in the Port of Tampa, Bayboro Harbor, western Old Tampa Bay and Boca Ciega Bay, had PEL or TEL exceedances for two or more metal compounds. All six metal COCs, as defined above, frequently exceeded PELs or TELs in these areas. Results of analyses for organics suggested a spatial trend in sediment contamination similar to that for the metals analyses, with the sites located near likely or known contaminant sources (Port of Tampa, coastal Pinellas County and Boca Ciega Bay) having multiple PEL or TEL exceedances. Chlordane, tPCB and tDDT were most often observed in high concentrations at these sites.

Toxicity Testing

To determine if sediment-associated contaminants were bioavailable and toxic, a battery of toxicity tests was performed in the laboratory (Long et al. 1994). To test sediment toxicity, a variety of aquatic organisms considered to be "indicator species" were placed in contact with whole sediments, solvent extracts or sediment pore water. Tests were conducted to determine the fertilization success of the sea urchin *Arbacia punctulata* (gametes), survival of the amphipod *Ampelisca abdita* (adult) and the bivalve *Mulinia lateralis* (larvae), and reduction in metabolic function of a marine bacterium *Photobacterium phosphorium* (Microtox™ bioluminescence). In whole sediment and pore water tests, individual contaminants were not identified as toxic; rather, the overall effect of all components of the sediment was evaluated.

Toxicity testing was completed on samples collected at sites in Hillsborough Bay, McKay Bay, Old Tampa Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ciega Bay, Cockroach Bay, Terra Ceia Bay and the Manatee River. Several sites near potential sources of contamination (i.e., within the Port of Tampa, Hillsborough Bay, Bayboro Harbor, coastal Pinellas County and Boca Ciega Bay) showed positive toxicity test results. Sites in the middle of major bay segments did not exhibit toxicity. Based on the sea urchin fertilization tests, the most toxic sediments were observed in northern Hillsborough Bay (Ybor Channel, McKay Bay), eastern Hillsborough Bay, western Old Tampa Bay and Bayboro Harbor. Cockroach Bay, which is a relatively undisturbed area but which receives agricultural runoff, also had positive test results. Using the amphipod survival assay, the most toxic sediments were observed in northern and eastern Hillsborough Bay, and at a site in central Boca Ciega Bay. Microtox™ testing resulted in positive results only in the ship channels in northern Hillsborough Bay. It should be noted that Long et al. (1994) did not sample with equal effort in all regions of the system, but rather put relatively more emphasis on sites that were likely to exhibit contaminant-related impacts.

Benthic Invertebrate Community Assessments

Several large-scale benthic sampling programs have been completed in Tampa Bay, including surveys dating back to the mid-1970s by University of South Florida researchers (Simon and Mahadevan 1985). Much of this early work was intent upon documenting midsummer die-offs coincident with periods of low dissolved oxygen concentrations. More recent studies have provided a substantial quantity of contemporary benthic invertebrate data, collected with a focus more toward evaluating the effects of sediment-associated toxicants. In 1992, for example, benthic community analyses were conducted (Bell, unpublished data; MacDonald, unpublished data) on 75 samples collected by NOAA and FDEP at sites located in Hillsborough Bay, Old Tampa Bay, Boca Ciega Bay and near St. Petersburg in conjunction with the NOAA toxicity and sediment chemistry sampling (Long et al. 1994). Additionally, more than 80 samples were collected in Tampa Bay in both 1993 and 1994 using the TBNEP/EMAP design protocol for site selection and sample collection (Grabe et al. 1995). This sampling effort has continued on an annual basis.

Sediment Quality Triad

Based on the results of a sediment quality workshop held in 1995 (MacDonald 1995), TBNEP initiated a project in 1996 to characterize Tampa Bay's sediments using the

SQT, or triad, approach. The triad method is used to develop a weight of evidence by combining sediment contaminant analysis, sediment toxicity testing and measures of biological (benthic) conditions to quantitatively assess pollution-induced degradation (Long and Chapman 1985). The SQT is an integrated approach that links sediment contaminant levels both to their potential toxic effects, as measured by toxicity testing, and to their effects on populations of benthic organisms, as measured by benthic community status indicators.

In 1996, the available sediment chemistry, toxicity testing and benthic structure data were obtained and examined to determine their appropriateness for use in the triad analysis (Zarbock et al. 1996). Only the sediment chemistry and toxicity testing conducted by NOAA and FDEP (Long et al. 1994) with concurrent benthic sampling (Bell, unpublished data; MacDonald, unpublished data) was suitable for use in a synoptic triad analysis. These data met all the requirements for the synoptic SQT assessment and yielded much useful information. However, there were not enough data provided from the samples to provide a thorough baywide characterization of sediment contamination.

As an alternative approach, other data sets were assembled and used for a non-synoptic triad analysis. That is, data collected at different times were pooled to develop a single data set. The weight of evidence provided by the non-synoptic data is not considered to be as robust as the synoptic approach because of the difference in times, methods and locations of independently sampled sites. However, the wider coverage and higher density of data permitted a broader classification of the relative degree of contamination of Tampa Bay's sediments.

Each site of the synoptic data set and the non-synoptic data set was assigned an index score according to specific criteria. Results from sediment chemistry analyses, toxicity tests and benthic analyses were evaluated with separate criteria. Using a conservative approach, the sites were classified according to the individual criteria that indicated the highest level of contamination. That is, if a site's chemical contaminant levels exceeded a PEL or TEL concentration, but toxicity testing and benthic data did not indicate degradation, the site was classified according to the PEL or TEL score. The index scores were established as follows:

Sediment Chemistry: An index score of 0 was assigned when no TEL or PEL was equaled or exceeded; a score of 1 was given when one or more TEL, but no PEL, was equaled or exceeded. Sites with one PEL, and possibly one or more TEL, equaled or exceeded were assigned an index score of 2. Finally, sites with two or more PELs equaled or exceeded received a score of 3.

Toxicity Testing: For each of the 90 Phase I sampling stations, a value of 1 was assigned for each of the three toxicity test results that was identified as significantly toxic by Long et al. (1994). A value of 0 was assigned if toxicity was not observed in the test. The results were summed for each site and index scores of 0 (least toxic), 1, 2 or 3 (most toxic) were assigned.

Benthic Invertebrate Community Structure: Several methods were evaluated to determine an appropriate measure of benthic invertebrate community structure, including the EMAP Louisianian Province Benthic Index, Shannon Index, species richness, the presence or absence of benthic invertebrates, and the presence or absence of amphipods. Based on the results of this evaluation, the Shannon Index was selected and applied to the benthic data. Results were scored by quartile, with the least diverse sites receiving the score of 3 (most impacted) and the most diverse sites receiving a score of 0 (least impacted).

In total, sediment chemistry, sediment toxicity and/or benthic invertebrate community structure data were available for 447 sample sites in Tampa Bay. Based on applying index scores to the pooled data set, bay sediments were classified as one of four categories. These four categories describe the relative degree of contamination in the sediments, as follows:

- **most contaminated areas**—contaminant concentrations exceeding one or more PEL, multiple positive toxicity test results, or degraded benthic community structure, resulting in an index score of 2 or 3;
- **slightly contaminated areas**—contaminant concentrations greater than TELs but not exceeding PELs, toxicity indicated in only one test, or benthic community moderately diverse, resulting in an index score of 1;
- **least contaminated areas**—relatively unstressed areas to be protected from any further contamination (i.e., index scores for all measures of sediment quality are 0); and
- **insufficient data**—areas with insufficient data to make an assessment.

The classifications of this system provide an indication of the relative degree of sediment contamination with Tampa Bay. It must be stressed, however, that Tampa Bay is much less contaminated than many other estuaries in the vicinity of urbanized watersheds. In fact, Tampa Bay is among the least contaminated urbanized estuaries that have been studied by NOAA (Long et al. 1996). The sediment classifications were developed only to compare relative levels of contamination within different areas of Tampa Bay and thus, to identify relative degrees of priority. Thus, it should not be assumed, for example, that an area classified as "most contaminated" is not restorable. Conversely, because of the patchy nature of sediment contaminant accumulation and gaps in coverage of sampling, it should not be assumed that areas classified as "least contaminated" do not have any elevated levels of sediment contamination. Nevertheless, some relatively clear patterns in the quality of sediments became apparent when baywide data were illustrated (Fig. 3).

It was originally intended to use quantitative methods to estimate the areal extent of each sediment classification based on the location of individual sampling sites. However, the data for both the synoptic and non-synoptic data sets had been collected using a variety of methods and for a variety of reasons (for example, in some cases sampling sites were located where high levels of contaminants were expected to be found). Thus, it was concluded that the data had significant bias and that there was no technically defensible method available to convert the point data into a spatial coverage.

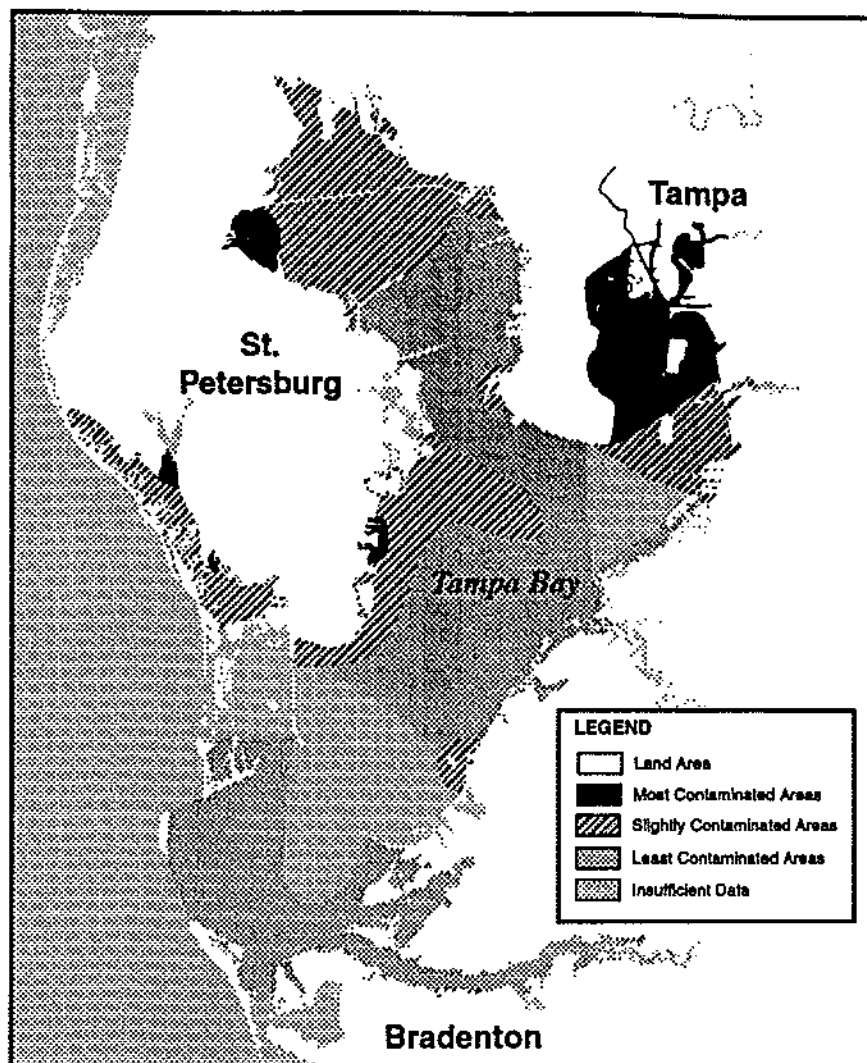


Figure 3. Characterization of contamination in Tampa Bay sediments.

In an attempt to generally define those areas of Tampa Bay that had some degree of sediment contamination, a qualitative assessment of the pooled data sampling sites was made. Areas of the bay were delineated based on the relative occurrence of sampling sites with different index scores. Sediments were identified according to their relative degree of contamination with respect to other areas of the bay. In general, areas with less contaminated sediment were offshore and areas with sediments exhibiting the highest levels of contamination were most often found adjacent to urban land, especially in areas subject to runoff from intensive urban and industrial land uses.

Upper and middle Hillsborough Bay, and portions of Old Tampa Bay, Boca Ciega Bay and western Middle Tampa Bay all are classified as most contaminated, relative to other areas of Tampa Bay. Southern Hillsborough Bay, northern Old Tampa Bay, western Middle Tampa Bay and Boca Ciega Bay were all generally classified as slightly contaminated, and sediments in southern Old Tampa Bay, central and eastern

Middle Tampa Bay, and Lower Tampa bay were found to be least contaminated (Zarbock et al. 1996).

CHARACTERIZING SOURCES OF CONTAMINANT LOADINGS

Several attempts had been made to identify sources of contaminant inputs to Tampa Bay, but these efforts were usually aimed at a specific group of sources or activities (e.g., industry, agriculture, urban runoff). Not until 1995 was a report published that provided a relatively comprehensive accounting for contaminant loadings to the bay. Frithsen et al. (1995), in a study sponsored by TBNEP, examined COC loadings from urban and agricultural runoff, domestic and industrial point sources, atmospheric deposition (recently shown to be a significant source of nutrient loading as well) and groundwater.

Loadings from urban runoff were estimated using land use-specific contaminant concentrations and simple runoff calculations. Agricultural loading estimates were developed using published rates of fertilizer and pesticide application. Residual loadings from pesticides that are now banned from use (such as DDT) were also estimated. Contaminant loadings from point sources were estimated using reported effluent flow and quality data obtained from FDEP and from the NOAA National Coastal Pollutant Discharge Inventory (NCPDI) database. Atmospheric deposition loads were estimated using values of wetfall and dryfall contaminant concentrations from the literature, while groundwater loads were developed using previously determined flow estimates and reported data from local sources. Because of lack of data and the screening-level scale of the loading estimates, inputs from facilities such as landfills and Superfund sites were not considered.

Frithsen et al. (1995) reported that, of the major sources, urban runoff was the largest single source of chromium, copper, lead, mercury, zinc and chlordane loadings to the bay. Point sources were found to contribute the highest loadings of arsenic and iron, while atmospheric deposition was responsible for much of the cadmium and PCB loadings. Agricultural runoff was believed to be the primary source of DDTs, dieldrin and endosulfan. Groundwater (not including potential inputs from Superfund sites, landfills, etc.) did not contribute significantly to the total loadings of any COC. It must be noted that these results are incomplete due to the lack of data on the loadings of several COCs from some potential sources.

Comparison of the contaminant loading estimates developed by Frithsen et al. (1995) with the information on the extent and severity of chemical contamination in Tampa Bay sediments yields some important results. As might be expected, the bay segments that receive the highest loadings of contaminants also have the highest incidence of sediment contamination. Of the seven bay segments, Hillsborough Bay received the largest loadings of all of the COCs, due partly to its large drainage area. Also, contaminant inputs in this area of the bay are strongly influenced by historical and current industrial activity, an active shipping industry, agricultural activities in the watershed and large population densities adjacent to the bay. Other segments of the bay that receive large quantities of contaminants include Old Tampa Bay and Boca Ciega Bay. Both these bay segments adjoin highly urbanized watersheds.

Information linking sources of contaminant loading with sediment degradation is useful for developing specific management strategies for reducing contaminant loadings. For example, the management of chromium contamination in Hillsborough Bay should focus on the major sources that were identified—point sources and urban runoff. Therefore, control of point sources and nonpoint source runoff should be identified as high priorities in urban areas that impact bay segments of highest concern.

ASSESSING POTENTIAL RISKS OF CONTAMINANT IMPACTS

In another TBNEP-sponsored study, McConnell et al. (1996) evaluated the potential ecological and human health risks associated with the contaminants observed in selected priority basins, including Hillsborough Bay, McKay Bay, Boca Ciega Bay, Bayboro Harbor and adjacent areas in western Middle Tampa Bay and western Old Tampa Bay. In the context of resource protection, "risk" refers to the potential effects of sediment contamination on ecological resources, human health or the designated uses of a waterbody. However, evaluation of the actual effects of sediment contamination is difficult for a number of reasons, due to the uncertainties associated with the complex interrelationships affecting potential contaminant impacts.

First, factors such as physical and chemical properties of contaminants, the characteristics of surface water and the nature of sediments can influence the bioavailability, and thus the toxicity, of many contaminants. In addition, exposure to the contaminants may vary by life stage, species and position in the food web. Furthermore, aquatic organisms exhibit a range of tolerances to stressors that, in turn, can influence populations and community structure or dynamics.

The use of a risk-based management approach facilitates the prioritization of management efforts to address *in situ* contamination and the most important sources of these contaminants. Current analyses of sediment contamination in Tampa Bay identified a potential for adverse effects using sediment quality assessment guidelines and conducting direct tests of toxicity. In contrast, risk-based approaches provide a means of considering additional factors, such as the potential for cumulative effects from multiple contaminants, bioaccumulation of persistent toxicants and adverse effects on higher trophic level organisms, to determine the magnitude of risks. McCain et al. (1996) observed elevated chemical concentrations and hepatic lesions in fish collected in several north Hillsborough Bay sites compared with fish from Charlotte Harbor and Terra Ceia Bay, thus confirming the general conclusions of the risk assessment.

As part of the TBNEP-sponsored risk assessment work (McConnell et al. 1996), specific chemicals were identified as COCs. The criteria used to identify COCs for this study included: 1) estimated exposures representing a significant potential for adverse effects based on the magnitude of exceedance of the risk threshold; 2) the number of receptors affected; 3) potential effects from direct and food web exposure; 4) the frequency of contaminant detection; and 5) the uncertainty associated with components of the risk estimate.

Ecological risks related to sediment contamination were evaluated using hazard quotients (HQs) to estimate the potential for adverse effects to indicator species. COCs were identified based on concentrations with a significant potential for effects to a specific indicator species, effects to two or more indicator species at different trophic levels, or the potential for effects from direct as well as food web exposure.

Potential human health risks associated with noncarcinogenic and carcinogenic contaminants were evaluated using HQs and cancer risk estimates as measures of the likelihood of adverse effects occurring as a result of ingestion of contaminated fish. COCs were those chemicals that occurred in the fish tissues at concentrations that could cause adverse effects on human health.

The results of the ecological and human health risk assessment indicated that certain chlorinated pesticides (DDTs, heptachlor and lindane), PCBs, high molecular weight PAHs (HMW-PAHs) and several metals (chromium, copper, mercury, nickel and silver) should be considered priority COCs for specific areas of Tampa Bay, as follows:

- In upper Hillsborough Bay, the priority COCs, based on ecological health, were heptachlor, DDTs, lindane, HPAHs, chromium, copper, mercury and nickel. The priority COCs, based on potential human health effects, were HPAHs and PCBs.
- In lower Hillsborough Bay, PCBs were the highest priority COCs based on potential ecological and human health risk. However, the exposures and risks associated with observed levels of PCBs in this area were not especially significant.
- In McKay Bay, the priority COCs, based on a significant potential for ecological effects, included heptachlor/heptachlor epoxide, HMW-PAHs, chromium and copper. Priority COCs based on potential human health effects included HMW-PAHs and PCBs.
- In Boca Ciega Bay, the priority COC, based on potential ecological and human health risks, was PCBs. However, exposures and associated risks of PCBs in this area were considered to be relatively low.
- In Bayboro Harbor, priority COCs, based on a significant potential for ecological effects, included HMW-PAHs, copper, mercury and silver. The priority COCs based on potential human health effects were HMW-PAHs.
- In Middle Tampa Bay adjacent to Bayboro Harbor, priority COCs based on a significant potential for ecological effects included one chlorinated pesticide, lindane and HMW-PAHs, including fluoranthene and total HMW-PAHs. No priority COCs were identified based on potential human health effects.
- In western Old Tampa Bay, priority COCs based on a significant potential for ecological effects included total PCBs, chromium and nickel. The HMW-PAH

benzo(a)pyrene was the priority COC, based on potential human health effects.

Some uncertainty exists regarding these risk estimates. In some cases, all of the data required to make risk estimates were not available (e.g., lack of receptor- and site-specific exposure and bioavailability data), so conservative (protective) assumptions and judgments were made to minimize the potential for overlooking or underestimating potential risks. This conservative approach may overstate actual risks. In spite of these uncertainties, the approach used for this assessment represents a significant contribution to the sediment assessment process in Tampa Bay because both exposure and toxicity are considered. The level of uncertainty must be considered prior to making management decisions regarding actions to address particular contaminants. Nonetheless, the risk estimates provided through this analysis serve as a defensible means of prioritizing sediment-associated contaminants and contaminated areas.

Ongoing work to control sediment contamination in Tampa Bay includes the development of a Sediment Contamination Action Plan by TBNEP. The Action Plan will describe opportunities and methods for reducing inputs of contaminants from specific sources in priority portions of the watershed, and will serve as a model for future management efforts. Future work to assess and manage sediment contamination should include the continuation of sediment sampling, toxicity testing and benthic invertebrate community structure assessment to improve the SQT database. In addition, uncertainties associated with ecological and human health risk assessment should be reduced if this approach is to be used in making management decisions. Finally, numeric targets for COCs in sediments should be developed to allow technically defensible criteria to be applied regarding the control of sediment contamination in Tampa Bay.

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ON HYDRODYNAMICS AND WATER QUALITY DYNAMICS IN TAMPA BAY

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ABSTRACT

This paper presents a few recent examples of studies on the hydrodynamic processes (currents and waves) and their effects on water quality dynamics in Tampa Bay, Florida. The first example is a study on the resuspension fluxes of sediments and nutrients during episodic events in Tampa Bay (Sheng et al. 1993). Field data collected during two episodic events, one in 1992 and another in 1993, showed that wave-induced resuspension of sediments led to significant resuspension of ammonia nitrogen from the bottom sediments in Hillsborough Bay. A vertical one-dimensional hydrodynamics-water quality model was developed and used to simulate the episodic events. The second example study, funded by the Tampa Bay National Estuary Program, involved the application of a curvilinear grid three-dimensional hydrodynamics model CH3D (see e.g., Sheng 1989, 1994; Sheng and Yassuda 1995) to simulate the three-dimensional flow and salinity fields in Tampa Bay during a variety of climatological and hydrographic conditions. The purpose of the study was to provide detailed flow and salinity fields to improve the results of the WASP water quality model which divides Tampa Bay into only 14 boxes. Results indicate that rainfall and watershed inflows have noticeable influences on the local salinity field but little influence on the flow field. Moreover, the residual flows for all cases showed a two-layer structure which cannot be represented by the one-layer WASP model of Tampa Bay. The last example involves the simulation of water quality dynamics in Tampa Bay during the summer and fall of 1991 (Yassuda and Sheng 1996). A coupled three-dimensional hydrodynamics-water quality model was able to simulate the development and evolution of a hypoxia event which was indicated by existing data.

INTRODUCTION

Tampa Bay (Fig. 1) is the largest coastal-plain estuary in Florida. The bay extends about 60 km northeastward from the 8 km wide mouth that connects it to the Gulf of Mexico. The width of Tampa Bay is about 15 km and the total open water area is about 1,030 km². Tampa Bay is relatively wide and shallow, with an average depth of about 4 meters. The depth generally does not exceed 10 meters except within the navigation channel. The watershed area of Tampa Bay covers 4,600 square kilometers and delivers about 63 m³/sec into the bay annually. The major freshwater runoff into the bay is from the Manatee, Little Manatee, Alafia and Hillsborough Rivers, which deliver annual mean freshwater discharges of 15, 13, 6 and 10 m³/sec, respectively, comprising about 70% of the total freshwater discharge (Lewis and Estevez 1988). Bottom sediments are sandy in most of Tampa Bay. Muddy sediments are found in Hillsborough Bay (Fig. 2).

The mean annual phosphate concentration in Tampa Bay can be as high as 1.28 mg/L (Fanning and Bell 1985). The major source of phosphorus in Tampa Bay is the Alafia River. Johansson and Squires (1989) found that the Alafia River loading rate is sufficient to meet 51% of the phosphate uptake estimated for phytoplankton growth and sediment flux rates are sufficient to meet 140% of the uptake. Hence phosphorus levels in Hillsborough Bay are much higher than what is needed for phytoplankton production and phosphorus is not a limiting factor to plant growth in the bay. On the other hand, nitrogenous nutrients may limit phytoplankton production in Tampa

Bay. Fanning and Bell (1985) calculated that the N:P ratio in Tampa Bay ranged from 0.3 to 1.3 in 1981, indicating that nitrogen is limiting phytoplankton production in the bay. The ranges of nitrogenous nutrient levels in Tampa Bay are 1–280 $\mu\text{g/L}$ nitrate plus nitrite and 10–280 $\mu\text{g/L}$ ammonia (Fanning and Bell 1985). Fanning and Bell found a relatively high ammonia to total inorganic nitrogen ratio of 0.84 in Tampa Bay, and suggested that among other causes, ammonia recycling in the sediment (resuspension flux) may be more important in Tampa Bay than in some other estuaries because of the shallowness of the bay.

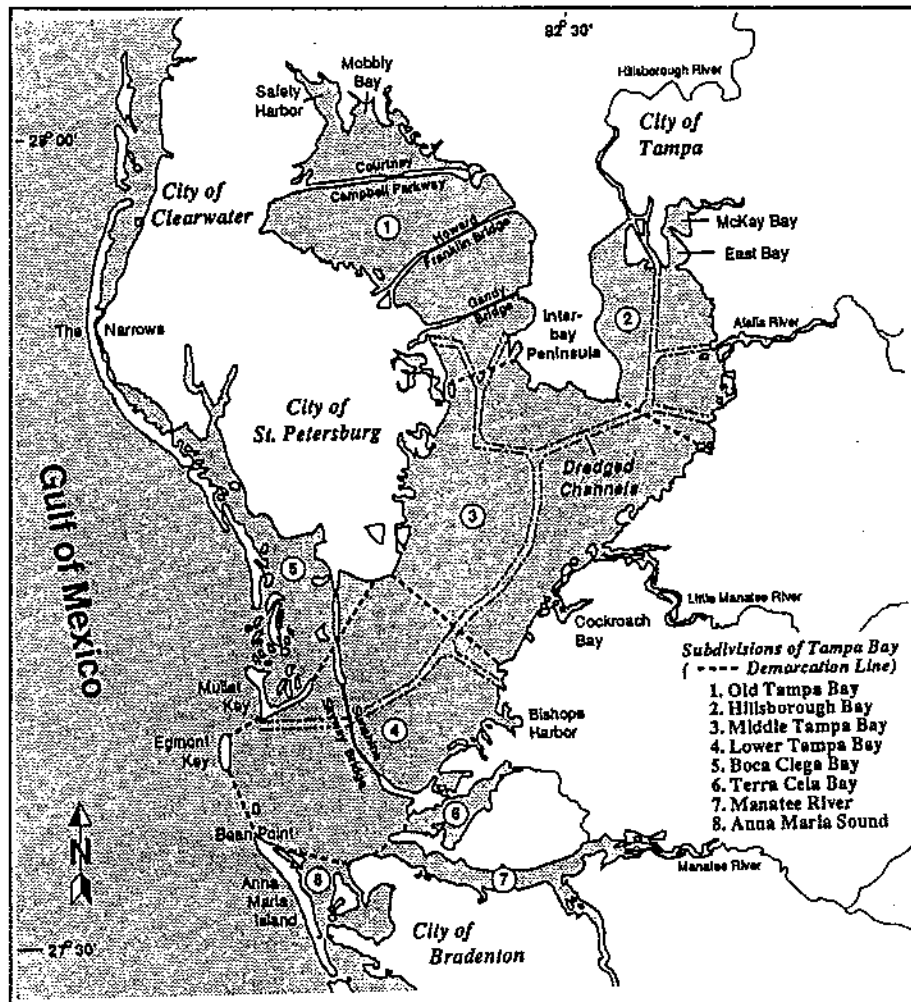


Figure 1. Tampa Bay estuarine system subdivisions as defined by Lewis and Whitman (1985) (from Wolf and Drew 1990).

More recently, two modeling studies attempted to address the effect of nitrogen load reduction on the water quality and seagrass growth in Tampa Bay. Coastal Environmental, Inc. (1995) developed a regression model (which does not include any cause-effect relationships among water quality parameters) to investigate the correlations among nutrient loading, water quality parameters (chlorophyll-*a*), and light attenuation in a 4-segment Tampa Bay. Their analysis suggested that, to retain

20% near-bottom light level, no reduction in annual average nitrogen loading is required. AScl (1996) applied the WASP model (Ambrose et al. 1994) to produce the annually averaged nutrient budget in a 14-segment Tampa Bay. Their model contains equations for nitrogen, phosphorus, oxygen and phytoplankton but calculates tidally-averaged flow velocities along the segment boundaries by solving the mass conservation equations of water and salt instead of the equations of motion. The dispersion coefficients are obtained by fitting simulated salinity to measured data. Neither model accounted for the benthic nutrient flux and its effect on the nutrient dynamics and budget in Tampa Bay. Johansson (1991) suggested the significant effect of benthic nutrient flux.



Figure 2. Mud zone (shaded) in Hillsborough Bay (Johansson and Squires 1989) with University of Florida stations A and B (Sheng et al. 1993).

This paper presents some results from a few recent studies on Tampa Bay conducted by the Coastal & Oceanographic Engineering Department of the University of Florida. The first study, funded by Florida Sea Grant, aimed to quantify the benthic nutrient fluxes associated with resuspension and diffusion processes. Field data of wind, current, water temperature, salinity, suspended sediment concentration, pH,

dissolved oxygen (DO) and nutrient concentrations were collected at two stations in Hillsborough Bay during two storm events, one in February 1992 and another in March 1993 (Sheng et al. 1993). A vertical one-dimensional model was deployed to simulate the currents, suspended sediment concentration and nitrogen concentration in the entire water column during the storm events.

The second study was funded by the Tampa Bay National Estuary Program to provide more accurate estimations of residual flow and salinity fields along the boundaries of the 14 segments in the Tampa Bay WASP model, using the three-dimensional curvilinear grid circulation model CH3D developed by Sheng (1989, 1994). Model simulations were obtained for four different hydrodynamic and climatological conditions (Sheng and Yassuda 1995).

The third study, supported by the University of Florida, involved the simulation of hydrodynamics, nitrogen dynamics and hypoxia events in Tampa Bay in 1991 (Yassuda and Sheng 1996). A coupled hydrodynamics-water quality-seagrass model was developed. Earlier, Sheng et al. (1995a) developed a coupled hydrodynamics-water quality-seagrass model to simulate the effect of reduced nitrogen loading on the water quality and seagrass biomass in Roberts Bay, which is part of the Sarasota Bay estuarine system.

RESUSPENSION OF SEDIMENTS AND NUTRIENTS DURING STORM EVENTS

In February 1992 and March 1993, field measurements were conducted at two locations (Stations A and B, Fig. 2) in Hillsborough Bay by the Coastal & Oceanographic Engineering Department of the University of Florida. Station A is in the muddy zone with a mean depth of about 4 meters, and Station B is in the sandy zone with a depth of about 2 meters. Data measured at both stations include wind, tide, current, suspended sediment, salinity, and water temperature. In addition, pH, DO, and nutrients at Station A were also measured. A Peeper tube was placed in the sediments to measure the sediment-column nutrient distribution.

Figure 3 shows a measured wind stick diagram at Station A during Julian Day 70.5 to 71.1 when the "Storm of the Century" went through Tampa Bay. The wind continued to increase until Julian Day 71.6, then decreased continuously until Julian Day 76. Measured currents and suspended sediment concentration at Station A are shown in Figure 4. The measured salinity, temperature, pH and DO varied little during Julian day 70.5 to 71.1. The SRP and TP concentrations during the period varied between 180 to 220 $\mu\text{g/L}$ and 380 to 470 $\mu\text{g/L}$. The measured suspended sediment concentration measured during this time period correlated well with the wind. The increased wind speed caused sediment resuspension and increased suspended sediment concentration in the water column after Julian day 70.8. The storm event appeared to have no significant effect on the SRP concentration in the water column. However, as shown in Figure 6, the ammonium nitrogen concentration in the water column did increase with the increasing suspended sediment concentration, although the reason for the peak values at the middle and the bottom layers around Julian day 70.6 is still unclear.

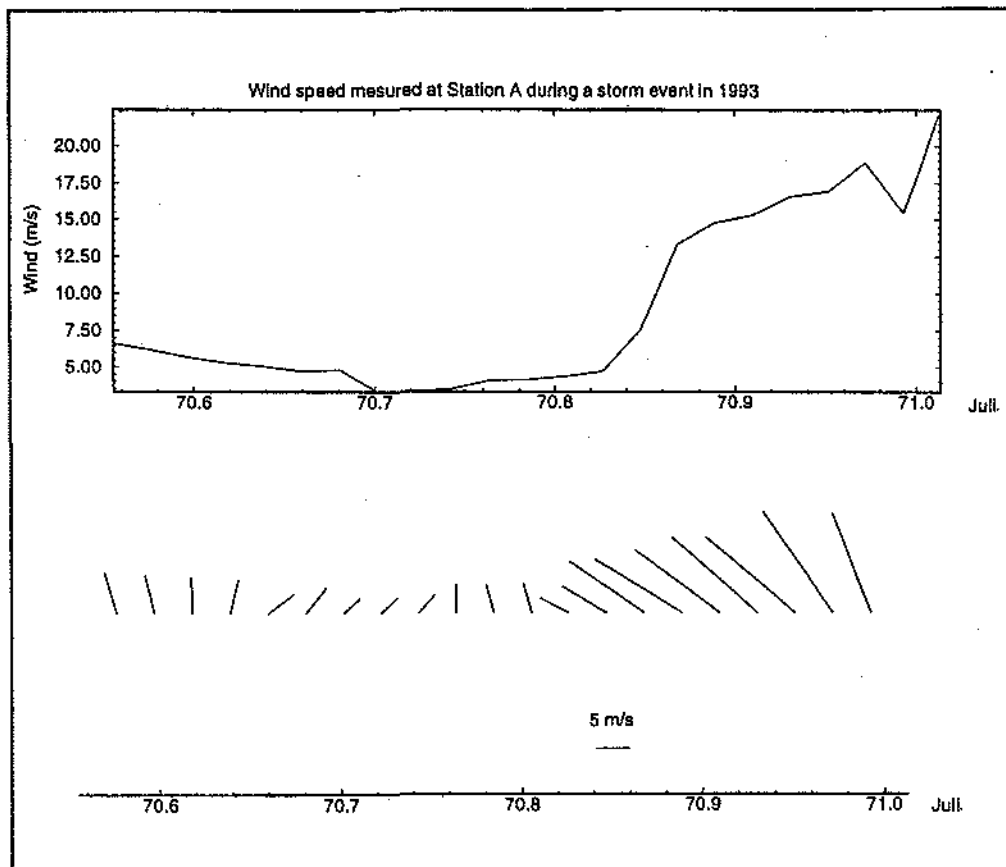


Figure 3. Measured wind speed (top) and wind stick diagram (bottom) at Station A in Hillsborough Bay during Julian Day 70.5 to 71.1 in 1993.

A vertical one-dimensional coupled hydrodynamics-sediment-water quality model was deployed to simulate the vertical structures of currents, suspended sediment concentration and nutrient concentrations at Stations A and B during the 1993 storm. The model (Sheng et al. 1993; Chen and Sheng 1994) resolves the high-frequency wave-induced motion as well as the low-frequency tidal and wind-driven currents in the water column. The horizontal pressure gradient is composed of an oscillatory part and a wave-averaged part. Before simulating the wave-induced motion, significant wave period and amplitude are first simulated with a simple SMB wave model. For the low frequency motion, the surface slopes are assumed to vary linearly vertically and are determined by matching the simulated and measured currents. The simulated currents and suspended sediment concentrations as shown in Figure 5 are almost identical with the measured data in Figure 4. The simulated ammonium concentration at two vertical levels are shown in Figure 6. These suggest that, during Julian Day 70.8 and 71.0, the near-bottom ammonium concentration increased due to resuspension of sediments and subsequent release of adsorbed ammonium.

SIMULATION OF THREE-DIMENSIONAL RESIDUAL FLOW AND SALINITY FIELDS

The 3-D curvilinear-grid hydrodynamics model CH3D (Sheng 1989, 1994) was modified to simulate the flow and salinity fields in Tampa Bay. Four simulation

scenarios are based on different combinations of ocean tide conditions, river flows (dry season vs. wet season), watershed flows (small creeks/canals vs. no small creeks/canals), rainfall (with vs. without), and wind (no vs. with). Typically, the model is run for 35 days to allow spin-up of the flow and salinity fields. After that, the

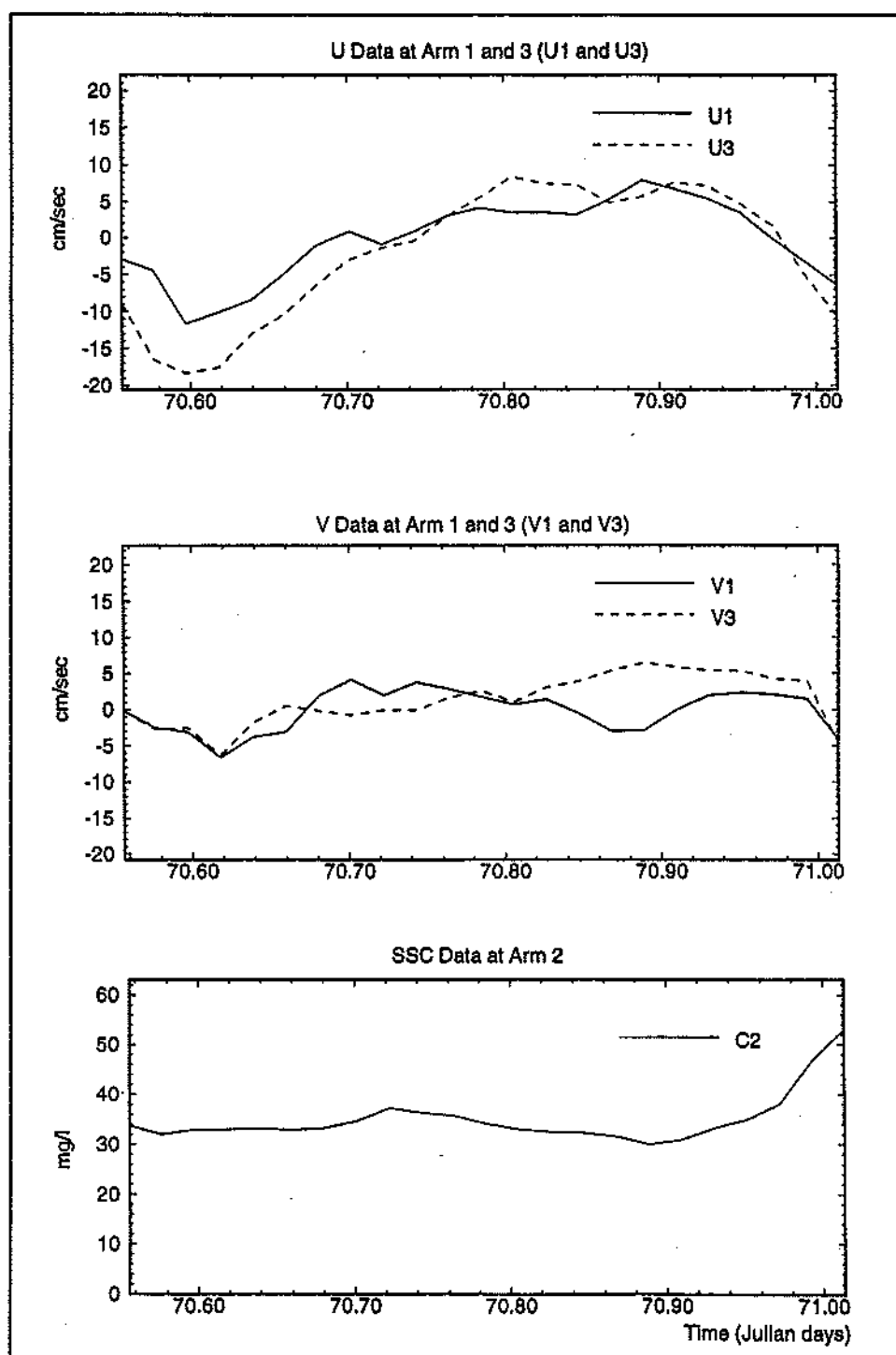


Figure 4. Measured u-velocity, v-velocity and suspended sediment concentration at Station A in Tampa Bay during Julian Days 70.5 to 71.1, 1993.

model is run for another 30 days to reach dynamic equilibrium. Results of the last 30-day model simulation are averaged over time to obtain the residual flow and salinity fields. As an example, the simulated residual flow and salinity fields for the "major river" scenario and the "rainfall" scenario are shown in Figures 7 and 8, respectively.

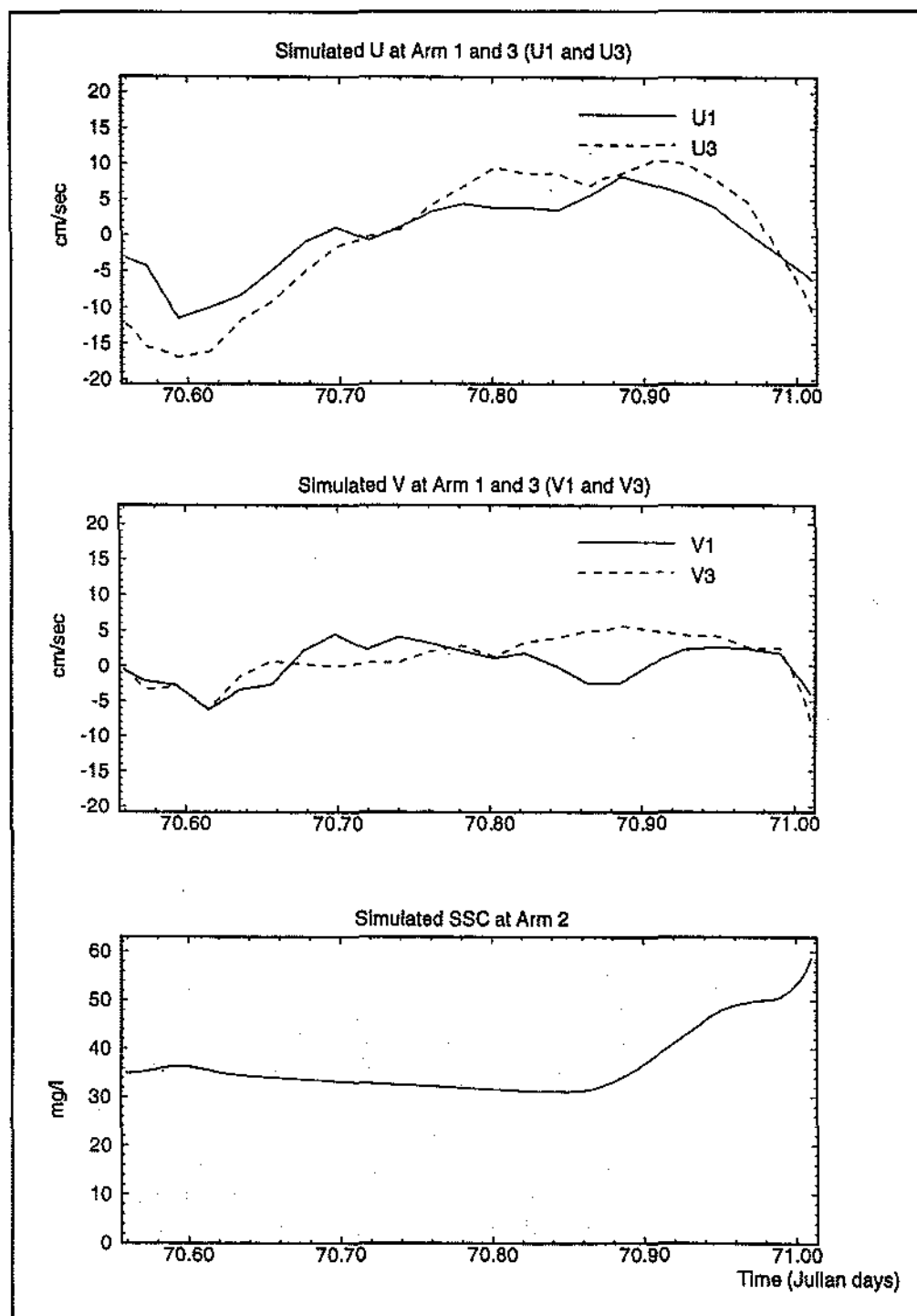


Figure 5. Simulated u-velocity, v-velocity and suspended sediment concentration at Station A in Tampa Bay during Julian Days 70.5 to 71.1, 1993.

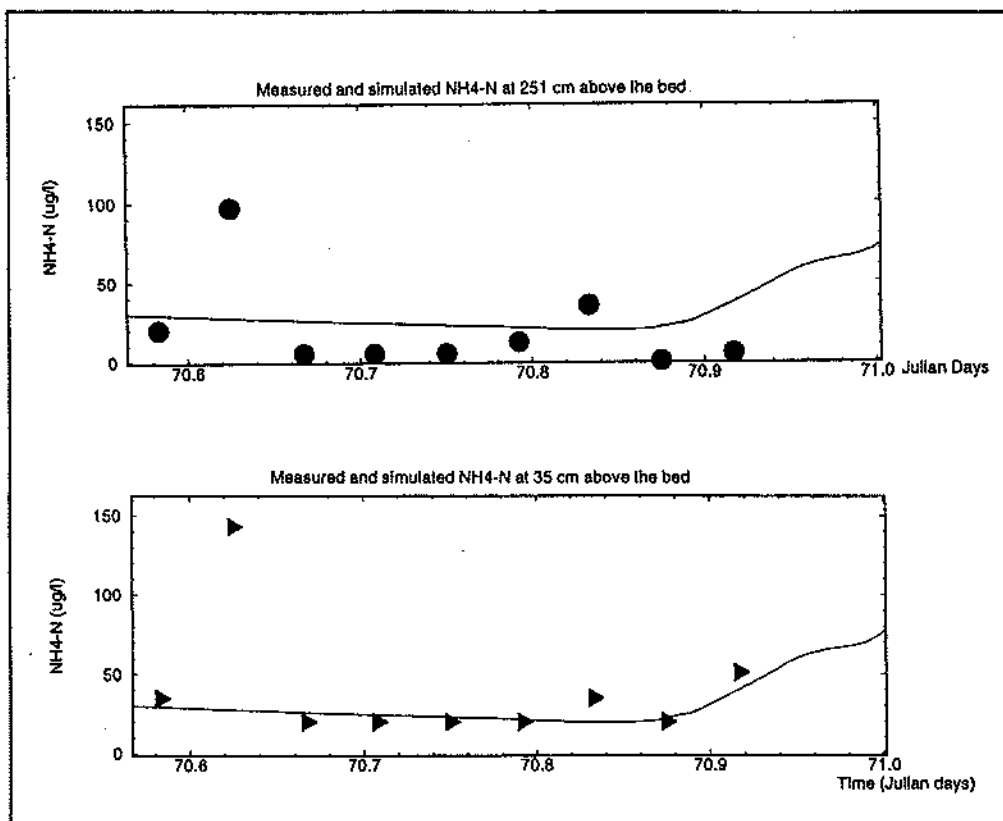


Figure 6. Measured and simulated ammonium nitrogen at two vertical levels at Station A in Tampa Bay during Julian day 70.56 to 71.0 in 1993.

These results, however, are not fully calibrated and verified due to the limited scope of this study. Model calibration and verification were carried out earlier by Sheng and Peene (1992) as well as more recently by Yassuda and Sheng (1996), using NOS data obtained in 1990 and 1991.

As shown in Figure 7, the near-bottom currents are toward the river, with stronger currents on the order of 2–5 cm/sec along the navigation channel. The residual flow exhibits localized patterns related to the bathymetric and geometrical features. The near-surface residual currents are seaward, with stronger currents on the order of 10 cm/sec inside the channel. Model results show relatively strong currents along the east coast of Pinellas Peninsula near St. Petersburg, which are most likely caused by the sharp bottom slopes there. The residual salinity distribution shows a vertically homogeneous distribution over the entire bay. Higher salinity water penetrates farther into the bay inside the channel, but this intrusion is limited to the upper reaches of Tampa Bay. In Hillsborough Bay, the salinity distribution indicates a complete mixing pattern between river discharges and saltier water, with salinity ranging from 22 to 26 ppt. The low salinity region shown in the upper reaches of Hillsborough Bay may indicate poor mixing, and this null zone was later studied with a more refined grid. The relatively low salinity (around 22 ppt) in Old Tampa Bay is due to the lack of a freshwater source to Old Tampa Bay in this simulation. The residual circulation and salinity fields during the last 30 days of the simulated “rainfall” scenario are shown in Figure 8. The velocity field is similar to the “watershed, wet condition”, which

suggests that the rainfall does not have a major effect on the 30-day residual calculation. The residual salinity distribution is markedly different from the results of all previous simulations. Comparing this salinity in Figure 8 with the residual salinity distribution in the "watershed, wet condition" simulation, it showed that the upper reaches of the Bay became less saltier, and that a vertical salinity structure developed.

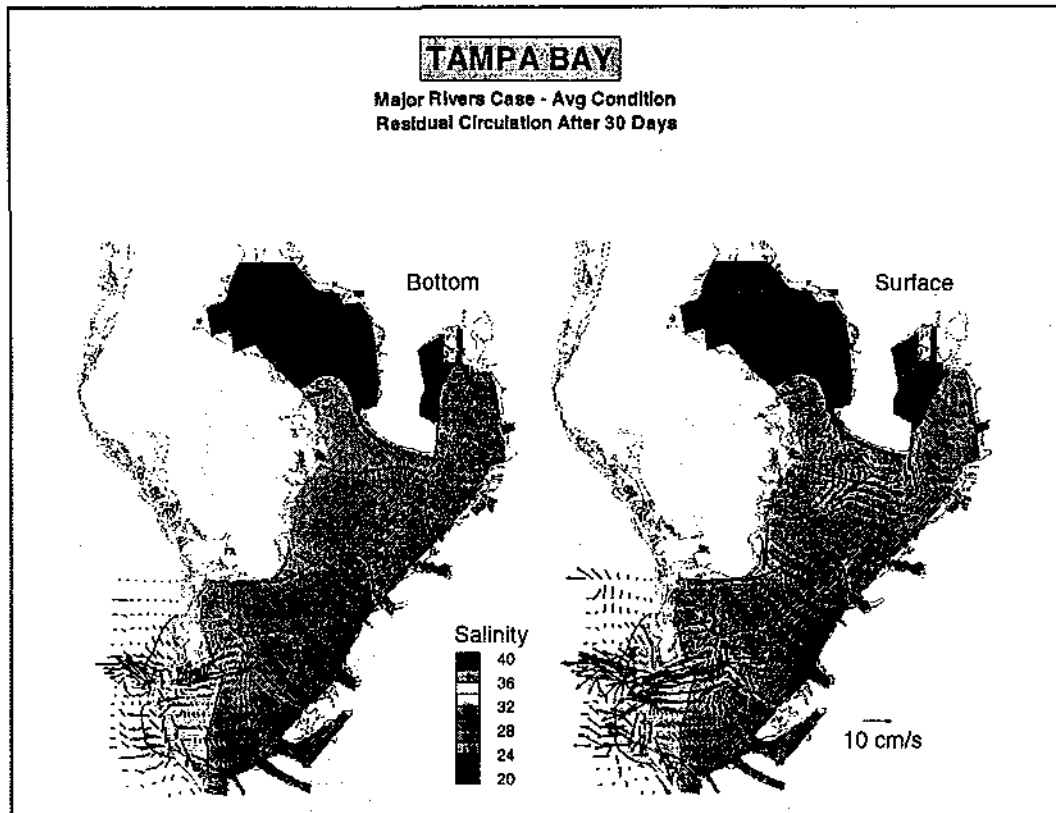


Figure 7. Residual circulation after 30 days, major rivers / avg. case.

The numerical grid used for CH3D simulation (Fig. 9) contains a total of 39 by 62 horizontal cells and four vertical layers. This grid was generated by using a grid generation code and digitized Florida coastline data. The curvilinear boundary-fitted grid allows better representation of the complex geometry and bathymetry of the bay, particularly the shoreline, causeways, bridges and navigation channel. The depth information was based on the raw data from NGDC and is plotted in Figure 10. Figure 11 shows the 14 segments which overlap with the CH3D grid and the geometrical features of Tampa Bay. Although this 14-segment system was recommended by us to the Tampa Bay NEP, it was not used by the Tampa Bay WASP model which used a segment system which does not fully overlap with Tampa Bay geometrical features and CH3D grid.

SIMULATION OF 1991 HYPOXIA IN HILLSBOROUGH BAY

Since 1972, routine water quality data in Tampa Bay have been collected by the Hillsborough County Environmental Protection Commission (EPC). During 1991, data were collected at 52 bay stations (Fig. 12) and 40 tributary stations at

approximately monthly intervals (Boler 1992). The 1991 data indicated that the water quality declined appreciably between June 1991 and September 1991, a wet season with increased rainfall and freshwater discharge. Chlorophyll-*a*, color and total Kjeldahl nitrogen all increased in concentration, while DO concentration decreased. By October, the water quality in Hillsborough Bay recovered. These EPC data during June and October 1991 were thus chosen as a database for a preliminary evaluation of the nitrogen model developed by us.

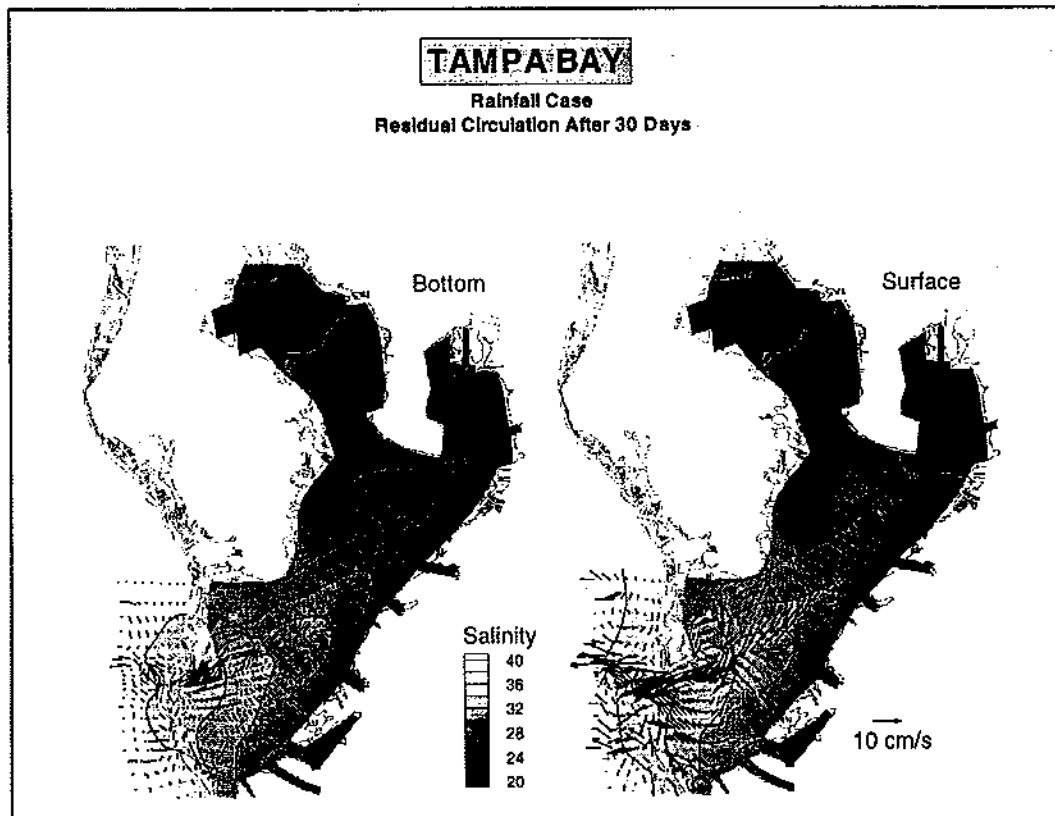


Figure 8. Residual circulation after 30 days, rainfall case.

Prior to the 120-day water quality simulation, we conducted a hydrodynamic simulation of the 1991 summer circulation in Tampa Bay using the 3-D curvilinear-grid hydrodynamics model CH3D (Sheng 1987, 1989, 1994; Sheng and Yassuda 1995) and the NOS hydrodynamic data which were collected primarily inside the navigation channels. As presented in detail in Yassuda and Sheng (1996), model-simulated water surface elevation and currents compared well with available field data, as in earlier model studies (e.g., Peene et al. 1991; Sheng and Peene 1992; Sheng and Peene 1993). Yassuda and Sheng (1996) also simulated the salinity distribution successfully, although salinity was not significantly stratified in the vertical direction.

The EPC data were used to develop the initial fields of DO, organic nitrogen, ammonium, nitrate plus nitrite, and chlorophyll-*a* in June 1991 for model simulation. Total nitrogen loading from various tributaries estimated by Coastal Env. Inc. (1995)

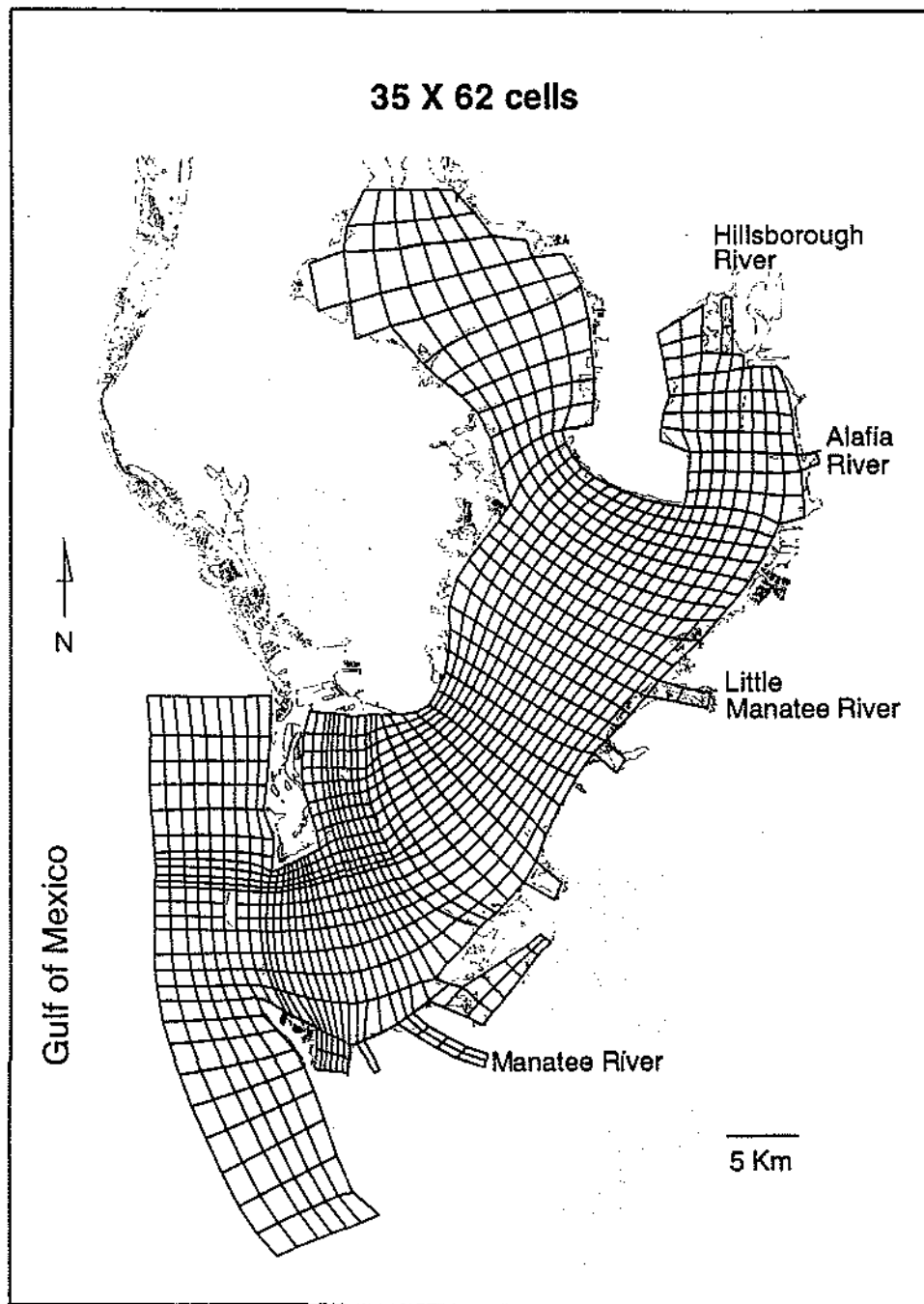


Figure 9. CH3D grid and major rivers location.

was partitioned into total organic nitrogen, nitrate plus nitrite, and ammonium nitrogen, following the procedure developed by Asci (1996). Based on the EPC data and the sediment distribution, we divided the Tampa Bay into four segments (Hillsborough Bay plus upper Old Tampa Bay, upper Middle Tampa Bay, Lower Tampa Bay and Gulf of Mexico, and a transition zone between the last two segments) within which the model coefficients (including the partition coefficients) are uniform. For the sediment column, we used the results of sediment nitrogen studies conducted

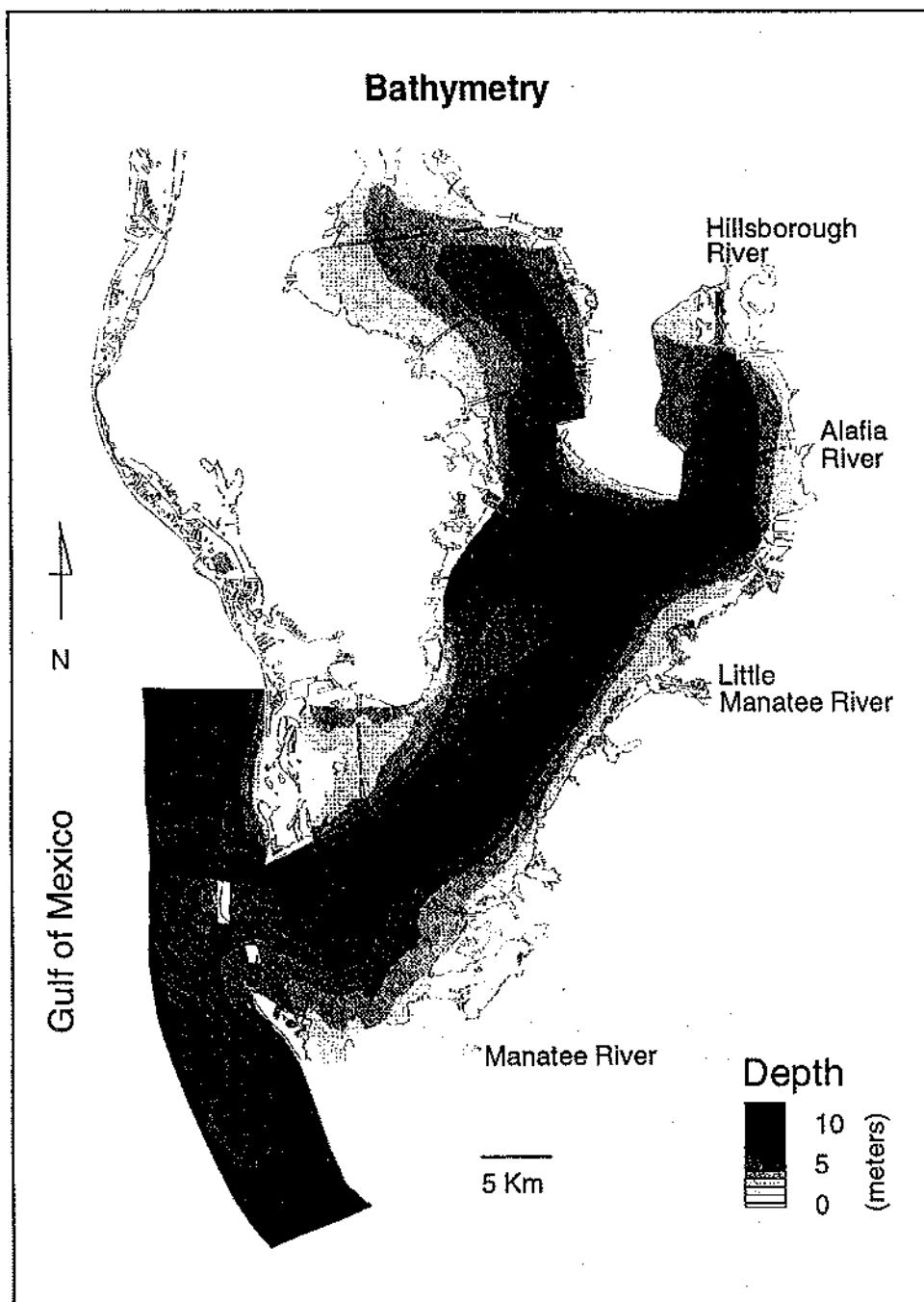


Figure 10. Tampa Bay bathymetric contours.

in 1963 (Taylor and Saloman 1969), 1985–1986 (Brooks and Doyle 1992), 1991–1992 (NOAA 1994) and 1992–1993 (Sheng et al. 1993). All studies collected grab samples except Sheng et al. (1993) which used core samples. Based on these data, sediment nutrient concentrations and model coefficients in the aerobic and anaerobic layers of each of the four segments were specified. Using these initial fields and model coefficients, sensitivity model runs were conducted to determine the sensitivity of model results to such parameters as desorption and absorption rates, mineralization

rate, diffusion coefficient, aerobic layer thickness, nitrification/denitrification rates, and algal growth, death and excretion rates.

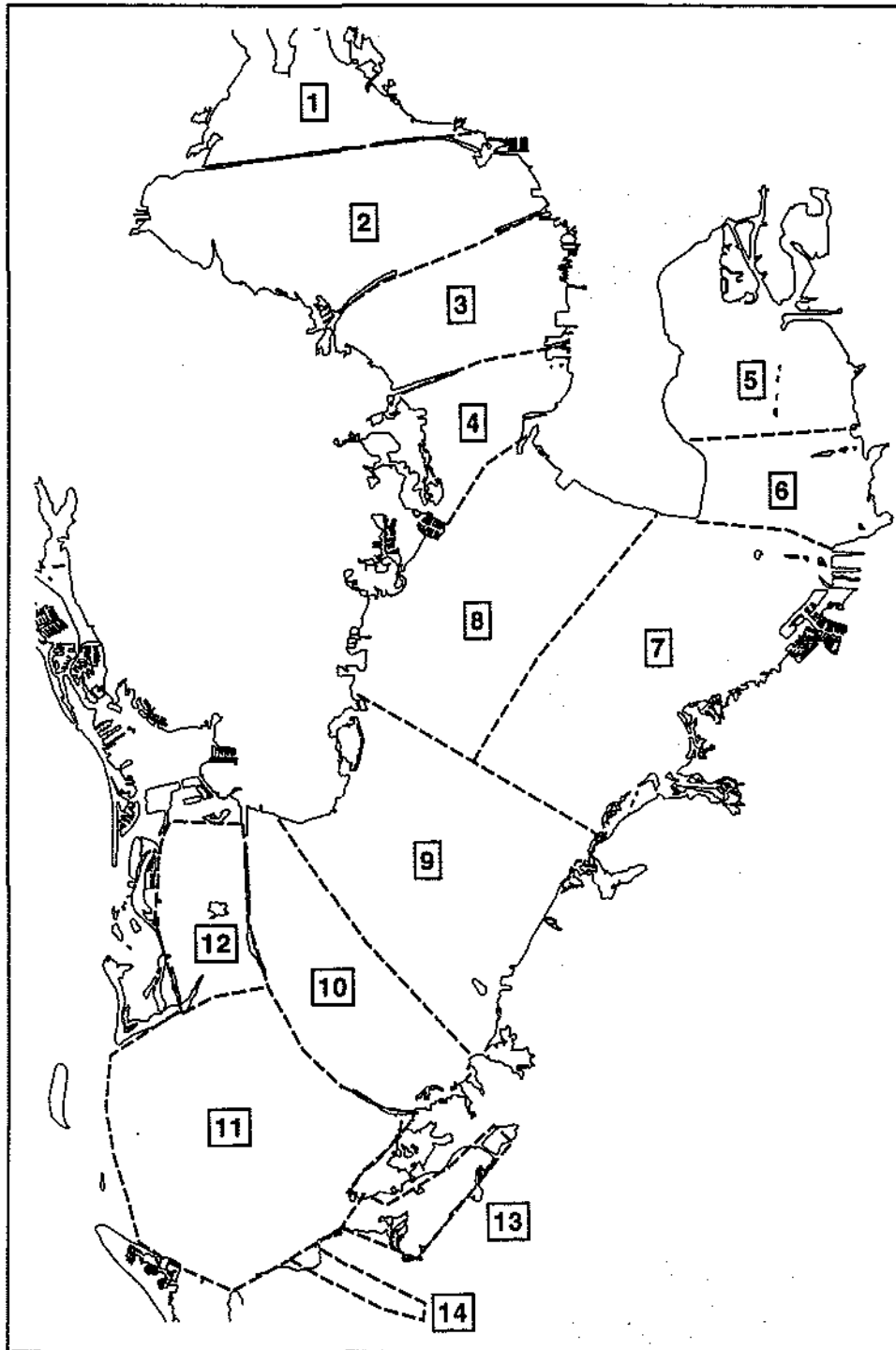


Figure 11. CH3D grid with proposed WASP segments.

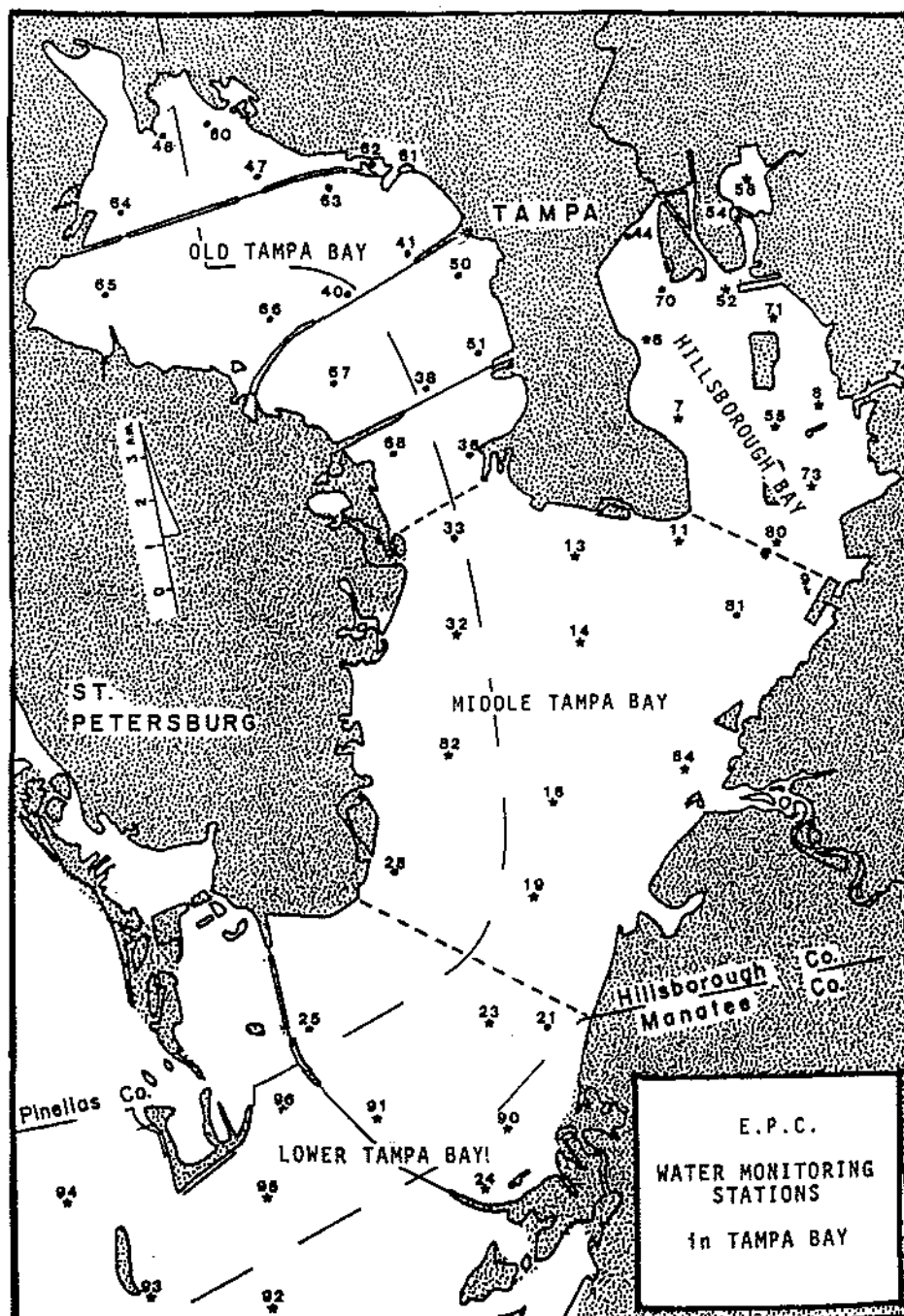


Figure 12. Water quality monitoring stations of the Hillsborough County Environmental Protection Commission (Boler 1992).

Following the sensitivity study, the hypoxia event in the summer (120 days between June and October) of 1991 was simulated. The near-bottom DO concentration in Tampa Bay at 30, 60, 90 and 120 days of the model simulation are shown in Figures 13, 14, 15 and 16, respectively. The results clearly showed that the DO concentration in Hillsborough Bay decreased between July and September, but increased in October. The temporal evolution of the hypoxia event can be better visualized by examining

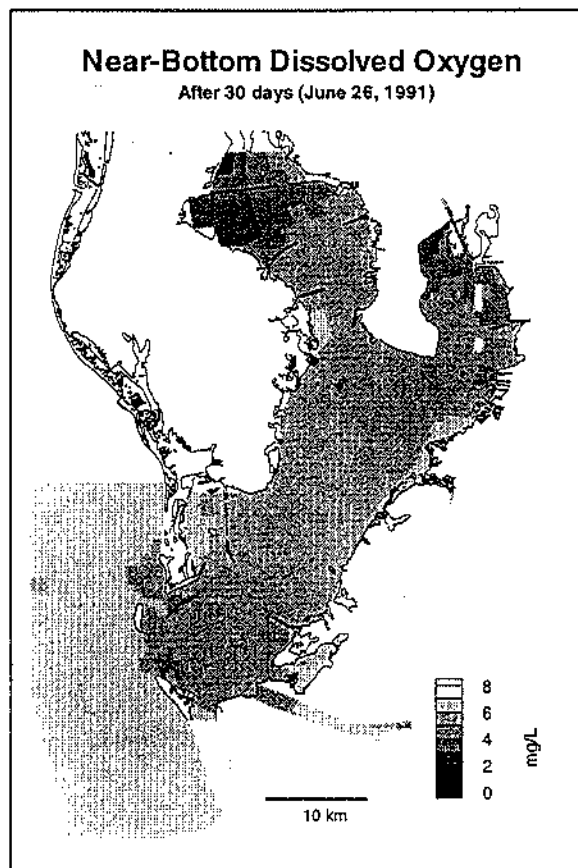


Figure 13. Near-bottom dissolved oxygen concentration in Tampa Bay on June 26, 1991, after 30 days of simulation.

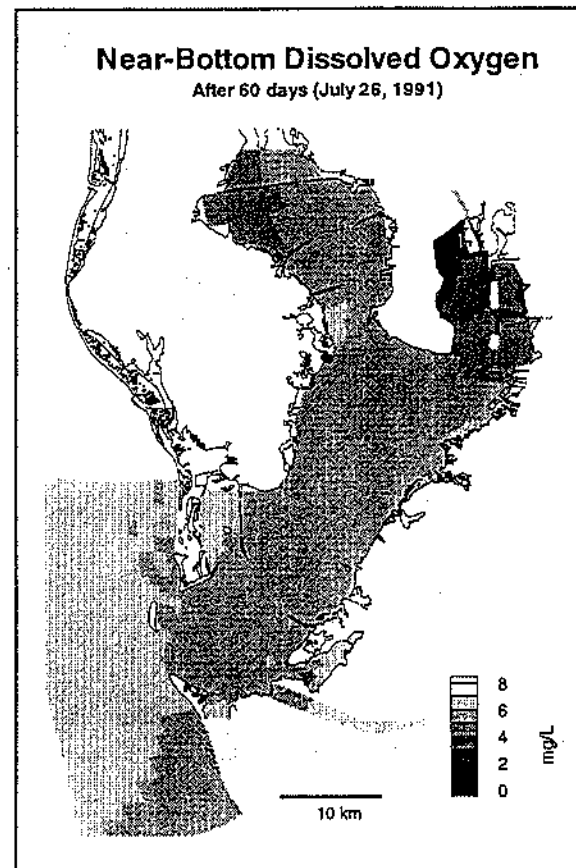


Figure 14. Near-bottom dissolved oxygen concentration in Tampa Bay on July 26, 1991, after 60 days of simulation.

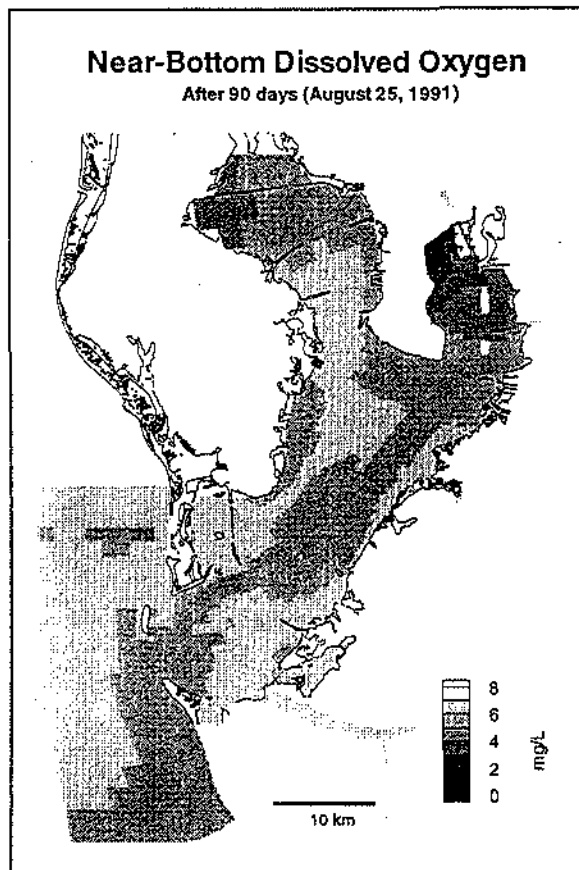


Figure 15. Near-bottom dissolved oxygen concentration in Tampa Bay on August 25, 1991, after 90 days of simulation.

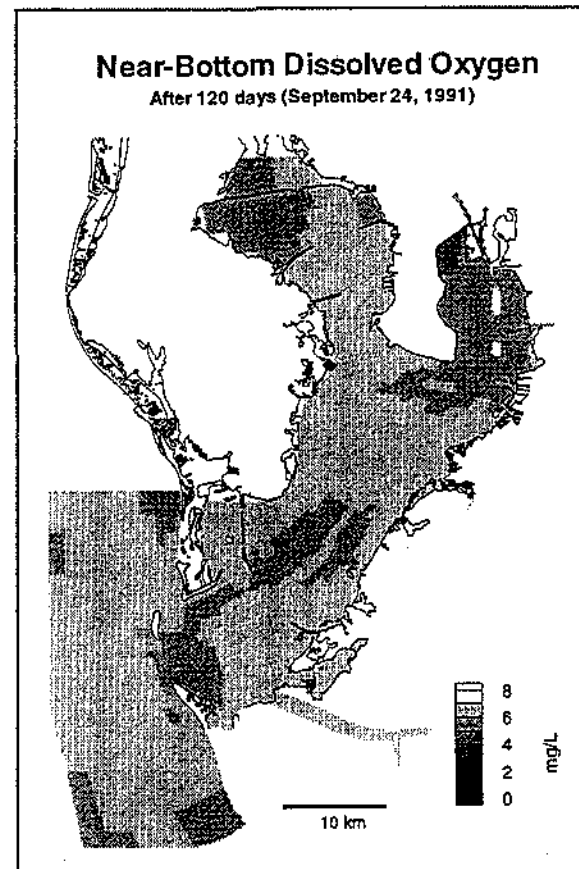


Figure 16. Near-bottom dissolved oxygen concentration in Tampa Bay on September 24, 1991, after 120 days of simulation.

the segment-averaged DO concentration in Hillsborough Bay (Fig. 17) and Old Tampa Bay (Fig. 18).

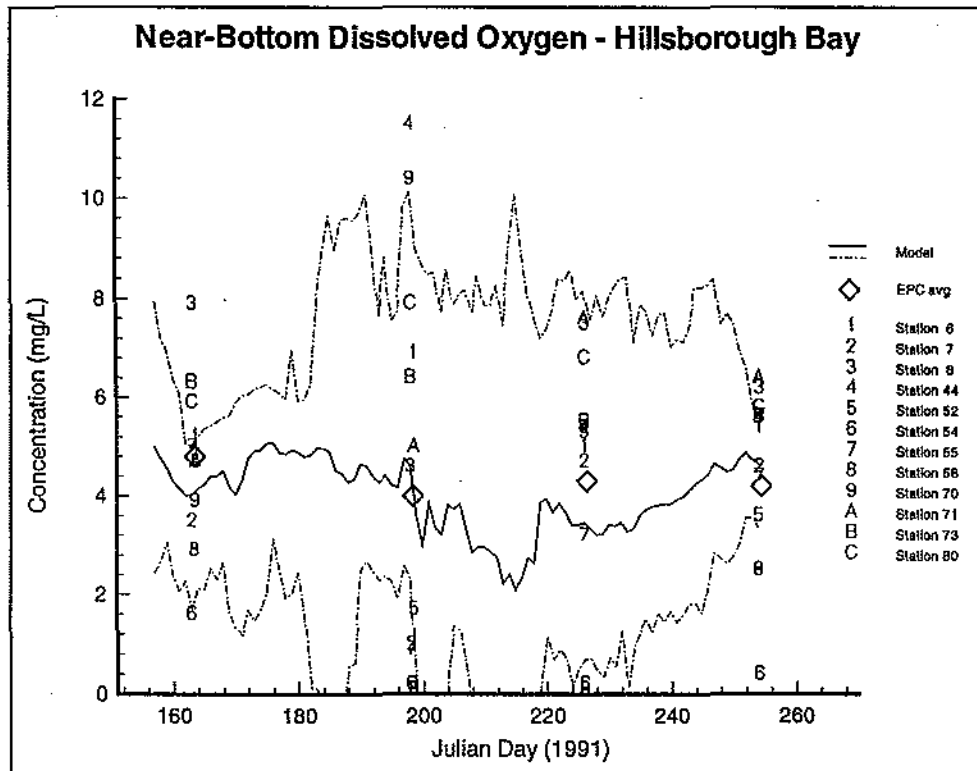


Figure 17. Simulated (solid line) segment-averaged near-bottom DO concentration, segment maximum and minimum concentrations (dashed line), and the EPC data inside Hillsborough Bay.

CONCLUDING REMARKS

A few recent studies on the hydrodynamics and water quality dynamics in Tampa Bay conducted by the University of Florida have been presented. Some conclusions are:

- During episodic events, wave-induced sediment resuspension can lead to subsequent release of adsorbed nutrients into the water column in Hillsborough Bay area. Benthic processes should be included in the estimation of the nutrient budget for Tampa Bay.
- A coupled hydrodynamics-sediment-water quality model, which includes important benthic processes, was developed to successfully simulate the observed data during two storm events, one in 1992 and another in 1993.
- The 3-D curvilinear-grid hydrodynamics model CH3D has been successfully applied to simulate the residual flow and salinity fields in Tampa Bay during a variety of hydrologic conditions. The residual flow fields showed distinct two-layer flow patterns with seaward surface flow and up-the-channel bottom flow. These distinct two-layer flow structures cannot be and were not represented by the one-layer segments (or boxes) used by the Tampa Bay WASP model.
- To accurately simulate the water quality dynamics in Tampa Bay, it is important to couple the hydrodynamics model with the water quality model so that the

effects of hydrodynamic processes on water quality processes are accurately represented.

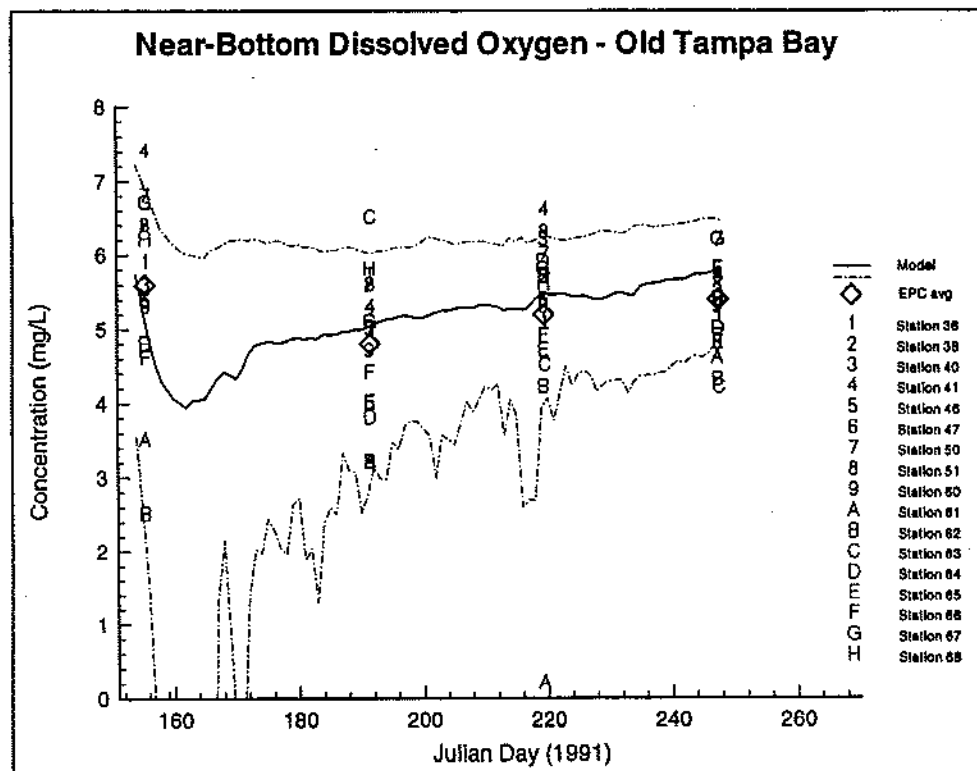


Figure 18. Simulated (solid line) segment-averaged near-bottom DO concentration, segment maximum and minimum concentrations (dashed line), and the EPC data inside Old Tampa Bay.

- A coupled hydrodynamics-sediment-water quality model has been developed and applied to Roberts Bay, Tampa Bay and the Indian River Lagoon. The coupled model also includes a seagrass model for three species and an empirical light attenuation model.
- The coupled model for Tampa Bay can accurately simulate the water surface elevation, flow, salinity and hypoxia events in Tampa Bay, based on 1990 and 1991 data, and can be used to simulate the response of Tampa Bay water quality to various load-reduction scenarios.
- Sediment chemistry data in Tampa Bay are very scarce and inadequate to provide a definitive quantitative description of the spatial and temporal distributions of the various water quality constituents (e.g., nitrogen, phosphorus and carbon) in the sediment column.
- Although EPC data were extremely useful for preliminary evaluation of the water quality model, future monitoring programs should gather more synoptic data over more frequent intervals.
- Although model simulations of seagrass growth and decay appeared to be reasonable, existing seagrass data in Tampa Bay are inadequate for complete model calibration and verification of the conceptual seagrass model which was

- based on the work by Fong and Harwell (1994). More comprehensive and concurrent data of hydrodynamics, water quality, light and seagrass are needed.
- The coupled hydrodynamics-sediment-water quality model contains comprehensive cause-effect relationships and is hence more robust than the regression model and simple box model. It is thus more appropriate to use the coupled model to predict the response of Tampa Bay estuarine system to future alterations in nutrient loading.
 - To develop a fully predictive model of the Tampa Bay system, additional calibration and verification of the 3-D coupled model, along with additional field data of water-column and sediment-column nutrient concentrations, is recommended.

ACKNOWLEDGMENTS

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COORDINATED BAYWIDE MONITORING

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ABSTRACT

There is a rich history of environmental awareness in the Tampa Bay area. With this awareness comes a wealth of data and information generated by local (cities and counties), regional, state and federal governments necessary for proper bay management. Most of the established monitoring programs were created to respond to local needs for information on bay and tributary conditions relative to anthropogenic impacts such as point source discharges and impacts from development.

The creation and implementation of the Tampa Bay National Estuary Program (TBNEP) has brought together bay partners (surrounding governments and regulatory agencies) to evaluate and propose baywide management strategies. It was determined that adequate monitoring data was essential for establishing current baywide conditions and for evaluating the effectiveness of future management activities. In 1992, Versar, Inc. and Coastal Environmental Services, Inc. prepared a report documenting the goals of a monitoring program for TBNEP. The goals were: "to measure the effectiveness of management actions and programs implemented under the Comprehensive Conservation & Management Plan (CCMP)", and "to provide information that can be used to redirect and refocus the management plan over time."

With the help of a TBNEP-sponsored monitoring workshop in January of 1992, more specific objectives were devised and were outlined in a technical report by Coastal Environmental, Inc. (1994). An overview of historical independent and proposed coordinated water and sediment quality monitoring programs are presented along with proposed implementation schedules and data reporting criteria.

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STORMWATER TREATMENT— EFFECTIVENESS AND MANAGEMENT

**E. Araj
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ABSTRACT

Hillsborough County (including its municipalities) encompasses 1,072 square miles and a population of more than 850,000. The unincorporated portion is about 931 square miles, with more than 60% of the land use in agricultural or undeveloped designation. The largest municipality is the City of Tampa with more than 280,000 residents, and consists of mostly developed land. Temple Terrace and Plant City are the other two municipalities.

The projected population growth for the Tampa Bay metropolitan area between 1993 through 2005 is expected to be 20.7%, ranking it 14th among the nation's fastest-growing metropolitan areas. That growth will result in the development of new areas, re-development of existing sites, more demand on the existing infrastructure, and more importantly, the generation of more pollution. Seeking ways to prevent this pollution from being generated (prevention), and from ending up in our receiving water bodies (treatment) is a challenge that has faced policy makers and scientists for some time. In addition, the Tampa Bay National Estuary Program has adopted a "hold the line" strategy on nitrogen loading to the Bay—nitrogen in this case being the limiting pollutant for the Bay.

Experience, research and time have shed some light on what works, what does not, and what might. Research has also shown that the existing state requirements on water quality abatement have differing efficiencies on the pollutants in question. The challenge to scientists and engineers in our region would be to find ways to "hold the line" on pollutant loading, while assimilating the projected growth without the introduction of new permitting and bureaucratic layers.

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MEASUREMENTS OF TIDAL FLOW IN TAMPA BAY USING AN ACOUSTIC DOPPLER CURRENT PROFILER

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ABSTRACT

The U.S. Geological Survey, in cooperation with the Southwest Florida Water Management District Surface Water Improvement and Management Department, is measuring flow velocities and patterns near the mouth of Tampa Bay and Anna Maria Sound with a broad-band Acoustic Doppler Current Profiler (ADCP). The direct measurement of velocity profiles over long distances in shallow estuarine environments during the last five years has been made possible by the development of this new generation ADCP. The broad-band ADCP measures velocities in as little as 6 feet of water depth, whereas the previous narrow-band ADCP required about 15 feet. Because of the measurement capability at shallow depths, the broad-band ADCP can more accurately measure velocity profiles at the mouths of Tampa Bay and its tributaries and passes. This has allowed for the measurement of tidal-flow exchange between Tampa Bay and Sarasota Bay through Anna Maria Sound. Measurement of the tidal flow exchange between these two water bodies is important for the understanding of the physical processes that drive the water quality and flushing characteristics of the area.

Since February 1995, 31 measurements have been made under various tidal and flow conditions at the mouth of Tampa Bay and 11 measurements have been made at the mouth of Anna Maria Sound. Preliminary assessment of the flow data for measurements made at the mouth of Tampa Bay indicates a measured maximum of 954,000 cubic feet per second (cfs) inflow on a flood tide, 1,260,000 cfs outflow on an ebb tide, and measured minimum of 16,000 cfs inflow near low slack and 11,500 cfs outflow near high slack tide. Maximum flows measured at Anna Maria Sound were 13,300 cfs inflow at flood tide and 16,700 cfs outflow at ebb tide. Minimum measured flow was 490 cfs inflow. During a rising stage of almost 2 feet in six hours at the mouth of Tampa Bay (flood tide) on December 12, 1995, flow into Anna Maria Sound varied from 490 cfs to 5,850 cfs. Future project activities may include simultaneous measurements at the mouth of Tampa Bay and Anna Maria Sound and comparisons to Physical Oceanographic Real-Time System data taken at the Sunshine Skyway Bridge.

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THE TAMPA BAY PHYSICAL OCEANOGRAPHIC REAL-TIME SYSTEM (PORTS)

**Mark E. Luther
Nancy Schmidt
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POSTER ABSTRACT

Real-time oceanographic and meteorological data from Tampa Bay, Florida, are collected by PORTS (Physical Oceanographic Real-Time System), an information acquisition and dissemination technology developed by the NOAA National Ocean Service (NOS). PORTS integrates real-time current, water level, water and air temperature, barometric pressure and wind measurements collected every six minutes from sensor arrays at six location in Tampa Bay. The data are telemetered via line-of-sight radio to a central processor, which generates a real-time report available to the public by modem, Internet, or touch-tone telephone. PORTS has been operational since May 1992, and has achieved better than 95% data return to date. All data are archived and are available via anonymous FTP to kelvin.marine.usf.edu or via the Internet from URL <http://ompl.marine.usf.edu>. A major expansion of PORTS is underway. New sensors are being installed on Palatine Shoal, just south of buoy #10 in the Egmont Channel (27° 5.74'N, 82° 51.59'W) and at the turn in the ship channel leading to Port Manatee (27° 39.70'N, 82° 35.80'W). Both these sites will measure currents and winds. In addition, the Palatine Shoal site will measure waves and visibility. Visibility sensors will be added to existing sites at the Sunshine Skyway Bridge center span and at Old Port Tampa. All existing sites are being refurbished and upgraded as well.

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PROGRESS TOWARD NOWCASTING AND FORECASTING OF TAMPA BAY WATER LEVELS AND CURRENTS

Kurt Hess
Chris Zervas
Boris Galperin

ABSTRACT

Historically, the National Ocean Service (NOS) has been supplying daily predictions of the astronomical tide and current in Tampa Bay, but actual conditions may vary due to fluctuations in water levels on the west Florida shelf, changing river discharges and local winds. Real-time observations from the Physical Oceanographic Real-Time System (PORTS) give the actual conditions, but there is a demand for the forecast of future conditions. NOS has been testing short-term statistical forecasts of non-tidal water levels using observations from PORTS and from a gauge at Panama City Beach. An alternative way to obtain a longer-range forecast is by the use of numerical models. Researchers at NOS and the University of South Florida (USF) are planning to develop nowcasts and forecasts of water levels and currents using a numerical circulation model combined with driving forces supplied by observations from the Tampa Bay PORTS and from forecast winds. A three-dimensional time-dependent model has been calibrated and validated both at NOS and USF using various data sets, particularly the NOS survey conducted in 1990-91. The model was shown to successfully replicate tidal elevations and currents in a hindcast mode. The modeling component is planned to be operated in both nowcast (or near real-time) and forecast modes. The output information would be accessible to the navigational, management and scientific community in a variety of formats. Progress in implementing these approaches is discussed.

INTRODUCTION

Knowledge of the water levels and currents in Tampa Bay is essential for a variety of users, and it has been demonstrated that these variables in Tampa Bay can be monitored at many temporal and spatial scales, and that their past conditions can be simulated using numerical models. However, the ultimate task is to predict them for the future. To meet this need, researchers at the National Oceanic and Atmospheric Administration's (NOAA's) National Ocean Service (NOS) and the University of South Florida (USF) are planning to develop nowcasts and forecasts of water levels and currents using numerical circulation models and driving forces supplied by observations from the Tampa Bay Physical Oceanographic Real-Time System (PORTS) and from forecast winds. These forecasts are intended primarily to support the navigational community, but will have applications to other activities such as emergency responses (e.g., to oil spills), definition of environmental monitoring and prediction strategies, and general scientific research.

NOS has been supplying daily predictions of the astronomical tide and current at numerous locations in Tampa Bay, but it is well known that actual conditions may vary due to many factors, including fluctuations in water levels on the west Florida shelf, changing river discharges and local winds (Fig. 1). As a first step in overcoming this deficiency, NOS installed the Tampa Bay PORTS (Frey 1991; Bethem 1991; Appell et al. 1994). This system takes nearly continuous observations of: 1) water levels at St. Petersburg, Port Manatee, Port of Tampa and Old Port Tampa; 2) currents at Sunshine Skyway and in the navigation channel near Old Port Tampa; and 3) winds and other meteorological variables near Sunshine Skyway, St. Petersburg, Port Manatee, Port of Tampa and Old Port Tampa. In addition to the observations, a nowcast is made for the current in the navigation channel near the turn to Port

Manatee. Locations of the PORTS sensors are shown in Figure 2. The data are telemetered to the central computer located at and maintained by USF, and the latest values are disseminated every 6 minutes via voice message and PC screen. Although the PORTS provides valuable information on the bay's present state, there still remains the need for a forecast of future conditions.

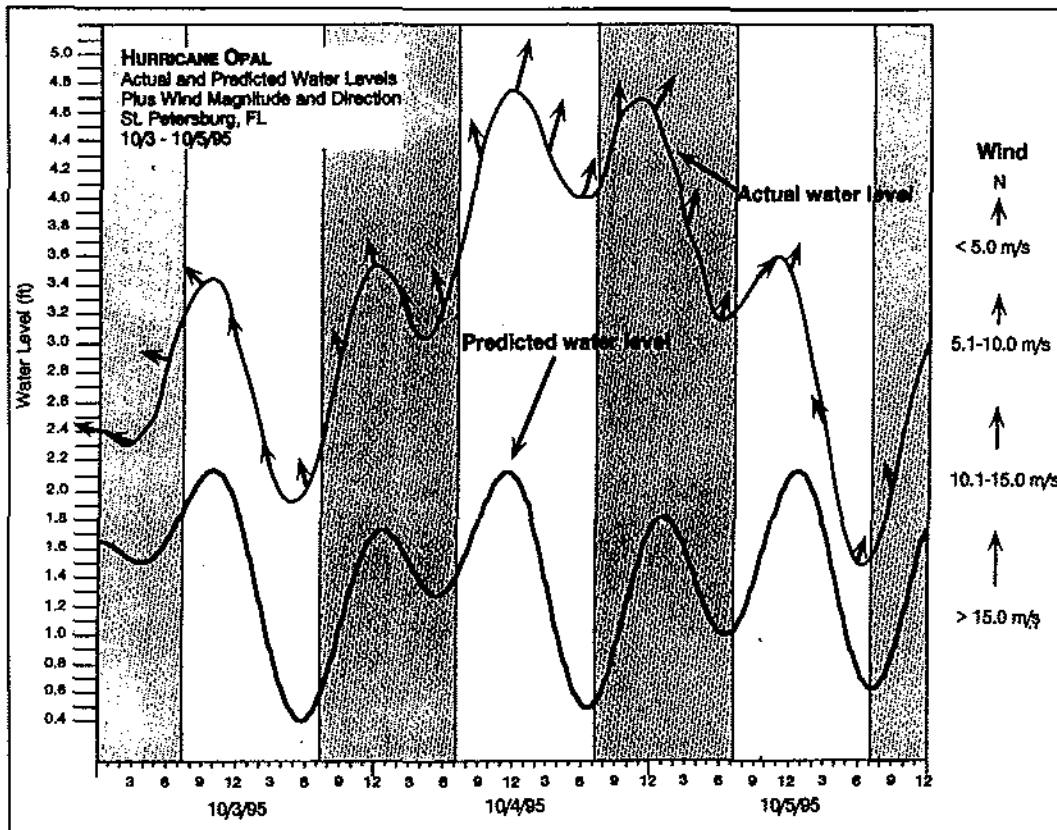


Figure 1. Observed water level at St. Petersburg vs. predicted astronomical tide. Although the discrepancies are expected to be relatively large during the passage of a hurricane, differences of a smaller magnitude occur frequently.

Two approaches to forecasting are discussed in this paper. The first is statistical forecasting, which predicts a future value of some variable using one or more present observations as the input to an equation which has been developed by the statistical analysis of historical data. This approach does not incorporate any physical relationships and works best when applied to a small number of locations for which a large amount of data exists. The second approach is the use of a numerical model which solves conservation equations simultaneously at many locations on a grid and thereby produces a field of predicted values at the resolution of the grid. A nowcast is produced by using recent observations to drive the model simulation of baywide conditions up to the present, i.e., when the latest observations are available. However, a bay forecast requires a forecast of the driving coastal water levels and winds. Progress in implementing these approaches is discussed.

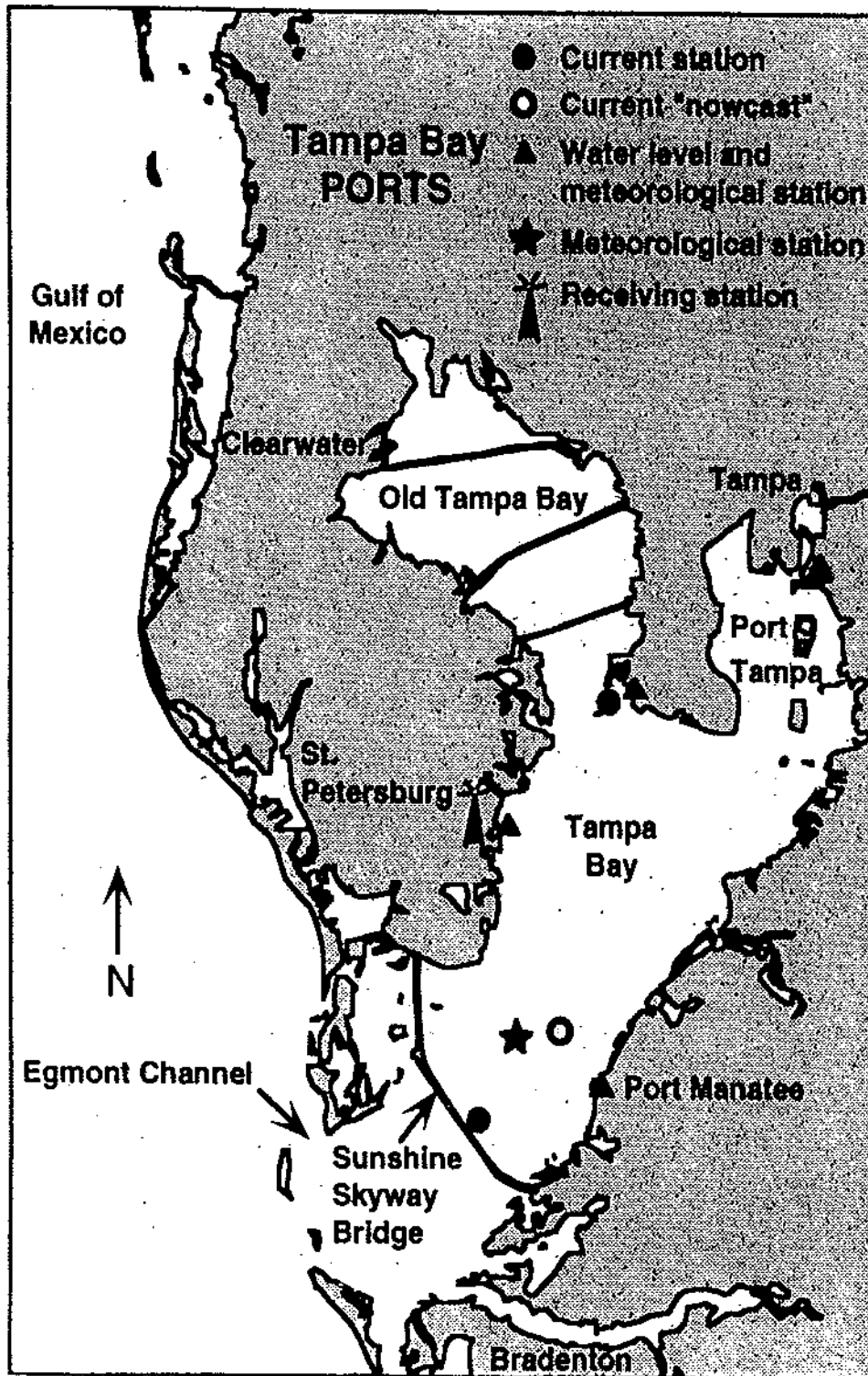


Figure 2. PORTS locations in Tampa Bay. Water levels, currents and meteorological data (including winds) are telemetered into the central computer at USF.

THE NEED FOR FORECASTING

The need for nowcasts and forecasts has frequently been expressed by the navigational and environmental communities. To obtain more specific information, a survey of needs was recently conducted by researchers at USF. Survey forms were sent out to individuals on the mailing lists of PORTS and of the Greater Tampa Bay Marine Advisory Council, and to a number of harbor pilots. There were twenty-four responses, including nine from harbor pilots. The first part of the survey was designed to gather information about the present usage of the PORTS, while the second part was designed to determine the level of interest in water level and current forecasts. The harbor pilots were mainly interested in the times of slack water for making turns and for docking vessels. Both harbor pilots and shippers were interested in water levels for planning deep-draft berths, preventing groundings and maximizing cargo loading. The main locations of interest were those presently instrumented by PORTS plus additional locations (for current meters) in Hillsborough Bay.

Preliminary results indicate that about two thirds of the respondents had a preference for total water level forecasts over nontidal water level forecasts. The preferred lead times for forecasts were 4 to 6 hours for water levels and 2 to 6 hours for currents. Although forecasts in the form of numbers were preferred over graphic forecasts, about half the respondents asked to see both. The preferred forecast accuracy levels were 0.2' to 0.3' for water levels and 0.1 to 0.3 kn for currents (the respondents considered any current below 0.2 to 0.25 kn to be slack). The respondents were about equally interested in the following four methods of accessing forecasts—PC display via modem dial-up, voice system, Internet, and fax-on-demand.

There are additional needs that were not addressed in the survey. The water's specific gravity can be useful in ship loading by more accurately determining the ship's cargo capacity. Emergency situations, including oil spills and search-and-rescue operations, require accurate forecasts. There is also an opportunity to make water quality monitoring more cost-effective by helping to focus efforts on critical geographic areas or to trigger event-driven monitoring.

STATISTICAL FORECASTS OF WATER LEVELS

The first and simplest approach to forecasting nontidal water levels is through the use of statistical correlations. NOS has been producing such forecasts since January 1996 using a method which incorporates the observed water level at Panama City Beach (PCB), located about 250 mi to the northwest of the bay, and the observed water level at PORTS gauges inside the bay (Zervas 1996). The nontidal water level is defined as the residual when the predicted astronomical tide is subtracted from the total water level (the predicted astronomical tide is generated by the summation of a cosine series of tidal constituents).

Most of the nontidal water level variability in Tampa Bay is caused by fluctuations on the west Florida continental shelf, making it possible to develop forecasting methods based on observations of water levels there. It has been shown that water levels at stations along the west Florida coast are highly correlated with each other (Marmorino 1982; Cragg et al. 1983). Results from a cross spectral analysis designed to correlate water levels at stations inside Tampa Bay with stations on the continental

shelf (Zervas 1993) show high coherences across the subtidal frequency band (greater than 1 cycle/day) which contains most of the nontidal energy in the signal. The transfer amplitude and phase difference is relatively stable across these frequencies indicating that a linear relationship exists between water level inside the bay and water level at PCB. Such a relationship can be described simply in terms of a scaling factor and a time delay. Observed phase differences indicate that signals generally propagate from north to south and reach stations in bays or rivers later than they reach stations on the coast. The largest nontidal amplitudes occur during the winter months and are associated with the passage of cold fronts.

Forecasting parameters (the scaling factor and a time delay) were obtained by cross-correlating a time series of water levels at PCB with a time series in the bay. Both time series were 30-hour low-pass Fourier-filtered so that the parameters were determined for frequencies where a linear relationship exists. The bay time series was lagged by multiples of 1-hour time intervals relative to the PCB time series, and the lag producing the highest correlation coefficient was chosen as the appropriate time delay. The scaling factor corresponds to the slope of the least squares straight line. To further increase accuracy, a 6-hour persistence forecast, in which the nontidal water level at the present time is persisted 6 hours into the future, was then averaged with the PCB forecast. These forecasts are most effective in predicting the longer period (1 to 5 days), large amplitude (greater than 20 cm), nontidal signals created by the passage of winter cold fronts. The prediction equation for nontidal water level, N_i , at 6 hours ahead of the present time, t , for each station is

$$N_i(t+6) = 0.5[a_i N_{PCB}(t) + N_i(t)] \pm b_i \quad (1)$$

where the subscript i denotes the location, a_i is the scaling factor, N_{PCB} is the nontidal water level at Panama City Beach, and b_i denotes the incremental water level added or subtracted to encompass 80% of the test forecast water levels. The pair of numbers corresponding to the addition and subtraction of b_i are the upper and lower predicted values; these define the 80% confidence interval. The total water level forecast is obtained by adding the nontidal forecast to the predicted astronomical tide. Table 1 gives the scaling factors for forecasting water levels at the four PORTS water level stations.

Table 1. Characteristics of the Tampa Bay nontidal water level statistical forecasting system. Locations are the PORTS stations. Observational data used in test forecast equation development for each station were used to determine the following parameters. The factor a and term b are those used in Equation 1. H_{30} is the number of hourly values per year that the absolute difference between the test forecast and the observed water level exceeded 30 cm; similarly for H_{20} .

LOCATION	a_i	b_i (cm)	H_{30} (hr)	H_{20} (hr)
St. Petersburg	0.84	8	10	51
Port Manatee	0.74	7	7	32
Old Port Tampa	0.86	9	19	101
Port of Tampa	0.91	11	23	188

In order to examine the accuracy of the forecasting equations, a predicted time series is subtracted from the observed time series to obtain the residual time series. Although the prediction will include high frequency noise which is not coherent from station to station, the amplitude of this noise is significantly smaller than the subtidal signal. A method for assessing forecast skill is to sum the hours per year when the absolute value of the demeaned residual water level is greater than a specific value representing an acceptable forecasting error. The hour values are shown in Table 1.

A prototype of the operational forecasting system is as follows. A desktop computer located at a satellite campus of Florida State University in Panama City retrieves water levels from the NOS water level gauge at PCB over local phone lines. The data is then transferred via Internet to the PORTS Data Acquisition System at USF. Every hour a new 6-hour forecast is made for four stations in Tampa Bay. The forecasts are available as a voice message, as a screen transmitted via modem, and as a fax-on-demand. The system is under evaluation by selected users before possibly being made available to the general public.

The forecast for the total water level is given as a set of values relative to mean lower low water (MLLW) representing a specific confidence interval and is available by a voice system or via modem on a screen display. A graphic output plot (Fig. 3) is also produced every hour which shows the astronomical tide, the observed water level up to the present time, and a widening forecast envelope for 6 hours into the future to represent the 80% confidence interval. This plot is available as a fax-on-demand to selected local users.

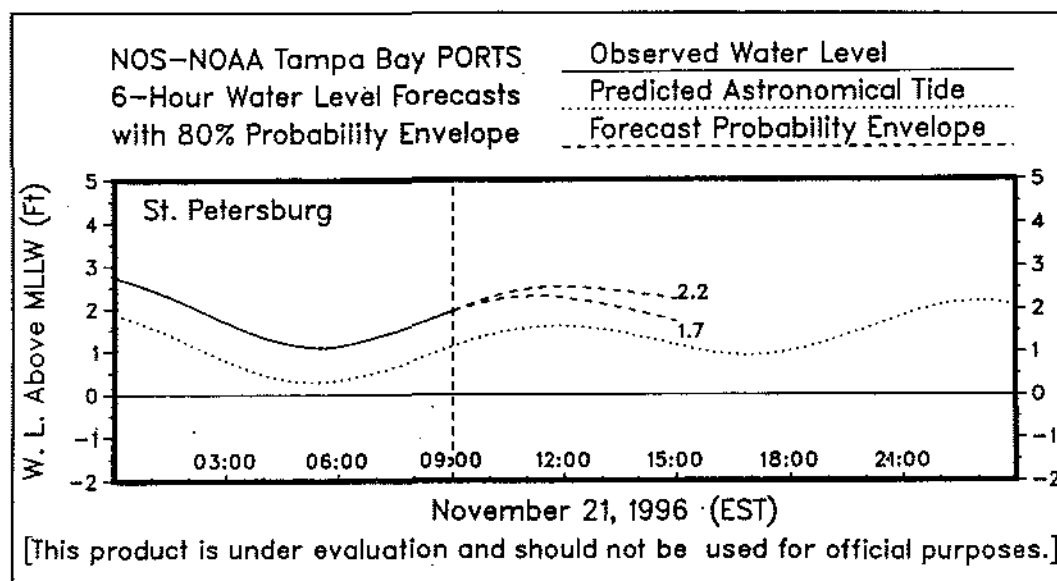


Figure 3. Sample of a statistical water level forecast for St. Petersburg portrayed in graphical form. The forecast was produced by applying Equation 1 and indicates that the total water level is to be in the range of 1.7' to 2.2' above MLLW at 1500 hours. The same information can be disseminated in a voice message. The dashed lines connecting the latest observation and each 6-hour forecast was determined by adding the astronomical tidal forecast to a simple linear interpolation of the nontidal component.

Although the statistical approach for forecasting water levels is good up to 6 hours, it is practical only for a limited number of locations. In addition, preliminary experiments suggest that statistical forecasts of currents may not be as accurate as statistical water level forecasts. Therefore, the use of numerical models may be better suited for forecasting water levels and currents in the bay.

NUMERICAL MODEL-BASED FORECASTS

A high-resolution numerical circulation model of currents and water levels in the bay has been under development by researchers at NOS (Hess 1994) and USF (Galperin et al. 1991, 1992) and has been used extensively for hindcasting. This makes it the ideal candidate model to use for nowcasting and forecasting.

The Numerical Circulation Model

The Princeton three-dimensional numerical circulation model (Blumberg and Mellor 1987) was chosen as best suited to: 1) simulate tidal, wind, density and shelf-induced currents in Tampa Bay at a wide range of time scales (from minutes to years); 2) resolve currents in the navigation and port channels, and other locations important for navigation; and 3) meet NOS quality assurance working standards for accuracy. This model includes a terrain-following sigma vertical coordinate, a level 2½ turbulence closure representation, and an orthogonal curvilinear horizontal coordinate system. The code is structured to take advantage of high-speed vector processing.

The modern approach to estuarine modeling holds that three spatial dimensions are required to simulate the essential dynamics. These include the vertical shear produced by bottom and wind stresses and by horizontal density gradients, horizontal differences between the deep channels and the shallow side embayments, and the significant horizontal and vertical salinity and temperature gradients that were observed in Tampa Bay during the 1990–91 survey. In addition, resolution of the vertical structure of currents is a requirement for navigation under strong wind and tidal conditions, and it is necessary for accurate modeling of bottom stress and extremely valuable for oil spill transport simulation.

The Tampa Bay model runs on a 2400-cell, orthogonal curvilinear grid closely fitted to the bay's lateral boundaries (Fig. 4). Grid cells are closely spaced in regions where higher resolution is needed, such as near the navigation channel, passages under causeways and entrances to sub-basins. Cell spacing varies from 300 meters to 2000 meters. Each cell has a depth value obtained from bathymetric data for Tampa Bay available from NOAA's National Geophysical Data Center in gridded (15-second interval) format. A substantial number of cells cover the Florida shelf region west of the bay entrance. This placement of the boundaries allows for internal dynamics to dominate the simulation of currents and the density field in the bathymetrically complex entrance region around Egmont Key. The grid has another connection to the shelf through Pass-a-Grille. The grid is detailed enough to represent the following features explicitly—Hillsborough River, Tampa Bypass Canal and Manatee River. Additional rivers—Rocky Creek, Alafia River and Little Manatee—were included by adding a single cell along the perimeter. In the vertical, there are eight equally spaced sigma levels. Shallow water areas are allowed to emerge or submerge as water levels

decrease or increase. The model is run with an external-mode time step of 24 s and an internal mode time step of 120 s. A 24-hour simulation requires 8 minutes on a Silicon Graphics Inc. SGI 380-4DX computer.

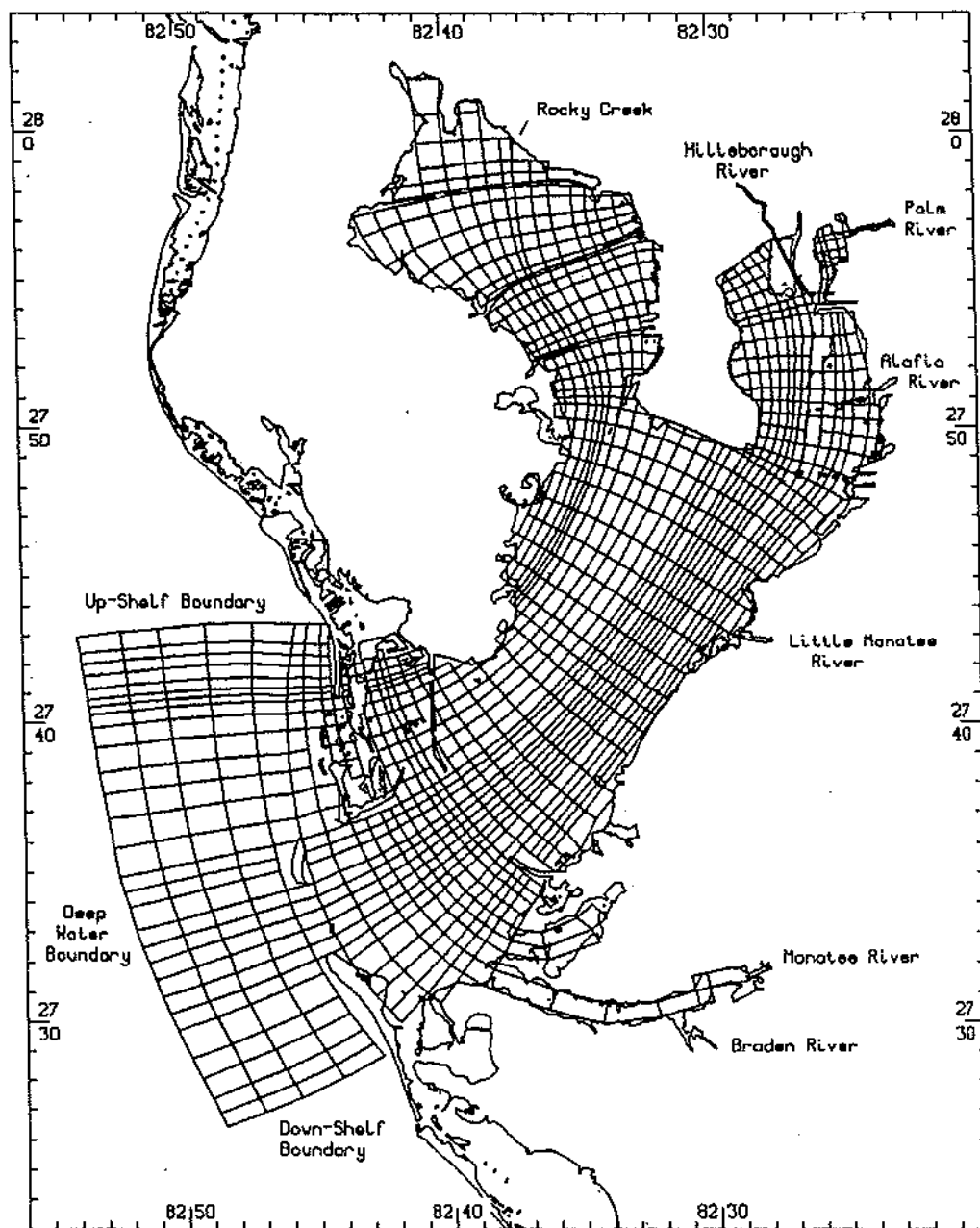


Figure 4. The Tampa Bay circulation model grid. The grid is in orthogonal curvilinear coordinates and shows the west Florida shelf boundaries and seven rivers.

The Hindcast Model

In any numerical circulation model simulation, the boundary conditions are extremely important in determining the patterns and strength of the modeled flow. In the hindcast mode, a time series of observed values is generally used. At the model's open ocean boundaries, the water level must be explicitly specified. At the water surface,

wind stress is the essential input variable, although the determination of a detailed baywide wind field is not a trivial exercise. Other input variables are river (and other freshwater) inflows and water densities at the ocean boundary. Density is usually generated from observed salinities and temperatures by using an equation of state.

The model has been calibrated and validated both at NOS and USF using various data sets, particularly data from the NOS survey conducted in 1990-91 (Zervas 1993) and, for river and freshwater inflows, data from the U.S. Geological Survey and state agencies. The model, when calibrated for tidal constituent amplitudes and phases (Hess 1994), was shown to successfully replicate water levels (Fig. 5) and currents.

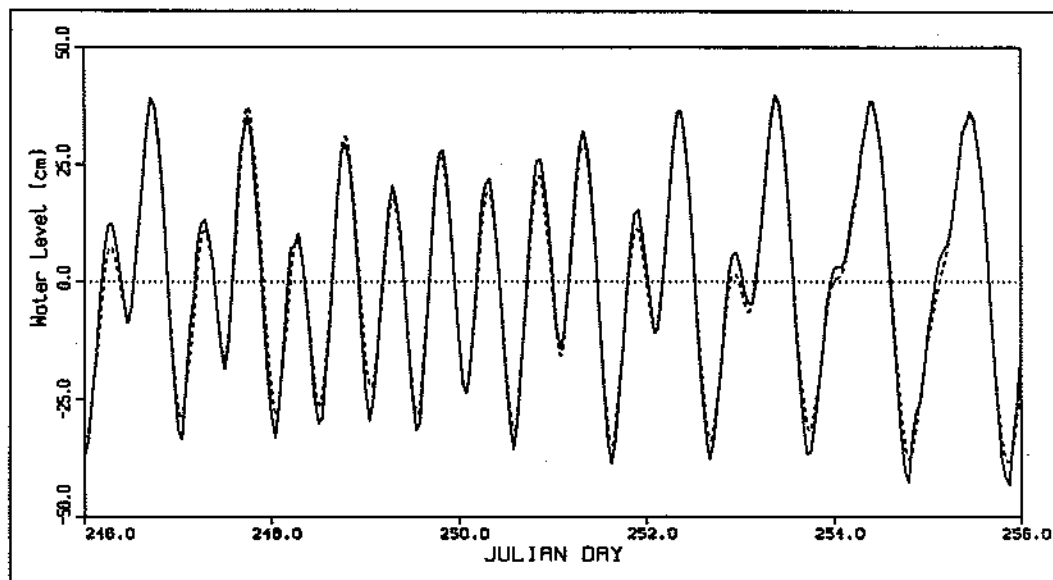


Figure 5. Comparison of observed (solid line) and model-generated (dashed line) total water levels at St. Petersburg for 10 days in 1990. The model was driven by winds and observed water level (computed from pressure) on the shelf.

The Nowcast/Forecast Model

With little modification, the hindcast model can be run in both nowcast and forecast mode. A nowcast is a prediction of the present state of the bay, whereas a forecast is a prediction of the future state. For example, the nowcast model can be run every 12 hours to bring the simulation up to the present and to create an initial field for the forecast which incorporates the most recent observations. The nowcast mode requires an entirely different set of data than does the forecast mode.

For the nowcast, the bay model must be driven by recent observations. Water levels are routinely observed and available at stations near the bay's entrance (Egmont Key, Clearwater Beach). Limited salinity and temperature data are also available there. Wind observations are available from the PORTS, local airports and offshore data buoys. Observations of river flows, or river stages that can be converted into flow rates, are available for a number of tributaries (some at locations significantly upstream of large parts of the watershed), although not on a real time basis.

For the forecast mode, the model must be driven by forecasts of future values of the same variables. A water level forecast must be made using either a statistical forecast analogous to that described in the preceding section or a model-based forecast using a larger computational domain (covering either the west Florida shelf or the entire Gulf of Mexico). Models like these are now under development at USF and at NOS as part of the Coastal Ocean Forecast System. For the future wind values, NOS has access to NOAA's National Weather Service (NWS) daily wind forecasts to drive these regional models.

Many of the components of a forecasting system have been developed and are in place. However, there are additional components yet to be created and brought into operation. For example, although forecasts of river flow rates and shelf salinities and water temperatures are needed, sources for these have yet to be determined.

PLANS FOR THE FUTURE

Both USF and NOS have an interest in forecasting and each group brings resources to bear on the problem. NOS is planning to extend the statistical forecast of water levels by developing a statistical forecast of currents. For model-based forecasts, NOS has a version of the model, calibrated for tidal water levels and currents, which is ready for further development. NOS has been collecting and archiving NWS model-based wind forecasts and has experience in developing and applying nowcast/forecast systems in other coastal areas (Chesapeake Bay, Galveston Bay and New York Harbor). NOS has also begun developing a regional (west Florida shelf) model which can be linked to an experimental Gulf of Mexico (GOM) model NOS is also developing. At present, USF operates and maintains the PORTS system and has added sensor systems. USF has had a similar version of the numerical circulation model and has experience in simulating Tampa Bay's gravitational circulation. USF plans to refine the model's calibration using recent PORTS data, develop a spatially-interpolated wind field, investigate the forecasting of river flows, investigate water level forcing using observations from the Egmont Key gauge, and set up a preliminary nowcast/forecast system. Finally, USF has interest and experience in oil spill and hazardous substance fate forecasting, the improvement and refinement of which are among the major research focus areas of its programs.

Starting with the PORTS and a shared capability in coastal modeling, NOS and USF have continued their collaboration by sharing data and information, coordinating research, exploring methods of leveraging resources, and seeking additional support for forecast system development. Several issues of common interest and concern remain to be addressed before a system can be implemented. These include modeling, establishing an operational environment, and developing output products and formats.

Numerical Modeling

Additional numerical modeling and related studies that need to be undertaken include recalibration for currents during storm events, development of a high-resolution grid to better account for the navigation channels, and obtaining additional bathymetric data for the dredged channels. Access to NWS forecast winds and studies for model

accuracy using forecast winds is another issue. Finally, the development of a GOM model and/or a west Florida shelf model need(s) to be completed.

Operational Environment

Any nowcast/forecast system can function properly only within an dedicated operational environment. This requires that a round-the-clock computer system be maintained. It also requires that both the environmental sensors and the input data streams, such as those for water levels and winds, be continually maintained. Assuming that the nowcast/forecast cycle operates by automatic submission, there is still the need for human intervention to ensure that the system is operating according to specification. A decision is needed on where to locate the operational computer environment—locally at USF, remotely at NOS headquarters in Silver Spring (Maryland), or at both. Another issue is the capability of archiving forecast data.

Output Products

Each user group may have different needs that will influence the format and timeliness of output products. The tremendous volume of model 'data' generated will also influence the format. Pilots aboard ship may prefer telephone messages or fax-on-demand before departure. Forecasts by either of these methods would necessarily be limited to a few locations and time projections. Land-based users, especially the scientific community with access to computer work stations, may seek a greater amount of data such as maps of current fields or surface temperatures. Internet dissemination may be the ideal carrier for this community. Hazardous materials response users may need digitized data that includes time, location, current velocity, temperature and salinity for rapid insertion into spill prediction models. Note that some data are presently available at USF and NOS web sites (www.marine.usf.edu, www.ceob.nos.noaa.gov).

Liability

The issue of liability must be resolved for any joint NOS-USF forecast products. This probably will require a certification process for USF products before NOS accepts liability for them. NOS has begun an internal study aimed at developing systematic quality control measures, including documentation, skill assessment and maintenance requirements, for its forecasts. Another possibility is that USF may issue its own products and accept liability for them.

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DESIGNING A CONSTRUCTED WETLAND TREATMENT SYSTEM FOR NUTRIENT REMOVAL FROM STORMWATER

Eugene R. Masters
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ABSTRACT

Nutrient loading has been identified as the primary historic cause of degradation in Hillsborough Bay. Many substantial reductions in point source loadings have been effected over the past twenty years. Stormwater runoff remains a significant component of current nutrient loading to the bay. This load is introduced to the bay either through natural rivers and streams which discharge into the bay or by point source stormwater outfalls located directly on the bay. Constructed wetland treatment systems (CWTs) offer an attractive, cost-effective means of treating stormwater for nutrient removal. There are two types of CWTs: a surface flow design with sections of open water and plantings in the water and on littoral shelves and embankments, and a subsurface flow system which relies on closely packed plants grown in a porous medium. Both of these designs require an upstream sedimentation basin to reduce total suspended solids (TSS) loading and remove nutrients adsorbed to settled particles. Vegetated cells are designed for ease of maintenance, and access to harvesting equipment. Harvesting is required in most surface flow systems, and in submerged flow systems where phosphorus removal is critical. Besides adsorption, other mechanisms operating in CWTs are volatilization, nitrification-denitrification and plant uptake. Plants frequently used in these systems include reeds, arrowhead, bulrushes, cattails and sedges. One facility which discharges directly to the bay is the IMC-Agrico Company Port Sutton Shiploading Terminal. At this site, a 22.5-acre surface flow CWT has been constructed. The basic elements of design and operation were applied to the IMC-Agrico site.

INTRODUCTION

Eutrophication of our nation's streams and waterways occurs when an excess of dissolved nutrients, in the form of the compounds of nitrogen and phosphorus, foster excessive algal growth and the resultant seasonal and diurnal deficiencies in dissolved oxygen. Nutrient loading has been identified as the primary historic cause of degradation in Hillsborough Bay. While many substantial reductions in point source loadings have been effected over the past twenty years, stormwater runoff remains a significant component of current nutrient loading to the bay. This load is introduced to the bay either through natural rivers and streams which discharge into the bay or by point source stormwater outfalls located directly on the bay. One such facility which discharges directly to the bay is the IMC-Agrico Company (IMCA) Port Sutton Shiploading Terminal. At this site, a 22.5-acre constructed wetland treatment system (CWT) has been installed. This paper discusses the basic design elements of CWTs with regard to design and operation, as well as how these elements were applied to the IMC-Agrico site.

DISCUSSION

There are two basic types of CWTs, surface flow systems and subsurface flow systems. The surface flow design, such as the system at IMCA's Port Sutton facility, employs sections of open water and plantings in the water and on littoral shelves and embankments in the form of vegetated cells. The other type of wetland treatment system, the subsurface flow system, relies on closely packed plants grown in a porous medium, usually gravel, to form the vegetated cells. Water treated flows through the rooted beds in the subsurface, and there are no open water areas. Subsurface systems are more efficient than surface flow systems and require less land area. They are also

more costly to construct, operate and maintain. Climate and growing seasons are obviously a concern to the system designer, in that they affect the efficiency and usefulness of either system; in general, in colder climates, subsurface flow systems have been found to be more effective over a wider range of climatic conditions than surface flow systems. In central Florida, climate is not a consideration in system selection.

Land Requirements

Sufficient land area must be available before a CWTS can even be considered. While even a small CWTS relative to the size of the watershed being treated will have some effect on nutrient removal, the effectiveness of the system is related directly to the hydraulic retention time. James (1995) notes that subsurface flow systems require only about one-fifth of the land area required by surface flow systems. He fixes the land requirements for subsurface flow systems at 0.459 ft²/gpd and at 2.178 ft²/gpd for surface flow systems. Using the 25-year, 24-hour storm event for the Tampa Bay Area (9" of rainfall), this translates into 0.046 acre (2,000 ft²) of subsurface flow treatment area and 0.22 acre (9,500 ft²) of surface flow treatment area for every acre of area drained to the system. The use of average rainfall data is appropriate to this design criterion rather than rainfall intensity data, because a sedimentation basin upstream of the CWTS serves as a buffer to storm surge.

Sedimentation Basins

An adequate sedimentation basin upstream of the vegetated cells is vital to the performance of the CWTS. Stormwater always carries a total suspended solids (TSS) load. As much of this sediment load as possible should be removed from the stream before it reaches the vegetated cells. Sediment deposited in the vegetated cells raises pond depths, reduces hydraulic retention time, reduces exposed root area (and thus plant uptake capacity) of some aquatic species, and, in subsurface systems, clogs the media. The most important reason to incorporate a sedimentation basin in the CWTS design, however, is that pollutants in stormwater, including nutrients, organic pollutants and heavy metals, have an affinity for suspended particles less than 100 μ in diameter transported during storm events. The properly designed basin will remove 30% to 70% of nutrients from the stream with 95% solids removal, depending on the particle size distribution (Wanielista and Yousef 1992). Phosphorus removal rates are reported to be about 30% higher across the board than nitrogen removal rates in wet settling ponds (Scheuler 1987). This is important, since the effectiveness of downstream vegetated cells in phosphorus removal is limited.

In designing a sedimentation basin, the engineer must consider the size of the watershed, and the intensity of the of the rainfall in the area where the basin is to be constructed. The following example uses tables and criteria suggested by Wanielista and Yousef (1992) for the Tampa Bay area:

Example:

Assume a 10-acre watershed (435,600 ft²).

Tampa (Zone 3), summer rainfall: mean intensity = 0.133, C_v (coefficient of variation) = 1.34;

Rainfall intensity associated with 95% or less occurrence: multiple of 3.78;

Runoff coefficient = 0.60 (Heavy industrial);
Start with an assumed detention time (T_d) = 4 hrs

Design Runoff Rate (Q)

$$Q = (0.133 \times 3.78) (0.60) (435,600) (1 \text{ ft}/12 \text{ in}) (1 \text{ hr}/3600 \text{ sec}) = 3.04 \text{ ft}^3/\text{sec}.$$

Pond Volume (V):

$$V = T_d Q = 4 \text{ hrs} \times 3.04 \text{ ft}^3/\text{sec} \times 3600 \text{ sec/hr} = 43,776 \text{ ft}^3$$

Design Settling Velocity (V_o):

$$V_o = \text{Pond Depth}/T_d$$

With these data, the following table is constructed:

Table 1.

POND DEPTH (ft)	V_o (ft/sec)	POND AREA (ft ²)	SMALLEST PARTICLE SETTLED (μ)
1.0	0.0000694	43,776	<2
1.5	0.000104	29,184	2
2.0	0.000139	21,888	4
2.5	0.000174	17,510	7
3.0	0.000208	14,592	8
3.5	0.000243	12,507	9
4.0	0.000278	10,944	10
4.5	0.000313	9,728	10.5
5.0	0.000347	8,755	11
5.5	0.000382	7,959	11.5
6.0	0.000417	7,296	12

The engineer can now select an appropriate pond depth for settling the smallest particle size desired, based on the particle size distribution in the typical runoff for the site. Obviously, shorter detention times will affect the tabulated values, and detention time must be selected based on the storm surge capacity desired, and based on the expected intervals between rain events in a particular area.

Particle size distribution is not established in TSS analysis and is important information to the engineer. EPA Method 106.2 for TSS determination allows the operator to select among several filters for separating solids from a wastewater sample. These filters vary in mesh size from 0.3μ to 1.5μ . In most instances, this discrepancy is not critical; in some cases, however, where stormwater runoff contains a significant number of particles in the colloidal range, this information becomes critical. Since colloidal particles tend to remain in suspension over periods of time far longer than those normally obtainable in sedimentation basins, they can be expected to course through the CWTs, bringing their attached pollutants with them. Other

means are required to deal with this problem, such as the introduction of flocculants to the stream prior to the sedimentation basin.

Sedimentation basins require regular maintenance to be effective. The collected sediments must be removed as often as their accumulation in significant amounts requires, and this period will vary from site to site. Care must be taken in removing these sediments not to resuspend them and allow them to enter the downstream vegetated beds.

Vegetated Cells

The number and size of the downstream vegetated cells depends on the available terrain and on the design objectives of a particular project. Sloped terrain will require the design of multiple terraced cells; for flat terrain, one large treatment cell may suffice, although, in most cases, multiple cell designs are still favored for placement of access roads and ease of maintenance, especially where plant harvesting is a system requirement. Reed et al. (1988) report that surface flow CWTS cells should be designed with a large aspect ratio (length:width) to ensure plug-flow conditions and optimum treatment. A long narrow channel wetland may therefore be expected to produce better performance than a rectangular one. It should also be easier to operate and maintain.

Treatment Mechanisms

The treatment mechanisms taking place in vegetated cells are volatilization of ammonia, settling and adsorption in the benthic layer, nitrification-denitrification and plant uptake. Some controversy exists as to exactly which of these mechanisms dominates.

Nitrogen removal through volatilization of ammonia may be significant, but is difficult to quantify. Reed et al. (1988) report that it is a function of the initial ammonia concentration, open water surface area, detention time, water pH and temperature. They report that in wastewater stabilization ponds, which, under ideal conditions, can remove up to 98% of the applied nitrogen, the dominant mechanism of nitrogen removal under favorable conditions appears to be losses to the atmosphere.

Burgoon et al. (1991) reported on experiments in subsurface flow pilot CWTSs with plants growing in various media. With gravel substrate alone and no plants, nitrogen removal rates varied from about 46% to 72% with increasing hydraulic residence times, whereas with vegetated beds under the same conditions, nitrogen removal rates increased from about 83% to 95%. This would indicate that whatever adsorption took place on the gravel substrate, coupled with nitrification-denitrification, was the principal mechanism of about half of the nitrogen removal that took place at the highest hydraulic load, while plant uptake, as a mechanism for nitrogen removal became less important (but still significant) at the lowest hydraulic load. Reed et al. (1988) note that a regular harvesting of cattails in one system accounted for only 10% of the nitrogen removal, and that this finding had been confirmed elsewhere. They note further that the major pathway for nitrogen removal appears to be nitrification-denitrification. A pilot system in California which cuts and mulches the wetland

vegetation in place to provide an additional carbon source achieves about 98% nitrogen removal.

In subsurface flow systems, the penetration of the plant roots and rhizomes into the media provides the aerobic microsites in an otherwise anaerobic environment. The opportunity for nitrification-denitrification exists within the aerobic attached growth biota and in the adjacent anaerobic sites in the litter and benthic layer. These same conditions should be approached in surface flow systems using aquatic plants in shallow (two feet deep or less) water.

Burgoon et al. (1991) notes that in subsurface flow CWTs, phosphorus removal may plateau as the load increases, whereas phosphorus removal associated with adsorption by sand or gravel may continue to increase in proportion to the load. Reed et al. (1988) note that adsorption and precipitation are the major pathways for phosphorus removal. This mechanism is limited by the opportunity for contact with the benthic layer. They report that phosphorus removal by water hyacinths and other aquatic plants is limited to the plant needs and will not exceed 50% to 70% of the phosphorus present in the stream, even with careful management and regular harvests. They contend further that for wetland systems, that the vegetation typically used is not considered a factor in phosphorus removal, even if harvesting is practiced; and if the plants are not harvested, their decomposition releases phosphorus back into the system.

To be aesthetically pleasing and effective overall in nutrient removal, the surface flow CWTs contains open water area, aquatic plant areas, planted littoral shelves, and planted uplands. Planted uplands using larger trees, such as cypress, ash, willow, and so forth, are found in natural systems, such as bogs, strands, and "domes", used in wastewater treatment in Florida and elsewhere. Their use in constructed wetlands to date has been limited, and it is unclear what role (other than aesthetics) such plantings have on wastewater treatment, although a stand of eucalyptus trees is being used for groundwater treatment currently at Port Sutton.

Plant Selection

Reed et al. (1988) note that the water level in the system and the duration of flooding are important factors in the selection of wetland vegetation. Cattails (*Typha* spp.) will dominate where standing water is over six inches. Reeds (*Phragmites* spp.) grow well along shorelines where the water table is below the surface, but will also grow in water deeper than five feet. The common reed (*Phragmites communis*) is reportedly a poor competitor and will give way to other species in nutrient-rich shallow waters. Bulrushes (*Scirpus* spp.) can tolerate long periods of soil submergence and occur at water depths of 1/3" to 10" in temperate climates. In cold climates and in deeper water, bulrushes give way to cattails. In central Florida, however, bulrushes do quite well in water up to 8' deep, and compete well with cattails. Sedges (*Carex* spp.) will occur along the shore or in shallower water than bulrushes.

Vegetation is also chosen for its ability to uptake target pollutants. Experiments by Burgoon et al. (1991) compared nitrogen and phosphorus uptakes for four species of emergent aquatic plants grown in gravel media. The species studied were the reed

Phragmites australis, *Sagittaria latifolia*, bulrushes *Scirpus pungens*, and cattails *Typha latifolia*. The results obtained for a target hydraulic loading rate of 9.4 cm/day are summarized in Table 2.

Table 2. Nitrogen and phosphorus loading and removal by four plant species (from Burgoon et al. 1991).

	LOAD (g/m ² ·day)	PERCENT REMOVED	EFFLUENT g/m ³	EFFLUENT COEFF. OF VAR. %
NITROGEN:				
<i>Phragmites</i>	1.72	79.8±11.6	5.4	55
<i>Sagittaria</i>	1.53	95.0±0.7	1.9	16
<i>Scirpus</i>	2.12	78.8±2.8	5.2	12
<i>Typha</i>	1.99	89.5±5.1	3.2	47
PHOSPHORUS:				
<i>Phragmites</i>	0.37	49.6±22.2	2.7	44
<i>Sagittaria</i>	0.33	75.9±24.3	1.1	55
<i>Scirpus</i>	0.46	8.7±31.2	4.7	30
<i>Typha</i>	0.43	87.4±14.4	0.7	130

The results of these experiments indicate that the *Sagittaria latifolia* was clearly superior in both nitrogen and phosphorus removal under experimental conditions. The superior phosphorus removal capacity of the *Sagittaria* was attributed to its superior biomass production and subsequent higher phosphorus assimilation.

Floating and submerged plant species as well as phraetophytes (plants rooted on the banks but growing out over the water) may also be used. It is these plantings which produce the productive root zones which facilitate nitrification-denitrification.

System Management

As noted above, sediment basins will require sediment removal at regular intervals, depending on their loading. Similarly, to achieve target nutrient removal rates in surface flow systems, especially for phosphorus, regular plant harvesting may be required. To facilitate these operations, CWTSS should be designed with adequate access roads, boat ramps, and harvester ramps. Multiple cell systems with parallel flow regimes are ideal, in that one cell can handle the flow while its parallel cell is undergoing maintenance. In subsurface flow systems, routine harvests are not necessary (unless phosphorus removal targets require harvesting) since the accumulation of litter on the surface of these systems will not interfere with subsurface flow. On the other hand, the closely packed planting regimes for these systems are subject to die-offs and make them more difficult to operate and maintain.

Mosquito control is essential in all but the most remote CWTSS sites. The quiescent conditions in the treatment cells which exist most of the time are ideal for mosquito breeding. Reed et al. (1988) report that *Gambusia* fish have provided effective control in climates where freezing is not a factor. Removal of accumulated plant litter contributes to mosquito control by removing dead spots and allowing access for the *Gambusia*. Also reported as effective was the use of both *Gambusia* and the pupacide

Altosid at one site in California. At one site in Ontario, where freezing is a factor and *Gambusia* would not survive, effective mosquito control using the bacterial insecticide *Bacillus thuringiensis* var. *israeliensis* was obtained.

Costs

James (1995) notes that CWTs can be designed, built and operated at a fraction (about 25%) of the cost of traditional industrial wastewater treatment systems. Likewise, operation and maintenance costs are estimated to be about 10% to 30% of those for conventional treatment systems. Another advantage is the time it takes to design, build, and place a CWT into operation is about three to six months. Designing and building a conventional plant to perform similar service, with transportation times, site electrical and plumbing hookups, and so forth, would take at least a year, probably longer. Startup times for concrete and steel plants vary, but six months is usually a minimum.

IMC-AGRIC PORT SUTTON STORMWATER SYSTEM

Background

The IMCA Port Sutton Terminal is located on Hillsborough Bay, immediately south of the Tampa Electric Company's Gannon Station and west of US Highway 41 in Hillsborough County, Florida. Products handled at this facility include wet and dry phosphate rock, mon-ammonium phosphate (MAP), di-ammonium phosphate (DAP), granular triple super phosphate (GTSP), and animal feed ingredients (AFI). These products are delivered to the terminal by truck and rail from IMCA's phosphate mining operations and final crop concentrate manufacturing facilities in Central Florida. At Port Sutton, these products are loaded onto barges and cargo freighters for distribution around the world. Also at Port Sutton, anhydrous ammonia is offloaded from ships and barges to an on-site storage tank before being shipped to the concentrate manufacturing facilities via pipeline.

During 1990, the then Florida Department of Environmental Regulation (FDER) and the Environmental Protection Commission of Hillsborough County (HCEPC) began a compliance initiative with the six phosphate loading terminals located on Tampa Bay, in the East Bay region, which included IMCA's Port Sutton Terminal. The agencies' primary concern was the discharge of nutrient-laden untreated stormwater from these facilities. Tested effluents from these facilities were found to contain elevated levels of both nitrogen and phosphorus, and enforcement proceedings were initiated against each of the terminals.

At the IMCA Port Sutton Terminal, there were six stormwater outfalls as well as some direct runoff from small areas. Besides stormwater issues, some product spillage was occurring at the shiploading gantry. These materials were falling directly into the Port Sutton Shipping Channel. Elimination of product spillage and the reduction in the nutrient concentrations in the stormwater became the goals of both IMCA and the agencies.

Solutions

An immediate effort was begun to eliminate the spillage. Spillage meant not only lost product and revenue, but provided a source of nutrients in the stormwater. IMCA engineers and management improved product control in several ways:

1. A deflector shield was installed beneath the entire length of the shiploading gantry. This shield stopped material from falling into the water. The area adjacent to the shield was paved to facilitate cleanup of spilled material.
2. Railcars leaving the concentrate plants were cleaned to reduce spillage of fugitive materials during transport along rail lines and in the port.
3. Additional areas were paved to facilitate cleanup.
4. Improvements to the scrapers on all conveyor belts and increased maintenance of the covers over the conveyors further reduced the spillage of materials.
5. Additional staff was hired at the site to increase housekeeping support.
6. Spilled materials were removed from the rail yard on a regular basis.

A decision was made to consolidate stormwater collection to a central treatment system. This would provide both increased control and superior treatment. The actions taken included:

1. Exposed soil was sodded or paved to reduce erosion and control sediment transport.
2. Drainage features were installed beneath the on-site rail yard to ensure collection of water from the railcar storage area. A 3,000'-long wall was constructed on the north side of the rail yard to stop sheetflow from reaching the roadside drainage ditch.
3. Existing stormwater outfalls were closed and the waters redirected to the central collection system shown in Figure 1.
4. Stormwater from the westernmost 54 acres on the site, which include the loading and storage areas, was directed to a sedimentation basin. The basin overflows to a pumping station which pipes the stormwater to a system of four ponds which make up a CWTS. These ponds were constructed on 22.5 acres of property to the north of the terminal, and planted with cattails to provide plant nutrient uptake.
5. The CWTS ponds are a series of cells which gravity flow from the inlet pipes to a discharge spillway. Roadways between the ponds allow access for maintenance. The discharge spillway was provided with a variable-control riser which allows the storage level in the cells to be increased as appropriate.
6. Overflow from the CWTS was directed to a final two-cell settling pond, which also collects stormwater from the remainder of the facility, approximately 39 acres, along with non-contact cooling water from the ammonia storage area. Overflow from this two-cell pond was directed to the industrial wastewater outfall for discharge.

These actions were completed after obtaining the necessary permits from the FDER and the U.S. Environmental Protection Agency (EPA). Site improvements were completed at the end of 1992. During most periods, no stormwater is returned from the CWTS for discharge; the majority of the water in the pond system either evaporates or percolates into the ground.

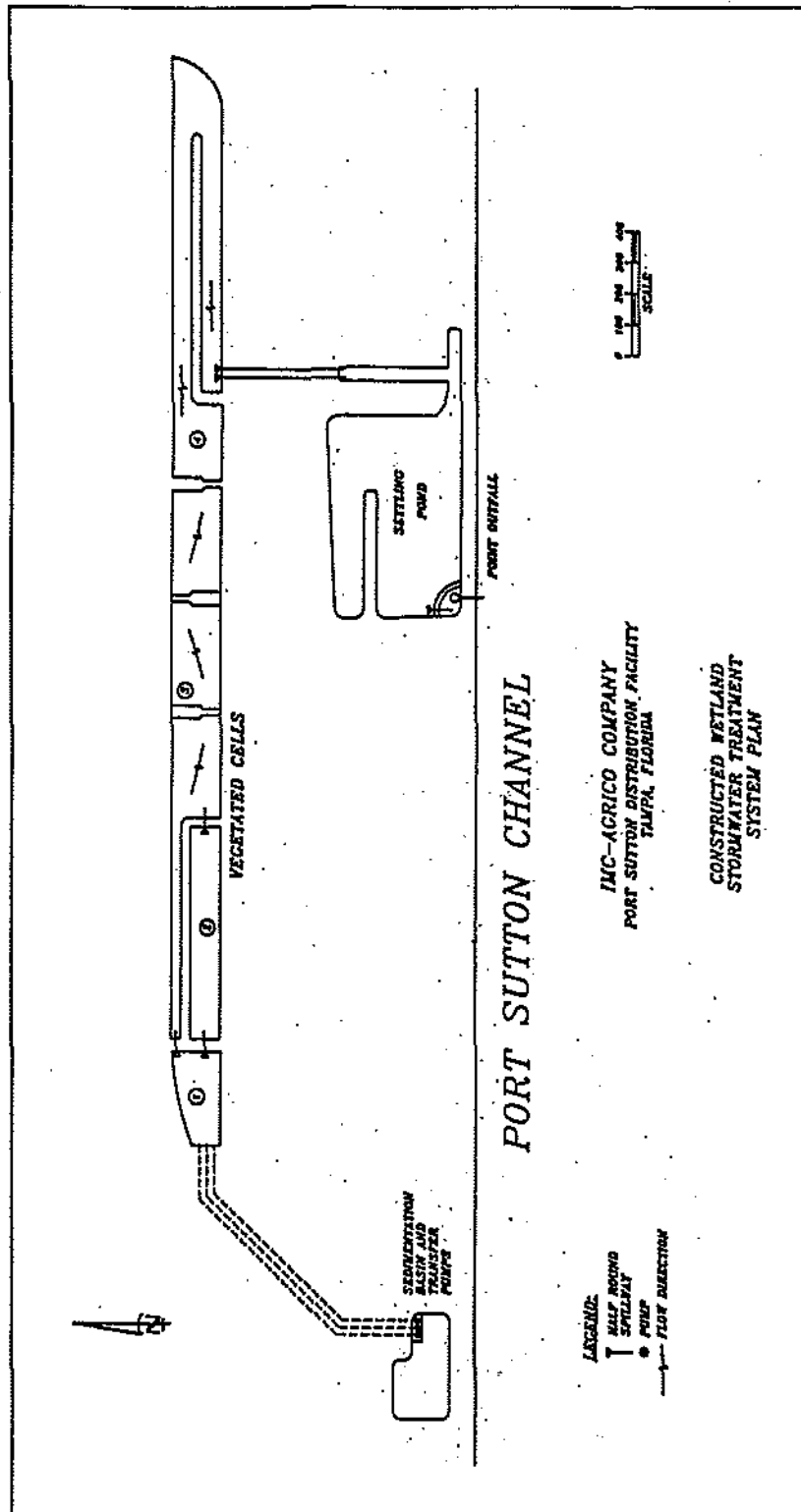


Figure 1. Constructed wetland stormwater treatment system plan.

Wildlife, particularly birds, have eagerly adopted the CWTS cells as a new feeding ground. Identified visitors include brown pelicans, wood storks, roseate spoonbills, several species of herons, cormorants, stilts and several species of ducks.

The stormwater treatment system is maintained by IMCA staff. Maintenance consists primarily of mowing the inner and outer slopes of the cell embankments.

These efforts have resulted in substantive reduction in nutrient loading to the bay from the IMCA Port Sutton facility. These engineered solutions should prove adequate for control for as long as the facility is operated.

Design Criteria

The IMCA Port Sutton CWTS is an open flow system. Since it serves an approximately 54-acre watershed, from the calculations presented above for the Tampa Bay Area, 54×0.22 acres, or 11.9 acres, of wetland are required for adequate stormwater treatment. The IMCA facility has almost twice the needed land area.

IMCA's Port Sutton sedimentation basin can also be evaluated from the design criteria presented above:

54-acre watershed (2,352,240 SF).

Tampa (Zone 3), summer rainfall: mean intensity = 0.133, $C_v = 1.34$

Rainfall intensity associated with 95% or less occurrence: multiple of 3.78

Runoff coefficient = 0.60 (Heavy industrial)

Pond Area (A) = 52,800 ft²

Pond Volume (V) = 1.5 acre-feet = 65,340 ft³

Pond Depth (D) = 1.24 ft

Design Runoff Rate (Q):

$$Q = (0.133 \times 3.78) (0.60) (2,352,240) (1 \text{ ft}/12 \text{ in}) (1 \text{ hr}/3600 \text{ sec}) = 16.42 \text{ ft}^3/\text{sec}$$

Detention Time (T_D):

$$T_D = V/Q = 65,340 / (16.42 \times 3600 \text{ sec/hr}) = 1.10 \text{ hr.}$$

Design Settling Velocity (V_o):

$$V_o = D/T_D = 1.24 / (1.10 \times 3600) = 0.000313 \text{ ft/sec}$$

Smallest Particle Removed: 10.5 μ

From the plant uptake data presented above, the cattails with which the CWTS is planted are the most efficient among the species presented at phosphorus removal, while also extremely efficient at nitrogen removal.

CONCLUSIONS

Where sufficient land is available to build them, CWTS plants for nutrient removal from stormwater are an increasingly attractive option. At sites such as IMCA's Port Sutton facility, such systems protect sensitive waterways while allowing commerce to continue unrestricted except by common sense and reasonable Best Management

Practices. These systems rely on natural mechanisms for the removal of the soluble compounds of nitrogen and phosphorus—mechanisms which include volatilization, sedimentation, adsorption, nitrification-denitrification and plant uptake. Rather than a concrete and steel system, CWTS plants provide aesthetically pleasing sites similar to nature's own stormwater treatment plants—fresh and saltwater marshlands. And like these marshlands, and as evident at the IMCA Port Sutton facility, CWTS sites become host to wildlife of all forms. A distinct advantage to CWTS plants is that they are cost-effective to build and maintain, and can be designed, built and placed into operation in less than half the time when compared with conventional industrial wastewater treatment plants.

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**AN OVERVIEW OF CURRENT MANAGEMENT PRACTICES
FOR THE CONTROL OF NITROGEN FROM
WASTEWATER RESIDUALS AND
ON-SITE WASTEWATER TREATMENT SYSTEMS
WITHIN THE TAMPA BAY WATERSHED**

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ABSTRACT

Despite technical advances in wastewater treatment and the recent movement toward wastewater reuse, an estimated 17% of the Tampa Bay area's population was still served by on-site wastewater treatment systems (OWTS) as of 1990. The occurrence of OWTS and other related wastewater activities in coastal areas have been the subject of continuing controversy and debate, with regard to their ultimate contribution of nutrients to Tampa Bay.

It is estimated that centralized wastewater treatment facilities and OWTS in the Tampa Bay watershed together may generate as much as 30,000 tons per year (by dried weight) of wastewater residuals. These organic solids may require further stabilization, management and ultimately land application at permitted, designated sites. Wastewater residuals may contain concentrations of nutrients that are as much as 30 times greater than those found in raw sewage.

A recent study by the Southwest Florida Water Management District Surface Water Improvement and Management Program evaluated the potential impacts of OWTS and wastewater residuals land application to the overall nutrient loading budget of Tampa Bay. Results suggest that the overall baywide nutrient impacts from OWTS are minimal, but more localized tributary impacts may be important in sub-drainage basins where high density waterfront communities are served by OWTS. In terms of the impact from land application of wastewater residuals, there is little data available for accurate nutrient loading estimates over large areas. However, if all of the currently permitted land application sites are fully utilized for land application, nitrogen loading to the Hillsborough River and Manatee Basins may represent a significant fraction of the total loadings within these watersheds.

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THE TAMPA BAY RESOURCE-BASED MANAGEMENT APPROACH

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ABSTRACT

Tampa Bay managers have sought to develop an estuarine management framework based on measurable and achievable goals for restoring and protecting the bay's vital biological resources. This resource-based approach was initiated in the early 1980s by the Tampa Bay Management Study Committee, which ranked observed declines in seagrass acreage as a priority management issue. During the late 1980s, the Southwest Florida Water Management District's (SWFWMD) SWIM program, acting on advice from the Agency on Bay Management, adopted a water quality assessment strategy which linked the management of nitrogen loadings to the restoration and protection of seagrasses. During the early 1990s, local, state and federal partners working cooperatively through the Tampa Bay National Estuary Program (TBNEP) have refined the resource-based approach and begun extending it to a number of additional estuarine management issues (e.g., toxic sediment contamination, fish and wildlife management, habitat protection and restoration).

Participants in the TBNEP have agreed to adopt nitrogen loading targets for Tampa Bay based on the water quality requirements of *Thalassia testudinum* and other native seagrass species. Participants have adopted as a long-term goal the restoration of seagrass acreage to 95% of that observed in 1950 (38,000 acres). Reaching this goal will require preservation of the approximately 25,650 acres currently in the bay and restoration of approximately 12,350 additional acres on a baywide basis. Field measurements indicate that the maximum depths to which *T. testudinum* meadows grow in Tampa Bay are determined by the amount of light reaching the bay bottom. Maximum depths of seagrass growth tend to occur at the point where 20–25% of subsurface irradiance (the amount of light that penetrates the water surface) reaches the bottom on an average annual basis. Two independent modeling approaches have been used to estimate nitrogen loading rates consistent with reaching and maintaining these irradiance levels at target depths (i.e., estimated depths of maximum seagrass growth in 1950) in each of the major bay segments. Based on monitoring data from the period 1985–94, it appears that light levels equivalent to 20–21% of subsurface irradiance can be maintained at target depths in most bay segments by “holding the line” at existing nitrogen loadings. However, the “hold the line” goal may be difficult to achieve given the 20% increase in the watershed's human population and associated 7% increase in nitrogen loadings that are projected to occur over the next 20 years. Through an intergovernmental agreement addressing the issue of nitrogen load allocation, partners in the TBNEP will be committing to develop action plans detailing specific projects that will be implemented to ensure that nitrogen management targets are met.

BACKGROUND

The concept of resource-based management has been under development in the Tampa Bay area since at least 1982, when the Tampa Bay Management Study Committee identified the loss of seagrass acreage as a priority problem facing bay managers (cf. Lewis et al. 1985). In response to perceived degradation of water quality and natural systems, the Florida Legislature designated Tampa Bay a Surface Water Improvement and Management (SWIM) priority waterbody in 1987, and directed the Southwest Florida Water Management District (SWFWMD) to “design and implement plans and programs for the improvement and management” of the estuary (Chapter 87-97, Laws of Florida). Acting on the advice of the Tampa Bay Regional Planning Council's Agency on Bay Management (ABM), SWFWMD adopted

a Tampa Bay water quality assessment strategy which sought to identify links between nitrogen loading, bay water quality and the management of seagrass systems (SWFWMD 1988; Spaulding et al. 1989; Ries 1993).

Tampa Bay was accepted into the U.S. Environmental Protection Agency's (USEPA) National Estuary Program in 1990. The Tampa Bay National Estuary Program (TBNEP), a partnership that includes the USEPA, Florida Department of Environmental Protection (FDEP), SWFWMD, Hillsborough, Pinellas and Manatee Counties, and the cities of St. Petersburg, Tampa and Clearwater, is charged with development and initiation of a comprehensive conservation and management plan (CCMP) for the long-term management of Tampa Bay. The TBNEP partnership has built on the resource-based approach initiated by earlier bay management efforts, developing water quality models (Zarbock et al. 1994, 1996b; Janicki and Wade 1996; Martin et al. 1996; Morrison et al. 1997) to quantify linkages between nitrogen loadings and bay water quality, and linking loadings and water quality to seagrass acreage goals (Janicki and Wade 1996; Greening and Eckenrod 1994; Greening 1996; TBNEP 1996). The TBNEP has also attempted to extend the resource-based approach to additional estuarine management issues such as toxic sediment contamination, habitat protection and restoration, and fish and wildlife management (TBNEP 1996).

A STRATEGY FOR RESOURCE-BASED MANAGEMENT

To demonstrate the conceptual strategy used by the TBNEP partnership to develop and implement a resource-based management program, a simplified three-step approach, using the protection and restoration of seagrasses as an example, is summarized below. Major steps of the process are:

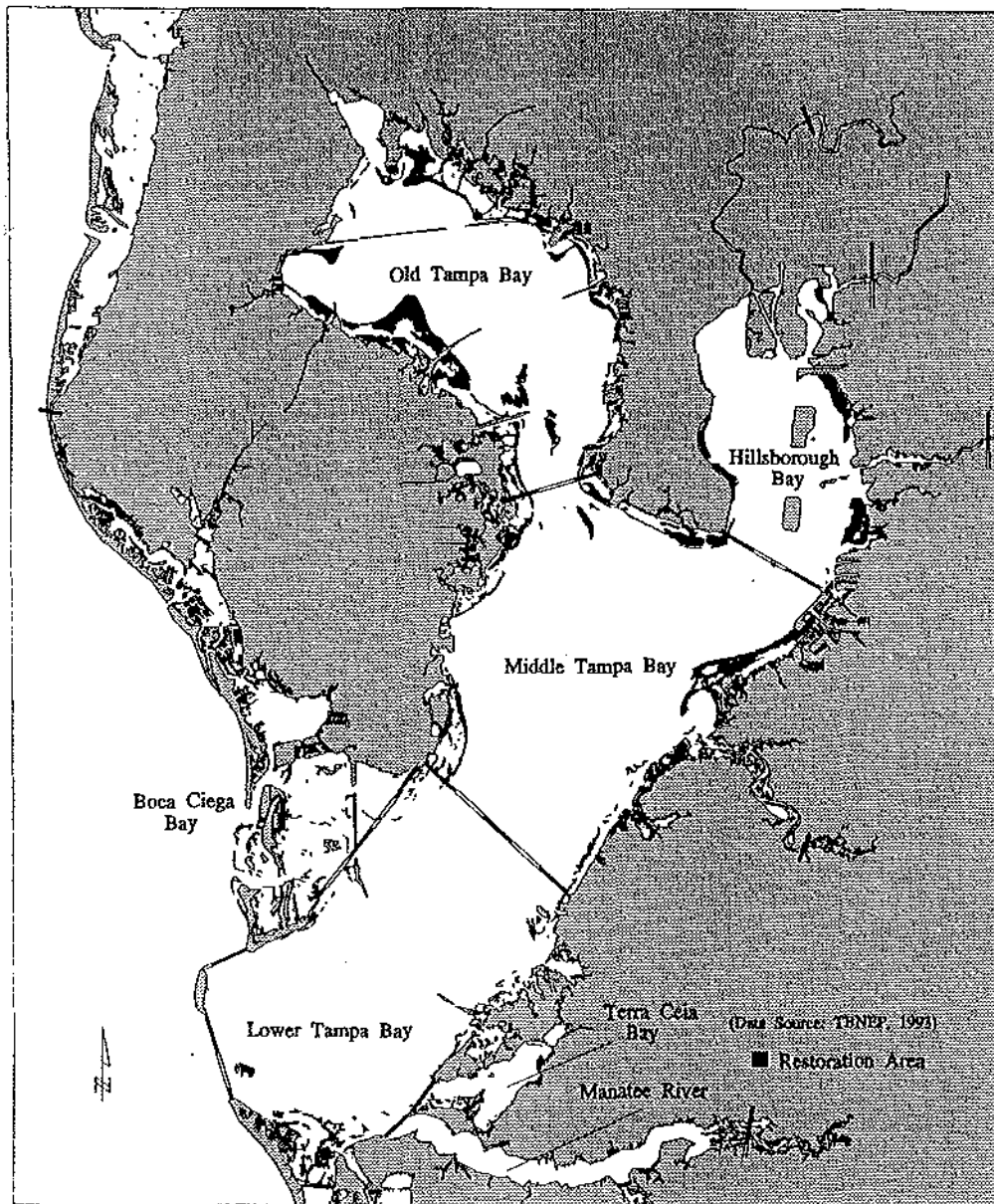
1. Set specific, quantitative resource management goals (e.g., seagrass acreage goals for each bay segment);
2. Determine the nutrient (e.g., nitrogen) loadings that a bay segment can receive while maintaining water quality conditions that allow its seagrass acreage goal to be met. Based on existing nitrogen loads from the watershed and airshed, estimate the load reductions (if any) needed to reach nitrogen loading targets.
3. Define and implement nitrogen management strategies needed to achieve load management targets.

Step 1. Set quantitative resource management goals

The establishment of clearly defined and measurable goals appears crucial for any resource management effort. In the development of nitrogen loading targets for Tampa Bay, the TBNEP Management Conference has approved the use of the estimated 1950 seagrass acreage for this purpose.

Based on digitized aerial photographic images, it is estimated that approximately 40,400 acres of seagrass existed in Tampa Bay in 1950 (Janicki and Wade 1993). In most areas of the bay seagrasses grew to depths of 1.5 to 2 meters. By 1992,

approximately 25,650 acres of seagrass remained in Tampa Bay (Janicki and Wade 1993), a loss of more than 35% since the 1950 benchmark period. Some of the observed loss (a net loss of about 400 acres) occurred as the result of direct habitat destruction associated with the construction of navigation channels and other dredging and filling projects within existing seagrass meadows, and is assumed to be non-restorable through water quality management actions. Those areas where seagrass was lost between 1950 and 1990 are shown in Figure 1.



Map Prepared by Coastal Environmental, Inc.

Figure 1. Seagrass restoration areas for Tampa Bay. The shading represents those areas where seagrasses occurred in 1950 but were not present in 1990.

In 1996, the TBNEP adopted a minimum seagrass acreage goal of 38,000 acres baywide. This goal represented 95% of the estimated 1950 acreage (minus the non-restorable areas), and includes protection of the existing 25,650 acres and restoration of 12,350 additional acres (TBNEP 1996).

Step 2. Determine seagrass water quality requirements and appropriate nitrogen loading rates

Once a seagrass acreage restoration and protection goal was established by the participants, the next steps established the environmental requirements necessary to meet the agreed-upon goal, and subsequent management actions necessary to meet those requirements. Elements of this process include the following:

- a. **Determine environmental requirements needed to meet seagrass restoration goal:** Recent research indicates that the deep edges of *Thalassia testudinum* meadows, the primary seagrass species for which nitrogen loading targets are being set, correspond to the depth at which 20.5% of subsurface irradiance (the light that penetrates the water surface) reaches the bay bottom on an annual average basis (Dixon and Leverone 1995). The long-term seagrass acreage goal can thus be restated as a light penetration and water clarity target: to restore seagrass acreage to 1950 levels in a given bay segment, water clarity in that segment should be restored to the point that allows 20.5% of subsurface irradiance to reach the same depths that were reached in 1950.
- b. **Determine water clarity necessary to allow adequate light to penetrate to historic seagrass depths:** Water clarity and light penetration in Tampa Bay are affected by a number of factors, such as phytoplankton density, non-phytoplankton turbidity, and water color. Janicki and Wade (1996) used regression analyses, based on long-term data provided by the Environmental Protection Commission of Hillsborough County, to develop an empirical model describing water clarity variations in the four largest bay segments (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay, and Lower Tampa Bay). The model which provided the best fit (highest R^2) to the observed water clarity data took the form:

$$S_{t,s} = \alpha_{t,s} + (\beta_{1,t,s} * C_{t,s}) + (\beta_{2,t,s} * T_{t,s})$$

where $S_{t,s}$ = Secchi disk depth at month t and bay segment s ,
 $C_{t,s}$ = average chlorophyll- a concentration at month t and bay segment s ,
 $T_{t,s}$ = average turbidity at month t and bay segment s , and
 $\alpha_{t,s}$, $\beta_{1,t,s}$ and $\beta_{2,t,s}$ = regression parameters.

Although water color is an important cause of light attenuation in some bay segments, inclusion of color in the regression model did not produce a significant improvement in the model's predictive ability (Janicki and Wade 1996). Results of the modeling effort indicate that, on a baywide basis,

variation in chlorophyll-*a* concentration is the major factor affecting variation in average annual water clarity.

- c. **Determine chlorophyll-*a* concentration targets necessary to maintain water clarity needed to meet seagrass light requirements:** The empirical regression model developed by Janicki and Wade (1996) was used to estimate chlorophyll-*a* concentrations necessary to maintain water clarity needed for seagrass growth for each major bay segment. The adopted segment-specific annual average chlorophyll-*a* targets (8.5 $\mu\text{g/L}$ for Old Tampa Bay, 12.3 $\mu\text{g/L}$ for Hillsborough Bay, 7.4 $\mu\text{g/L}$ for Middle Tampa Bay, and 4.6 $\mu\text{g/L}$ for Lower Tampa Bay) are easily measured and tracked through time, and will be used as intermediate measures for assessing success in maintaining water quality requirements necessary to meet long-term seagrass goals.
- d. **Determine nutrient loadings necessary to achieve and maintain chlorophyll-*a* targets:** A technical workshop sponsored by the TBNEP in 1992 recommended implementation of a multi-pronged (empirical and mechanistic) water quality modeling approach to provide a quantitative description of the relationship between nitrogen loadings and in-bay chlorophyll-*a* concentrations. In accordance with that recommendation, the TBNEP funded the development of an empirical regression-based water quality model (Janicki and Wade 1996), and SWFWMD funded the application of a mechanistic model (Martin et al. 1996; Morrison et al., this volume) to Tampa Bay. To ensure comparability, the two models simulate the same ten-year time period (1985–94) and are driven by the same estimated hydrologic and nutrient loadings (Zarbock et al. 1994, 1996a; Janicki and Wade 1996). Observed relationships between chlorophyll-*a* concentrations and estimated nitrogen loadings, and relationships predicted by the two water quality models, are summarized by Morrison et al. (this volume).

Under present-day (1992–94) conditions, analyses performed by Janicki and Wade (1996) indicate that bay water quality allows an annual average of more than 20.5% of subsurface irradiance to reach target depths (i.e., the depths to which seagrasses grew in 1950) in three of the four largest bay segments. Water quality in the Middle Tampa Bay segment currently allows slightly less than 20.5% to target depth. Thus, a management strategy based on “holding the line” at existing (1992–94) nitrogen loadings should be adequate to achieve seagrass restoration goals in three of the four segments. This “hold the line” approach, combined with careful monitoring of water quality and seagrass extent, has been adopted by the TBNEP partnership as its initial nitrogen load management strategy.

As an additional complicating factor, successful adherence to the “hold the line” nitrogen loading strategy may be hindered by the continuing population growth that is projected to occur in the watershed. A 20% increase in population, and a 7% increase in annual nitrogen load, are anticipated by the year 2010 (Zarbock et al. 1996b). Clearly, if the projected loading increase is not prevented by watershed

management actions, the "hold the line" load management strategy will not be achieved.

Step 3. Define and implement nitrogen management strategies needed to achieve load management goals.

Local government and agency partners in the Tampa Bay NEP anticipate signing an agreement in early 1997 pledging to carry out specific actions needed to "hold the line" on nitrogen loadings. The agreement will include each partner's responsibility for meeting nitrogen management goals and a timetable for achieving them. How those goals are reached will be left up to the individual communities as defined by them in their Action Plans, to be finalized in early 1998 (TBNEP 1996).

To maintain nitrogen loadings at existing (1992-94) levels, local government Action Plans will address that portion of the nitrogen target which relates to non-agricultural stormwater runoff and municipal point sources within their jurisdictions, a total of an additional 6 tons of nitrogen per year through the year 2010. A Nitrogen Management Consortium of local electric utilities, industries and agricultural interests, as well as local governments and regulatory agency representatives, has been established to develop a Consortium Action Plan to address the remainder (a total of 11 tons of nitrogen per year each year through the year 2010), which is attributed to atmospheric deposition, industrial and agricultural sources, and springs (Janicki and Wade 1996). The Consortium is expected to deliver its Action Plan by August 1997.

Measuring Progress Towards Targets and Goals

An important element of the resource-based management approach is the measurement of progress toward the resource goal (seagrass acreage) and tracking implementation of the nitrogen management strategies needed to reach the long-term seagrass restoration goal. Actions necessary in ongoing oversight efforts to ensure that progress (or lack of progress) is adequately tracked and appropriate actions taken as needed include the following:

- Develop an explicit method for evaluating whether targets are being met;
- Monitor progress in implementing government/agency and Consortium Action Plans;
- Produce a Biennial Environmental Monitoring Report for bay resource managers, updating ongoing monitoring results and highlighting areas of concern;
- Rerun models as additional data becomes available (a minimum of every 5 years);
- Revise nitrogen management goals and strategies as necessary, based on updated model results;
- Prepare an annual progress report for bay managers on progress or problems with reaching targets and goals.

CONCLUSION

The Tampa Bay management community has agreed that the protection and restoration of the bay's living resources are of primary importance. Through the watershed management process developed by local government, agency and community partners of the TBNEP and Nitrogen Management Consortium, regulatory agencies and regulated interests in the Tampa Bay area have an

opportunity to ensure that the water quality conditions necessary to meet long-term living resource restoration goals are successfully achieved.

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INTEGRATION AND IMPLEMENTATION OF ECOSYSTEM MANAGEMENT OBJECTIVES IN THE HILLSBOROUGH RIVER AND BAY ECOSYSTEM DEMONSTRATION PROJECT AREA

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ABSTRACT

The 1993 Legislature directed the Florida Department of Environmental Protection to "protect the functions of entire ecological systems" which launched the Department's ecosystem management initiative in the Hillsborough River and Bay Ecosystem Demonstration Project Area (Hillsborough EMA). Within the Hillsborough EMA, the Hillsborough River Integration and Coordination Committee was convened to serve as an umbrella organization to integrate many of the ongoing ecosystem management initiatives. The Hillsborough River Greenways Task Force, the Hillsborough River Interlocal Planning Board and the Tampa Bay National Estuary Program are three integral community-based teams operating independently yet within the structure of this committee. With the support of local government, the Southwest Florida Water Management District, the Environmental Protection Commission of Hillsborough County, and the Department of Environmental Protection, basin-wide initiatives such as the Southwest Florida Water Management District's strategic Comprehensive Surface Water Management Initiative have been launched and projects have been initiated which are directed towards meeting the needs of a sustainable future for the Hillsborough River and Bay watershed.

INTRODUCTION

During the 1993 session, the Florida Legislature directed the Florida Department of Environmental Protection (FDEP) to "protect the functions of entire ecological systems" which launched the Department's ecosystem management initiative in the Hillsborough River and Bay Ecosystem Demonstration Project Area. This introduced a new aspect of environmental protection to complement the existing regulatory process in Florida.

According to FDEP, Ecosystem Management is an integrated flexible approach to management of biological and physical environments. It is conducted through the use of tools such as planning, land acquisition, environmental education, economic incentives, pollution prevention and regulation, and designed to maintain, protect and improve the state's natural, managed and human communities. This new concept emphasizes flexibility and implements alternatives to the traditional regulatory process. Ecosystem Management (EM) initiatives bring together stakeholders, develop a common base of knowledge, identify watershed-based issues, prioritize issues, develop and implement strategies, and audit and evaluate effectiveness.

There are four main tenets of this new management system. FDEP terms them the "Four Cornerstones of Ecosystem Management". They are: Place-based Management, Common Sense Regulation, Cultural Change and Foundations.

Place-based Management

The first cornerstone, place-based management, focuses management efforts on particular areas large enough to address hydrological and ecological connections on a regional scale. Ecosystem Management recognizes that the environment is

comprised of many interrelated and interconnected systems, including land, water, air, and living plants and animals, including humans. Place-based management initiatives bring together diverse interests to address important issues using flexible innovative strategies. Grassroots support and a sense of ownership develop within the stakeholders of a region. The region may include urban and suburban as well as rural and undeveloped environments and may cross several political and administrative boundaries. The Department has identified 24 ecosystem management areas (EMAs). The Hillsborough River and Bay Demonstration Project area is a component of the Greater Tampa Bay EMA.

The central theme of Ecosystem Management is stewardship. Place-based management encourages stewardship and the involvement of stakeholders in identifying issues and developing strategies. Team approaches to management are also encouraged. These teams typically consist of interested and affected parties including landowners, governmental and regulatory agency representatives, businesses, industries, agricultural interests, conservation groups and private citizens.

In the Hillsborough River and Bay EMA, management is implemented under the umbrella of the Hillsborough River Integration and Coordination Committee (HRICC). Three separate on-going programs operate independently but are integrated under this umbrella to identify issues and to develop strategies in the watershed.

Agencies participating in the HRICC include FDEP, the Tampa Bay National Estuary Program (TBNEP), Hillsborough River Greenways Task Force (HRGTF), Hillsborough County, the Southwest Florida Water Management District (SWFWMD), the Hillsborough River Interlocal Planning Board (River Board), the City of Tampa and the Environmental Protection Commission of Hillsborough County (Fig. 1). The NEP, HRGTF and the River Board include private sector and citizen interests.

Participating stakeholders in these program, read like a who's who in the Hillsborough River and Bay EMA. The HRGTF alone is comprised of over 35 different entities plus interested citizens (more than 150 people).

SWFWMD is one party sitting on the HRICC with an internal initiative complementing the ecosystem management system approach of FDEP. They are implementing their Comprehensive Surface Water Management Initiative for the Hillsborough River watershed (HILLSWIM), a watershed-based approach to surface water management. HILLSWIM incorporates watershed assessments with a multidisciplinary, multiagency team including City of Tampa, Hillsborough County, Pasco County, Polk County, HRGTF, Interlocal Planning Board and FDEP. HILLSWIM is identifying issues and developing strategies which address the Water Management District's areas of responsibility—water quality, water supply, flood protection and natural systems. The assessment provides the District with the basis for making decisions within the watershed and is focused on implementation.

SWFWMD's HILLSWIM initiative is just one of 32 ongoing projects within the watershed identified in a FDEP interim status report to the legislature. Many more

projects are ongoing and find their support in place-based management teams from all walks of life.

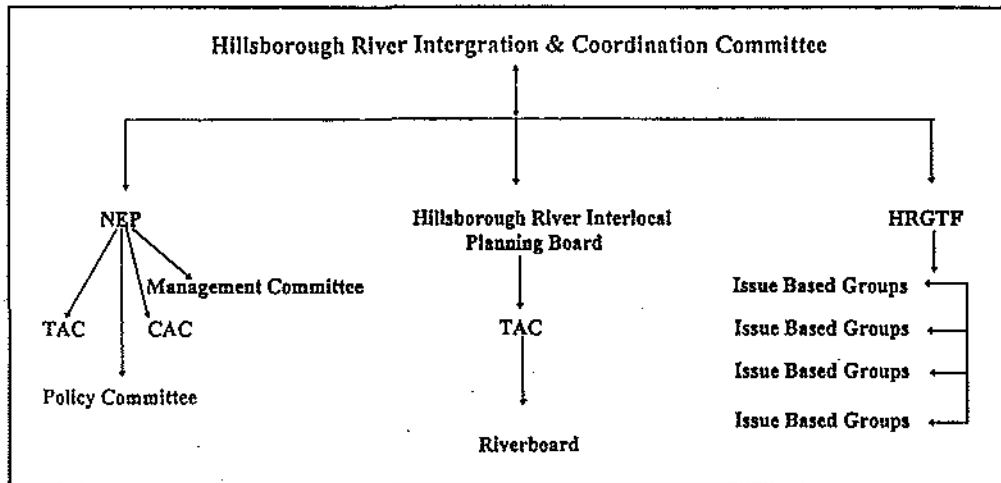


Figure 1.

Common-sense Regulation

The next cornerstone is common-sense regulation. This tenet encourages voluntary alternatives and emphasizes a net ecosystem benefit (NEB) over the traditional approach to regulation. Common-sense regulation achieves protection of the environment with less cost, in less time and with less red tape. Team permitting is an exciting new common-sense approach to the regulatory process. Instead of approaching each permitting agency independently, a permittee sits at the table with all concerned agencies. The agencies interact with the permittee, with each other, and with interested third parties in an effort to expedite the process. In return, the permittee offers a NEB to the watershed, benefits above and beyond what the traditional process requires.

An example of team permitting is the CF Industries (CFI) Team Permitting Project. The CFI gypsum stack expansion permit application process is the first team permitting project to take place in the EMA. The CFI project is especially challenging because of many environmental impact questions concerning the expansion. Eleven agencies, HRGTF, and private citizens are working together to reduce the number, time, and expense of permits. In fact, the time for the permitting has been halved from the traditional process. In return for this savings, CFI is offering additional environmental benefits such as :

- A double-lined stack versus a single liner;
- Stepped-up closure for the existing unlined stack, thus eliminating an existing source of contamination prior to its scheduled closure date; and
- Restoration of a critical greenways linkage to the Green Swamp.

During 1996, CFI exchanged land with Hillsborough County for a site on which to build the stack expansion. The county gained approximately 380 acres of land in a

critical corridor linkage from the Hillsborough River to the Green Swamp. CFI has developed a detailed restoration plan for this land as part of the requirements of DRI review. Incorporation of the detailed restoration plan into FDEP's State Lands Environmental Resource Permitting will assure that restoration and monitoring of this critical area will occur.

As a result of the team process, CFI has used a higher level of subsurface investigation than is typically applied in processing a phosphogypsum stack expansion. They have also recognized the importance of the public in the long term activities of the site. The Hillsborough River Greenways Task Force is identified as a member of the Restoration Review Team which will monitor and evaluate the effectiveness of the adaptive detailed restoration plan.

Cultural Change

The third cornerstone is cultural change. This requires a substantial change of attitude both within governmental agencies as well as from stakeholders and the private sector. This tenet moves away from "how it has always been" to an attitude of cooperation and stewardship. Ecosystem Management encourages partnerships between government and the citizenry with everyone sharing responsibility for environmental protection. Cultural change means agency restructuring and reallocation of agency staff to better meet the needs of an entire EMA. Agencies will work together and staff will be empowered to make decisions which move projects forward more quickly. All team players develop an understanding of the dominant principles of ecosystem management and use them in making permitting and design decisions.

These changes may evoke growing pains within the agencies, but one of the most important changes involves a significant change of focus—from traditional environmental protection to an emphasis on pollution prevention. This change will rely on community vision and the stewardship and buy-in of the regulated public.

Foundations

The fourth cornerstone is foundations. Foundations include the science, technology, planning, education and other tools required to make ecosystem management work. SWFWMD's HILLSWIM initiative is a foundation-level tool. These tools are not the direct agent of change; however, they are critical to the creation of an environment in which change can occur. The use of "audit and evaluation" ensures that science and technology are not only incorporated into EMA actions, but actually result in a desired end product.

SPECIAL PROJECTS

FDEP's Ecosystem Management staff applied for several EPA 319 research-based grants in the Hillsborough River and Bay EMA. Two of these grants in implementation are the Cone Ranch Restoration Project and the Dairy BMP (best management practices) Project. All of these projects recognize and cross the four cornerstones of ecosystem management.

The Hillsborough River Greenways Task Force (HRGTF) developed a "sponge" concept for the restoration and enhancement of wetland systems on the 12,700-acre Cone Ranch. Using the HRGTF concept as the basis, FDEP requested funding from EPA to implement the sponge concept and additionally seek water quality, floodplain and wildlife habitat improvements. Nine governmental agencies join the HRGTF in this restoration effort which have \$460,000 pledged for phases I and II of the project. The project focuses on restoring the site, principally by de-ditching, but also recognizes the site's potential use as a wellfield. An additional \$30,000 was awarded to the project by FDEP in 1996. A year of scientific data collection will be completed in March 1997 and actual construction will begin in May of 1997. Completion of the entire project is anticipated in 1999.

Another project examines the effects of the few remaining dairies in the EMA, some of which have been associated with nonpoint pollution in the watershed. To help reduce this nutrient load, FDEP has joined forces with other agencies including the Southwest Florida Water Management District, the Hillsborough County Environmental Protection Commission, the Natural Resources Conservation Service, the University of Florida's Dairy Science Department, Cooperative Extension Service and Agricultural and Biological Engineering Department, Dairy Farmers, Inc., the Department of Corrections and private industry to implement an EPA grant for land-limited dairy best management practices in the EMA. Two project designs are underway. One is a vegetated wastewater treatment system at a local dairy which will be used as a demonstration site for other dairy farmers. The second project will be a regional compost facility at a prison site using prison labor to produce fertilizers and soil amendments from manure and yard waste. The project objective is to reduce nutrient loading into the watershed while providing economic incentives to dairy farmers for on-site manure management and supplying a valuable organic fertilizer for crops and home gardens.

In conclusion, implementation of Ecosystem Management in the Hillsborough and Bay EMA is making rapid progress. Diverse groups of citizens and government staff work together cooperatively despite philosophical differences and legal constraints. Community vision and consensus have formed the groundwork for progress. Along with education and stewardship, the framework is in place to promote sustainability of the Hillsborough River watershed and Tampa Bay.

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WATERSHED MANAGEMENT—WHAT WE HAVE LEARNED

Donald D. Moores

ABSTRACT

In the late 1980s, Pinellas County became involved in watershed management with the initiation of planning for the Allen's Creek Basin, Lake Tarpon and Lake Seminole. Pinellas County included in its Comprehensive Plan goals to correct problems in County waters by the development of watershed management plans which would address drainage, water quality and wildlife habitat. This report discusses some of the specific issues which we have encountered in attempting to manage urban watersheds in Pinellas County.

There does not appear to be a single clearinghouse for urban stream management issues. Most professional organizations dealing with stream management, and most available information on stream watershed management, deal with watersheds in agricultural areas, or trout stream management as opposed to urban streams.

Most urban streams, particularly those in older urbanized areas, have been altered to some extent to "improve" drainage. Alterations include road crossings which act as partial controls, hardening of land areas which generally accelerates the rate of runoff, and drainage by ditches or culverts. These drainage modifications have several impacts on the natural history and water quality of streams.

In the Tampa Bay area, as elsewhere, a great deal of the highly productive estuarine system historically existed in its numerous small tidal streams, supporting a number of species of finfish and shellfish of sportfishing or commercial importance including red drum and snook. The modifications which have probably had the greatest impact on these species' habitats are shoreline hardening, drainage improvements which accelerate runoff, and controls (either weirs or road crossings).

BACKGROUND

In the late 1980s, Pinellas County became involved in watershed management. The first basin for which management planning began was the Allen's Creek Basin. The County was included in a threatened lawsuit over the water quality of the stream, and entered an agreement with the State of Florida Department of Environmental Regulation and the two cities who share the watershed, to conduct an intensive study of the stream and develop a corrective.

Shortly afterward, concerns over the condition of the unincorporated County's two largest lakes, Lake Tarpon and Lake Seminole, led the Board of County Commissioners to mandate similar studies and watershed management plan development in those basins.

Pinellas County also included in its Comprehensive Plan goals to correct problems in County waters by the development of watershed management plans. These plans were not to address simply drainage as in past plans, but also to address problems with water quality and wildlife habitat.

Pinellas County Watersheds

Pinellas County has been divided into 52 drainage basins based on topography and historic drainage patterns. Originally, most of these were drained by small tidal streams ranging from about 2 miles to about 10 miles in length; a few of the basins were coastal basins which do not appear to have had distinct drainage channels.

In contrast to many other Florida counties, Pinellas has relatively few lakes. According to Gant (1987), there are 30 natural lakes listed for the County, but less than ten are 20 acres or larger.

Pinellas County is dominated by small streams, with 45 streams and 68 tributaries. Some of these streams have been more seriously altered than others; in general, those in the more urbanized areas of the county, particularly those areas that became urbanized earlier, have received the greatest alteration. In the older areas, many of the original streams have been channelized for drainage improvement, and hard-lined or walled. Some, in fact, have been totally replaced by underground storm sewer systems.

Many streams and stream segments in those areas developed more recently show much less effect of alteration, since modern development practices and regulations call for preservation of wetlands, onsite stormwater treatment, and minimal alteration to stream channels. As might be expected, these streams tend to display higher water quality than those in older, more highly urbanized areas.

The purpose of this report is to discuss some of the specific issues which we have encountered in attempting to manage urban watersheds in Pinellas County. It is primarily intended as a means of sharing what we have learned with others who may wish to begin managing their urban streams and lakes.

Networking vs Reinventing

When embarking on a new experience, it is always wise to first find out what we can learn from others. We have unfortunately found a deficiency in shared information on urban stream management. Although the recent widespread use of the Internet has made it possible to obtain information more readily, there does not appear to be a single clearinghouse for urban stream management issues.

By contrast, there is considerable information available concerning lake management. Most of what we have learned about watershed management was learned from conferences and symposia hosted by the North American Lakes Management Society (NALMS) and its state and regional chapters. NALMS has existed 16 years, and in that time the state-of-the-art of lake and watershed management has grown precipitously. This is primarily due to the avenue provided by NALMS for sharing of information among researchers and professional lake managers.

No similar organization exists for urban streams. While there are a few professional organizations dealing with stream management, most available information on stream watershed management deals with watersheds in agricultural areas or trout stream management. Urban streams comprise an entirely separate class of streams with their own special characteristics, problems and issues. What follows is a discussion of some of those issues. It is hoped that further refinement of urban stream management issues will continue, as well as the process of information sharing.

DRAINAGE MODIFICATIONS AND THEIR EFFECTS

As mentioned previously, most urban streams, particularly those in older urbanized areas, have been altered to some extent to "improve" drainage (i.e., to get rid of surface water sooner after a rain event, and to make more marginal land able to be developed without fear of flooding). No urban stream has totally escaped alteration: road crossings act as partial controls, affecting flow, and land areas have been hardened and drained by ditches or culverts, generally accelerating the rate of runoff from the drainage basin. These drainage modifications have several impacts on the natural history and water quality of streams.

Effect of Drainage and Channel Alteration on Oligohaline Areas

This particular problem is peculiar to urbanized areas adjacent to saltwater bodies, where streams are partly tidal. In the Tampa Bay area, as elsewhere, a great deal of the highly productive estuarine system historically existed in its numerous small tidal streams. A number of species of finfish and shellfish of sportfishing or commercial importance depend upon the low salinity environment provided by tidal streams to complete early stages of their development. Among these are red drum and snook (Edwards 1991; Clark 1991; Peebles et al. 1991).

The modifications which have probably had the greatest impact on these species' habitats are shoreline hardening, drainage improvements which accelerate runoff, and controls (either weirs or road crossings). Shoreline hardening, seawalls and creation of distinct stream margins by dredging and filling have resulted in elimination of the physical habitat (primarily consisting of mangrove or black rush in the Tampa Bay area) preferred by the affected species in areas where otherwise the salinity regime is appropriate. Weirs and other controls result in a sharp line of demarcation between segments of higher salinity and completely fresh water, eliminating the low salinity, or oligohaline, zone. Thus, species which must rely on oligohaline habitats are unable to proceed farther upstream than the control. Finally, drainage acceleration results in eliminating baseflow from the stream, so that the tidal portion remains higher in salinity than is optimal except immediately following a rain event, when the stream becomes completely fresh for a short time (Zarbock 1991).

Effect of Drainage on Base Flow and Peak Flow of Freshwater Portions

A more common situation which affects all urban streams, and not just those in coastal communities, is the effect of drainage modifications on bank storage, baseflow and peak flow of freshwater streams (Zarbock 1991). In Florida, stream fauna are adapted to a distinct rainy season and a nonrainy season. Species which predominate in streams during the dry season tend to be those adapted to, and requiring, low flows for survival (including such examples as web-spinning caddisflies whose webs would be swept away by unseasonable increases in flow). Species predominating in the wet season, by contrast, are those that favor higher velocities. Hydrologic modifications that have tended to lower baseflow and increase post-storm event velocities have had significant impacts on stream biota. Unfortunately, this is very poorly documented in stream invertebrate studies.

WHAT IS THE STATUS OF OUR KNOWLEDGE?

This brings us to the limited knowledge of many of the impacts of urbanization on streams. In the absence of a central clearinghouse, or urban stream management organization, for the sharing of knowledge and experience, it is difficult to even find out what is known. Scientific literature may contain information on the biota of streams which might happen to be urban, but this may not be easily identified as a source of urban stream issue information. Most information on management probably exists as consultant reports to the particular city or county that hired them, but these are not disseminated widely among the urban stream management community.

How do streams, and hence management techniques, vary geographically? NALMS has found regional differences among the kinds of lakes and their manner of formation which significantly affect the types of problems encountered and ways of dealing with them. The Tennessee Valley Authority, for example, has provided a great deal of information about ecological conditions in reservoirs, which tend to be the dominant type of lake in that region. Little is known about geographical variation in types and ecological conditions of urban streams.

OTHER STREAM MANAGEMENT ISSUES

Instream Management Techniques

Generally speaking, watershed management techniques don't differ much from lake watersheds to stream watersheds, at least in terms of managing runoff and other watershed issues. Techniques for improving water quality and habitat in the stream itself, however, will differ from those for lakes or wild trout streams.

Property Ownership

Many urban streams have had adjacent properties platted to the center of the channel, and are therefore in private ownership. This fact creates a number of significant issues. How does one manage a stream whose channel is partly in private ownership? If shoreline hardening and loss of habitat is a problem, how do we get stream bank owners to agree that removal of seawalls and restoration of wetlands is desirable? How do we go about creating habitat, at the taxpayers' expense, on privately owned stream banks, even if the stream bank owner agrees? If we aren't going to restore habitat to the stream, why bother treating stormwater to improve the water quality of a stream that is basically a concrete-lined stormwater conveyance?

Public Support

Most people are unaware that they even live in a stream watershed. As they drive the city streets, every time the road dips between two adjacent hills, they are crossing a stream channel, yet most people don't even notice it. Except for those that live directly on one of the channels, many citizens don't even know that the channel exists. Since the stream is largely in private ownership, citizens in a stream watershed who can't use the stream for recreation, or even see it, may not feel any connection to the stream or have any interest in protecting it. Conversely, lake bottoms are usually for the most part in public ownership, and public access is often provided for recreation. Citizens who live in the vicinity of a large public lake generally will have no problem understanding that their runoff goes to the lake, and can at least appreciate the need to take protective measures. Getting the involvement and

commitment of the community in protecting urban streams is considerably more difficult.

PUBLIC INVOLVEMENT

How do we get public involvement? When should we approach the public? What has been done successfully elsewhere? One thing experience has taught us is that major plans and projects will probably not succeed without public acceptance of what you're doing. Sooner or later you're going to want to construct something, perhaps a detention pond or a wetland, and don't want to run into a wall of opposition. Furthermore, if the public generally lacks a feeling of trust in its local government, it really doesn't matter what the project is, how good it is, or how noble the cause—someone is very likely to oppose it and mobilize popular opinion against it. It is important to start building an atmosphere of trust from the very beginning, rather than waiting until you have a project you want to complete to start communicating, otherwise you may experience having to start your planning all over again.

We need to get public input on issues and problems they perceive, as well as educate them to those we, as professionals, perceive. There is often a tendency of government employees to view the public hearing process as simply a way to inform the public about what we're planning to do, or to try to implant some change in attitude or opinion in the public mind. If the public doesn't like wetlands, we feel it is our obligation to get them to start liking wetlands, and start disliking seawalls and bulkheads. To a certain extent, there is some validity in providing public environmental education; after all, we are presumably the experts that have been hired to represent the public's interest in environmental affairs, but communication has to be a two-way thing, or it isn't effective communication. We need to show from the outset that we are interested in what the people think, and let them know that we want to do things in a way that they will like.

There are a variety of ways to enlist the public and get them involved in what you are planning. The recent satellite uplink of the special plenary session of the conference Watershed-96 was enlightening in terms of the variety of ways in which public involvement was accomplished. Of paramount importance is to get people to have some sense of ownership in their urban stream or lake. As mentioned before, urban streams are often mostly invisible to the general public, while lakes are less so. Such public involvement projects as letting citizens paint "Don't Dump—Drains to Creek" on storm drain inlets, shoreline trash cleanups, citizen water quality monitoring, removal of exotic vegetation, and planting of wetland plants are all extremely valuable ways to get the public to begin to understand the need to protect their stream or lake.

Timing is important if you are planning to lead into something more serious, like the development of a watershed plan for your urban stream. While you want to engage in citizen activities long enough for a sense of involvement to develop, you don't want to do it so far in advance of your plans that all the initial fervor has died down, and many of your original activists have moved away.

To Committee or not to Committee?

Once you begin to think about developing a watershed plan, you need to begin thinking about how to provide for public input into the planning process. How long the process is going to take is a serious issue; based on our experience, people get tired of committee meetings and stop participating if no progress is evident.

Why have a committee in the first place? Committees make your project take longer, require you to spend time educating the laypeople on the committee and bringing them around to the realization of facts you were aware of from the start, and they don't always go the way you would have if you were able to just get about your work. This sometimes seems to be the attitude of government employees who forget whose benefit they were hired to protect in the first place.

It should be clear by now, however, that if you want to succeed, you should be providing a serious mechanism for getting stakeholders involved in the planning process. Notice that we have stopped using the word "public" and begun using the word "stakeholders". The public, in general, are certainly stakeholders, not only in what happens to their stream or lake, and the quality of life in their community, but also in how their tax dollars are spent. Other cities, state, federal and regional governmental agencies are also stakeholders that you're going to have to deal with sooner or later, and just like the public, it is important to begin developing a sense of trust and cooperative involvement among all the entities that have some kind of interest, regulatory or otherwise, in your water body. It is important to have the stakeholders pulling together instead of apart—you want everyone working toward the same goal, and not to have one stakeholder group intervening in the activities planned by the rest.

Agency Representatives

To begin with, let us discuss agency participation on advisory or planning committees. The first thing to realize is that if you can get the agencies to participate actively, you are extremely lucky; agencies have enough meetings to participate in, and have many more counties and cities in their jurisdictional area than yours. As a result, they may either send the most expendable members of their staff, or tend not to come at all.

This is fortunately not always true. In Pinellas County, we have been extremely fortunate to have continued long-term involvement from several agencies. To a certain extent, our success may stem from the fact that there weren't many competing watershed plan committees when we began. At some point, we need to understand that the ability of state and regional agencies to participate in committee meetings will become limited and that this doesn't reflect a lack of concern on their part, just a shortage of people.

Agencies that may have a stake in your stream or lake include the Florida Game and Fresh Water Fish Commission; the Florida Department of Environmental Protection, both from a wetland regulatory and aquatic plant management permitting position; and the water management districts, from several perspectives including cooperative funding, wetland regulatory functions and the Surface Water Improvement and Management (SWIM) program. The U.S. Army Corps of Engineers is also a

stakeholder, but one which you are unlikely to be able to get involved up front because of their large area of jurisdiction.

Why do we want to get agencies' representatives to participate in our planning and advisory committees? For one thing, we need to bounce ideas off them. Their staff are a valuable resource and are highly trained and possess valuable experience in various technical areas which are extremely relevant. They can share ideas with us that have been tried elsewhere.

We also need to know their agencies' policies with regard to our plans. We need to know when something we are planning will require a permit, and whether the idea we have is likely to be acceptable to permit reviewers. To this end, the people that are sent to represent the agency need to be able to speak for their agency on matters of policy, or at least have the ability to get policy decisions from their agencies back to the committee in a timely fashion. It is important that, wherever possible, commitments be as binding as possible, or made in writing if they are likely to affect the project significantly.

It is desirable for the agency person to be one who is able to make decisions on policy matters. Of course that means getting someone in a more responsible position, such as a regional administrator, and you are unlikely to get this. Some agencies have people especially assigned to the job of serving as liaison between various governmental agencies, and these are the most likely to be assigned. Unfortunately, these people tend to be spread very thin, and they may not be the ones with the particular expertise that would be most useful to your project.

Do agency representatives always represent their agency, or their own private biases? When they participate in discussion, are they always reflecting the policy of their agency, or just talking "off the cuff" from a personal point-of-view? This is a serious philosophical issue: you want to be able to take advantage of the technical expertise that agency representatives can provide, but it is important to know when they are expressing an agency policy position rather than a technical or scientific judgement, or a personal opinion. As mentioned before, you want the comfort of knowing that your agency representative is actually taking your policy questions up with management and getting official positions and not simply making up policy on the fly. If you are heading a watershed committee, it will be your responsibility to make sure you get significant policy positions clearly identified as such, and make sure you know which is which.

Citizen Representatives

The important consideration in getting public involvement on your advisory committee is to get people who can truly represent "the public". To a certain extent, a single individual on a committee may still serve as a surrogate for the public to get a feel for whether the public is likely to welcome a particular idea. The problem is that, after a certain time in being involved with the committee, a citizen member will become much more technically sophisticated than the general public, and may no longer reflect a good measure of public attitude.

Factors to consider in soliciting citizen participation include:

- Are there well-defined organizations? In the case of lakes, there are often lake associations, or homeowner associations for large housing developments in the watershed. Such organizations may sometimes be hard to identify in the case of streams, where neighborhoods tend to be less cohesive. Other potential stakeholder organizations, especially for lakes, include environmental organizations and fishing clubs.
- How well does the individual represent the organization? You hope that group representatives will keep their members aware of progress and plans that are being made, and will seek their organization's feedback on issues that affect them.

If no organization, then what?

- One option is to have the city council or county commission appoint representatives to the committee. We have had experience with this approach in the Lake Seminole project.
- Individual environmental activists, while not representing a group, may be willing to organize people into an interest group.
- Some areas have community-wide environmental advisory boards whose members can serve to provide contact with the public. Pinellas has not had any experience with this approach.

MONEY

What sources of funding are available for watershed planning? This is an area where it may be advisable to consider what has been done elsewhere. Sources of funding are as varied as imagination allows. In Pinellas County, because watershed management planning is mandated by our comprehensive plan, funding of watershed planning efforts is supported through the Capital Improvement Program. We have also benefited greatly, particularly in the implementation of projects, from the largesse of a generous and enlightened water management basin board. Since our waters either are, or directly affect, SWIM waters, the SWIM program has provided either funds or technical assistance in several instances. Likewise, the Tampa Bay National Estuary Program has been able to assist in projects which affect Tampa Bay.

As more and more organizations get into the watershed management planning business, competition for funds may be greater, and more innovative ways of funding may need to be sought. In many communities, stormwater utility fees are used for watershed planning and implementation of projects.

WHAT ARE THE TANGIBLE BENEFITS OF WATERSHED MANAGEMENT?

It is fairly easy to estimate the cost of developing watershed plans, or of creating wetlands and stormwater treatment facilities. It is considerably more difficult, however, to put a dollar figure on the benefits that are expected. Such benefits include many intangibles such as improved fisheries, improved sportfishing and ancillary benefits (boat rentals, tackle, bait, etc.), aesthetic improvement to the waterfront, associated improvement in the value of waterfront property, increased recreational potential, and so on. Putting a dollar value on these benefits is at best very difficult.

It is also very difficult to convince waterfront property owners about the benefits of allowing aquatic vegetation to proliferate on their bank. The benefits of such vegetation are felt in terms of improved wildlife utilization, improved fisheries, and so on. To the homeowner, vegetation is more likely to be viewed as a nuisance, minimizing navigable access from their dock, or blocking the view of the water (although sometimes people who have dense stands of exotic vegetation on their property don't want to lose it because of the privacy that it affords).

The aesthetics of management also is an issue: people may object to the creation of a stormwater detention pond in their neighborhood despite the proven benefit of ponds in treating stormwater. They may object to creation of wetlands or other habitat improvements; many homeowners don't want rabbits or squirrels in their yards, and even try to eradicate them. The chance of getting the average citizen to appreciate the benefits of having snakes in their garden is extremely slim.

CHALLENGES

Interjurisdictional Coordination

Watersheds rarely are consistent with jurisdictional boundaries (except in the case of water management districts). Getting adjacent municipalities who share a stream or lake to participate in plan development is relatively easy. The problem comes when it is time to pay for improvements. When a problem (e.g., poor water quality) is generated from the upstream municipality, but the benefit of improvement is in the downstream municipality, it may be difficult to decide who will pay what share of the improvement project. When all the subbasins contributing the highest pollutant load to a lake are in the same municipality, how does one equitably allocate the share of the cost of improvements among the participants? These issues have provided a serious challenge to our imagination. In some cases, it has been appropriate to allocate the shares in terms of the relative contributing drainage area to be treated. In other cases, this may not be equitable and other formulas have to be used.

Regulatory Issues

Watershed management has several regulatory implications. First is the fact that the regulations requiring large and medium sized municipalities to obtain an NPDES permit for their municipal storm sewer systems (40 CFR Part 122) explicitly recognize development of management programs on a watershed-specific basis as an acceptable way to approach stormwater management. Of issue is the question of just how specific one wants to be in their NPDES permit regarding their watershed plans. In other words, it is entirely possible that one's NPDES permit conditions might be written so as to mandate implementation of every recommendation contained in the plan, thus eliminating the local government's options or flexibility, and essentially turning the plan into a regulatory mandate. If this begins to happen in NPDES, it will severely affect the willingness of local governments to develop plans.

A second area of regulatory significance is the development by the water management districts of pollutant load reduction goals, and of minimum flows and levels, for district waters. Clearly both of these items are essential parts of the planning process for water bodies, and the desire would be to have those goals developed as part of a watershed planning process adopted by the water management district. Thus there

needs to be close interaction with the water management district in the development of these aspects of any watershed plan.

Finally, whether explicitly discussed in the local government comprehensive plan or not, development of a watershed management plan will probably carry out many of the goals and objectives of the comp plan. The issue here is whether or not the local government wants to officially adopt watershed plans as a part of their comp plan, or simply refer to them as supporting completion of a plan element. Formal adoption as a part of the comp plan would, again, tend to reduce the local government's flexibility, and would run the risk of having the Department of Community Affairs viewing the minute aspects of the watershed plan in terms of compliance.

Habitat Expectations

This may be an issue that is peculiar to the type of watersheds that predominate in Pinellas County and possibly other coastal counties. Our watersheds usually are drained by short streams, varying in length from about two to about ten miles. Typically, the downstream portion of these streams is tidal, sometimes as much as half the total length of the stream. The streams have been urbanized since long before agencies began studying them. As a result, little is known about the typical biota of this type of stream in a natural condition. There is little technical basis for knowing whether we can expect an urban stream to support such things as bass or bluegills if we don't know whether the stream historically supported them. From what we have observed, stream drift fauna, which are extremely important in most stream communities, are relatively depauperate in these short-run streams. Much more study specifically oriented toward the biota of coastal streams is needed. Also needed is a sharing of any successes that might have been experienced in restoring predevelopment biological conditions to such systems.

Other Sources of Water Quality Problems

We are becoming increasingly aware that there are other sources of water quality problems in watersheds besides stormwater runoff. In the Allen's Creek watershed, we estimate that seepage from septic tanks may contribute from 50% to 80% of the total nutrient load to the creek (Andersen et al. 1996). Groundwater seepage has traditionally been overlooked in stream and lake studies, and is almost never monitored. In fact, there is no well-established procedure for monitoring stormwater seepage.

Atmospheric deposition is another new issue in watershed management. In lakes and estuaries, atmospheric deposition directly onto the surface of the water body may contribute as much as 30% to 40% of the total nutrient load. Local governments in the Tampa Bay area, working with the Tampa Bay NEP, are working toward attempting to define what portion of the load in runoff comes from atmospheric deposition. How one manages watersheds partly depends on the answer to this question. For example, best management practices (BMPs) such as fertilizer management may be totally ineffective if the majority of runoff load from the watershed turns out to be of atmospheric origin. In such a case, the local government would be left with structural BMPs (e.g., treatment systems) as a solution.

Water Quality Improvement in Streams

Leaving aside watershed management, little is known about innovative instream techniques that can improve water quality. Much research has been done on stream restoration techniques for trout habitat, for example, but little research exists on instream water quality improvement techniques.

Use Conflicts

Whatever the problems with an urban watershed or waterbody, and whatever the causes, one factor that you will have to deal with is conflicts between different users of the resource. Lake Tarpon provides a perfect illustration: lakefront homeowners and management agencies alike favor lowering boat speeds within a certain distance from shore, and particularly in the outfall canal, to minimize shoreline erosion; agencies, however, favor increasing the littoral vegetation to combat erosion, while homeowners would like to see vegetation eliminated; water ski clubs object to limiting boat speeds near shore because they prefer skiing in the calmer waters there, and especially in the outfall canal; fishermen support restricting skiing from the canal, but don't want speed limits imposed on themselves; most lake users want *Hydrilla* (and just about any other submergent vegetation) eliminated or greatly reduced; fishermen on the other hand claim that *Hydrilla* greatly increases fishing success and object to its elimination. In just about any area where one chooses to conduct some sort of management, there are likely to be conflicts between various user groups as to their preferences.

How have these conflicts been resolved elsewhere? In some states, large waterbodies have been zoned into fishing areas, skiing areas, etc. Whether it is appropriate, let alone legal, to preclude groups of people from using a portion of a public water body recreationally is a good issue for further exploration.

Condemnation for Treatment for Water Quality

If your plan is to provide stormwater treatment or restore habitat in an urban setting, you will undoubtedly need to acquire property to build ponds or habitat. Rarely will you find available vacant property in just the right spot to create a detention pond; often you won't find any available vacant property at all in a highly urbanized watershed. What happens when you need to build a pond and can't find a willing seller? To our knowledge, condemnation has never been attempted in order to obtain property for water quality improvement. There remains a serious concern as to whether condemnation for this purpose would even be legal, assuming one wanted to do it. Condemnation of streambank properties for floodplain habitat restoration would be orders of magnitude more difficult.

In Pinellas County, the direction we have taken is that we will not even consider condemnation. If a parcel is offered freely for sale to the county, and is adequate (right size and location), and appropriate for use as a pond or wetland (a pond or wetland may not be appropriate right in the middle of a typical subdivision), then the county will attempt to purchase and develop the site. We have been lucky in several cases, and have been able to obtain joint funding from adjoining municipalities and the water management district for restoration activities at County-purchased sites. We

will have to be willing to accept the best we can hope to get in some watersheds, and in others where we have more opportunities, to try to do even more.

SUMMARY

We haven't provided many answers; we have only begun in this discussion to touch on some of the more significant issues. It seems that the longer we are engaged in watershed planning, the more issues surface that we wish we had thought of earlier. The technical issues are generally fairly straightforward, although more emphasis is probably needed in seeking stormwater treatment alternatives that aren't land-intensive for urban areas; the really sticky issues are the social and philosophical ones, and unless you are able to take advantage of the experience of others through networking or professional organizations, you're probably going to have to come up with your own solutions tailored to your particular situation and stakeholder perceptions.

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THE ROLES OF STAKEHOLDER INVOLVEMENT, SUSTAINABLE DEVELOPMENT AND ENVIRONMENTAL JUSTICE IN DEVELOPING AND IMPLEMENTING WATERSHED MANAGEMENT PLANS

Thomas R. Cuba

ABSTRACT

The fundamental concept behind the philosophy of holistic watershed management planning is the *principle of inclusion*. Simply stated, inclusion dictates that: *If an event occurs within a watershed and that event has an impact upon the overall functions of the watershed, the event, along with its causes, synergisms and suggested solutions, must be addressed in the plan.* Unfortunately, this principle is commonly either overlooked entirely or is compromised during the planning process. Of the factors commonly eliminated are the voice of the stakeholder, the sustainability of the plan, and the environmental justice of the implementation. Stakeholder involvement has been sought in some local efforts, the most notable of which is the National Estuary Program's plan for Tampa Bay. The Surface Water Improvement and Management department of the Southwest Florida Water Management District and Pinellas County have made similar attempts with a number of smaller projects. Even in these far-reaching and groundbreaking efforts, however, the principles of sustainable development and environmental justice have not surfaced, have been compromised, or have been sacrificed. In some cases, the issues of sustainable development have been raised and then, more often than not, have been buried, labeled as not being achievable. The issues of environmental justice have seldom been suggested and so could not be brought to bear in the problem solving process. Despite these omissions or deletions, these plans are still being erroneously presented as *holistic* watershed management plans. It is only through an ongoing and iterative process of analysis and inclusive problem solving that true holistic management can be achieved. Stakeholder involvement, environmental justice and sustainable development include processes and considerations that absolutely must commence in the data gathering and planning stages and continue uninterrupted and unabated through final plan implementation.

INTRODUCTION

In order to properly discuss this topic, it is important to review the concepts of some of the terms and philosophies. In particular, we will review holistic planning, stakeholder involvement, sustainable development and environmental justice.

Holistic Planning

The ability to plan for the future is a fundamental trait improving the chances for survival. At the level of squirrels packing away acorns, this planning for the future may be instinctive and self-serving. Elevating this trait one step, we can see that planning for the future of others is beneficial because it sustains the communal aspects of survival. But it is still instinct that drives the digger wasp to paralyze prey which it then buries with its eggs. The wasp is planning for the survival of its offspring by providing a living but captive food source.

Planning was once a fairly well defined and very local process. Planning boundaries were distinct and simple. Plans for local development, zoning and water use have roots in property rights. It was only when unrestricted use of property had an undesirable effect on the neighbor that government began to plan and restrict development. Early zoning rules were developed to keep livestock out of the city. As with other issues, the plan was simple and defined—livestock in one place and restaurants in the other.

Cuba

Ripple effects of plan implementation projects within one boundary did not dramatically complicate plans in the neighboring area. Human planning processes became more complex as the population grew. Effective solutions to the problem of sewage disposal became unacceptable as the disposal sites became inhabited. The planning boundaries expanded to cover more than what was once considered offsite.

To combat the complex overlap of planning boundaries and planning agencies, the planning boundaries were redefined first through the creation of agencies like the Regional Planning Councils and the Department of Community Affairs with their comprehensive planning responsibilities. But the physical boundaries needed to change as well and watersheds rose to the top as the most manageable.

Watersheds are discrete in that there are real and surveyable boundaries. They are identifiable as ecological units. Municipal patterns generally tend to center around water features. And they are nested. The nesting of smaller watersheds within larger ones allows for broad regional planning to occur at higher levels of government and detailed local plans to be enacted in smaller watersheds. Like the comprehensive plan, the local plan should be consistent with the larger one. After the watershed basis was formed, the concept of holistic plans became obviously necessary.

The fundamental concept behind the philosophy of holistic watershed management planning is what I call the *principle of inclusion*. Simply stated, inclusion dictates that: If an event occurs within a watershed and that event has an impact upon the overall functions of the watershed, the event, along with its causes, synergisms and suggested solutions, must be addressed in the plan.

This principle is required by the very nature of the holistic process. To violate this principle leads to unpredicted or unaccounted-for processes which insert stochastic influences into the project implementation. It complicates the planning process because it is now unlikely that a single specialist can address the engineering, environmental, economic and social issues.

It is of interest to note that the philosophies of holistic watershed management included the elemental portions of sustainability and maintainability before "sustainable development" achieved buzzword status.¹

Unfortunately, the Principle of Inclusion is commonly either overlooked entirely or is compromised during the planning process. If this principle is ignored, the result is an endless process of replanning to include the issues left out previously. This occurs when the omitted issue becomes significantly irritating to the public that they demand it be addressed.

¹ As watershed management failed and became more similar to ecosystem management in its redefined state, others recognized that the philosophy remained sound and renamed it as sustainable development.

Stakeholder Involvement

The underlying concept of this relatively new buzzword has been around for years. It is public participation. It is why government advertises the issuance of permits and proposed ordinances. And still, it carries a nuance of change that is critical to the future successes. In its simplest form, it is a simple and basic reminder to governments and government contractors that they work for the people. Too often, a development order or construction permit has been an agreement reached between a developer and a bureaucrat. Stakeholder involvement, as a policy initiative, should remind us that the bureaucrat is a hired representative of the people and, since the permit or order is actually an agreement between the developer and the people, the people (stakeholder) have a right and need to be involved.

Stakeholder involvement policy is in fact an admonition to the bureaucrat to proactively get people involved. It is an admonition to seek public opinion at a level above the minimums required by Florida Statute. It reminds government that serving the people includes more than the responsibility to simply make information available—it is a responsibility to actively *seek* the opinion of the public.

If this responsibility is ignored, it can often result in public revolt against proposed plans developed under the “meet the minimums” policy of public involvement. This is embarrassing to the elected and appointed officials and can lead to overreactions. Reactions such as these can elevate the impact of the opinion such that other issues are overshadowed. The plan can then be imbalanced in favor of uninformed public opinion over other issues such as environmental justice, ecosystems’ needs, economics, or sustainability. Ultimately the same replanning will be required.

Sustainable Development

As noted previously, this is not a new concept. Thomas Jefferson in 1789 opined that “...no generation can contract debts greater than may be paid during the course of its existence.” This note applies equally to economic and ecological debts. Also noted previously, there are a great many similarities, if not a total equivalence, between sustainable development and holistic watershed management, the major difference being the identifiable physical boundaries of the latter.

Sustainable development is philosophically simple. It asks the question at each step in development, *is this proposal sustainable?* It is only the answer that becomes complex and difficult to implement. But it is in developing the answers that other issues can also unduly complicate the question. The key to keeping the implementation as manageable as possible is to not lose sight of the question—hold on to the philosophy. Is this proposal sustainable or isn’t it?

A few key factors need to be added before firm concepts form around this simple cornerstone. The first is the recognition that sustainability is not limited to ecological or economic terms but includes social and political sustainability as well. The second is that in virtually each case, the project will fail this test. There are, in short, no self-sustaining projects. Sustainability can only be achieved through the inclusion of ongoing activities such as maintenance or expansion. By including the latter considerations, seemingly inexpensive construction projects will be eliminated if they

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create an unmanageably large drain in manpower or finances in order to maintain it throughout its lifetime. Social or political sustainability can be examined within the same general criteria of ecology and economy, but asks instead if the people and government of the future will be disposed to keeping the maintenance commitments necessary to develop the project. It asks the nature of the political will to manage the future that today's development will bring.

It asks that each development be examined within the context of the community and not simply the context of the rule. It asks for a so far extremely evasive definition of cumulative impacts and requires development to be conducted within the context of relationships among development, community economics, parks, preserves, and municipal services. It is the cumulative philosophies of holistic management, ecosystem management and sustainable development that have really fostered such programs as the excellence in leadership (XL) development process promoted by the EPA.

What sustainable development has not addressed formally, yet, but will in the very near future, is how to apply the precepts of sustainability to existing developments.

When these precepts are ignored or not employed, we often end up with extraordinarily large maintenance costs, replanning and redevelopment. New York City essentially went bankrupt when the managers realized that their entire fundraising capacity was totally consumed by maintenance costs for existing facilities. They could make no improvements. Detroit could well present us with the most extensive example of brownfields. Many people moved to Miami because they liked the beach. To accommodate them the city allowed the construction observed there today. The problem was that the people did not move in next to the beach, but moved in on top of it. The attraction that stimulated development was destroyed by the development and it was not sustainable. These cities are solving these problems and have made a great deal of progress in their replanning and reconstruction. It could have been avoided.

Environmental Justice

Environmental justice is a very old issue with a fairly new name. The issue has its roots in the same place as other injustices. Those in power make the choices. Undesirable things are visited on those not in power. In past years government erred in more often favoring the opinion of one economic or ethnic group over that of another. This is an injustice when tested against such precepts as *all men are created equal* and *one man, one vote*. The cumulative result of this commonly practiced error of public service is that landfills, chemical plants and superhighways were and still are located in areas of the disenfranchised citizen. In some instances this discrimination was a result of an economic logic that looked for inexpensive property upon which to place these facilities. Because those who were ignored by governments because of their economic and ethnic status often were the residents of the least expensive land, the discrimination that occurred was incidental to the economic decision. In a significant number of examples, however, the decisions made were, and perhaps still are, made purely on the prejudices of the individuals involved. Environmental justice

as a federal and state policy initiative seeks to rectify the process and remedy the injustice.

Like stakeholder involvement, these remedies are founded in an empowerment process. In the previous discussion, economic class and ethnicity are highlighted. The injustices, however, have been based on a wide variety of factors including economic class, median age of the community, commercial or residential development patterns, and even the type of business currently occupying the properties.

Like the other issues, the philosophical solution is simply stated and very difficult to implement. In this instance, the solution is the same as with other injustices—do not let these issues and biases exert undue influence on the decision to be made—make decisions based on the relevant issues and become blind to special interests.

Applying this principle to the resolution of environmental justice issues properly relegates these to the status of being a special subset of stakeholder involvement issues.

CONFLICTS

In considering the issues of sustainable development, stakeholder involvement and environmental justice in the watershed management planning process, there are conflicts which are forced to arise. And, even though these issues are fairly new on the policy scene, they are already being interpreted to meet special interest needs. Stakeholders previously disenfranchised are seeking an elevated status over the previously favored groups. To do so would create as large an imbalance as did the making of the first set of errors. It is important to first realize that each person represented by the collective governments of this country has an equal voice. Empowerment meted out based on past wrongs is no more equitable nor sustainable than it was when it was based on past favoritism.

Because the stakeholders include all peoples of all economic classes, ages, ethnic backgrounds, business interests, and all of their residual prejudices, there will be conflict in the decision making process.² It becomes the responsibility of the government to resolve the conflicts and balance the interests. The criteria for balance can be found in the sustainability and holistic nature of the decisions being made.

Resolving these conflicts lies in the ability to educate the stakeholders with respect to the sustainability issues. The premise is that stakeholders who are aware of the projects overall impacts to economics, ecology, and society will make an informed decision that, if not technically the best decision, carries with it the public commitment to sustain the decision being made. A city, therefore, that decides to grow beyond its water supply capacity with the full knowledge that it may need to import water or desalinate it or reuse the wastewater stream has made a valid choice. Similarly a city that decides to discharge wastes to a water body or landfill without dealing with pollution issues must accept the degraded nature of their environment.

²Even the bureaucrat and the elected official are, in fact, stakeholders.

Knowledge of the future conditions and acceptance of the responsibilities associated with the choices makes the choice valid.

The key factors to the resolution of the conflicts are adherence to the principle of inclusion, and the education and empowerment of the stakeholder through active involvement.

Current Weaknesses in the Application of Holistic Planning Techniques

One of the most common errors observed in holistic planning is the violation of the recognition of requisite physical planning boundaries. In one example a national laboratory facility determined that it would conduct holistic watershed planning as an example of the implementation of the process. This effort was exemplary in many ways and should be used as an educational tool. In other ways, it avoided two elemental problems that the others of us must face. First, the planning boundary was the property boundary, not the ridge line of the watershed. The plan qualifies as a watershed plan in that it extended water management planning into the watershed, but it is not a plan for the entire watershed of the receiving water. The second was that it was applied to a single property under a single owner by the staff of that owner. Stakeholders were reduced to one major entity, the owner. An effort was made to involve the surrounding community in the process and many ideas from outside the facility were incorporated into the plans, but the extended stakeholders population no longer matched the planning boundaries. The weakness highlighted here is the ability to redefine the processes based on the current situation and still use it as an example of the entire process.

A second weakness lies in the political areas encompassed. In the example of the Tampa Bay National Estuary Program (TBNEP), stakeholder involvement has been central to the development of the plans.³ The watershed boundaries have been honored. The plan is general and suitable for a large regional watershed where the expectation is that in the nested watersheds, government will develop very specific implementation plans. Politically, however, not all of the governments having responsibility within the watershed have been included in the planning process.⁴ This is not the fault of the NEP program, it is the fault of the invited local government not responding. But it still impacts the process and potentially the validity of the plan.

Also in the TBNEP, principles of inclusion and sustainable development may have been violated. Under inclusion, there has been a good effort aimed at educating the adult population, but the effort to provide a commitment to educate the future adults has been overlooked. The sustainability is brought into question by the exclusion of the School Board. Educators as individuals, however, have been involved and may represent an alternative support of the project.

³The TBNEP program actively sought the input of large citizen and technical groups and avoided the tokenism exhibited by other agencies.

⁴As a designated committed entity. Representatives have been involved in most, if not all the committee work.

Perhaps the most widespread weakness is the practice of tokenism. There are numerous examples where a government has elected to form an advisory board for projects or plans and selection of the individual is done based on his or her known predispositions on issues rather than his or her ability to represent neighborhood issues or concerns. This is often the case where new regulations are proposed and the advisory board is made up entirely of members of the regulated community. In one case, new development regulations were developed through a board made up of consultants, lawyers and landowners but excluded homeowner associations, civic, and environmental groups. This represents a manipulation of the stakeholder process and ignores the fact that people living in developments have an interest in the development as much as do the developers in the first place. The reverse is often true as well. In many instances preserve and parkland advisors have been composed of individuals selected under similar preconceptions of opinions.

In today's sensitive climate with its overtones of political correctness, environmental justice errors within the implementation of projects are seldom ethnically directed. And yet these errors are still made on a routine basis. As previously noted, these are more often made under the guise of being an economic decision. To use a common example, when a watershed plan calls for the construction of a stormwater treatment pond, the agency typically goes through a process of examining costs and benefits. Because the process fails to include issues of sustainability, it most often results in the selection of an alternative that includes high engineering, construction and maintenance costs, and low property acquisition costs. In many cases the property that is in the correct place for intercepting runoff is so highly priced that increases in construction costs on remote sites can appear minimal. Waterfront property and outfall pipes are commonly co-located. Rather than pay the high land costs, the agency often chooses to select both a site and an alternative that require extra effort in the development and maintenance costs. This choice violates sustainability precepts because it fails to recognize (as opposed to consciously accept) the permanent commitment to ongoing costs. It violates environmental justice precepts because it automatically selects for the displacement of the less well-off resident in favor of the waterfront land owner. Even when vacant land is available in well-off neighborhoods, it is often selected against because of the economic status of the neighborhood.

The balance of these impacts can often be most clearly seen when one recognizes that roads and treatment ponds will likely be located in the same place for hundreds of years. Neighborhoods change in character and status. Landowners move. Selecting sensible locations for public facilities have a greater benefit in the longer term than could ever be offset by short term special interests.

SOME NOTABLE SUCCESSES

Even though I previously mentioned the TBNEP as an example where a weakness has been observed, it is also an excellent example of some groundbreaking successes. The TBNEP network of stakeholders includes the technical community, the interested citizen, local, regional, state and federal governments, the business community, and the elected community. This was not accomplished by accident. The NEP staff proactively seeks out opinion and has held open forums on a very routine and widely publicized basis.

Also of note are the efforts of the SWIM Department at the Southwest Florida Water Management District where environmental restoration efforts often involve the community. The Bayworks program being conducted by Hillsborough County under their NPDES stormwater management initiative is a model of a program that uses proactive outreach and voluntary compliance and improvement to meet community-wide goals. In Pinellas County, the Brooker Creek Preserve was purchased through a local option tax and is being managed in close cooperation with the community through an advisory group.⁵ Some Pinellas County watershed management initiatives have made progress in including these tenets as well.

SOME NOTABLE FAILURES

Failure is difficult to recognize publicly but integral to the learning process. The largest failure apparently is our inability to recognize and admit that a failure has occurred. Until this happens, there can be no lessons learned. In most of the failures that are noted, the source can be traced back to what I will call the principle *de minimus*. It is the process whereby the responsible party makes a choice of alternatives or makes any decision based on meeting the minimum requirements of the law or policy. In the successes noted above, the *de minimus* principle has been violated, and the chances for success have been improved.

The classic example is in road design. It is required by law that various roads meet certain standards related to how long a wait is experienced at intersections and other criteria. These levels of service are referred to as A for best through F for worst. In some areas, new development cannot occur where the local roads are at a level of service of F. What is surprising is that most road projects designed to upgrade roads are only calculated to result in roads of level of service D, the minimum acceptable by law.⁶ In some cases roads have actually been constructed and then nearly immediately upgraded because during the time from design to construction of the first upgrade, ancillary private development increased traffic enough to require more lanes.

Treatment ponds have been subjected to the same criteria. Ponds are often over-engineered and squeezed into parcels that satisfy the absolute minimum size requirements to meet the functional performance standards required by law. To the *de minimus* principle we can attribute the concrete block, weed choked, chain link fenced pits that, under other criteria, could more resemble the lakes seen in subdivisions and apartment complexes.⁷

What makes this principle so attractive is that it is defensible. The argument is made that the public dollar is served by keeping costs low. It is incomplete because the analysis does not include all the costs of the project. While it is a defensible position, the emergence of the issues of stakeholder involvement, environmental justice and

⁵This advisory group also includes volunteer workers, trail guides and clerical personnel.

⁶There is no level of service E.

⁷While both are retention ponds created under the same rule, the landowner has recognized the value of aesthetics while the agency has applied the principle of *de minimus*.

sustainable development as national policy initiatives testifies to the fact that it is not a responsible position.

Other examples include governments that advertise public hearings in newspapers with poor or selective circulation or on cable channels that are not available to their entire constituency.

There are several cases where initiatives have arisen relative to environmental issues that are analogous to the popular Crime Watch programs of police departments. The proposals centered around educating the public about the specifics regarding environmental crimes, misdemeanors and code violations in order to gain their assistance in meeting the missions of compliance and enforcement. In every single case of which I am aware, the agency management has declined to implement the program. The reasons were that the agency did not have the manpower or funds to respond to the environmental reports that the program would generate. The choice was made to avoid discovery in order to avoid the need to deal with violations.

CONCLUSION

In examining the combination of the issues of sustainable development, environmental justice, and stakeholder involvement in contrast to the *de minimus* principle, one can speculate that we have uncovered the answer to the question most often asked about government, "Why'd they do that?"

When we, or our constituents, ask this question, it is because they have not been involved or educated during the development of alternatives or the making of decisions. It further points out that they can readily see the futility of the common practice of providing public service that only meets minimum standards. If the stakeholders had been involved and educated, they wouldn't be asking why government made the choices made, although as individuals they still may disagree. It is precisely this *de minimus* policy that has given government the image of being uncaring and unresponsive as well as being incompetent. The shift in policy to a more open and participatory process is a prerequisite to restoring people's faith in the management of the country at any level.

But, in fairness to the government bureaucrat, there are many times that he or she is not able to select any other than the *de minimus* choice. Each agency has a set of authorizing statutes and regulations and these regulate the actions of the agent as well as the citizen. If the agent is not authorized to think in terms of what is best, but is limited to a precise set of choices and criteria enacted by law, he is not to be held at fault for the failure. New laws are needed and actually are in the experimental stage (Project XL and Florida Sustainable Communities, for example).

While these new initiatives should be tailored to each individual situation, they must not be interpreted to advance a personal agenda. Government should not choose the no-build option for a new potable water supply simply because local surface waters will be depleted or drawn down through infiltration and lowering of the water table. That would be too narrow an interpretation and based only on ecological impacts.

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It should be applied such that the decision to develop the new wellfield is made with the full knowledge that the surface waters and their ecological functions will be impacted. The elected officials and the constituency are aware of the fact and have accepted the responsibility to restore the imbalance and sustain it. It represents an up front commitment to provide sustainability through economic, ecological, and political mechanisms.

All together, these policy initiatives represent a shift from defensible management to responsible management. They are a recognition of the fact that it is only through an ongoing and iterative process of analysis and inclusive problem solving that true holistic management can be achieved. Stakeholder involvement, environmental justice and sustainable development include processes and considerations that absolutely must commence in the data gathering and planning stages and continue uninterrupted and unabated through final plan implementation.

More often than not, it fundamentally means that we need to throw out the old set of guidelines that direct us to find the easiest solution that meets mandated minimums and actually begin to manage our cities as if we mean for them to be around for a while.

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DEVELOPMENT OF THE CONSERVATION CORPS VOLUNTEER NETWORK

Peter A. Clark
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ABSTRACT

There are a variety of individuals and organizations interested in participating in bay protection activities, and a number of local and state programs which need the support of community groups to accomplish restoration activities. With the support of the Tampa Bay National Estuary Program, Tampa BayWatch developed a Conservation Corps network in 1994 to expand its ability to solicit volunteers and to match volunteers and community groups with the appropriate environmental projects. Included in this program is the development of regional restoration projects including numerous salt marsh planting events, the "Great Bay Scallop Search", "Catch Fish, Not Birds" (a monofilament fishing line cleanup), "Paint Tampa Bay Clean" (a regional storm drain marking program), the Little Manatee River agricultural plastic cleanup, coastal and river cleanups, and others. Tampa BayWatch was supported by the Hillsborough Community College citizens environmental volunteer training program to develop team leaders for community restoration efforts.

INTRODUCTION

Once the state's most diverse and productive estuarine system, Tampa Bay's character and ecology have been significantly changed by rapid urban and industrial development. A review of the historic wetlands indicate that 44% of the original 25,000 acres of mangrove forest and salt marshes have been destroyed, and 81% of the original 76,500 acres of seagrasses have disappeared. This habitat loss has resulted in declining populations of economically important fish and shellfish, including a complete collapse of scallop and oyster fisheries, and major declines of bait and food shrimp, spotted sea trout and redfish.

Over the past 20 years the Tampa Bay community has acknowledged the tremendous habitat losses within our estuary and has made significant strides to address the problem through permitting actions, water quality improvements and habitat restoration initiatives. Restoration of habitats has become an increasingly popular tool to revitalize saltmarsh and mangrove communities by grading shoreline areas and planting native vegetation that will mimic natural communities. Habitat restoration events, as one example, also allow the opportunity for the public to take an active role in restoring the environment while promoting education of volunteers on the bay's problems and solutions.

In the early 1980s, New York's Hudson River faced many of the same threats as Tampa Bay. To help stem the tide of environmental degradation, the Hudson River Fishermens Association appointed a "Riverkeeper" to aid regulatory agencies in detecting violations of environmental laws. The advantages of a stewardship approach, like the Hudson Riverkeeper, have been widely recognized in coastal and river areas across the country. Tampa Bay is one of areas to most recently initiate a similar bay stewardship program, which is the first of its kind in the southeastern United States.

Tampa BayWatch is a non-profit environmental stewardship program devoted exclusively to the charitable and scientific purpose of restoring and protecting the marine and wetland environment of the Tampa Bay estuary. Tampa BayWatch utilizes trained professional staff to monitor and protect the bay, as well as to coordinate habitat restoration and protection activities. The program serves as a focal point for citizen volunteer participation in restoration and protection of the estuary, providing a conduit for community restoration activities. Tampa BayWatch provides an avenue for participation in restoration activities by community groups, scout troops, high schools and interested individuals.

Tampa BayWatch also promotes early identification of environmental problems by providing a steward to patrol and monitor Tampa Bay, while coordinating activities with existing governmental agencies (i.e., Florida Marine Patrol, Coast Guard, Florida Department of Environmental Protection and local governments). Since many existing governmental agencies are insufficiently staffed to provide adequate field monitoring, the bay steward provides valuable assistance that is otherwise unavailable.

CONSERVATION CORPS ACTIVITIES

There are a variety of individuals and organizations interested in participating in bay protection activities, as well as a number of local and state programs which need the support of community groups to accomplish restoration activities. With the support of the Tampa Bay National Estuary Program, Tampa BayWatch developed a Conservation Corps network in 1994 to expand its ability to solicit volunteers and to match volunteers and community groups with the appropriate environmental projects. Included in this program was the Great Bay Scallop Search, which surveyed shallow grassbeds throughout Tampa Bay for scallops. Tampa BayWatch was supported by Lewis Environmental Services (Scallop Search) and Hillsborough Community College (Volunteer Training Program) in comprehensively addressing the requirements of community restoration efforts.

As stewards of the bay, many residents and visitors who view the bay as a community resource actively desire to become more involved with bay protection efforts. Tampa BayWatch provides a conduit for community groups and organizations to participate in restoration and protection efforts. Without community support, the bay will continue to suffer from habitat losses, water quality perturbations, boating impacts and other debilitating effects of overuse.

Community Outreach

In order to establish the Conservation Corps Program, Tampa BayWatch initiated an extensive public outreach program using a collection of techniques to reach the widest audiences including: a program brochure, the bi-monthly newsletter *BayWatch Log*, slide presentations to community groups, and monthly Paragon cable television shows called *Protecting Tampa Bay Today*.

When interested individuals or groups contact Tampa BayWatch to participate in activities, the Conservation Corps Program uses a structured framework to provide various opportunities for participation, which include Team Leaders, Community Leaders and Network Volunteers. Volunteer Associates are individuals who have

indicated they are willing to devote a specific amount of time to facilitate a particular requirement for the Tampa BayWatch program. The associates play a critical role in supporting the Tampa BayWatch program by providing additional specialized support that would otherwise require the time of paid program staff or additional funding.

As each environmental project arises it is extremely helpful to have a number of trained Team Leaders to help direct each restoration event. Team leaders have been established around the bay to lead local efforts and projects with supervision being provided by Tampa BayWatch, the appropriate governmental (water management district, Department of Environmental Protection, local governments) or other organizational entity (Audubon, Center for Marine Conservation, etc.). Tampa BayWatch maintains a listing of interested graduates of the Hillsborough Community College (HCC) Environmental Short Course and experienced team leaders from past projects to help facilitate future projects. Community Leaders may not have the specific expertise for a project but they are able to provide the organizational support and volunteers necessary for a specific activity. Heads of homeowners associations, scout troops, and recreational and social clubs that have an interest can conduct a project with the support of Tampa BayWatch or through a trained team leader.

The Conservation Corps Volunteer Network forms the main body of individuals available for or interested in restoration and protection activities. Tampa BayWatch actively solicits volunteers for the network through its existing membership, participation in environmental events, our newsletter, and media outlets (newspaper advertisements and articles, cable television, television reports). The framework is required to comprehensively manage the wide variety of participants and to make the best use of experience many members of our community can provide.

Volunteer Training

As the Tampa Bay community becomes more involved with restoration activities, a real need develops to adequately prepare our volunteers to accomplish the projects and direct newcomers. Many projects, like the Great Bay Scallop Search and seagrass transplanting projects, are constrained by specific needs which require special instructions and techniques. The Conservation Corps Program participated in the HCC Environmental Short Course in the fall and spring of each year, trained boat captains to participate in the Great Bay Scallop Search, taught team leaders wildlife handling techniques for the "Catch Fish, Not Birds" program, and conducted a one-day workshop in Manatee County to train leaders in specific restoration activity techniques. Tampa BayWatch, through the Conservation Corps Program, has been able to provide the leadership to organize the required training events as specialty projects arise.

1996 Restoration and Protection Activities

Salt Marsh Planting Projects have been a major emphasis for the Tampa BayWatch program to restore critical habitat systems that grow on the intertidal fringe of the bay, preventing erosion, filtering pollutants, and providing important breeding and nursery habitat for fish and wildlife. Our first saltmarsh planting in 1994 involved 125 volunteers who planted 5,000 marsh grass plants on Dog Leg Key to restore vegetation impacted by the 1993 oil spill. Since then, our projects have grown

Clark, Hoppe, Webb

significantly: in February 1996, Tampa BayWatch coordinated 400 volunteers to install 37,000 plants in a habitat restoration project at Cockroach Bay Aquatic Preserve. A second effort was accomplished in December when 130 volunteers installed an additional 15,000 plants over four acres of newly restored tidal ponds.

The Agricultural Plastic Survey of the Little Manatee River is conducted in cooperation with the Tampa Bay National Estuary Program. To conduct the survey, volunteers canoe to assigned survey sites and stretch a 30-foot long cord along the bank. An area one meter wide on each side of the cord is searched for plastic, which is collected and examined to develop a better understanding of how much plastic is getting into the river, as well as where the quantities are greatest. The results of the volunteer survey are used to document the volume of plastic and help develop best management practices to prevent plastic from leaving the fields and entering the river system.

The Great Bay Scallop Search is an important annual event when volunteers snorkel seagrass beds in Lower Tampa Bay to document scallop populations in the estuary. Scallops completely disappeared from the bay in the 1960s because of heavily polluted water. The Clean Water Act and local water treatment initiatives have cleaned up the bay significantly, and scallops now appear to be able to survive in bay waters. Additionally, results of past scallop searches have convinced Tampa BayWatch scientists to develop a transplanting program, removing scallops from healthy donor sites farther north and transplanting them into Tampa Bay to expedite the return of a viable breeding population of scallops. This project is an opportunity for the bay community to take an active role in monitoring and restoring a resource that has been sadly missing from bay waters for more than 30 years. This year's search focused on Boca Ciega Bay and the Fort DeSoto area in an effort to better document recovery areas. A total of 75 scallops were found using the new format.

Derelict Boats are a real problem in Tampa Bay. Hundreds of boats have been left in secluded bayous and mangrove stands where they decay into navigational and environmental hazards. Many contain yard trash, engine debris and other potential pollutants. Tampa BayWatch has taken the lead in identifying and reporting derelict boats to the Florida Marine Patrol. Aerial survey is the most effective method of locating the derelicts as they are generally abandoned in remote mangrove embayments. When an abandoned boat is located by staff or volunteers, Tampa BayWatch reports it to the Marine Patrol, which then confirms the boat to be derelict. Once confirmed derelict, the county within which the boat is located may remove it and receive reimbursement from the Boaters Improvement Trust Fund.

The Tampa BayWatch "Catch Fish, Not Birds!" monofilament fishing line cleanup of bird nesting islands in Tampa Bay is done in cooperation with the National Audubon Society's Florida Coastal Island Sanctuaries and is the largest event of its kind in the nation. In 1996, Tampa BayWatch volunteers cleared a record 53 islands of deadly monofilament fishing line, which is the leading cause of death for adult brown pelicans in Florida. "Catch Fish, Not Birds!" ensures a safer nesting environment for our unique population of colonial nesting birds.

The Tampa Bay Watch High School Wetland Nursery Program is designed to directly involve our youth in active restoration of saltmarsh habitats for the bay. The program received a national award in 1996 from the Society for Ecological Restoration and is being duplicated in other estuaries around the country. Students in five high schools around the bay have built and are maintaining wetland nurseries on their school campuses. Students gain hands-on experience in resource management and environmental stewardship, and thrive on feelings of accomplishment they earn after having nurtured the plants into maturity in the campus nursery and then installing the grass plants into major restoration projects around the bay. The High School Wetland Nursery Program is a critical element in the development of an environmental ethic in our youth to benefit the long-term health and recovery of Tampa Bay.

SUMMARY

The Conservation Corps Volunteer Network provides an excellent avenue to support restoration and protection efforts by enhancing the opportunities for community involvement and creating a network to be more accessible to the agencies and organizations most in need of volunteer support. Public involvement and education are instrumental in helping our community better understand the condition of the bay and opportunities available to better restore and protect the Tampa Bay estuary.

For more information or to participate in future initiatives contact Tampa Bay Watch at (813) 896-5320 or visit our web site at www.arch.usf.edu/ficus/ and select organizations.

ADDRESSES: (PC) Tampa Bay Watch, 8401 9th St. N, Suite 230B, St. Petersburg, FL 33702; (MH) Tampa Bay National Estuary Program, 111 7th Ave. S, St. Petersburg, FL 33701; (FW) Hillsborough Community College, 1206 N. Park Rd., Plant City, FL 33566.

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ALAFIA WATERSHED AREA RESTORATION EFFORT (AWARE)

A. Schnapf

POSTER ABSTRACT

The National Audubon Society Florida Coastal Islands Sanctuaries has initiated the Alafia Watershed Area Restoration Effort (AWARE) to protect and restore the inland area surrounding the Alafia Bank, the largest colonial waterbird colony in Florida and the most diverse in North America. Essential to wildlife and substantially affected by human activity, the AWARE project area extends from Pendola Point to Port Redwing, and east to Highway 301. Pine flatwoods communities with live oaks and cabbage palms remain, interspersed with hundreds of small wetlands and relict oak scrub habitats along old beach ridges. Extensive coastal marshes and mangrove forests border the bay and its tributaries. Within this area are the communities of Gibsonton, Progress Village and Riverview. Development includes the Cargill Fertilizer plant, gypsum stacks and cooling ponds, smaller industries, dredge disposal sites, an old landfill, extensive fish farms, and mixed agriculture and residential areas.

Restoration and protection projects for the estuaries, tributaries and associated uplands bordering Hillsborough Bay and the Alafia River are being developed to improve wetland functions (water quality enhancement and fisheries values) and restore upland habitats. AWARE also strives for public support and understanding of the need to protect, manage and restore habitats.

Funding for AWARE has been provided by Lewis Environmental Services, Inc., Cargill Fertilizer Inc., the Alafia River Basin Board of the Southwest Florida Water Management District, and the National Audubon Society.

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FLORIDA YARDS & NEIGHBORHOODS

Shannon T. Waters

POSTER ABSTRACT

Florida's unbridled growth has harmed its unique ecosystems. As communities expand, stormwater runoff from homes and neighborhoods increases, which pollutes waters and threatens marine resources. Residents within Tampa Bay's 2,200 square-mile watershed often do not understand that their landscape design and maintenance practices have environmental impacts on the bay. Many perceive turf grass as the testimonial of a well-landscaped home, and require excessive amounts of fertilizer, pesticides and water. Urban runoff from residential areas contributes 13% of nitrogen loads to the bay.

The Florida Yards & Neighborhoods Program was developed to address the increasingly serious problems of pollution and habitat loss. In 1990, the National Estuary Programs of Tampa and Sarasota Bays originated the partnership with the Florida Cooperative Extension Services, and in 1994 were joined by the West Coast Regional Water Supply Authority. Florida Yards & Neighborhoods advocates environmentally sound landscape maintenance practices in order to reduce stormwater runoff, improve habitats and conserve water. In Hillsborough, Manatee, Pasco and Pinellas counties, residents committed to improving the environmental quality of their yards may work with the Florida Yards & Neighborhoods team. This is a group of experts trained to identify ways to improve landscapes and shorelines, save water and reduce pollution. Additionally, the team assists citizens by conducting unique on-site demonstrations and workshops.

ADDRESS: Pinellas County: 12175 125th St. N, Largo, FL 34644; Hillsborough County: 5339 South Country Road 579, Seffner, FL 33584; Manatee County: 1303 17th St. W, Palmetto, FL 34221.

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Bill Matuszeski is the director of EPA's Chesapeake Bay Program Office, and kindly served as facilitator of Tampa BASIS 3. He wrote the following article for the *Chesapeake Bay Journal*, and it was reprinted in the *Tampa Tribune-Times* on February 16, 1997.

TAMPA BAY OFFERS MODEL

Bill Matuszeski

In what must go down as just about the least accurate observation in history, U.S. muckraker Lincoln Steffens wrote to a friend in 1919, after a trip to the newly created Soviet Union, "I have seen the future, and it works."

Those famous words came back to me recently when I was invited to facilitate a three-day scientific review of conditions in Tampa Bay, site of one of the National Estuary Programs.

And while I hope my observations are more on target than Steffens', I admit to being impressed and humbled by what has been accomplished by the citizens and governments of Tampa, St. Petersburg, Clearwater and the other towns and counties that constitute Tampa Bay's watershed. Impressed by the way they have brought back much of the clarity and living resources that had been lost. And humbled by the tough decisions they made and stuck by.

Here in the Chesapeake region, for example, we are still debating how many of our treatment plants should reduce nitrogen discharges to 7 or 8 milligrams per liter. Around Tampa Bay, they took all of them to 3 milligrams per liter 15 years ago. And they got back the clear water and the grasses.

Admittedly, it was an easier system to nurse back to health than is the Chesapeake. There is relatively little freshwater flow into that Bay compared with ours; the Tampa Bay watershed is a lot smaller in size and in proportion to the receiving waters; and there is a much lower level of agricultural activity than in the Chesapeake watershed. Nonetheless, the citizens of Tampa Bay started with a sick system and made it well. And they have been very careful to preserve their gains against new perceived threats.

In many respects, they are where we in the Chesapeake hope to be in 10 years or so, conserving our successes in the face of the mix of avoidable and inevitable changes around us.

It is interesting to see what they focus on now as their remaining problems. Number one, for sure, is handling the impacts of development, something we are only beginning to get a handle on in the Chesapeake Region.

While the state has some of the best growth management laws on the books, the rate of growth and the preference for spread-out development patterns simply outpace the

capacity to manage. The result is a continued loss of valuable agricultural lands, greater demand for limited fresh water supplies and ever-increasing amounts of impervious surfaces (driveways, roads and parking lots).

None of this is good for Tampa Bay. So maintaining the quality of the waters and the quality of the fresh water flowing into Tampa Bay has led to the call for careful management of growth boundaries, urban stormwater and fresh water withdrawals.

All this makes especially interesting the discussions that have begun here in the Chesapeake about what life will be like after 2000, when we will have hopefully returned the Bay to some degree of its former self.

A place like Tampa Bay makes us think about the future and what it really means to "Save the Bay."