

Proceedings
THE FOURTH TAMPA BAY AREA SCIENTIFIC INFORMATION SYMPOSIUM
BASIS 4

October 27–30, 2003
St. Petersburg, Florida

S.F. Treat
Editor

FOREWORD

These Proceedings contain presentations given at the fourth Tampa Bay Area Scientific Information Symposium held October 27–30, 2003 in St. Petersburg, Florida. Since its inception in 1987, the BASIS conference series has provided a forum for sharing state-of-the-art research on Tampa Bay. The theme of BASIS-4, Linking Science and Management, is organized around the major elements of the Tampa Bay Estuary Program's Comprehensive Conservation and Management Plan: Water and Sediment Quality; Habitat Protection and Restoration; Fish and Wildlife Protection; Dredging and Dredged Material Management; Spill Prevention and Response; Watershed Management; and Invasive Species. More than 200 scientists, resource managers and students from the Tampa Bay area participated in the four-day symposium, which included 60 oral presentations and more than 80 posters.

ACKNOWLEDGMENTS

In addition to the input and direction provided by the Steering Committee for BASIS-4, we gratefully acknowledge the wisdom provided by Fred Holland, NOAA Hollings Marine Laboratory for providing his expertise and critique on the status of science and management in Tampa Bay and recommendations for future focus. We also extend our sincere thanks to Ernie Estevez, Mote Marine Laboratory for providing a keynote address which set the tone and historic setting for the symposium.

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Thanks are also extended to the many student volunteers who helped throughout the conference, and to the staff of the TBEP for their logistic help, especially Lindsay Griffen, Kristin Thoms, Misty Cladas, Ron Hosler and Cheryl Cooper.

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**BASIS 4:
GENERATIONS OF BAY SCIENCE AND MANAGEMENT
Preface**

*“Everything is what it is because it got that way.”
Sir D’Arcy Thompson 1917*

To speak of generations of bay science and management is somewhat misleading if taken to mean that many human generations have gone into the effort. In fact, many of the people engaged in the early phases of modern bay science and management are alive today and some are still active. It is more precise to say that bay science and management have themselves matured through multiple stages or phases of development akin to our own generations, but over a livelier time-frame (Table 1). Bay science alone would make an excellent historical thesis, but neither Florida nor science tend to look back, much, so the history of bay science may have to wait for now.

Still, for the contemplative type of person, a history of bay science and management can be read in the bay itself—in those areas that are pristine or restored; in other areas that are highly altered and beyond redemption; and in parks, preserves, and other special places. Almost every part of the Bay and its shores and adjoining uplands can be associated with the works of this person or that, for good or bad. The names of some scientists, managers, and community leaders would be matched to just one place. Other names could be associated with all wetlands or grassbeds, and some names might appear in nearly every part of the bay. “Every thing about Tampa Bay is what it is because it got that way through the efforts of individual people,” Sir Thompson might have said had he studied the development and form of estuaries.

A few years ago demographers estimated that the world population had reached six billion people. Dividing the Earth’s surface area by 6,000,000,000 produces approximately 15 acres of water (mostly ocean) per person. Tampa Bay has a surface area of 254,720 acres, which when divided by 15 acres, equals 16,981 people. In the largest sense one could argue that a tenth as many people have probably played an important role in bay science and management. The number may be larger but the point is that people who have chosen to commit themselves to the betterment of Tampa Bay, either through research or management, have had extraordinary impact.

This proceedings marks the accomplishments of science and management during the past few years. As part of the BASIS series it marks the latest effort to bring together the information needed to guide the bay’s effective stewardship. Every paper of every volume has made important contributions in this regard, but there are still-greater contributions to be made. As of 2004, one or more people had yet to step forward with the next necessary, and ultra-ordinary effort, that of ecosystem synthesis.

Years ago I proposed to the organizers of the first conference that we call the meeting BASIS. The acronym preceded the name, which we contrived to be Bay Area Scientific Information Symposium. Perhaps the next BASIS should stand for Bay Area Scientific Information Synthesis. Calls for synthesis are not new; “In further development of sea science, the keynote must be physical, chemical, and biological unity.” (Henry Bigelow, 1930). Locally, Carl Goodwin first proposed that we undertake a comprehensive ecological model of Tampa Bay Bay, a “model of everything” in 1987. That such calls remain unanswered signifies that genuine synthesis is, well, hard. It is as different from our present circumstance as Star Trek’s *Next Generation* would seem to the crew of the first Enterprise.

How such synthesis is accomplished I leave to others, but suspect it must entail larger and more complex models than heretofore exist. Much progress has been made in this regard but we are still far from a grand unified model of the bay. Working toward one would do much to fill existing gaps, such as the empirical roles of wetlands in bay ecology. Ideally, such a model would be able to link previously disparate bay features and processes. And allow for some tough calls to be made. For example, we limit nitrogen input to the bay so grasses may grow as deep as we deem reasonable. But the same nutrient supports phytoplankton blooms that drive secondary fish production. Could a synthetic model ever tell us how many fewer pounds of desirable fish the bay will produce in order to achieve that deepest foot of grassbed expansion? Or that last trap-full of blue crabs?

A new initiative by the Tampa Bay Estuary Program and U.S. Geological Survey holds considerable promise where new synthetic understandings—deterministic, statistical, or otherwise—of the Bay are concerned. The initiative kicks off in 2005 with an anticipated conclusion in 2008 and deserves the full attention and participation of all bay advocates and enthusiasts.

We are the generation that can bring together a broad, explicit and causal comprehension of the bay but the work of refining and especially applying it will fall to the human generations that succeed us. Should we be as committed to the next generation of bay scientists and managers as to the next generation of products? If we desire the next generation of products we need start now to attract and engage the new producers. Perhaps the time is ripe to reach into high schools across the bay area and encourage an entire cohort of talent toward bay careers. Another useful effort would be to commit now, when we know that BASIS 5 will debut the new synthesis, to hold the next meeting on a college campus, and feature special arrangements to involve students.

A college venue for the next BASIS, especially the Tampa campus of the University of South Florida, would also honor the memory of Dr. Joseph L. Simon, professor of biology and mentor to several generations of bay professionals. Although Joe died on March 22, 2004, his name will always be associated with the extraordinary betterment of Tampa Bay.

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Table 1. Post-War Milestones in the Science and Management of Tampa Bay

1953 FSU Review of Tampa Bay for US Naval Hydrographic Office
1954 US Public Health Service Report on Tampa Bay
1955 University of South Florida established
1959 First artificial reef placed in bay
1960 Florida Presbyterian (Eckerd) College established
1962 Four Rivers and Basins Project revived from 1950
1967 Hillsborough County Environmental Protection Commission
1968 University of South Florida Bay Conference
1969 National Environmental Policy Act
1969 Federal Water Pollution Control Administration Report
1970 Tampa Bay Conservation and Development Commission
1970 Congress authorizes 43 ft ship channel
1970 Earth Day
1971 Moratorium on Hillsborough County growth proposed
1971 First habitat restoration project
1972 HCEPC starts bay-wide monitoring program
1974 Florida Academy of Sciences Symposium
1975 Florida Aquatic Preserve Act
1979 City of Tampa begins advanced wastewater treatment
1980 Hillsborough River and Bay Workshop
1982 BASIS
1982 TBRPC Tampa Bay Study Committee
1983 Tampa Bay Management Steering Committee
1984 Tampa Bay Management Study Commission and <i>Future of Tampa Bay</i>
1985 Agency on Bay Management
1987 Tampa Bay SWIM Plan
1987 NOAA Seminar Series on Tampa Bay (Washington, D.C.)
1988 <i>Ecology of Tampa Bay</i>
1989 Goals and Strategies Forum
1990 Tampa Bay PORTS
1990 Tampa Bay enters EPA's National Estuary Program
1991 BASIS 2
1993 Tampa Bay Watch
1995 TBNEP <i>Charting the Course</i>
1996 BASIS 3
1996 Nitrogen Management Consortium Action Plan
2003 BASIS 4



COMMUNITY-BASED MANATEE PROTECTION IN TAMPA BAY

P. Leasure & N. Holland

In 1997, the Tampa Bay Regional Planning Council's Agency on Bay Management established the Manatee Protection Strategies Task Force, a workgroup tasked to explore recommendations for manatee protection in Tampa Bay. The Task Force members included representatives from the Florida Marine Research Institute (FMRI), Florida Department of Environmental Protection (FDEP) regulatory staff, the Florida Fish and Wildlife Conservation Commission Bureau of Protected Species, Save the Manatee Club, Florida Progress Energy (formerly Florida Power), Tampa Electric Company, Manatee and Hillsborough Counties, anglers, and citizens with local knowledge and experience.

The Task Force looked at existing protection strategies that have been implemented at the federal, state and local levels with little to no input from the waterway users. The Florida Marine Research Institute FMRI provided data for manatee use patterns, documented wintering and calving sites, other important manatee aggregation sites within the Bay, behavior patterns and causes of mortality. Other Task Force members were able to provide information on boating use and traffic data in order to determine areas of historic fisheries, recreational use, access and destination points and high traffic locations.

The recommendations of the Task Force were to: establish areas for manatee protection either through regulated or non-regulated zones; promote community stewardship through boater education; and assess the effectiveness of that education and changing boater behavior. The committee recommended regulation in 4 areas in Tampa Bay. These areas are:

1. No-Entry Manatee Refuge (Nov–Mar) at Bartow and Gandy Causeway; Slow Speed (Apr–Oct) at Bartow and Gandy Causeway,
2. Slow Speed Manatee Area—between the SE end of the Howard Frankland Causeway and Gun Branch,
3. No-Entry Manatee Refuge (Nov–Mar) at Port Sutton Channel; Normal Safe Operation (Apr–Oct) at Port Sutton Channel, and
4. Slow Speed—area south and southeast of channel marker 4 in Terra Ceia Bay, east of the Snead Island Cut.

Citizens with local knowledge provided recommendations for a number of unmarked access areas. These areas were recommended for formal marking.

Once the Task Force completed their recommendations, it was apparent that someone needed to oversee the implementation of these recommendations. The Manatee Awareness Coalition (MAC) was subsequently established as a sub-group of the Task Force to oversee implementation of the speed zones, water education for boaters, education of homeowners, and to provide the *Minute for Manatees* at the Coast Guard Safe Boater courses. MAC is an alliance of scientists, conservationists, local government officials, fisherman, utilities and other special interests was subsequently formed to assist local governments in implementing the community based manatee protection plan for Tampa Bay.

Managing the human-manatee interaction while providing protection and habitat for the manatees and recreation for the humans is a difficult but achievable task. The MAC has played an important facilitation role in resolving conflicts between user groups and manatee advocates over manatee protection regulations in Tampa Bay. With support of the MAC, each of the three Counties has implemented new boating regulations to establish and post speed zones.

MAC also oversees the education component that promotes safe boating, manatee and habitat protection through on the water boater education and the Manatee Friendly Neighborhood Program.

FMRI and the MAC monitored boat usage in some of the areas identified in the Task Force's recommendations. This monitoring program included a three-part study to compare the effectiveness of education versus regulation in influencing boater behavior. The Weedon Island Florida Power Bartow Plant area was monitored before and after the regulatory zones were posted. St. Petersburg's Maximo Park was monitored to determine boater behavior in response to education. Telephone surveys were conducted to evaluate effectiveness of the education program. Based on the survey as it was written, the methods of the education program had no measurable effect (Richard Flamm 2003).

MAC continues to evaluate the education programs and make changes where needed. The MAC is being viewed as a statewide model for successful community based manatee protection.

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POPULATIONS OF JUVENILE AND SMALL-ADULT FISHES IN TAMPA BAY: A DECADAL PERSPECTIVE

R. Matheson, Jr., R. McMichael, Jr., D. Leffler & T. MacDonald

ABSTRACT

We have observed large fluctuations in Tampa Bay fish populations over the last decade, and these changes may be associated with the environment, management practices, or other factors. Staff of the Florida Fish and Wildlife and Conservation Commission's Fish and Wildlife Research Institute began developing the Fisheries-Independent Monitoring (FIM) program in 1988 and have monitored fish populations in Tampa Bay continuously since 1989. Various types of sampling gear have been utilized during the history of FIM, but 21.3-m bag seines have been used since the beginning of the program. This small seine is effective at capturing juveniles of many economically valuable species (e.g., red drum, *Sciaenops ocellatus*, and spotted seatrout, *Cynoscion nebulosus*) and juveniles through adults of many small resident species (e.g., bay anchovy, *Anchoa mitchilli*, and various species of killifish, Fundulidae and Cyprinodontidae). We present indices of relative abundance for 12 groups of fishes (10 species and two multi-specific categories) in three coarsely delimited habitat types in the Tampa Bay system based on collections made with the 21.3-m seine. We then compare trends within these 36 comparisons to major environmental (i.e., drought) and regulatory (i.e., net ban) events that have occurred during the last decade. Significant differences among years were found in 75 % of the comparisons. Comparisons indicating no significant interannual changes in abundance were more than twice as common along bay shorelines as they were in offshore areas of the bay or in the tidal rivers, despite a major change in bay-shore sampling methodology by the FIM program in 1998. One-third of the 36 comparisons indicated significant changes in abundance before and after 1995 (i.e., pre- and post-net ban), and all but one of these trends indicated declines in abundance after 1995. This finding is perhaps not surprising because the fish included in this study were primarily small and would serve as prey for harvestable-sized fishes which may have become more abundant after the net ban. Approximately 47 % of our comparisons indicated that changes in relative abundance were related to annual levels of freshwater inflow (scored as either low, moderate, or high), and abundances peaked during years with moderate to high levels of freshwater inflow in more than three-fourths of these comparisons. Among the groups exhibiting maximum abundance during periods of moderate to high inflow were the most abundant species in Tampa Bay, *Anchoa mitchilli*, and the multi-specific category comprised of all species except *A. mitchilli*. Although these relationships between abundance and annual inflow must be interpreted with caution, we believe that our results indicate decreased production of small fishes in the Tampa Bay system during periods of drought.

INTRODUCTION

Tampa Bay and its tidal rivers are home to numerous species of fish and provide critical nursery habitat for many of these species, including some which support large commercial and recreational fisheries (Springer and Woodburn, 1960; McMichael and Peters, 1989; Peebles et al., 1991; Llanos et al., 1998; Peters et al., 1998; Rydene and Matheson, 2003). Fish populations in the Tampa Bay system have experienced various environmental and management changes in recent years. Major environmental events have included periods of both drought and unusually high rainfall (resulting in large variations in freshwater inflow to the system; see below), a large toxic spill (FMRI, 1998), cold kills (see <http://research.myfwc.com>), and red tides (see <http://research.myfwc.com>). The most obvious management event was an amendment to the Florida Constitution which limited net fishing in inshore waters as of July 1, 1995 (commonly known as the net ban; see Florida Constitution at <http://www.flsenate.gov>), but regulations affecting specific, economically important species were also changed during this period (e.g., see spotted seatrout stock assessment at <http://research.myfwc.com> and <http://marinefisheries.org/history>). The effects of toxic spills and red tides are usually limited in scope and cold kills are generally species- and size-specific (FMRI, 1998; Gilmore et al., 1978; Shafland and Foote, 1983). Management changes limited to individual species may have community-level effects if they are effective at increasing populations of target species, but these management changes are very numerous and were implemented at different times during our study period, making their community-level effects difficult to track.

In this paper, we concentrate on one major management action, the net ban, and one major environmental factor, freshwater inflow. After the imposition of the net ban, harvest mortality declined for a broad array of fish in inshore waters, including detritivores/planktivores such as striped mullet, *Mugil cephalus*, and abundant carnivores such as crevalle jack, *Caranx hippos*, and spotted seatrout, *Cynoscion nebulosus* (R. Muller, pers. comm.; research.myfwc.com). Thus, the net ban may have had large-scale effects on the Tampa Bay ecosystem, especially in terms of trophic dynamics. These effects may include an increase in the abundance of predators, perhaps leading to decreased abundance of the small fishes in our samples, or increases in the size of adult spawning populations of some harvested species such as spotted seatrout, perhaps leading to increases in the abundance of juveniles of these species in our samples. Similarly, levels of freshwater inflow can have far-reaching effects on estuarine ecosystems due to relationships between inflow and factors such as nutrient delivery, larval and juvenile transport, and salinity (Armstrong, 1982; Norcross and Shaw, 1984; Livingston, 1997; Livingston et al., 1997).

In order to correlate changes in fish populations with environmental and management events at the ecosystem level, we need a long-term monitoring program based on consistent methodology. The database produced by the Fisheries-Independent Monitoring (FIM) program of the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute fulfills this need. This database extends from 1989 through the present and is based on stratified-random sampling throughout Tampa Bay and in several major tributaries. Several types of sampling gear have been used by the FIM program, but the most consistently used gear type has been a 21.3-m, 3-mm-mesh bag seine.

In this paper, we use FIM program data collected with the 21.3-m bag seine to assess abundance trends for several fish species (and species groups) from 1989 through 2002. We then compare fish abundances before and after the institution of the net ban and during years with different levels of freshwater inflow.

METHODS

Fish Collection—All data presented in this study were collected with 21.3-m, 3-mm-mesh bag seines in Tampa Bay proper and the Alafia, Little Manatee, and Manatee rivers. Three seine deployment techniques were used during the study period. The river-seine technique was used for all collections made in the tidal rivers. In this technique, the seine is deployed along the shoreline in a semicircle from a moving skiff, thus effectively sampling shoreline fish communities in an area of approximately 68 m². Away from the shoreline (> 5 m) in the open bay (< 1.5 m water depth), samples were collected with the bay-seine technique. In this technique, the seine is set and retrieved offshore, using a 15.5-m line between seine poles to maintain a consistent width for the net opening. Bay seines are pulled over a distance of 9.1 m and sample an area of approximately 140 m². From January 1989 through December 1997, the beach-seine technique was used for samples collected along the shoreline in the open bay. This technique is similar to the bay-seine technique except that the net is pulled parallel to the shoreline for 9.1 m and then the more inshore person stops, and the more offshore person proceeds to the shore along a semicircular path, eventually retrieving the net on the beach. Beach seines cover an area of approximately 338 m². After December 1997, the beach-seine technique was replaced by the bay-seine technique used along the shoreline. Detailed descriptions of sampling gear and methodology are found in the FIM program Procedure Manual which can be obtained from the first author. For the remainder of this paper, we will refer to the collections made with these gear types by the coarsely defined habitat category that they sample: 1) bay shore—nearshore habitats sampled with the beach-seine technique (1989–1997) and the bay-seine technique used along the shoreline (1998–2002), 2) bay

offshore—offshore, shallow-water areas (< 1.5 m) sampled with the bay-seine technique, and 3) rivers—the lower portions of tidal rivers sampled with the river-seine technique. Abundances in our collections are not absolute abundances but are relative abundances based on the efficiency of our sampling techniques, thus the term index of relative abundance (IRA). We assume that the sampling efficiency of any of our three techniques did not change significantly during the course of this study.

Sites were selected in a stratified-random manner throughout the study, but other details of methodology changed from 1989 to 2002. Sampling sites were selected in five bay zones plus the tidal rivers (Fig. 1) (for detailed description of site selection see FIM Procedure Manual). Prior to 1995, sampling was conducted during day, night, and dawn and dusk crepuscular periods. Beginning in 1995, sampling was conducted only during daylight hours. Prior to 1996, sampling was conducted only during spring and fall (March–June and September–December, respectively). Beginning in 1996, sampling was conducted year round. Finally, the beach-seine technique was replaced by the bay-seine technique in the bay shore habitat in 1998. To account for seasonal versus year-round sampling, we analyzed only spring and fall data from all years. The effects of the discontinuation of nocturnal and crepuscular sampling and of the methodology change in the bay shore habitat are dealt with in our analyses (see below). After the data selection process, sample sizes for the rivers were too low to conduct analyses on the 1989 data, and this year was dropped from all analyses in this habitat. Minimum annual sample sizes (accounting for missing data for class variables or covariates for a few collections) for each of the three habitats ranged from 23 to 235, with most being < 200. Annual sample sizes < 30 were limited to 1990–1992 in the rivers, sample sizes < 36 were limited to 1989 in the bay shore habitat, and sample sizes < 50 were limited to 1989 in the bay offshore habitat. Habitat descriptions and water quality data were recorded with each seine sample. Among these data, bottom vegetation (seagrass, algae, or unvegetated) and surface salinity and water temperature were used in this study.

Species Selection—We selected 10 fish species and two multi-specific groups for our analyses. Eight of the species were among the most abundant and/or frequently collected fish in one or more of the three habitats (Table 1). These include bay anchovy, *Anchoa mitchilli*; pinfish, *Lagodon rhomboides*; striped killifish, *Fundulus majalis*; goldspotted killifish, *Floridichthys carpio*; clown goby, *Microgobius gulosus*; silver perch, *Bairdiella chrysoura*; Gulf pipefish, *Syngnathus scovelli*; and hogchoker, *Trinectes maculatus*. Two other species, red drum (*Sciaenops ocellatus*) and spotted seatrout (*Cynoscion nebulosus*), were selected because they were relatively abundant in our samples and are of major economic importance. One of our multi-specific groups included all fish except bay anchovies (we will refer to this group as non-bay anchovies). We included this group in order to ascertain abundance relationships for the other approximately one-half of the fish fauna. The second multi-specific group included all fishes in the families Cyprinodontidae, Fundulidae, and Poeciliidae (we will refer to this group as killifish). Killifish were included as a group because they are small, generally shallow-water fishes which are residents in various habitats throughout the entire Tampa Bay estuarine system, and we believed that their abundance might provide a reasonable index for the shallow-water forage base for predators utilizing this system.

Annual Freshwater Inflow Classification—We compared average annual freshwater inflow for the Tampa Bay system (compiled from <http://waterdata.usgs.gov/fl/nwis>) among the years covered by this study and sorted these years into three categories based on the 95% confidence interval for annual inflow during the study period as follows: high inflow—1994, 1995, 1997, and 1998; moderate inflow—1991, 1992, 1993, 1996, 2001, and 2002; low inflow—1989, 1990, 1999, and 2000 (Fig. 2).

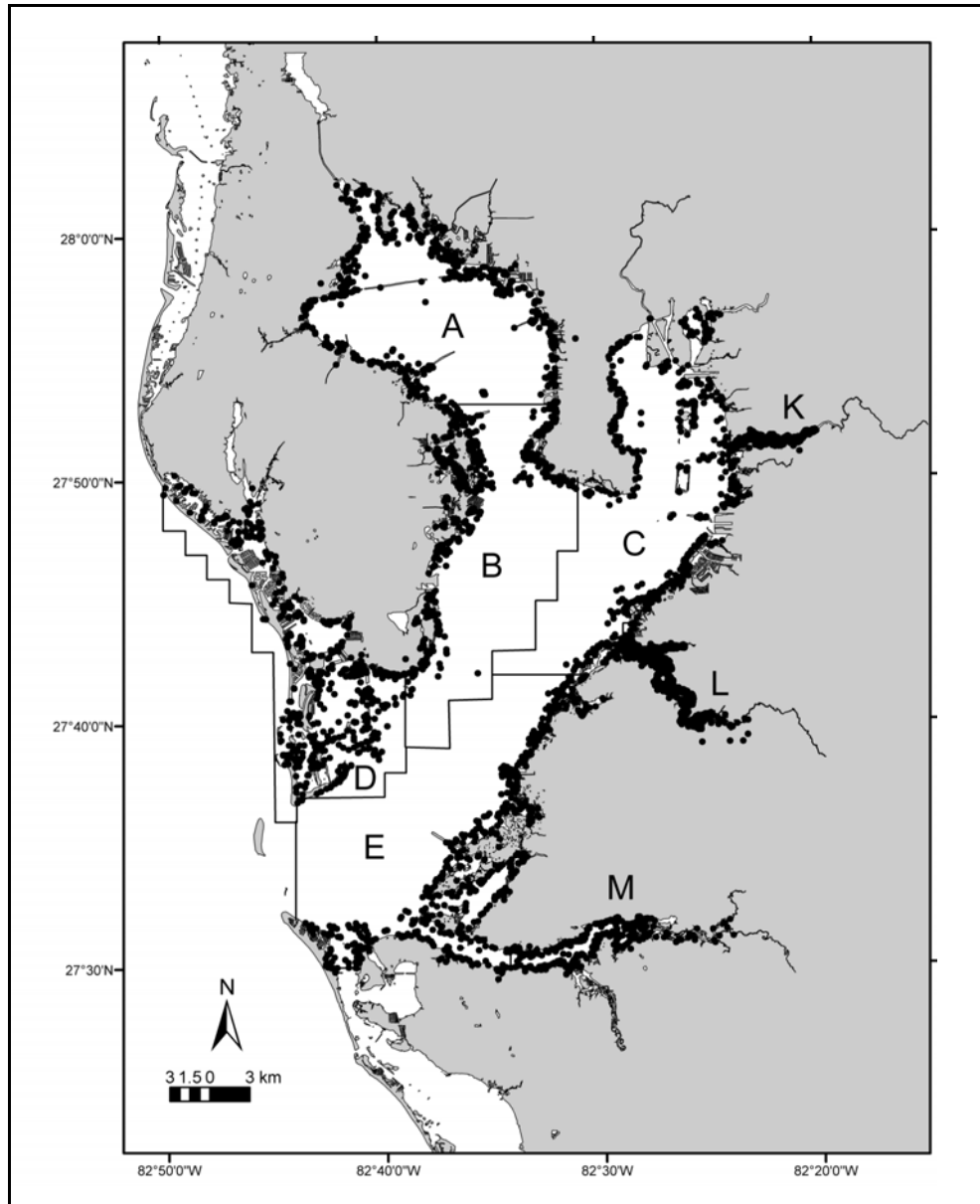


Figure 1. Study area in Tampa Bay indicating bay and river zones as defined by the FIM program (letters) and sites sampled with the 21.3-m bag seine during 1989–2002.

Analyses—Analysis of covariance (ANCOVA) was used to develop the IRAs used in our analyses. The IRAs were least-square means and standard errors generated with the GLM Procedure of the Statistical Analysis System (SAS Institute, 1988). Four separate sets of ANCOVAs were conducted, with slightly different sets of class variables among the three habitats (bottom vegetation was not included in models for the rivers because very little bottom vegetation was ever recorded in this habitat; gear deployment methodology was used only in models for the bay shore habitat because this was the only habitat in which more than one methodology was employed during the study period); surface salinity and water temperature were used as covariates in all models. Class variables used in these models are as follows:

1. model A (diel period effects): diel period, season, bottom vegetation
2. model B (interannual effects): year, season, bottom vegetation
3. model C (pre- and post-1995 effects): annual period (1989–1994 versus 1996–2002), gear deployment methodology, season, bottom vegetation
4. model D (freshwater inflow effects): annual freshwater inflow (low, moderate, high), gear deployment methodology, season, bottom vegetation

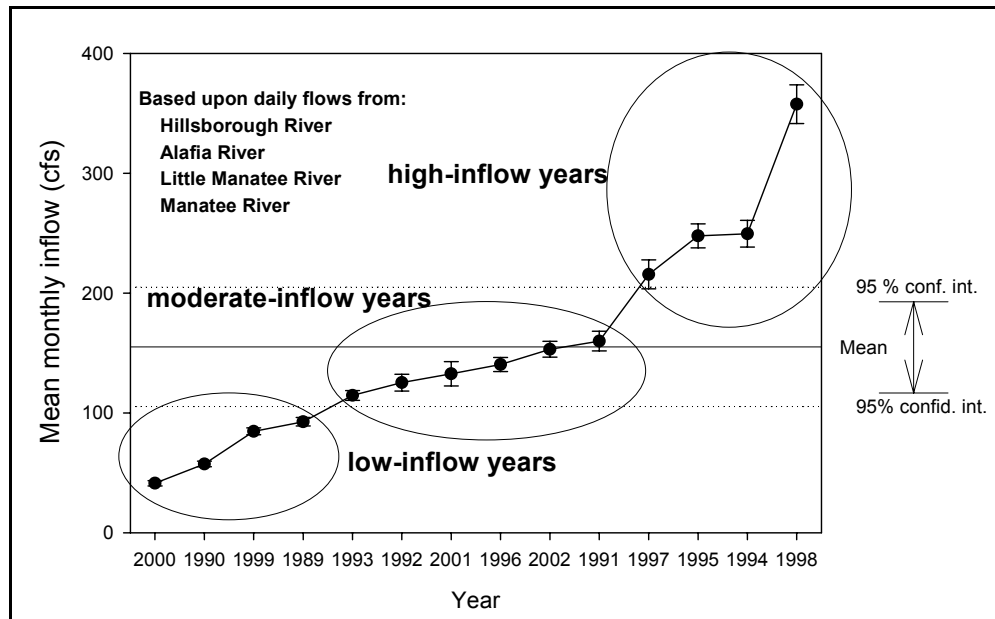


Figure 2. Interannual variation in freshwater inflow to Tampa Bay, 1989–2002. Values are mean monthly inflow for each year $\pm$ standard deviation. Horizontal lines represent overall mean and 95% confidence interval for all years combined. Years sorted in order of increasing freshwater inflow. Data from <http://waterdata.usgs.gov/fl/nwis>.

Analyses with model A were based only on data collected from 1989 through 1994, when sampling was conducted during four diel periods. For groups whose abundance was significantly related to both annual period and freshwater inflow, the significance of the pre-versus post-1995 relationship was further tested by adding annual freshwater inflow and an inflow-annual period interaction term to model C, but in no case did these analyses change the results based on model C alone. In all analyses, variables not significant at the 0.05 level were sequentially removed to arrive at a final model. Fish abundances were transformed ($\log_{10} + 1$) prior to all analyses, and least-square means were back transformed and presented as geometric means and standard errors. With the exception of references to total number of a species collected, all abundances referred to in this document are standardized to number of fish per 100 m², and the terms “abundance” and “IRA” will be used interchangeably. Separate analyses were conducted for each combination of species or group and habitat (e.g., *Anchoa mitchilli* in the bay shore habitat). Thus, 36 analyses (12 fish groups x 3 habitats) were conducted with each of the four models.

RESULTS

Overall Catch Summary—The collections analyzed in this study contained 3,097,146 fish collected in 4,091 seine hauls (Table 1). Dominant species collected in each habitat by each gear deployment methodology were either *Anchoa mitchilli*, *Menidia* spp. or *Eucinostomus*

spp., regardless of whether dominance was based on abundance or frequency of occurrence. In each habitat, the two most abundant species accounted for 58–84 % of all fish collected, and *Anchoa mitchilli* ranked first or second in abundance. The five most frequently collected species in each habitat occurred in 27–81 % of all seine hauls.

Table 1. The most abundant and most frequently collected species in Tampa Bay based on FIM sampling during 1989–2002. collections made with 21.3-m bag seine deployed with three different techniques: beach and bay techniques used in the bay and river technique used in tidal rivers. Values are number collected (#), percent of number collected (% #), and percent frequency of occurrence (% Freq.). See text for description of deployment techniques.

SPECIES	#	% #	SPECIES	% Freq.
—Beach Technique (1989–1997; 906,020 fish in 702 hauls)—				
<i>Menidia</i> spp.	277,823	31	<i>Menidia</i> spp.	77
<i>Anchoa mitchilli</i>	244,166	27	<i>Eucinostomus</i> spp.	67
<i>Eucinostomus</i> spp.	68,556	8	<i>Fundulus majalis</i>	54
<i>Fundulus majalis</i>	46,898	5	<i>Lagodon rhomboides</i>	52
<i>Lagodon rhomboides</i>	46,745	5	<i>Floridichthys carpio</i>	51
—Bay Technique, Nearshore (1998–2002; 168,450 fish in 200 hauls)—				
<i>Anchoa mitchilli</i>	95,022	56	<i>Eucinostomus</i> spp.	68
<i>Menidia</i> spp.	16,790	10	<i>Menidia</i> spp.	56
<i>Eucinostomus</i> spp.	14,012	8	<i>Floridichthys carpio</i>	45
<i>Anchoa hepsetus</i>	7,661	5	<i>Lagodon rhomboides</i>	45
<i>Lagodon rhomboides</i>	4,099	4	<i>Microgobius gulosus</i>	37
—Bay Technique, Offshore (all years; 742,203 fish in 1,847 hauls)—				
<i>Anchoa mitchilli</i>	360,055	49	<i>Eucinostomus</i> spp.	51
<i>Lagodon rhomboides</i>	117,860	16	<i>Lagodon rhomboides</i>	48
<i>Eucinostomus</i> spp.	62,020	8	<i>Syngnathus scovelli</i>	40
<i>Menidia</i> spp.	31,916	4	<i>Microgobius gulosus</i>	33
<i>Bairdiella chrysoura</i>	26,712	4	<i>Bairdiella chrysoura</i>	27
—River Technique (1990–2002; 1,280,473 fish in 1,342 hauls)—				
<i>Anchoa mitchilli</i>	929,836	73	<i>Eucinostomus</i> spp.	81
<i>Menidia</i> spp.	138,522	11	<i>Menidia</i> spp.	81
<i>Eucinostomus</i> spp.	57,557	4	<i>Anchoa mitchilli</i>	62
<i>Lagodon rhomboides</i>	18,532	1	<i>Lagodon rhomboides</i>	53
<i>Anchoa hepsetus</i>	15,581	1	<i>Trinectes maculatus</i>	36

Diel Period (Model A)—Time of sampling was significantly related to IRAs for only three species-habitat combinations, and in all three cases, abundance was greatest at night (Table 2).

Interannual Abundance (Model B)—Most groups exhibited significant interannual differences in abundance, with parallel trends among habitats within some groups and apparent interannual abundance cycles in others (Figs. 3–8). Of the 36 analyses conducted using model B, 27 (75 %) indicated significant year effects. Abundances of *Fundulus majalis* and the category killifish were generally lower after 1997 regardless of habitat (Figs. 3 and 5). The pattern of abundance of *Floridichthys carpio* in the bay shore habitat, the habitat in which this species was most abundant, seems to indicate a long-term abundance cycle with

approximately five years of declining abundance followed by five years of increasing abundance (Fig. 5d). This pattern is only disrupted during one year of our 14-year study period. Both marked parallelism between habitats and an apparent interannual abundance cycle are indicated for *Lagodon rhomboides*. In both the bay shore and bay offshore habitats, the abundance of *L. rhomboides* generally increased for three or four years, declined sharply, and then increased for the next three or four years (Fig. 4d, e).

Table 2. Indices of relative abundance (least-square mean catch per 100 m²) by diel period for three species in the Tampa Bay system, 1989–1994. Habitats are bay shore (BS), bay offshore (BO), and rivers (R). Model variables are diel period (PE), season (SE), bottom vegetation (BV), surface salinity (SA), and surface water temperature (TE). Underlined model variables were significant in final model. Means with the same superscript were not significantly different. Only species exhibiting significant differences in abundance among diel periods are included.

SPECIES	HABITAT	MODEL	DIEL PERIOD			
			DAWN	DAY	DUSK	NIGHT
<i>M. gulosus</i>	BS	<u>PE</u> SE BV <u>SA</u> TE	0.26 ^b	0.30 ^b	0.52 ^b	1.05 ^a
<i>T. maculatus</i>	R	<u>PE</u> SE <u>SA</u> TE	1.56 ^{ab}	0.81 ^b	0.65 ^b	2.90 ^a
<i>B. chrysoura</i>	BO	<u>PE</u> SE BV <u>SA</u> TE	1.10 ^{ab}	0.89 ^b	0.51 ^b	1.65 ^a

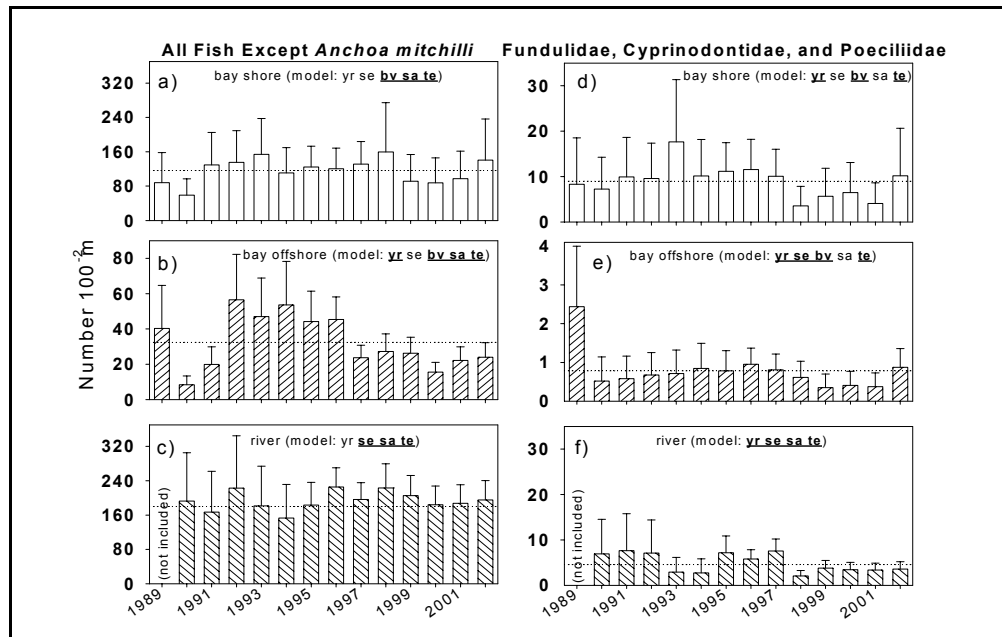


Figure 3. Interannual abundance patterns for all fish except *Anchoa mitchilli* and all species in the families Fundulidae, Cyprinodontidae, and Poeciliidae. Values are least square adjusted geometric means; error bars represent two standard errors. Model variables include year (yr), season (se), bottom vegetation (bv), surface salinity (sa), and water temperature (te). Dotted horizontal line indicates overall mean abundance. All variables in initial models are indicated for each comparison, and significant ($p < 0.05$) variables are underlined and in bold type. Data from 1989 were not included in river comparisons due to small sample size.

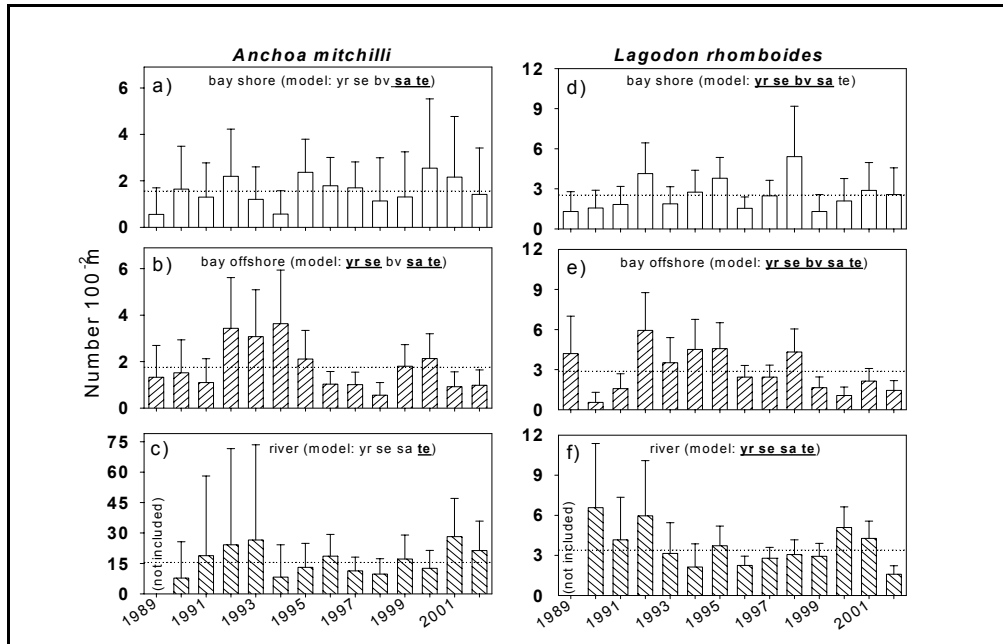


Figure 4. Interannual abundance patterns for *Anchoa mitchilli* and *Lagodon rhomboides*. Values are least square adjusted geometric means; error bars represent two standard errors. Model variables include year (yr), season (se), bottom vegetation (bv), surface salinity (sa), and water temperature (te). Dotted horizontal line indicates overall mean abundance. All variables in initial models are indicated for each comparison, and significant ($p < 0.05$) variables are underlined and in bold type. Data from 1989 were not included in river comparisons due to small sample size.

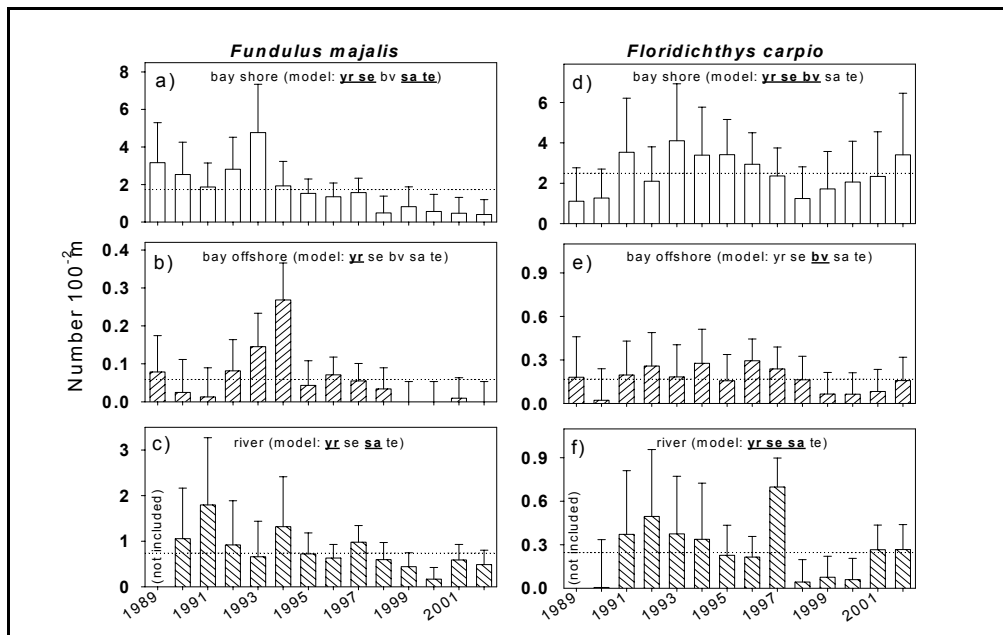


Figure 5. Interannual abundance patterns for *Fundulus majalis* and *Floridichthys carpio*. Values are least square adjusted geometric means; error bars represent two standard errors. Model variables include year (yr), season (se), bottom vegetation (bv), surface salinity (sa), and water temperature (te). Dotted horizontal line indicates overall mean abundance. All variables in initial models are indicated for each comparison, and significant ($p < 0.05$) variables are underlined and in bold type. Data from 1989 were not included in river comparisons due to small sample size.

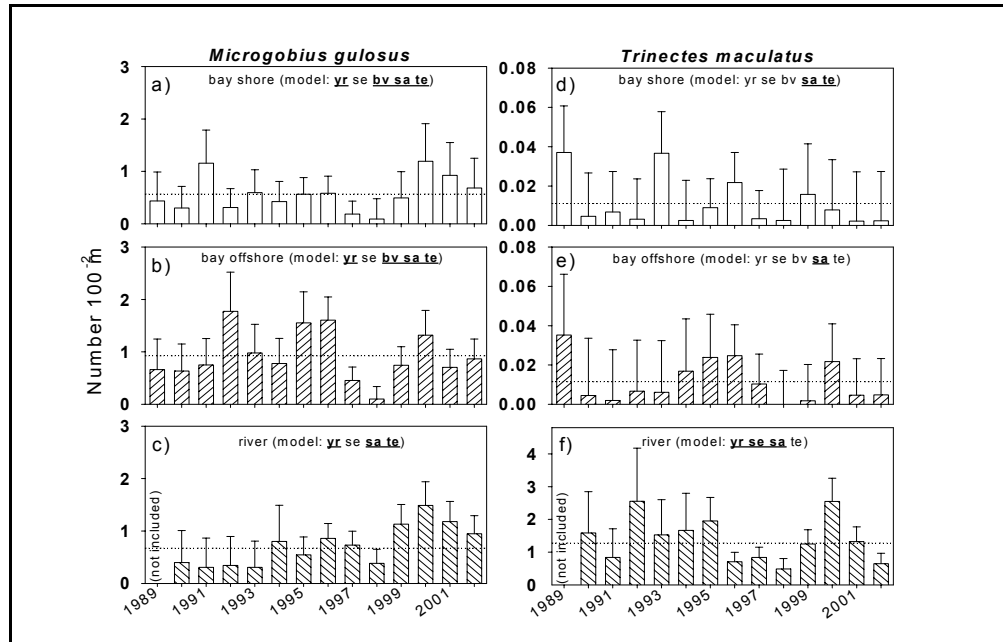


Figure 6. Interannual abundance patterns for *Microgobius gulosus* and *Trinectes maculatus*. Values are least square adjusted geometric means; error bars represent two standard errors. Model variables include year (yr), season (se), bottom vegetation (bv), surface salinity (sa), and water temperature (te). Dotted horizontal line indicates overall mean abundance. All variables in initial models are indicated for each comparison, and significant ($p < 0.05$) variables are underlined and in bold type. Data from 1989 were not included in river comparisons due to small sample size.

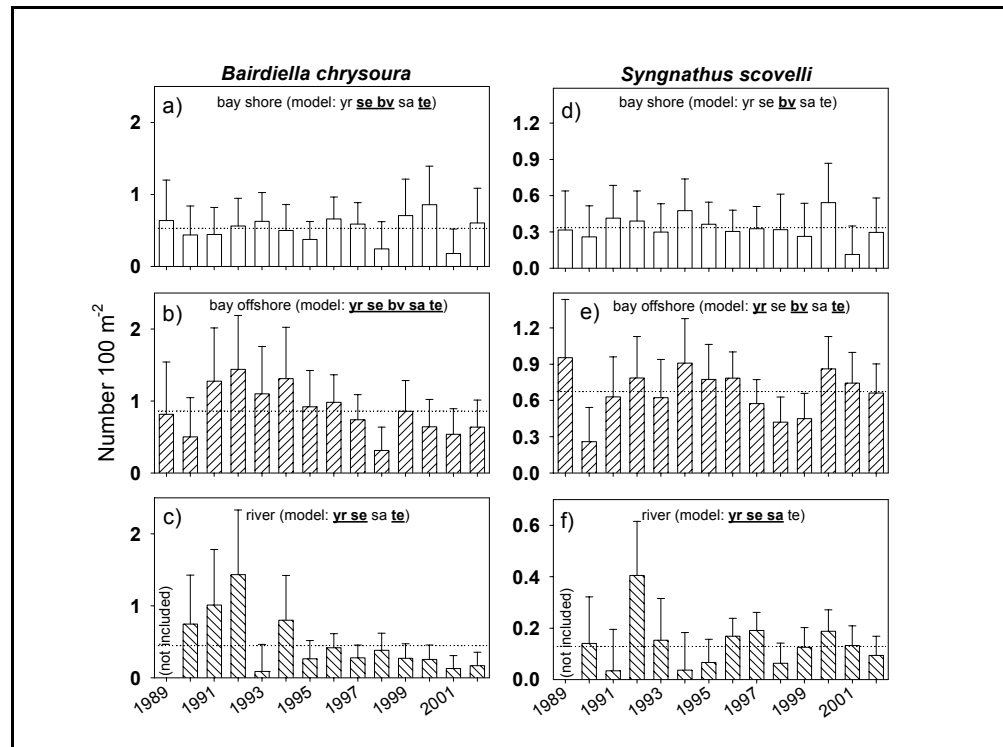


Figure 7. Interannual abundance patterns for *Bairdiella chrysoura* and *Syngnathus scovelli*. Values are least square adjusted geometric means; error bars represent two standard errors. Model variables include year (yr), season (se), bottom vegetation (bv), surface salinity (sa), and water temperature (te). Dotted horizontal line indicates overall mean abundance. All variables in initial models are indicated for each comparison, and significant ($p < 0.05$) variables are underlined and in bold type. Data from 1989 were not included in river comparisons due to small sample size.

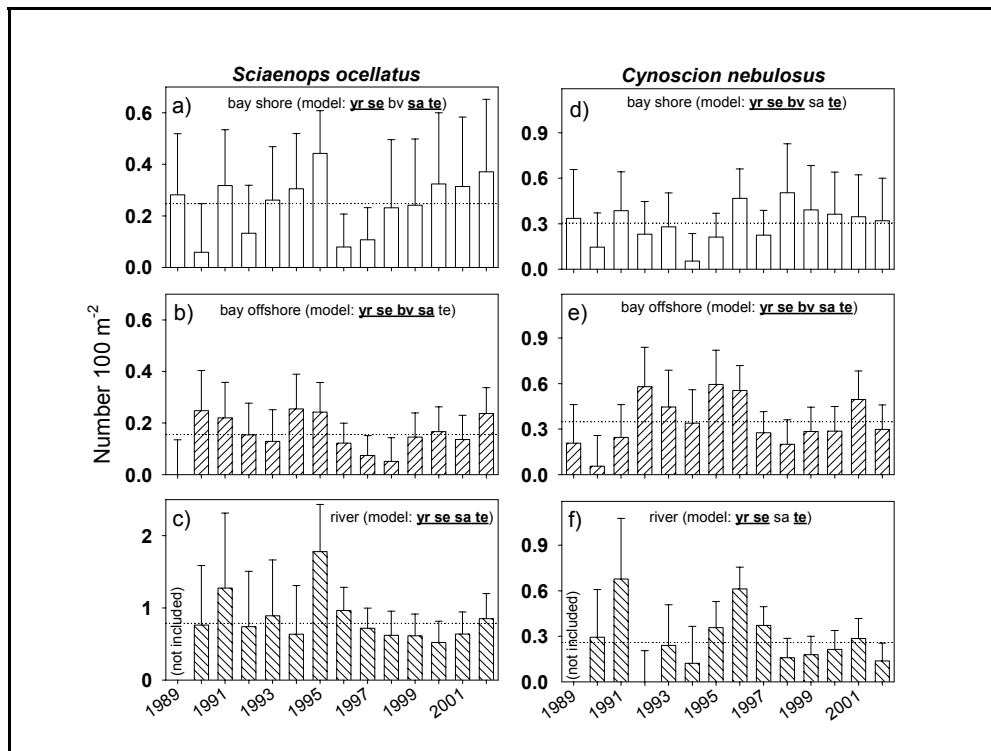


Figure 8. Interannual abundance patterns for *Sciaenops ocellatus* and *Cynoscion nebulosus*. Values are least square adjusted geometric means; error bars represent two standard errors. Model variables include year (yr), season (se), bottom vegetation (bv), surface salinity (sa), and water temperature (te). Dotted horizontal line indicates overall mean abundance. All variables in initial models are indicated for each comparison, and significant ($p < 0.05$) variables are underlined and in bold type. Data from 1989 were not included in river comparisons due to small sample size.

The lack of a significant year effect in some species apparently resulted from very low abundance in a particular habitat, extremely variable abundance, or extremely stable abundance over the entire study period. Only 9 of the 36 comparisons indicated no significant year effect, and five of these comparisons involved the bay shore habitat. Among these 9 comparisons, those for *Trinectes maculatus* in the bay shore and bay offshore habitats (Fig. 6d, e) and *Floridichthys carpio* in the bay offshore habitat (Fig. 5e) were based on very low mean abundances (< 0.02 and < 0.3 per 100 m², respectively). Those for *Anchoa mitchilli*, bay shore and rivers (Fig. 4b, c), were based on very high annual variability. The IRAs for *Bairdiella chrysoura*, *Syngnathus scovelli*, and non-bay anchovies in the bay shore habitat and non-bay anchovies in the river habitat were quite stable over the entire study period, and these were habitats in which these groups were reasonably abundant (Figs. 3a, b and 7a, d). This stability is perhaps most striking for non-bay anchovies over the 13-year time series in the rivers.

Abundances Before and After 1995 (Model C)—Most comparisons did not indicate significant differences between IRAs pre- and post-1995, but when differences were observed, most indicated declining abundance after 1995 (Table 3). Eleven of the 36 comparisons (31%) indicated significant declines in IRAs after 1995, and one (3%) comparison indicated an increase after 1995. Declining abundance was consistent across all habitats only for *Fundulus majalis*. In this species, IRAs for all three habitats were near or below the long-term average in every year after 1994 and very low after 1997 (Fig. 5). A significant effect of the change in gear-deployment methodology in 1998 affected this trend in the bay shore habitat (Table 3),

but model C adjusts for this effect, and there was no change in sampling methodology in the other two habitats. In the bay offshore habitat, the most abundant species, *Anchoa mitchilli*; two other abundant species, *Lagodon rhomboides* and *Bairdiella chrysoura*; and a multi-specific group, non-bay anchovies, all declined in abundance after 1995. The IRAs were near the long-term average or lower after 1996 or 1997 for all of these groups except *L. rhomboides*, which was relatively abundant in 1998 but not in other years after 1995 (Figs. 3b; 4b, e; and 7b). In the river habitat, the decline in IRAs after 1995 for *L. rhomboides* (Fig. 4f) and *B. chrysoura* (Fig. 7c) were both based on large annual abundance peaks from 1990 through 1992 and few or no above-average annual abundances after 1995. The abundance of *Sciaenops ocellatus* declined significantly in the bay shore habitat, but this difference is not very compelling based on the interannual trends (Fig. 8a). Also, the primary habitat for this species, based on abundance, was the rivers, and there was no significant difference between pre- and post-1995 IRAs for *S. ocellatus* in this habitat. For the one species-habitat combination where the IRA was higher after 1995, *Microgobius gulosus* in the rivers (Fig. 6c), abundance was very low for four consecutive years at the beginning of the study period (1990–1993) and very high for four consecutive years at the end of the study period (1999–2002). This is despite the fact that night sampling was only conducted prior to 1995, and, at least in the bay shore habitat, this species was more abundant at night. Two of the declines in abundance after 1995, those for *Trinectes maculatus* in the rivers and *B. chrysoura* in the bay offshore habitat, may have been due to the lack night sampling after 1995 (Tables 2 and 3).

Table 3. Indices of relative abundance (least-square mean catch per 100 m²) before and after 1995 for seven species and one multi-specific category of fish in the Tampa Bay system, 1989–2002. Habitats are bay shore (BS), bay offshore (BO), and rivers (R). Model variables are annual period (AP), gear deployment type (GT), season (SE), bottom vegetation (BV), surface salinity (SA), and surface water temperature (TE). Underlined model variables were significant in final model. Only species exhibiting significant differences in abundance among annual periods are included.

SPECIES	HABITAT	MODEL	ANNUAL PERIOD	
			Pre-1995	Post-1995
non-bay anchovies	BO	<u>AP</u> SE BV SA TE	34.84	27.44
<i>A. mitchilli</i>	BO	<u>AP</u> SE BV SA TE	2.91	1.60
<i>F. majalis</i>	BS	<u>AP</u> GT SE BV SA TE	1.86	0.93
<i>F. majalis</i>	BO	<u>AP</u> SE BV SA TE	0.10	0.03
<i>F. majalis</i>	R	<u>AP</u> SE SA TE	1.11	0.57
<i>L. rhomboides</i>	BO	<u>AP</u> SE BV SA TE	3.16	2.25
<i>L. rhomboides</i>	R	<u>AP</u> SE SA TE	4.02	2.96
<i>M. gulosus</i>	R	<u>AP</u> SE SA TE	0.42	0.92
<i>B. chrysoura</i>	BO	<u>AP</u> SE BV SA TE	1.11	0.70
<i>B. chrysoura</i>	R	<u>AP</u> SE SA TE	0.74	0.27
<i>T. maculatus</i>	R	<u>AP</u> SE SA TE	1.54	0.98
<i>S. ocellatus</i>	BS	<u>AP</u> GT SE BV SA TE	0.33	0.19

Abundances versus Freshwater Inflow (Model D)—Changes in abundance related to annual freshwater inflow were common, and most of these trends indicated increased abundance at moderate or high levels of freshwater inflow (Figs. 9–10). Of the 36 comparisons, 17 (47%) indicated a significant relationship between abundance and annual freshwater inflow, and the species/group in the comparison was most abundant at moderate or high levels of inflow in 13 of these 17 instances. The ecosystem-level importance of this trend is illustrated by the fact that *Anchoa mitchilli* in the rivers (Fig. 9c) and non-bay anchovies in the bay shore and bay offshore habitats (Fig. 9a, b) were both most abundant at moderate or high levels of inflow; *A. mitchilli* comprised 73% of the fish in our river collections and non-bay anchovies

comprised from 44% to 73% (depending on gear deployment type) of the fish in our bay collections (Table 1). Other species which were most abundant at moderate to high levels of inflow included *Fundulus majalis* (rivers; Fig. 9d), *Lagodon rhomboides* (bay shore and bay offshore habitats; Fig. 9e), *Floridichthys carpio* (all three habitats; Fig. 10a, b), and *Cynoscion nebulosus* (bay offshore and river habitats; Fig. 10f). Also, *Microgobius gulosus* (bay shore; Fig. 10c) and *C. nebulosus* (bay shore; Fig. 10f) were somewhat more abundant at moderate levels of inflow, but abundance at this level was not significantly different from that at low inflows. Comparisons which clearly indicated maximum abundance at low levels of inflow involved the following species in the river habitat: *L. rhomboides* (Fig. 9f), *M. gulosus* (Fig. 10d), and *Trinectes maculatus* (Fig. 10e). The trends among IRAs for *L. rhomboides* in the three habitats are quite strong. Mean abundances are nearly identical at each level of inflow in the bay shore and bay offshore habitats (Fig. 9e), with abundance increasing linearly with inflow. In the rivers, however, this pattern is reversed, with abundances at moderate and high inflows being significantly lower than those at low inflows (Fig. 9f).

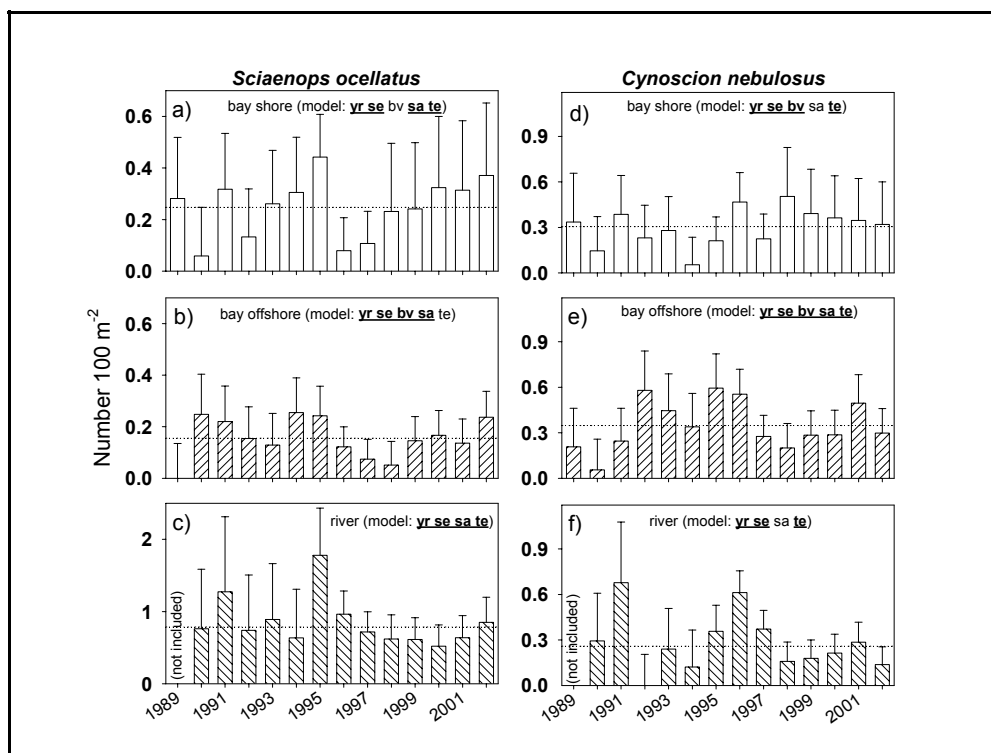


Figure 9. Abundances of all fish except *Anchoa mitchilli*, *Anchoa mitchilli*, *Fundulus majalis*, and *Lagodon rhomboides* in three Tampa Bay habitats during years with low, moderate, or high levels of freshwater inflow (see Fig. 2 for year included within each category). Values are least square adjusted geometric means; error bars represent two standard errors. Within each habitat, means with same letter above error bar are not significantly different. Graphs for bay shore and bay offshore habitats were combined for *L. rhomboides* because levels of abundance and trends were similar.

DISCUSSION

Our analyses documented two major trends in the relative abundance of small fishes in the Tampa Bay system from 1989–2002: 1) many species were less abundant after 1995 than they were before 1995, and 2) many species were more abundant during years with moderate to high levels of freshwater inflow than during those with low levels of inflow. The first trend is more likely the result of fishery management actions than is the second, but both trends are probably the result of multiple factors, including both management and natural events.

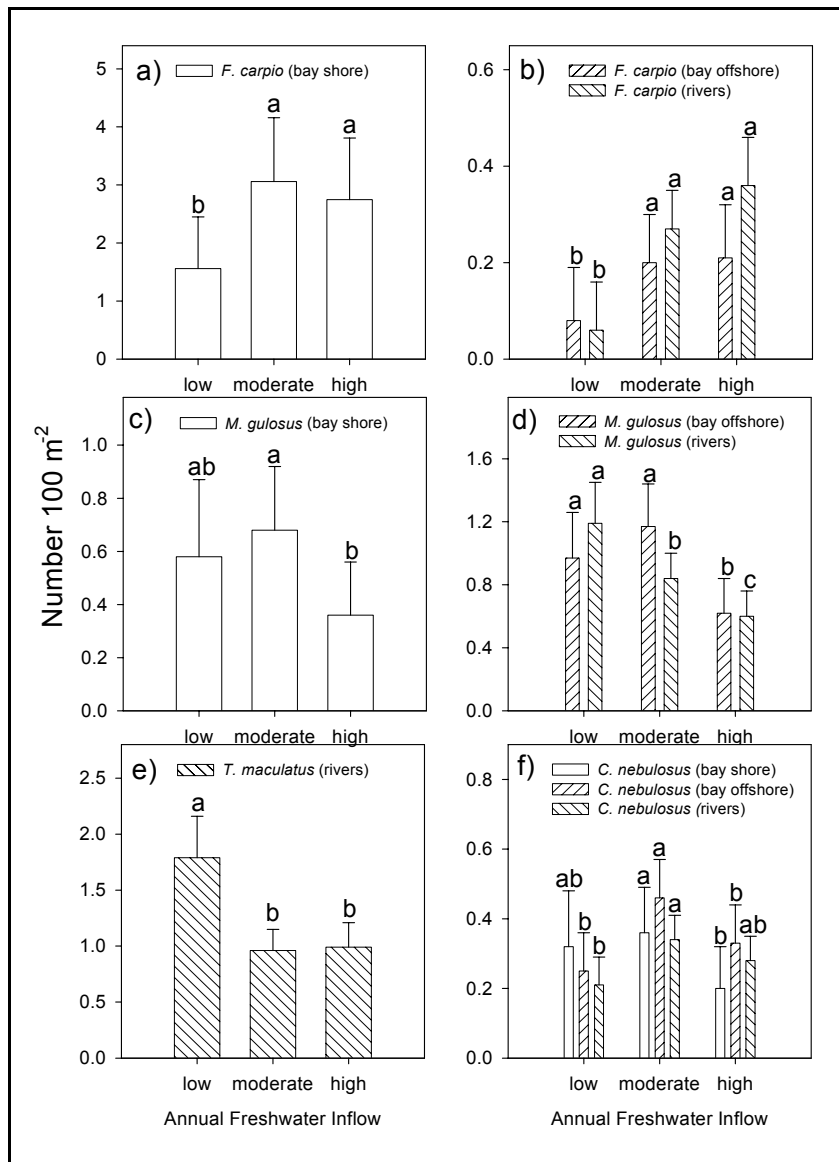


Figure 10. Abundances of *Floridichthys carpio*, *Microgobius gulosus*, and *Trinectes maculatus* in three Tampa Bay habitats during years with low, moderate, or high levels of freshwater inflow (see Fig. 2 for year included within each category). Values are least square adjusted geometric means; error bars represent two standard errors. Within each habitat, means with same letter above error bar are not significantly different. Graphs for bay offshore and river habitats for *F. carpio* and *M. gulosus* and those for all habitats for *C. nebulosus* were combined because levels of abundance and trends were similar.

Declines in IRAs in the years after 1995 were significant for a wide range of species, and we feel that it is not unreasonable to suggest that these declines were affected by the inshore net ban beginning in 1995 as well as other management actions. Species exhibiting these declines included abundant residents, such as *Anchoa mitchilli*, *Fundulus majalis*, *Bairdiella chrysoura*, and *Trinectes maculatus*; abundant (*Lagodon rhomboides*) and economically valuable (*Sciaenops ocellatus*) transients; and a large multi-specific group, non-bay anchovies. Factors leading to such a wide-spread trend must be operating at the community level, and we would

expect such factors to be based on trophic dynamics or habitat availability. We are aware of no widespread habitat change in the Tampa Bay system which would modify fish abundances after 1995. The institution of an inshore net ban in 1995 could have modified the trophic structure of the system by decreasing commercial fishing mortality on a wide variety of species, some of which are predators on the small fishes included in this study. Freshwater inflow can also affect the trophic structure of estuaries, primarily through nutrient delivery (e.g., Aleem, 1972; Flint, 1985; Livingston et al., 1997), but levels of inflow did not change systematically before and after 1995 and including inflow in the ANCOVA models did not affect the significance of the pre- and post-1995 differences.

Annual levels of freshwater inflow were, however, strongly associated with IRAs in nearly one-half of the comparisons conducted for this study, and most of these associations indicated greater abundance at moderate to high levels of freshwater inflow. As mentioned above, this result is not unexpected given the known relationship of freshwater inflow to estuarine productivity, but the strength, frequency, and intraspecific consistency of this relationship with a relatively gross measure of inflow, annual mean, is somewhat surprising. The two groups comprising most of the small fish community in the Tampa Bay system, *A. mitchilli* and non-bay anchovies, were both most abundant at moderate to high levels of inflow, the former in the rivers and the latter in the bay. This trend was also seen in four other abundant species in either the bay or the rivers (these species are of course included in the non-bay-anchovy group and may have contributed to the overall trend in that multi-specific group). Parallelism in this trend was documented for several species in two or more of the three habitats included in this study, and we believe that such parallelism lends additional support for the importance of freshwater inflow to these species. Perhaps the most remarkable parallelism was observed in *Lagodon rhomboides*. In this species, the relationship between annual inflow and abundance in the two bay habitats was identical, and the mean abundances at each level of inflow were also nearly identical. Given the variability of estuarine systems, the many factors which affect the abundance of an offshore-spawning species such as *L. rhomboides*, and the general variability of most fish populations with which we are familiar, this result was most unexpected and lends strong support to the importance of freshwater inflow to the abundance of *L. rhomboides*.

There are winners and losers in almost any environmental scenario, and low annual freshwater inflow, while being associated with decreased abundance in many species, was associated with increased abundance in some species in some habitats. This type of relationship was often not very pronounced and was often not consistent among habitats for a particular species. *Microgobius gulosus* tended to be abundant during years with low annual inflow, but the IRAs for this species during years with low inflow were not significantly different from those for years with moderate inflow in the two bay habitats. The abundance of *Cynoscion nebulosus* was not significantly lower at low inflows than at moderate inflows in the bay shore habitat but was significantly lower in the bay offshore and river habitats. Perhaps the most convincing examples of increased abundance at low annual inflow levels were provided by *Lagodon rhomboides* and *Trinectes maculatus* in the rivers. In *L. rhomboides* this trend is in contrast to the significant positive relationship between inflow and abundance which we observed in the two bay habitats.

Relationships between abundance and annual freshwater inflow should be interpreted with caution because of potential time lags between inflow and response and because apparent changes in abundance may be the result of movement into or out of a particular habitat. Fish abundance can be related to inflows occurring near the time of capture or many months prior to capture. If a species moves in response to, or is killed by, strong inflows or the accompanying salinity change, then short-term inflows may be controlling its abundance. On

the other hand, if the abundance of a species responds to overall system productivity, then long-term levels of inflow, and the accompanying long-term pattern of nutrient delivery to the system, may control its abundance. The relationship between average annual inflow and abundance should indicate the effects of long-term inflow, but short-term effects cannot be ruled out, especially if inflow events occurred during a relatively narrow recruitment window. Also, long-term effects of inflow on abundance may not be evident within one calendar year. For example, if a species recruits in the winter or spring (e.g., *Lagodon rhomboides*), then system productivity driven by inflow during the summer, fall, or early winter of the previous calendar year may affect its abundance. Recent reports by Greenwood et al. (2004) and Matheson et al. (2004) (the latter report incorporates a portion of the data used in the present study plus additional data sets) indicated that abundances of various species of fish in the Peace and Alafia rivers were highest at intermediate levels of freshwater inflow and that this relationship was often strongest for long-term inflow (i.e., inflows occurring during the 90 to 365 days prior to collection of the fish).

We also recommend a cautious interpretation of abundances in relation to freshwater inflow in the bay versus the rivers because apparent abundance may indicate movement between these two areas, especially if the species is avoiding either high or low salinities. Peebles (2002a, b), Greenwood et al. (2004), and Matheson et al. (2004) all found that most significant movements of larval and juvenile or small adult fish in the Alafia and Peace rivers were downstream with increasing inflow and upstream with decreasing inflow. This type of movement may increase abundance in the bay during periods of high inflow if the species involved moves completely out of the river system.

Despite the above-mentioned caveats, we believe that the strength, frequency, and intraspecific consistency of relationships indicating lower abundances of small fish during periods of reduced freshwater inflow provide strong evidence that fish production in the Tampa Bay system is reduced during prolonged periods of low freshwater inflow (e.g., droughts). The generality of this pattern for estuaries has been demonstrated many times in the literature for systems in Florida and elsewhere (e.g., Turner and Chadwick, 1972; Whitfield, 1994; Livingston, 1997; Greenwood et al., 2004). This finding has broad implications for the management of freshwater resources in the Tampa Bay watershed.

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ABSTRACTS
Session 1: FISH AND WILDLIFE

PRESENTATIONS

Overview of Manatee and Turtle Population Status in Tampa Bay. E. Haubold A. Foley, A. Meylan, B. Witherington (FWC Fla. Marine Research Inst.) Five species of sea turtles and the Florida manatee (*Trichechus manatus latirostris*) inhabit Florida waters. All are considered threatened or endangered at the state and federal levels.

Four of Florida's sea turtles, the loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*), green turtle (*Chelonia mydas*), and hawksbill (*Eretmochelys imbricata*) are found in Tampa Bay, but the loggerhead is the predominant sea turtle species in the area and the only one to regularly nest on nearby beaches. Concern about the current status of the loggerhead population in Florida is justified. Statewide, the number of loggerhead nests recorded at index beaches in 2002 represented the lowest total in 14 years. Loggerhead mortality in Florida, including that in Tampa Bay, has been near record levels during the past three years and far greater during 2003 than during any other year on record.

The FWC recently conducted a status review of the Florida manatee. Given the highest population count (3,276 in 2001) obtained through Florida's annual synoptic survey and a stable age distribution, the number of mature individuals was estimated to be 2,165. A population viability analysis model was developed using VORTEX to determine the probability of a future population decline and probability of extinction given a variety of plausible scenarios that incorporated expected declines in carrying capacity through loss of warm-water refugia and increases in mortality from human-related causes. The model indicated that given future threats to the species, the manatee population could decline by 50% over the next 45 years. [Elsa.Haubold@fwc.state.fl.us]

Status of Coastal Bird Populations of the Tampa Bay System. R. Paul, A. Paul (National Audubon Society). The Tampa Bay system is home to 28 species of colonial waterbirds and allies, totalling roughly 50,000 breeding pairs. A few species of songbirds, limited mostly to mangrove habitats, approach their northern range limits here. In addition, thousands of shorebirds and waterfowl migrate through or winter within the Bay. Since the early 1980s, some species have increased locally, chiefly rare species still recovering from population lows of past decades. Other, more widespread species are declining. Still other species have not received adequate study, so their local population status is not known. The apparent causes of population changes, the effectiveness of recent management efforts, and needs for additional survey and management are discussed. [rpaul@audubon.org]

Comparison of Fish and Macroinvertebrate Communities in Six Tampa Bay Tributaries. T. MacDonald, T.S. Tsou, R.H. McMichael, Jr. (FWC Fla. Marine Research Inst.). Between 1996 and 2002, the Florida Marine Research Institute's Fisheries-Independent Monitoring (FIM) program collected monthly samples in six Tampa Bay tributaries (Hillsborough, Palm, Alafia, Little Manatee, Manatee, and Braden rivers) in order to address fishery and water-management mandates. Sample sites, which were selected by stratified-random sampling design, were distributed from the river mouth to the upstream extent of saltwater intrusion in each tributary. Using 21.3-m seines (3,352 hauls) and 6.1-m otter trawls (1,720 hauls), FIM staff collected 3,719,117 fish and macro-invertebrates representing 142 taxa. The number of taxa collected per haul in both seines and trawls generally decreased as the distance from the river mouth to the Gulf of Mexico increased. Higher animal densities were collected in seine hauls from the Hillsborough and Palm rivers (1,174–2,282 animals/haul) than in the other rivers (705–1,044 animals/haul), largely due to the abundance of three schooling, pelagic taxa (*Anchoa mitchilli*, *A. hepsetus*, and *Menidia* spp.). In trawl hauls, animal densities were lower in the Hillsborough and Palm rivers (16–40 animals/haul) than in the other rivers (99–293 animals/haul), possibly due to the higher frequency of low (< 4mg/l) dissolved oxygen values (42–43% of samples in Palm and Hillsborough rivers; 10–24% in other rivers). Preliminary cluster analysis indicated that each tributary is quite dissimilar from the others. Because of these differences, management decisions should be based largely upon data collected within the tributary that is being managed. [tim.macdonald@fwc.state.fl.us]

Acoustic Telemetry: Its Application to Assess the Feasibility of Stock Enhancement of Red Drum in Tampa Bay. C. Neidig, K.M. Leber (Mote Marine Laboratory). Project Tampa Bay, a multi-institutional stock enhancement program has as a goal to increase the red drum population. In Tampa Bay active monitoring of acoustic tagged hatchery-reared red drum coupled with directed-target sampling was used to locate hatchery-reared red drum and subsequently wild fish with which these had congregated. In addition, a fin-clip program was initiated to take tissue samples after taking measurements and before their release with which mtDNA analysis could be performed. Fifty-eight red drum, (325–610 mm SL) were implanted with acoustic tags from Sonotronics® and released in 10 sites on the Alafia River, a major tributary of Tampa Bay. Acoustic tracking covered primarily the Alafia River and the eastern shoreline of adjacent Tampa Bay.

Acoustic tracking coupled with directed target sampling provided information on the location of red drum in and outside the Alafia River. Some fish were located in areas too difficult to sample by more traditional methods. Abiotic parameters and habitat preferences of acoustic fish and accompanying red drum were determined. Subsequent studies are in place to acoustically monitor Phase III (180–210mm TL) hatchery-reared red drum. Since little is known of the habitat and environmental preferences of these fish as well as their movements in and out of the river and their long-term survivability, this data will provide valuable information on which to base future releases of red drum in Tampa Bay. [cneidig@mote.org]

POSTERS

Least Tern Conservation Project: An Efficient Method to Census Rooftop Colonies. M. Abrams, B. Ackerman, B. Zias (St. Petersburg Audubon Society); E. DeVries, B. Fors (Eckerd College). The Least Tern is a small seabird that nests on open beaches throughout North America. Due to habitat destruction, increased predation, and disturbance, Least Tern numbers have decreased and the species has begun nesting on flat gravel roofs. In Florida, > 80% of Least Tern colonies occur on roof-tops and Pinellas County has the largest number of rooftop colonies. Unfortunately, gravel roof-tops are being replaced with a less expensive alternative that is not suitable for tern nesting. Because rooftops represent a large proportion of Florida's Least Tern population it is vital to monitor these populations, but the number of Least Terns in these colonies is difficult to estimate. The purpose of this research was to develop a method of census rooftop Least Terns from the ground. Research was conducted by a team of St. Petersburg Audubon volunteers and Eckerd College researchers. Throughout the summer of 2002, we counted Least Terns from the ground on 10 roofs by counting birds flying off the roof during 1, 3, and 5 minute intervals. These counts were compared using linear regression to roof top counts made from a bucket lift placed next to the buildings. All of the regressions were significant, but the earliest survey that was conducted at the beginning of the nesting season (late May), and the 3 minute counts produced the strongest regressions ($r^2 = 0.89$, $F = 31.4$, d.f. = 9, $p > 0.005$). These results indicate that ground counts might be an efficient method of monitoring Least Tern and other roof-nesting birds. [forysea@eckerd.edu]

Argos-linked GPS Tags as a New Tool to Investigate Manatee Behavior: Winter Movements and Attendance Patterns at a Warm-water Refuge in Tampa Bay, Florida. C.J. Deutsch, H.H. Edwards, A. J. Smith (FWC Fla. Marine Research Inst.). Florida manatees require access to warm-water refuges during winter because of their vulnerability to cold-related stress and mortality. We investigated manatee winter movements and attendance patterns at an industrial warm-water refuge in Tampa Bay, Florida, in relation to ambient temperature. We hypothesized that the distance and duration manatees spend away from the refuge should be positively correlated with ambient water temperature. Six manatees were tagged in December 2002 and tracked through February 2003 using state-of-the-art Global Positioning System (GPS) tags that relayed near-real-time and highly accurate movement data through the Argos system. The tags attempted GPS fixes every 20 minutes. Manatees behaved as "central-place foragers," making regular excursions to seagrass beds within 4-40 km of the power plant and then returning after several hours to a few days to thermoregulate in the heated discharge canal. Time spent away from the refuge increased significantly as ambient water temperature increased. In unusually cold weather, refueling bouts lasted up to 6 consecutive days, during which time the manatees fasted. Manatees exhibited a diel pattern, typically foraging at night and resting during the day. Distance to foraging grounds was positively correlated with ambient temperature for some individuals but not for others. Study animals demonstrated remarkable consistency in their daily movements and fidelity to their foraging grounds; daily distance traveled from the power plant varied among individuals (medians of 4-26 km). This new technology provides insights into decisions manatees make to optimize the energetic tradeoffs between foraging in cold water and fasting in warm water. [Chip.Deutsch@fwc.state.fl.us]

Shell Key Preserve—A Balancing Act. C.S. Flegel (Pinellas Co. Dept. of Environmental Mgt., Environmental Lands Division). Shell Key Preserve has been managed by Pinellas County's Department of Environmental Management since 2000. At 13,000 acres, Shell Key Preserve includes a 180-acre barrier island, several mangrove islands, mudflats, sand bars and extensive seagrass beds. This naturally productive complex that provides habitat for various fish and wildlife species is also attractive to the recreational public that use the area for fishing, boating, swimming, camping, and beachcombing. The management plan strives balance public recreational use and the needs of wildlife, particularly shorebirds that rely on the Preserve. Three State-listed species, the American oystercatcher, least tern, and black skimmer, currently nest on Shell Key and 72 species of shore and sea birds use the area during migration and winter months. On holiday weekends, visitation by people often exceeds 1000 on the island that is accessible only by boat.

To facilitate the balance between wildlife and people, a 60-acre core Bird Preservation Area (BPA) was established within which people are not allowed. Additional restrictions of no camping and no pets were applied to the areas adjacent to the BPA. Monitoring of nesting, roosting, and feeding birds as well as public use and habitat changes

on the island are conducted annually to provide data for informed management decisions. Additionally, aquatic use zones were established over the submerged land to protect seagrass beds and provide additional protection for wildlife. Educational outreach is an important tool for balancing public needs with the needs of wildlife. [cflegel@co.pinellas.fl.us]

Mapping Recreational Boating Patterns in Sarasota and Tampa Bays. C. Sidman (Florida Sea Grant, Univ. of Fla.), B. Sargent (Fla. Marine Research Inst.). This poster summarizes the methods and preliminary results of a project, initiated in February 2003, to characterize spatial and temporal recreational boating patterns in Sarasota and Tampa Bays. A map-based questionnaire was mailed to a random sample of 6,800 area boaters. The boater population was stratified first by County (Sarasota, Manatee, Hillsborough, Pinellas) and second, by trip origin type (marina wet-slip, dry-storage facility, ramp, private dock). Vessel and boat trailer registration numbers collected at over 100 area marinas and boat ramps were used to obtain names and mailing addresses from the State's Vessel Title Registration System (VTRS) for marina and ramp samples. Names and mailing addresses for waterfront parcel owners obtained from County tax records were compared to the VTRS to identify dock samples (those waterfront parcel owners that also own a boat). Questionnaire recipients marked the start and end point of their last two recreational boating trips, traced their travel routes, identified their favorite boating destinations, and the primary activities that they engaged in while at a particular destination. In addition, much descriptive data about boaters including preferences for selecting trip origins, destinations, and routes, favorite activities, vessel types, and frequency of use, was collected and linked to the mapped data. Data collected from over 1,700 returned surveys was digitized into aGIS. Methods to determine the degree to which spatial and temporal boating patterns differ by region and trip origin type will be presented. This information is to be used for resource management and planning applications, and as the basis for developing map-based products intended to improve boating experiences and instill resource stewardship. [cccf@ufl.edu]

St. Petersburg Audubon Society—Conservation in Your Own Neighborhood. B. Zias, B. Bilodeau, B. Ackerman (St. Petersburg Audubon Society). The St. Petersburg Audubon Society's Neighborhood Outreach Project is based on the premise that "Without habitat, there is no wildlife." Millions of acres of wildlife habitat are lost to development in the U.S. every year. The populations of many plant and animal species are in decline. Yards surrounding American homes total 35 million acres—50,000 square miles of land that could be reclaimed as wildlife habitat if landscaped properly. Millions of pounds of fertilizers and pesticides are used annually to maintain turf lawns in addition to 30–60% of potable municipal water supplies. Using a traveling slide program and beginning bird walks, we teach people about birds and habitat in their neighborhood. The slide show teaches homeowners what they can do in their own yards to conserve water (xeriscaping, controlling run-off); to reduce the use of fertilizers and pesticides (native plants); to improve the quality of storm-water run-off (the major source of water pollution in Florida); and to enhance habitat by landscaping for birds, butterflies, and wildlife using native plants and butterfly gardens. The slide program has been presented to 20 neighborhood associations, garden clubs and other audiences. A bird walk is conducted in their neighborhood to teach residents about beginning bird watching and show them the connection between habitat and the value of wildlife in their own yards and neighborhood. We provide a resource notebook to each group entitled "Eco-Friendly Opportunities" which contains the best pamphlets from local agencies about water conservation, wildlife, landscaping, native plants, composting and mulch. [Bruce.Ackerman@fwc.state.fl.us]



THE EFFECTS OF THE ASIAN GREEN MUSSEL *PERNA VIRIDIS* ON A SHALLOW ESTUARINE ENVIRONMENT: A PRELIMINARY ASSESSMENT

W. Avery & R. Johansson

INTRODUCTION

The green mussel, *Perna viridis*, was first observed in Tampa Bay in 1999 (Benson et al. 2001). Rapid expansion of this Indo-Pacific species within the Tampa Bay estuary has been viewed with growing concern. A similar invasion by the zebra mussel, *Dreissena polymorpha*, in the Great Lakes has reduced the particulate matter in the water column (Klerks et al. 1996), including phytoplankton biomass, thereby increasing water clarity (Bunt et al. 1993). Further impacts included increased organic loading to the sediment via *D. polymorpha* biodeposition (Klerks et al. 1996) and displacement of indigenous species through competition of resources (Findlay 1996).

The City of Tampa, Bay Study Group (BSG) has, since 1986, documented the changes in the seagrass community of Hillsborough Bay, the northwestern section of Tampa Bay (Figure 1). During a seasonal seagrass assessment in February 2003, the BSG encountered an area of *P. viridis* within a *H. wrightii* meadow (mid meadow site) near Macdill Air Force Base (MAC; Figure 1). Further, a second area of *P. viridis* was noted several hundred meters to the east near the deep edge of the *H. wrightii* meadow (edge meadow site). After inspecting aerial photography, it was concluded that the *P. viridis* beds had developed within 18 months prior to its discovery. This was the first observation of an extensive *P. viridis* presence within a Tampa Bay “soft bottom” community.

In a proposal to the Tampa Bay Estuary Program, the BSG offered to research the implications of the *P. viridis* expansion within a soft bottom seagrass community. The objectives of the investigation were to:

- document the size of the *P. viridis* bed within the *H. wrightii* meadow;
- determine if filter feeding by the *P. viridis* population improves local water clarity;
- ascertain the local seagrass response to potential increased water clarity; and
- determine if seagrass coverage was displaced through changes in *P. viridis* areal coverage.

Initial data concerning objectives 1 and 2 are presented in this paper. Also, preliminary water clarity measurements over *P. viridis* beds on Long Shoal, a hard bottom community in central Hillsborough Bay (Figure 1), are included.

METHODS

An initial size determination of the two *P. viridis* sites near MAC was made in June 2003. The perimeter of each mussel bed was measured by recording positions along periphery at five second intervals with a Trimble® Pro XR Global Positioning Unit (GPS). Smaller areas of *P. viridis* not contiguous with the main bed were not included in the areal coverage estimate. Areal coverage of *P. viridis* at Long Shoal was not determined.

A preliminary assessment of the impact of the *P. viridis* filtration activity on the water column was conducted at the MAC mid meadow site. Surface grab samples were collected in 250-ml plastic containers at sites up current, over the bed, and down current from the bed during an incoming tide. These samples were analyzed for chlorophyll *a* (chl*a*) using a fluorometric “whole water” method developed by the BSG (City of Tampa 1998) and percent light transmission using a C-Star® transmissometer (660 nm, 10 cm path length).

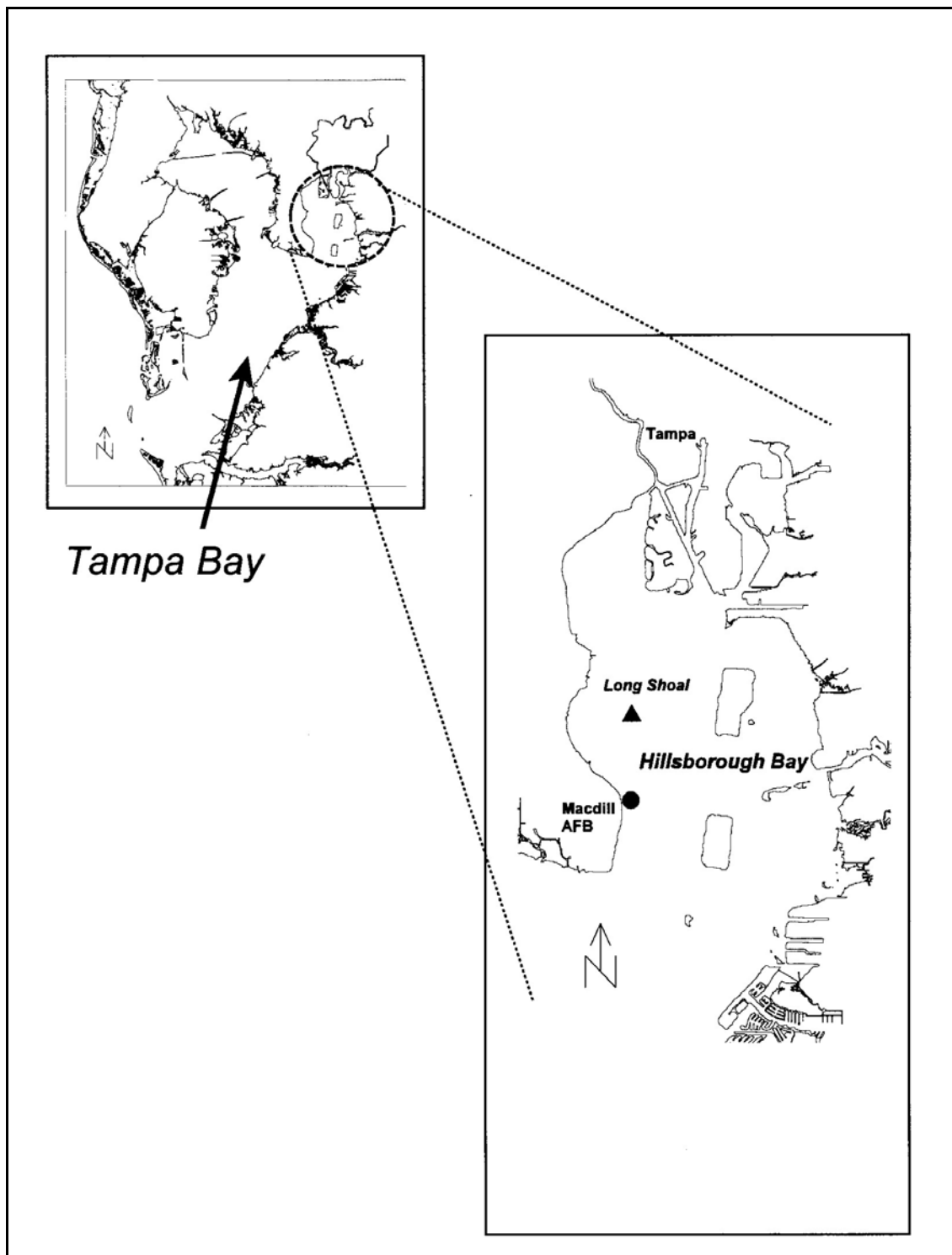


Figure 1. Location of the MacDill AFB (solid circle) and Long Shoal (solid triangle) *Perna viridis* study sites in Hillsborough Bay.

Subsequently, a 200 × 200 m study area surrounding the mid meadow *P. viridis* was established by marking the corners of the block with PVC poles. The location of each corner pole was predetermined and the final position confirmed with the GPS. Within the study area, the transmissometer was towed by a boat at a speed of ca. two knots. *In situ* transmissometer values were collected at 30 second intervals at a depth of ca. 50 cm, or close to mid depth near a slack high tide. All transmissometer values were recorded by a LiCor® 1000 datalogger and the location of each transmissometer reading was determined using the GPS. No transmissometer data were generated for the edge meadow *P. viridis*. Transmissometer readings were interpreted using Surfer® (Golden Software, Inc.).

Transmissometer measurements were collected using similar methods at the Long Shoal site. However, at this site, there was no predefined area for data collection.

RESULTS

Areal coverage for the mid meadow *P. viridis* site was determined to be ca. 1500 m². The edge meadow *P. viridis* areal coverage was about 4500 m².

Results for the surface grab collections (Figure 2) indicate a drop in chl *a* concentration from ca. 14 µg l⁻¹ at the up-current sample to 4 µg l⁻¹ over and down-current of the *P. viridis* bed. Further, transmissometer data indicate an inverse correlation to the chl *a* results with the least transmission at the up-current site and increased transmission (improved water clarity) over and down-current of the *P. viridis* bed.

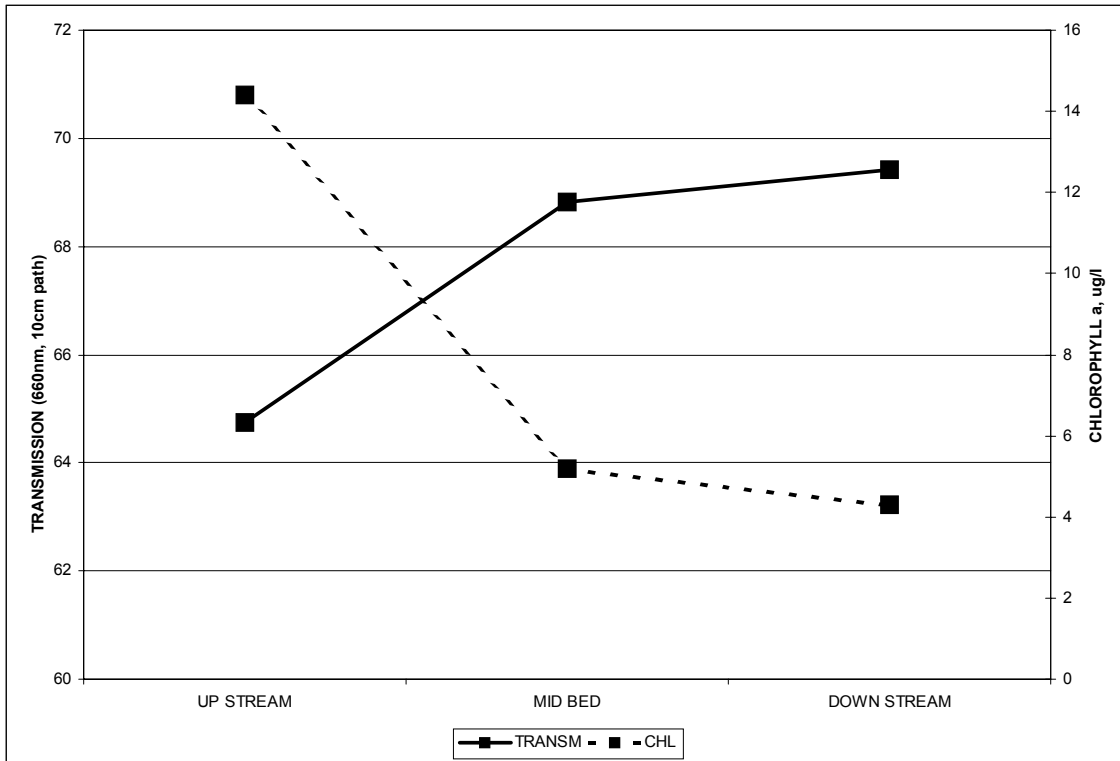


Figure 2. Percent light transmission (TRANSM) and chlorophyll a (CHL) values from surface grab samples at the Macdill AFB mid-bed *Perna viridis* site.

Transmissometer readings from the towed *in situ* study showed increased water clarity at both the MAC and the Long Shoal site. At the MAC site, water clarity increased as much as 14 percent over and just down current of the *P. viridis* bed (Figure 3). Similarly, readings from the Long Shoal area suggest a transmission increase of ca. 18% (Figure 4). However, since the extent of the bed had not been determined, changes in water clarity cannot be spatially correlated with areas of *P. viridis* abundance.

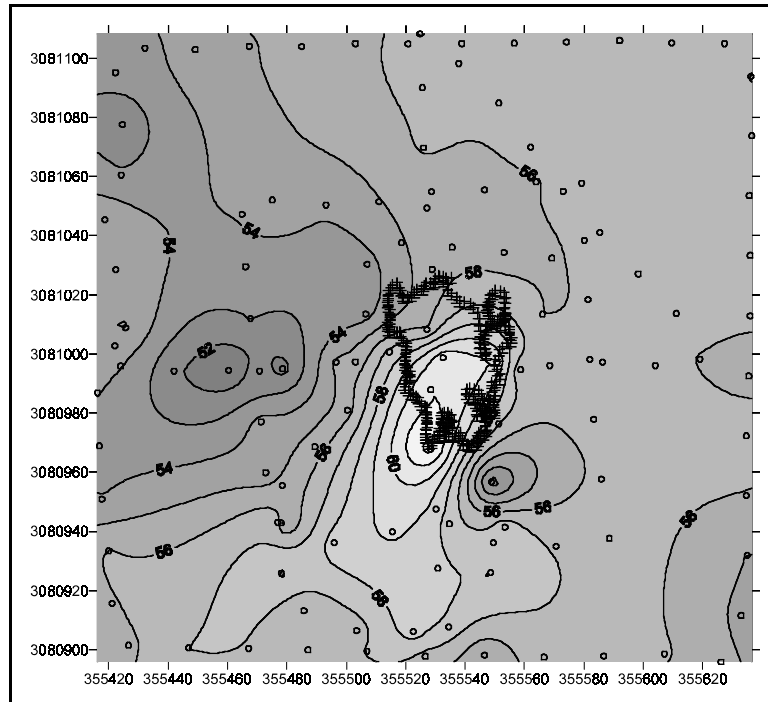


Figure 3. Surfer® contour plot indicating the percent light transmission (C-Star® transmissometer at 660 nm, 10 cm path length) at the MacDill AFB *Perna viridis* mid-bed site. Lighter colors indicate greater light transmission. Open circles are GPS referenced data collection sites. + indicate GPS positions logged around the perimeter of the bed.

DISCUSSION

P. viridis apparently exerts a strong “top down” control (predation) of phytoplankton biomass resulting in improved water clarity within a localized area. Although the effect of improved water clarity on local *H. wrightii* coverage has yet to be studied, it would be reasonable to expect an increase in above- and below-ground biomass near the mussel beds. Further, biodeposition by *P. viridis* may enrich local sediments thereby providing additional nutrients for developing *H. wrightii* coverage.

The establishment of extensive *P. viridis* populations in natural and created Tampa Bay habitats is of some concern. Prior to 2003, the development of this species has not been reported within soft bottom seagrass communities. Baker et al. (2004), however, indicate that adult *P. viridis* may become dislodged from a hard substrate and persist in soft sediments. Further, there is a potential that expansion of *P. viridis* beds within seagrass communities will displace this vital habitat. Indeed, some displacement of *H. wrightii* coverage at the MAC site is likely to have occurred already. Finally, Tampa Bay’s artificial reefs that had developed

extensive bryozoan, soft coral, sponge, barnacle, and tunicate communities prior to the green mussel invasion are now dominated by *P. viridis* (personal communication, Tom Ash, Hillsborough County Environmental Protection Commission).

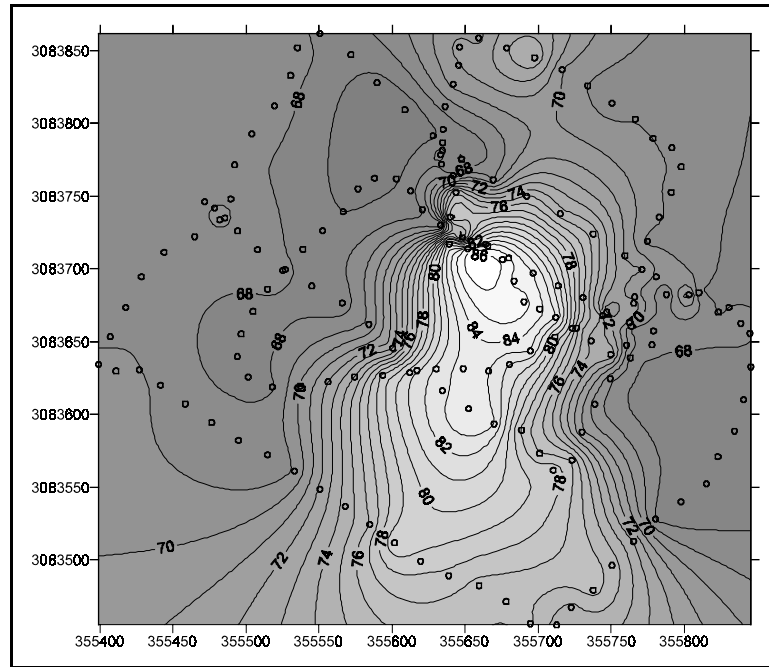


Figure 4. Surfer® contour plot indicating the percent light transmission (C-Star® transmissometer at 660 nm, 10 cm path length) at the Long Shoal *Perna viridis* site. Lighter colors indicate greater light transmission. Open circles are GPS referenced data collection sites.

ACKNOWLEDGEMENTS

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ABSTRACTS
Session 2: INVASIVE SPECIES

PRESENTATIONS

Survey of Non-indigenous Species in Tampa Bay. P. Baker, J.S. Fajans, S.M. Baker (Univ. of Fla. Dept. of Fisheries and Aquatic Sciences). Field data, literature, and museum collections were reviewed to estimate the number of nonindigenous species in the greater Tampa Bay ecosystem. Tampa Bay hosts at least 35 nonindigenous species, plus three probable nonindigenous residents. If cryptogenic (uncertain origin) species are included, the number of known and probable nonindigenous species rises to at least 50. These include 14 mollusks, eight crustaceans, seven fishes, five polychaete worms, four plants and macroalgae, and 12 other species ranging from diatoms to toads. The taxonomic breakdown is biased towards well-studied groups such as mollusks and fishes. It is likely that additional nonindigenous species occur in Tampa Bay within less-studied groups such as polychaetes worms, peracarid crustaceans, and bryozoans.

Several nonindigenous species in Tampa Bay have the potential for strong economic or ecological impacts. Several species of isopods and bivalves bore into wood (including mangrove prop roots) and damage other natural and artificial substrata in Tampa Bay. At least 12 species, including hydroids, polychaetes, barnacles, sea squirts, and bryozoans, are economically damaging fouling organisms here or in other parts of their range. Green mussels, *Perna viridis*, are abundant fouling organisms and also damage oyster reefs. Several tilapia are among the most abundant fishes in Tampa Bay.

Fifteen additional species were designated as expected or potential invaders of Tampa Bay based on their distribution outside of west Florida. Examples include the large purple mane jellyfish, *Drymonema dalmatinum*; the brown mussel, *Perna perna*, a close relative of the green mussel; and the venomous lionfish, *Pterois volitans*. [pbaker@mail.ifas.ufl.edu]

The Exotic Armored Catfishes (Loricariidae) and *Hoplosternum littorale* (Callichthyidae) in Florida, Particularly the Hillsborough River. R. Ruiz-Carus, H. J. Grier (FWC Fla. Marine Research Inst.). New records of non-native fishes are still being noted from shore waters of west Florida at a disturbing, regular rate. We compiled recent records of suckermouth armored catfishes and brown hoplo from 5 estuaries in Florida during 1990–2003 from incidental collections, museum specimens, and a fisheries-independent monitoring study. We examine the dispersion and spatial distribution of loricariid catfishes and brown hoplo. The abundance of loricariid fishes and brown hoplo appears to increase during the sampled time in the west-central part of Florida. We are examining samples (2001–2003) of *P. (L.) disjunctivus* and brown hoplo from the Hillsborough River to describe larval development. We are documenting morphological changes to distinguish *P. (L.) disjunctivus* from 2 other congeneric species established in Florida. Additionally, abundance, growth rate, and age of sexual maturation are being evaluated; these parameters will be compared with data from native localities in South America. [ramon.ruiz-carus@fwc.state.fl.us]



SHIFTS IN PHYTOPLANKTON, MACROALGAE, AND SEAGRASS WITH CHANGING NITROGEN LOADING RATES TO HILLSBOROUGH BAY, TAMPA BAY, FLORIDA

R. Johansson

ABSTRACT

Large ecological changes have occurred in Hillsborough Bay over the last century. During the first half of the 1900s, the shallow areas at the periphery of the bay had extensive seagrass meadows. Increasing population and expanding industrial development resulted in a period of severe eutrophication between the 1960s and early 1980s. At the end of this period, phytoplankton and macroalgae were at high abundance, and seagrass had essentially been eliminated. Improved treatment of wastewater from primarily point sources reduced the loading of inorganic nitrogen to the bay by about 60% from the late 1970s to the mid-1980s. Following the load reduction, phytoplankton and macroalgae abundance declined substantially and seagrass began to gradually recolonize the shallow areas. The observed shifts of these three important plant communities with increasing eutrophication is similar to scenarios observed in many other estuarine and marine systems, i.e. elevated rates of nitrogen loading leads to increased phytoplankton and macroalgae abundance, and the eventual loss of seagrass. To date, few marine systems have achieved a reversal in eutrophication and the scenario of restoration is less certain. The recent shifts in major primary producers in Hillsborough Bay suggest that eutrophication is reversible even in a severely impacted system. Further, the recovery process appears to follow a sequence that is the reversal of the eutrophication process. Albeit, seagrass restoration appears to occur at a slower rate than at which the losses occurred. With continued management of eutrophication, though, extensive seagrass meadows may eventually return to the shallow areas and seagrass may again become a major contributor to the trophic structure of Hillsborough Bay.

INTRODUCTION

Tampa Bay, and specifically Hillsborough Bay (Figure 1), has undergone extensive ecological changes over the last 100 years. A period of worsening bay conditions occurred from the mid 1960s to early 1980s concurrent with increases in population growth and expanding industrial development. A second period characterized by improving conditions, starting in the mid 1980s and still ongoing, was initiated by aggressive controls of nutrient (nitrogen) discharges from primarily point sources during the late 1970s and mid 1980s. Detailed documentation of ecological improvements in Hillsborough Bay during the period of recovery have been provided by Avery (1997), Boler (2002), Janicki and Wade (1996), Johansson (1991), Johansson and Lewis (1992), Johansson (2002) and Lewis et al. (1998).

Patterns and trends will be discussed that have developed between the three important Hillsborough Bay plant communities: phytoplankton, macroalgae, and seagrass, in an apparent response to large scale changes in nitrogen loading rates over the last century. Other primary producers, specifically benthic microalgae, are also substantial contributors to the system and have most probably been impacted by the changes in nitrogen loading. However, only limited information exists on the benthic microalgae community in Tampa Bay. This report will therefore be limited to the three plant groups that are better understood and that have been the subject of long-term studies.

The response of phytoplankton, macroalgae, and seagrass to altered nitrogen loading rates has also been investigated in numerous other marine systems and laboratory studies (see Duarte 1995). As a result of the worsening trend of eutrophication worldwide, these studies have to date generally reported on results from increasing nitrogen loading rates (e.g. Short et al. 1995; Taylor et al. 1995; Valiela et al. 1997). Relatively few examples exist of marine systems that have recovered, or are in the process of recovery, from eutrophication (see Duarte 1995). It has, however, been demonstrated from mesocosm experiments and field studies that a reversal of eutrophication is needed to restore lost important estuarine habitats, such as seagrass (e.g. Hauxwell et al. 2001; Short et al. 1995). Due to the paucity of examples of recovering shallow estuarine systems, the ongoing improvements in Hillsborough Bay

offers an excellent opportunity to expand the understanding of potential outcomes and time scales of estuarine recovery.

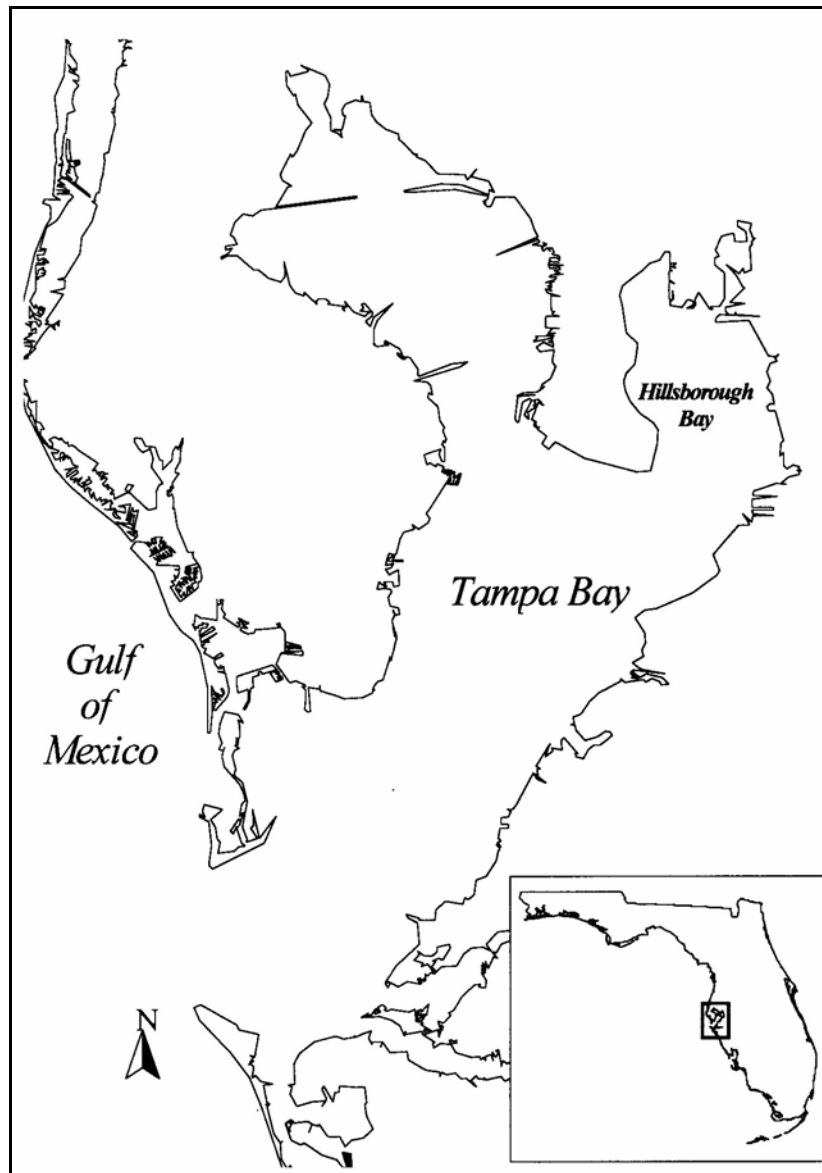


Figure 1. Map of Tampa Bay showing the location of Hillsborough Bay. Map kindly provided by Mote Marine Laboratory.

NITROGEN LOADING

Degraded water quality and decomposing algae along the shorelines of Hillsborough Bay occurred intermittently in the early 1940s. The degradation apparently intensified during the 1960s to the point that citizen complaints initiated efforts by local governments to improve bay conditions. A comprehensive study of Hillsborough Bay in 1967 and 1968 (FWPCA 1969) identified several major contributors to the degradation. The City of Tampa's wastewater treatment plant, which at that time discharged wastewater with relatively low levels of treatment to the upper portion of the bay, was the major individual nitrogen source. Other large nitrogen sources included several agricultural fertilizer processing facilities that discharged directly to the bay or to bay tributaries. A large fraction of the discharge from the

major sources consisted of inorganic nitrogen (DIN) that is readily available for plant growth. The FWPCA study recommended large reductions in nitrogen loading in order to reverse the degradation.

These recommendations and subsequent federal and state legislation assisted the City of Tampa to upgrade its wastewater plant from primary to advanced treatment in 1979. Also during this period, many fertilizer facilities greatly reduced their nitrogen effluents. The DIN loading from the major sources was reduced by about 60 percent between 1978 and 1984, which resulted in an annual reduction of nearly 200 kg DIN/ha to Hillsborough Bay (Figure 2A).

PHYTOPLANKTON

Phytoplankton biomass was first measured in Tampa Bay and Hillsborough Bay in the early 1950s (Marshall 1956). This pioneering study found relatively low biomass at that time (Figure 2A). A decade later more detailed phytoplankton biomass monitoring was initiated (see Johansson 1991), which also found relatively low biomass in Hillsborough Bay during the early to mid-1960s. However, during the following 20 years, phytoplankton biomass increased at a near steady rate and annual concentrations of chlorophyll-*a* increased from about 15 µg/l to near 50 µg/l. The high concentrations, at least during the latter portion of this period, were partly caused by late summer to early winter blooms of a large planktonic blue-green alga (*Schizothrix calcicola* sensu Drouet).

A few years following the nitrogen load reductions in the late 1970s and early 1980s, phytoplankton biomass rapidly decreased to levels similar to those found in the early to mid-1960s. This large decrease was in part due to the collapse of the blue-green alga population. Today, this alga is rarely encountered. This is a major change from the period of maximum abundance when this alga often reached concentrations of 30,000 filaments/ml throughout the water column. Now, a diverse population of estuarine diatoms most often dominates the community. However, several forms of dinoflagellates occasionally bloom in the bay, often after heavy rains during the warmer period of the year.

MACROALGAE

Massive drifts of macroalgae, primarily *Gracilaria* spp., often accumulated on the shallow sand flats in Hillsborough Bay and along seawalls near downtown Tampa during the 1950s and 1960s (FWPCA 1969). The FWPCA study, and a subsequent study in the early 1980s (Mangrove Systems 1985), both reported on high macroalgae abundance in Hillsborough Bay. The City of Tampa initiated a macroalgae study in 1986 that is still ongoing (see Kelly 1995). It is difficult, however, to quantitatively compare the results from the early studies with the City of Tampa study due to methodological differences. The record of macroalgae abundance is therefore uncertain prior to and during the period of the large nitrogen reductions.

The City of Tampa monitors macroalgae biomass and species composition in Hillsborough Bay from monthly trawl collections, and also estimates area coverage from frequent low-level flights. Both efforts show similar trends and indicate a very large reduction in macroalgae over the last 16 years. Area coverage has decreased by an order of magnitude and is currently less than 50 ha on an average day (Figure 2B). Standing crop has decreased from a peak of near 150 tons wet weight on an average day in 1988 to less than 5 tons since 1997.

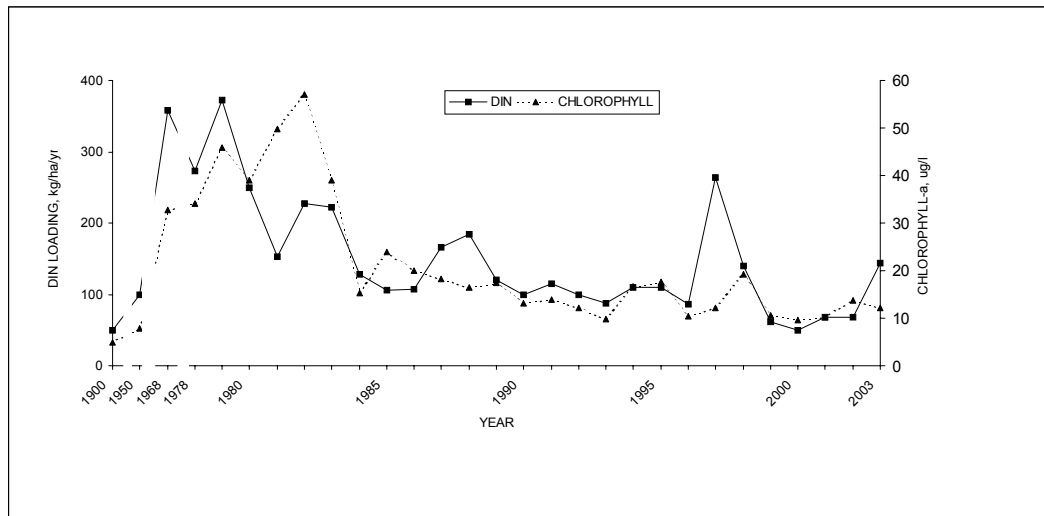


Figure 2A. Annual inorganic nitrogen (DIN) loading rates to Hillsborough Bay and annual Hillsborough Bay chlorophyll-a concentrations.

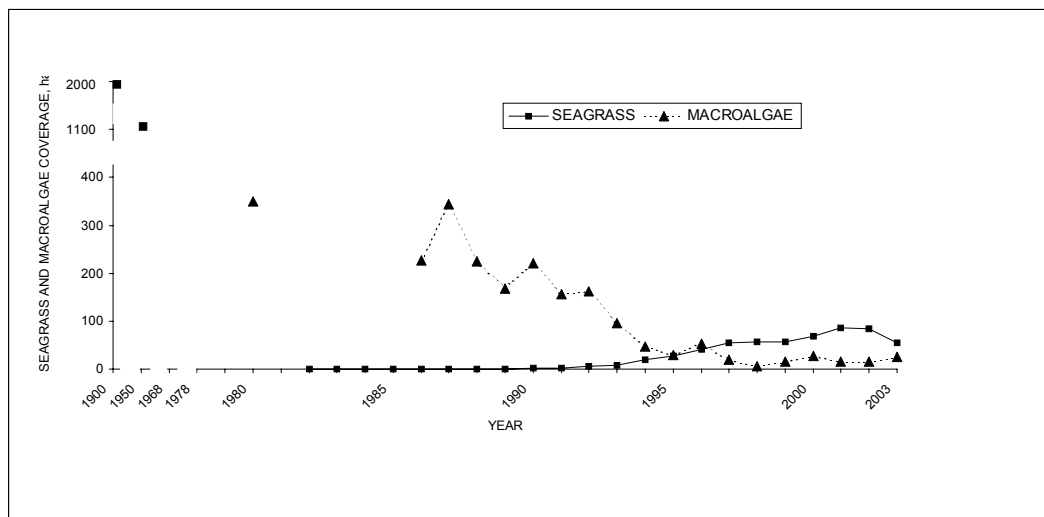


Figure 2B. Annual areal coverage of seagrass and macroalgae in Hillsborough Bay.

SEAGRASS

Seagrass meadows may have covered the entire shallow shelf at the perimeter of Hillsborough Bay in the late 1800s (Lewis et al. 1985). If so, Hillsborough Bay would then have had approximately 2000 ha of seagrass. The first Hillsborough Bay seagrass estimate based on interpretation of high altitude photography was from 1948 photos (TBRPC 1986). The area covered by seagrass at that time was about 1000 ha. The next estimate, from 1982 photography (Haddad 1989), detected no seagrass in Hillsborough Bay. The latter effort coincided with the period of maximum phytoplankton biomass and also high abundance of macroalgae.

During the mid-1980s, concurrent with the substantial reductions in phytoplankton biomass, sporadic colonization by the seagrass *Halodule wrightii* (shoal grass) began on the shallow sand flats at the perimeter of Hillsborough Bay. The rate of seagrass colonization increased gradually during the early and mid-1990s, concurrent with the large reductions in macroalgae

abundance. Ground and aerial seagrass surveys conducted by the City of Tampa since 1986 have shown that seagrass coverage has increased from near zero in 1986 to a maximum of about 85 ha in 2002 (COT 2004a; Figure 2B).

TRENDS IN TROPHIC STRUCTURE

The three plant groups have to this point been reviewed in various and not easily comparable units of biomass and abundance. To better illustrate their relative importance to the trophic structure of Hillsborough Bay, the following discussion will focus on the contribution of these plants to system carbon production.

The COT has measured phytoplankton production *in situ* in Hillsborough Bay since the late 1970s (COT 2004b). Phytoplankton production prior to initiation of field measurements was estimated from early Tampa Bay phytoplankton biomass values (Marshall 1956) and near-shore Gulf of Mexico primary production measurements (Johansson 1975).

Seagrass and macroalgae production rates were derived from area coverage estimates that were converted to carbon production, using literature and in-house derived conversion constants and field measurements. Seagrass production was estimated to be 2.4 tons C/ha/yr. This rate was determined from field measurements of *H. wrightii* in Hillsborough Bay and the rate includes production estimates of epiphytic algae (Avery personal com.). Macroalgae production was estimated to be 2 tons C /ha/yr based on rates reported by Iannuzzi et al. (1996). It should be noted that information on, specifically, macroalgae abundance is scarce prior to the mid 1980s and, therefore, the total production estimates of the three plant groups prior to that period are subject to much uncertainty.

The contribution of carbon production by different plant groups to the Tampa Bay system has been reviewed previously by Johansson (1985) and Lewis and Estevez (1988). Tampa Bay, including Hillsborough Bay, has a large deep area in comparison to shallow areas that are suitable for seagrass and macroalgae growth. Therefore, phytoplankton appear to have dominated bay-wide production in both Tampa Bay as a whole, and Hillsborough Bay, during recent times.

Phytoplankton production has historically been less dominant over the shallow areas at the perimeter of Hillsborough Bay where seagrass and macroalgae are found (Table 1). During the first half of the last century, seagrass potentially contributed 80%, or more, of the combined shallow area production by the three plant communities. However, as seagrass rapidly declined during the mid-1900s, and became virtually extinct during the 1970s, phytoplankton and macroalgae increased in abundance and became the principal carbon producers, contributing approximately 80% and 20%, respectively, of the shallow area primary production. Following the large nitrogen reductions 25 years ago, phytoplankton and macroalgae carbon production decreased substantially. As a result of seagrass recolonization, seagrass again began to contribute carbon to the system, albeit at a low level. However, phytoplankton continued to dominate the shallow area production.

Today, as a result of the recent reduction in macroalgae biomass, and gain in seagrass coverage, seagrass production is approaching the proportion of the shallow system production that potentially was supplied by macroalgae during the period of high nitrogen loading. Further, the total amount of carbon produced today over the shallow areas by the three plant groups may only be half or less of the production when seagrass dominated the system. Assuming that nitrogen loading at that time was considerably lower, it then follows that the seagrass dominated system was much more efficient in utilizing available nitrogen than

today's phytoplankton dominated system. A high nutrient utilization efficiency of seagrass in comparison to phytoplankton and macroalgae has also been found in other marine systems (see Duarte 1995; Kemp 2000).

Table 1. Estimated annual carbon production by phytoplankton, macroalgae and seagrass over the shallow areas (< 2 m) in Hillsborough Bay during several time periods over the last century.

TIME PERIOD	PHYTOPLANKTON		MACROALGAE		SEAGRASS + EPIPHYTES	
	tons C/yr	Percent	tons C/yr	Percent	tons C/yr	Percent
ca. 1900	1000*	17	30*	> 1	4700*	82
ca. 1950	1500*	37	100*	3	2400	60
ca. 1980	3700	83	700*	16	0	0
ca. 1990	2200	82	400	15	70	3
ca. 2000	1700	88	40	2	200	10

*estimates with high uncertainty

CONCEPTUAL SCHEME OF BAY DEGRADATION AND RECOVERY

The ongoing eutrophication of estuaries and other marine systems worldwide has created a need for tools to explain ecological trends and to predict future conditions. In many shallow estuaries and coastal systems, empirical relationships have been used to relate individual components of submerged aquatic vegetation with water quality conditions as a result of changes in nitrogen loading. Tools that include interactions between multiple components of the benthic plant community and the water column are less common.

Valiela et al. (1997) used observations from several small embayments of the Waquoit Bay estuary to quantitatively describe how increased loading rates of nitrogen would result in macroalgae and phytoplankton blooms that eventually may replace seagrass as the dominant primary producer. Similar scenarios of shifts in these plant communities with increasing eutrophication have also been reported in other marine systems and from laboratory experiments (e.g. Duarte 1995; Short et al. 1995; Taylor et al. 1995).

To date, relatively few impacted marine systems have experienced a reversal in eutrophication. However, as more systems are being managed for nutrient controls, questions arise about the potential for successful restoration of important habitats. In shallow estuarine systems, an understanding of requirements to restore lost seagrass is often of primary importance (e.g. Hauxwell 2001; Short et al. 1995). The trophic changes in Hillsborough Bay over the last 100 years, and specifically the changes during the recent period of recovery, offers an opportunity to evaluate the response of seagrass, and other important estuarine plant communities, to large scale changes in nitrogen loading.

A schematic, similar to one provided by Valiela et al. (1997), was constructed to conceptually illustrate changes in nitrogen loading rates and carbon production by the three plant groups in the shallow areas of Hillsborough Bay over the last century (Figure 3). In Hillsborough Bay, as in many other estuaries affected by eutrophication, increased nitrogen loading rates initiated a scenario that resulted in phytoplankton and macroalgae increases and seagrass loss. Although, the record of nitrogen loading for the early portion of the degraded period in Hillsborough Bay is quite uncertain, a best estimate suggests that the period of major seagrass loss almost 50 years ago was initiated when the loading rate surpassed 200 kg DIN/ha/yr. It should be noted that this was also a period of major dredging operations in Hillsborough Bay that caused additional seagrass loss. At the peak of the degradation period in the late 1970s and early 1980s, the loading rate was near 350 kg DIN/ha/yr. At that time, seagrass was

virtually absent from the bay and the system was dominated by phytoplankton, but macroalgae were also abundant.

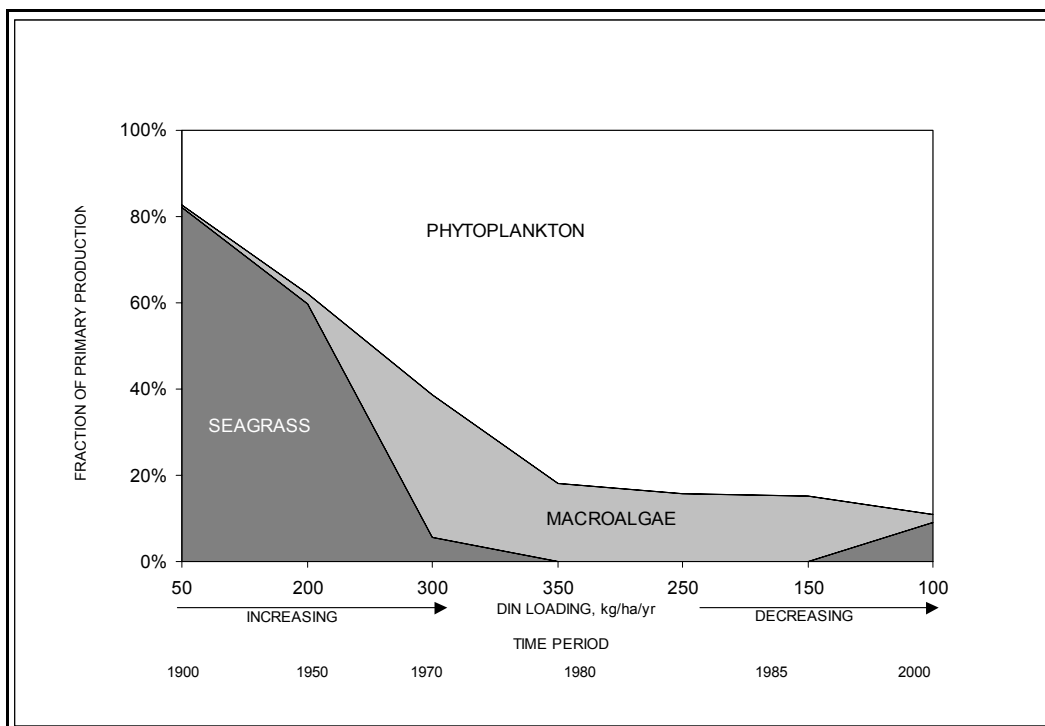


Figure 3. Generalized schematic depicting estimate proportions of phytoplankton, macroalgae and seagrass production in shallow areas of Hillsborough Bay, and changes in estimated inorganic nitrogen (DIN) loading rates to Hillsborough Bay, over the last century. Time periods are approximate. Format adopted from Valiela et al. 1997.

Following the large nitrogen loading reduction two decades ago, that reduced loading rates from near 350 kg DIN/ha/yr to about 150 kg DIN/ha/yr, macroalgae became less abundant and seagrass began to recolonize shallow areas. Smaller improvements in nitrogen loading have continued during the recent decade. Seagrass recolonization has progressed at a modest rate during this period and macroalgae abundance appears to have stabilized at a relatively low level. Phytoplankton, however, still dominate the shallow system production.

The recent changes of major primary producers in Hillsborough Bay suggest that the recovery process in this estuary follows an overall sequence that is the reversal of the eutrophication process. Albeit, the rate of restoration of the communities discussed may be different than the rates at which they were degraded. Improvements in water quality and the phytoplankton population occurred within a few years following the large DIN loading reduction during the late 1970s and early 1980s. It appears, specifically for phytoplankton, that biomass reductions occurred at a faster pace than the increase during the extended period of degradation. It is difficult to compare differences in time scales of macroalgae abundance due to the paucity of information. The recovery of lost seagrass habitat, in contrast to improvements in phytoplankton biomass, appears to occur more slowly than the rate of destruction. To illustrate, 1000ha of seagrass appear to have been lost in Hillsborough Bay during the 20 year period of worsening bay condition, a period that also included potentially large impacts from dredging operations. In contrast, less than 100ha have been recovered over the last 20 years following the bay improvements.

Although the restoration of seagrass meadows in Hillsborough Bay proceeds at a slow pace compared to the rapid losses historically, continued nitrogen management may eventually allow for seagrass meadows to flourish. However, phytoplankton will most likely continue to dominate the trophic structure of Hillsborough Bay in the foreseeable future.

CONCLUSION

This report has focused on the shifts of three important Hillsborough Bay plant communities: phytoplankton, macroalgae, and seagrass that have occurred concurrent with major changes in nitrogen loading to the system.

The changes observed in these communities as the bay underwent a period of severe anthropogenic impacts during the 1960s and 1970s are similar to scenarios observed in many estuarine and marine systems that have been affected by increased eutrophication. In these systems, as in Hillsborough Bay, elevated rates of nitrogen loading led to increases in phytoplankton and macroalgae, and loss of seagrass.

A period of improving bay conditions, that started in the mid-1980s and that is still ongoing, resulted from aggressive controls of primarily point source nitrogen discharges to Hillsborough Bay. Following these reductions, phytoplankton and macroalgae declined and seagrass began to recolonize shallow areas.

To date, relatively few marine systems have achieved a reversal in eutrophication and potential scenarios of restoration of the three plant communities discussed are less well known. However, the recent changes of major primary producers in Hillsborough Bay suggest that the recovery process follows a sequence that is the reversal of the eutrophication process.

Further, the rates of restoration, specifically for the phytoplankton and seagrass communities, appear different than the rates at which they were impacted. Phytoplankton biomass reductions appear to have occurred faster than the increase during the extended period of degradation. The ongoing recovery of lost seagrass habitat, in contrast, appears to occur more slowly than the rate of destruction. Nevertheless, with continued nitrogen management seagrass may again become a major contributor to the trophic structure of Hillsborough Bay.

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WATER QUALITY IN TIDAL REACHES OF HILLSBOROUGH COUNTY RIVERS AND STREAMS

G. Morrison & R. Boler

ABSTRACT

Tidal reaches of rivers and streams play an important role in the ecology of Tampa Bay, providing reduced-salinity habitats that are used as nursery areas by a number of estuarine-dependent fish and shellfish species. Bay managers have identified the protection and restoration of these habitats as a priority issue. Human activities, including dredging, filling, channelization and shoreline hardening have caused direct physical impacts in the tidal reaches of many of the bay's tributaries. In addition, hydrologic modifications associated with regional transportation, flood protection, stormwater conveyance, potable water supply, and wastewater treatment systems have altered the quantity, quality, location and timing of freshwater inflows to the tidal reaches of many tributaries. Analysis of recent water quality data from 10 stations monitored by the Environmental Protection Commission (EPC) of Hillsborough County suggests that future management efforts in these areas will involve a number of issues. On the positive side, significant reductions in annual mean DIN concentrations occurred at six of the 10 monitoring locations during the period 1984–2003, presumably reflecting the nitrogen load reduction efforts that have been underway in the Tampa Bay watershed since the early 1980s. However, DIN concentrations also showed significant increasing trends at four monitoring sites during the period 1994–2003, raising the possibility that the effectiveness of nitrogen management efforts may have declined in some portions of the watershed in recent years. Other potential water quality issues evident in the monitoring data include exceedances of the State's estuarine chlorophyll-*a* guideline, an increasing frequency of mid-depth DO concentrations < 4 mg/L, occurrences of mid-depth hypoxia, and possible changes in salinity regimes and salinity/rainfall relationships at several monitoring stations. In recent years a great deal of management attention has focused on the restoration of water quality and seagrass-based habitats in the open-water portions of Tampa Bay. Given the anthropogenic stresses currently affecting tidal streams, and the importance of their low-salinity habitats to the overall ecology of the bay, it appears appropriate to focus future management attention on these areas and issues as well.

INTRODUCTION

In addition to the open waters of the bay itself, the Tampa Bay estuary includes tidal portions of four rivers—the Hillsborough, Alafia, Manatee and Little Manatee—and more than 30 smaller streams that drain coastal portions of Hillsborough, Pinellas and Manatee counties (TBRPC 1986). The tidal reaches of these rivers and streams play an important role in the ecology of the bay, providing reduced-salinity habitats that are used as nursery areas by the immature stages of a number of estuarine-dependent species including shrimp, blue crabs, seatrout, anchovies, silver perch, menhaden, spot, striped mullet, red drum and snook (Flannery 1989, Browder 1991, Edwards 1991, Estevez et al. 1991, Peebles et al. 1991). Protection and restoration of low-salinity habitats has been identified as a priority issue by the Tampa Bay Estuary Program (TBEP) and its partners (TBEP 1996).

Several urban centers are located along the shoreline of Tampa Bay, including the cities of Tampa and St. Petersburg and their associated suburban communities. As a result, reduced-salinity habitats in the tidal reaches of many of the bay's tributaries have been physically removed or altered by activities such as dredging, filling, channelization and shoreline hardening (TBRPC 1986, Clark 1991). Extensive physical modifications—including the construction of shipping channels, dredge disposal islands, and causeways and bridges—have also occurred in the bay itself, particularly between the 1880s and early 1970s, altering the circulation and flushing characteristics of several bay segments (Goodwin 1987). In addition to these direct physical impacts the construction of urban infrastructure, including regional transportation, flood protection, stormwater conveyance, potable water supply and municipal wastewater treatment systems, have resulted in hydrologic modifications that have altered the quantity, quality, location and timing of freshwater inflows to the tidal reaches of many tributaries (Flannery 1989, Flannery et al. 1991, Zarbock 1991, Stoker et al. 1996).

Conceptually, important nursery areas for estuarine-dependent organisms are believed to occur in locations where favorable “dynamic habitats”—defined by salinity and other water quality attributes—coincide with favorable “stationary habitats” which are defined by shoreline and bottom types, dominant plant communities, and related physical and biological attributes (Browder 1991). This widely-used conceptual model suggests that salinity and other water quality characteristics play an important role in determining the environmental quality and productivity of the habitats present in tidal rivers and streams (Edwards 1991, Estevez et al. 1991).

The Environmental Protection Commission (EPC) of Hillsborough County performs monthly water quality monitoring in Tampa Bay and a number of its tributaries, providing a data set that can be used to characterize water quality status and trends in these areas (Boler et al. 1991). The purpose of this paper is to give an overview of water quality conditions in the tidal reaches of nine streams that drain portions of Hillsborough County and discharge to Tampa Bay. It focuses on four parameters—dissolved inorganic nitrogen, chlorophyll-*a*, dissolved oxygen, and salinity—that are helpful for characterizing some important water quality-related attributes of estuarine habitats in these areas.

MONITORING LOCATIONS AND METHODS

The EPC monitoring network currently includes 99 stations, 55 in Tampa Bay and 44 in rivers, streams and lakes within the Tampa Bay watershed. Ten of these stations are located in the downstream, tidally-influenced reaches of tributary streams (Fig. 1) and have been monitored on a monthly basis since at least 1984, providing a sufficient period of record to characterize longer-term trends in water quality while reducing the confounding effects of extreme hydrologic events (e.g., droughts, El Niño periods, tropical storms) that can cause pronounced year-to-year fluctuations in water quality.

The 10 long-term tidal-reach monitoring locations, shown in Fig. 1, include:

- Sta. 101, Double Branch Creek at Hillsborough Avenue
- Sta. 102, Channel “A” at Hillsborough Avenue
- Sta. 103, Rocky Creek at Hillsborough Avenue
- Sta. 104, Sweetwater Creek at Hillsborough Avenue
- Sta. 105, Hillsborough River at Rowlett Park Drive
- Sta. 137, Hillsborough River at Columbus Drive
- Sta. 109, Palm River at U.S. Highway 41
- Sta. 133, Delaney Creek at U.S. Highway 41
- Sta. 74, Alafia River at U.S. Highway 41
- Sta. 112, Little Manatee River at U.S. Highway 41

Field and laboratory methods used in the monitoring program have been summarized by Boler et al. (1991) and Boler (2001). Each station is sampled on a monthly basis. Four sampling runs are performed each month, in consecutive weeks, with the first three runs focusing on bay stations and the fourth focusing on river, stream and lake stations. Currently, hydrographic parameters (water temperature, DO, pH, specific conductance) are measured at three points in the water column (near-surface, mid-depth, and near-bottom) using Hydrolab® multi-probe instruments. Samples for water chemistry analysis are collected at mid-depth at Tampa Bay stations, and at a depth of 0.5m (or at mid-depth, if total station depth is less than 1m) at tributary stations. Laboratory analyses are conducted in accordance with standard methods and a state-certified quality assurance program.

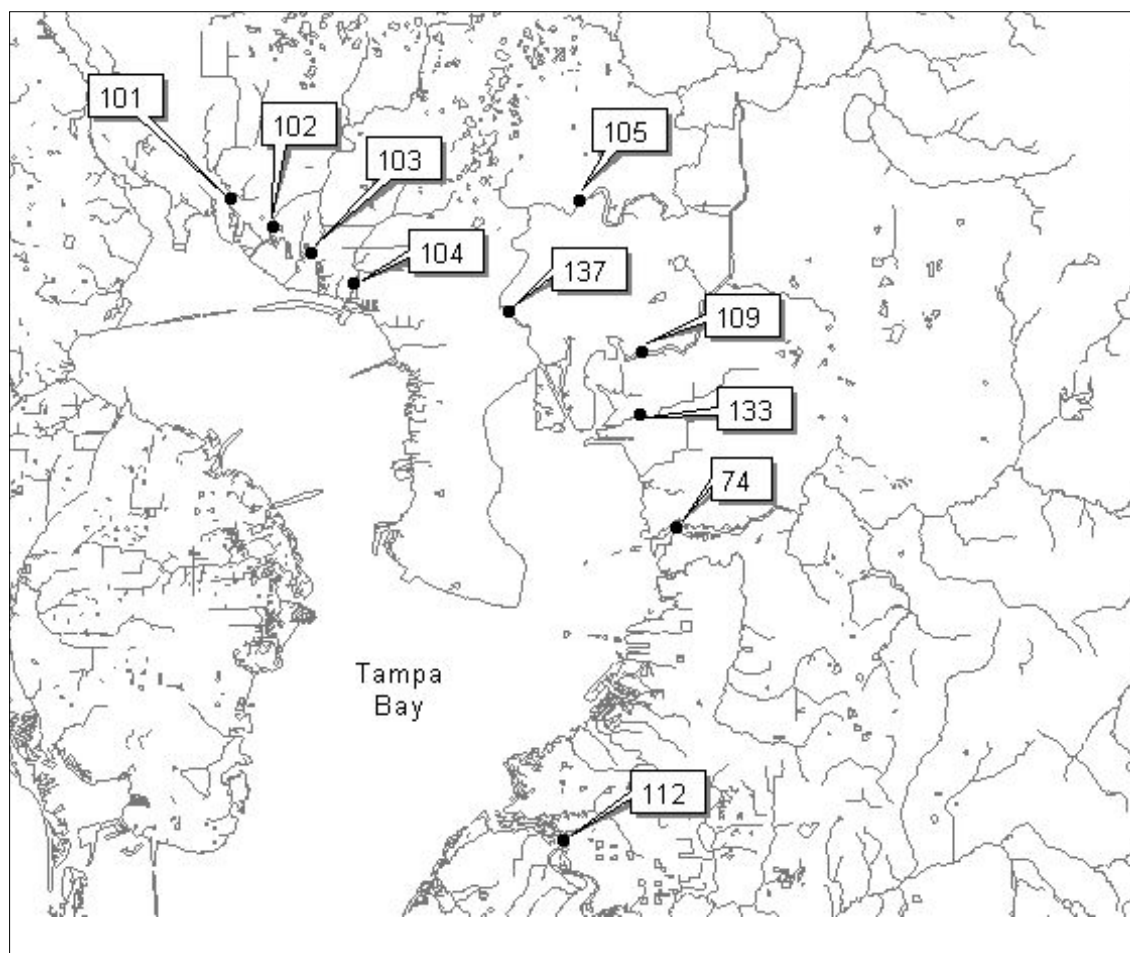


Figure 1. Locations of EPC tidal stream monitoring stations.

During the course of the monitoring program some sampling methods used at the tributary stations, including the tidal stream stations addressed in this report, have changed in ways that could potentially affect data variability and comparability. Prior to 1987, for example, hydrographic measurements at tributary stations were made only at mid-depth. Since 1987, near-surface and near-bottom measurements have also been made. From 1996 through 2002, concentrations of nutrients, chlorophyll, and other laboratory analytes were measured using water samples collected at mid-depth. Prior to 1996, and since 2002, laboratory analytes have been measured using near-surface samples, collected at depths of 0.3m to 0.5m.

All annual results reported here were calculated on a water year (October through September) rather than a calendar year (January through December) basis, for consistency with the rainfall and river flow data provided by the Southwest Florida Water Management District and the U.S. Geological Survey.

RESULTS

Dissolved Inorganic Nitrogen

Concentrations of dissolved inorganic nitrogen (DIN) often increase in estuaries whose watersheds are undergoing development. Human activities produce a variety of point and non-point source DIN discharges, increasing the annual loads of DIN discharged to coastal waters above the levels that occurred under pre-development conditions. In Tampa Bay long-term increases in nitrogen loadings have been linked to long-term changes in algal

productivity, chl-*a* concentrations, water clarity, and seagrass coverage (Johansson 1991, Greening 2002). As a result, the control of anthropogenic nitrogen loads is currently the highest priority of the baywide water quality management effort (Zarbock et al. 1994, Janicki and Wade 1996, TBEP 1996).

DIN levels, 1999–2003

Box plots summarizing DIN concentrations measured at each of the 10 tidal stream stations during water years 1999 through 2003 are shown in Fig. 2. During that five-year period, mean values ranged between 0.08 mg N/L at station 109 (Palm River) and 2.9 mg N/L at station 133 (Delaney Creek). Delaney Creek has received a variety of nitrogen-rich point and non point-source discharges, and has shown elevated DIN concentrations, since the beginning of the EPC monitoring program (Boler et al. 1991).

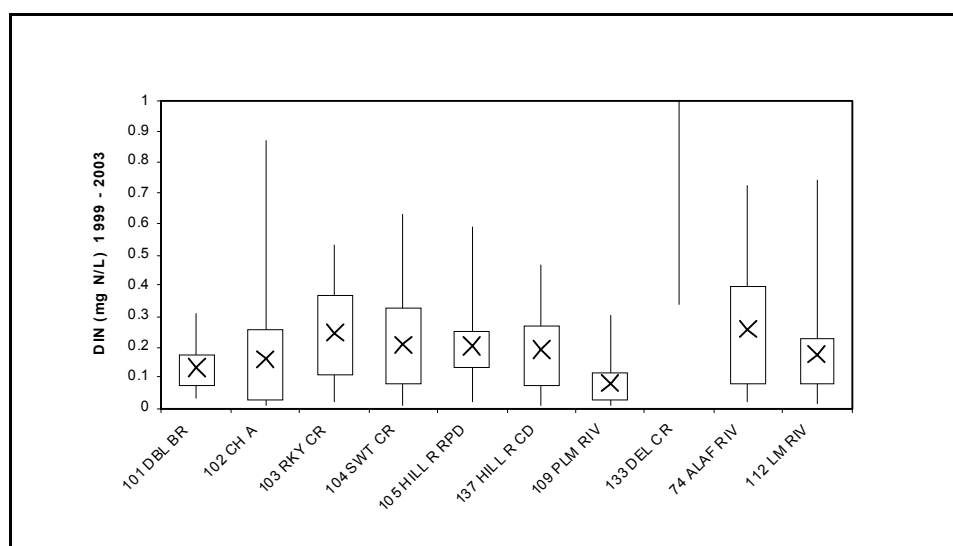


Figure 2. Boxplots summarizing dissolved inorganic nitrogen (DIN) concentrations, water years 1999 through 2003. Statistics plotted include mean (X), 25th and 75th percentiles (rectangles), and overall range (vertical lines).

When interpreting the ecological relevance of measured DIN concentrations, values in the range of 0.005–0.02 mg N/L are of particular interest. Nutrient uptake experiments have shown that concentrations in this range can limit the growth rates of many species of estuarine phytoplankton (Chapra 1997). In situations where ambient DIN concentrations are above this level, the growth rates of these species are not expected to be strongly limited by N availability.

Although DIN concentrations at the EPC tidal stream stations occasionally dropped to potentially limiting levels, at a frequency that appears to have increased at a number of stations in recent years, pronounced N limitation does not appear to have been a common occurrence at these stations during the years 1999 through 2003. No station exhibited a first quartile DIN concentration less than 0.02 mg N/L (Fig. 2), indicating that more than 75 % of the samples collected at each station during the 1999–2003 period exceeded that value. Similar results, indicating that ambient DIN concentrations were usually above the levels that would limit phytoplankton growth, have also been reported from the tidal reaches of the Alafia and Little Manatee rivers by Vargo et al. (1991) based on bioassay experiments, and from portions of Tampa Bay by Wang et al. (1999) based on a mechanistic water quality

model. Although year-to-year variations in phytoplankton biomass in the open waters of the bay are known to be correlated with nitrogen loading rates (Johansson 1991, Janicki and Wade 1996), nitrogen availability does not appear to be a particularly strong or frequent factor limiting phytoplankton growth at the tidal tributary locations monitored by EPC.

DIN trends, 1984–2003

We used a nonparametric test of association (Kendall tau) to identify potential long-term trends in DIN concentrations during the 20-year period extending from 1984 through 2003. Results of the analysis are summarized in Table 1. Over the entire 20-year period, significant ($p < 0.05$) decreases in DIN concentration are evident at the Rocky Creek (sta. 103), Sweetwater Creek (sta. 104), Hillsborough River at Rowlett Park Drive (sta. 105), Palm River (sta. 109), Alafia River (sta. 74) and Little Manatee River (sta. 112) sites. A marginally significant ($p < 0.10$) decrease occurred at the Delaney Creek (sta. 133) site.

Table 1. Nonparametric (Kendall tau) trend analysis of annual mean DIN concentrations. (Significance levels: **** < 0.005 ; *** < 0.01 ; ** < 0.05 ; * < 0.10 ; $- > 0.10$)

EPC STATION	TIME PERIOD 1984–2003		TIME PERIOD 1984–1993		TIME PERIOD 1994–2003	
	Tau	Signif. level	Tau	Signif. level	Tau	Signif. level
101 Double Branch at Hillsborough Ave.	–	–	-0.64	***	+ 0.56	**
102 Channel A at Hillsborough Ave.	--	–	-0.58	**	+ 0.69	***
103 Rocky Creek at Hillsborough Ave.	-0.61	****	-0.51	**	–	–
104 Sweetwater Creek at Memorial Pkwy.	-0.38	**	-0.60	**	–	–
105 Hillsborough River at Rowlett Park Dr.	-0.43	***	–	–	–	–
137 Hillsborough River at Columbus Dr.	–	–	–	–	–	–
109 Palm River at U.S. 41	-0.47	****	-0.60	**	–	–
133 Delaney Creek at U.S. 41	-0.28	*	-0.91	****	+ 0.73	****
74 Alafia River at U.S. 41	-0.60	****	-0.51	**	-0.47	*
112 Little Manatee River at U.S. 41	-0.38	**	–	–	–	–

Trend analyses for the 10-year periods 1984–1993 and 1994–2003 are also shown in Table 1, and may have implications for Tampa Bay’s ongoing nitrogen load management program. For the period 1984 through 1993, seven of the 10 monitoring sites showed significant decreases in annual mean DIN concentrations. During the period 1994 through 2003 only one station (Alafia River [sta. 74]) showed a marginally significant ($p < 0.10$) reduction, while three stations (Double Branch [sta. 101], Channel A [sta. 102], and Delaney Creek [sta. 133]) showed significant increases. While only suggestive, these patterns raise the possibility that the effectiveness of nitrogen load reduction efforts may have peaked in a number of sub-basins in the mid-1990s, and that nitrogen loads from some sub-basins may have begun increasing once again during the 1994–2003 period.

Rainfall patterns may offer an alternative explanation for these observed trends in DIN concentrations. For example, tidal areas presumably receive larger annual nonpoint-source DIN loads during years of higher rainfall, due to the larger volumes of stormwater runoff that are generated during wet years. If they were present, upward or downward trends in annual rainfall during the 1984–2003 period thus might help to explain trends in DIN concentrations observed during the period.

To examine this possibility we obtained annual rainfall data for the Tampa Bay watershed from the Southwest Florida Water Management District (SWFWMD), which provides tabulated summaries of annual rainfall for each of the major hydrologic basins addressed by

its Comprehensive Watershed Management (CWM) program. We used the following approach to generate annual rainfall estimates for the catchments discharging to the EPC tidal tributary monitoring stations:

- Rainfall values reported by SWFWMD for the Tampa Bay/Coastal CWM Basin were used for EPC stations 101, 102, 103 and 104, which are located on streams discharging to upper Old Tampa Bay;
- Rainfall values from the Hillsborough River CWM Basin were used for the EPC stations located on the Hillsborough River and Palm River (stations 105, 109, and 137);
- Rainfall values from the Alafia River CWM Basin and the Little Manatee River CWM Basin were used, respectively, for EPC stations 74 (Alafia River) and 112 (Little Manatee River); and
- For EPC station 133, located on Delaney Creek, annual rainfall values were calculated by averaging the annual values reported by SWFWMD for the Hillsborough River and Alafia River CWM basins.

During the period 1984–2003 annual rainfall in each of these basins fluctuated a great deal from year to year, with the highest levels occurring in water years 1998 and 2003 (Fig. 3). Kendall tau correlation tests showed no significant trends in annual rainfall during either the 1984–2003, 1984–1993, or 1994–2003 periods. All *p* values produced by these tests were substantially greater than 0.10. Significant ($p < 0.05$) correlations between annual mean DIN concentration and annual rainfall were found at two EPC monitoring sites (Sweetwater Creek [sta. 104] and Palm River [sta. 109]), and a marginally significant ($p < 0.10$) association was found at one site (Rocky Creek [sta. 103]) over the 1984–2003 period (Table 2). Significant and marginally significant associations between DIN and rainfall were also found at small subsets of sites during the 1984–1993 and 1994–2003 periods (Table 2). Overall, however, on the basis of these analyses rainfall patterns do not appear to explain the 10-year or 20-year trends in annual mean DIN concentrations observed during the 1984–2003 period.

Chlorophyll-*a*

As with DIN, concentrations of chlorophyll-*a* (chl-*a*)—an indicator of phytoplankton biomass—often increase in estuaries as development occurs in their watersheds. Over time, as the human population of a watershed grows, anthropogenic activities tend to produce larger discharges of nutrients and organic matter, fueling higher levels of algal productivity and increasing concentrations of chl-*a* in coastal waters (Day et al. 1989).

Chlorophyll-*a* levels, 1999–2003

For the 10 tidal stream stations monitored by EPC, boxplots summarizing chl-*a* concentrations measured during the five-year period extending from 1999 through 2003 are shown in Fig. 4. During this period the lowest chl-*a* concentrations—mean values $< 7 \mu\text{g/L}$ occurred consistently at two monitoring sites: station 101 (Double Branch at Hillsborough Avenue) and station 112 (Little Manatee River at U.S. Highway 41). The highest mean concentrations, exceeding $20 \mu\text{g/L}$, occurred at stations 102 (Channel A) and 105 (Hillsborough River at Rowlett Park Drive). Mean concentrations $> 11 \mu\text{g/L}$ —the State of Florida’s current guideline for estuarine waters—also occurred at the Rocky Creek, Sweetwater Creek, Palm River, and Hillsborough River at Columbus Drive monitoring stations.

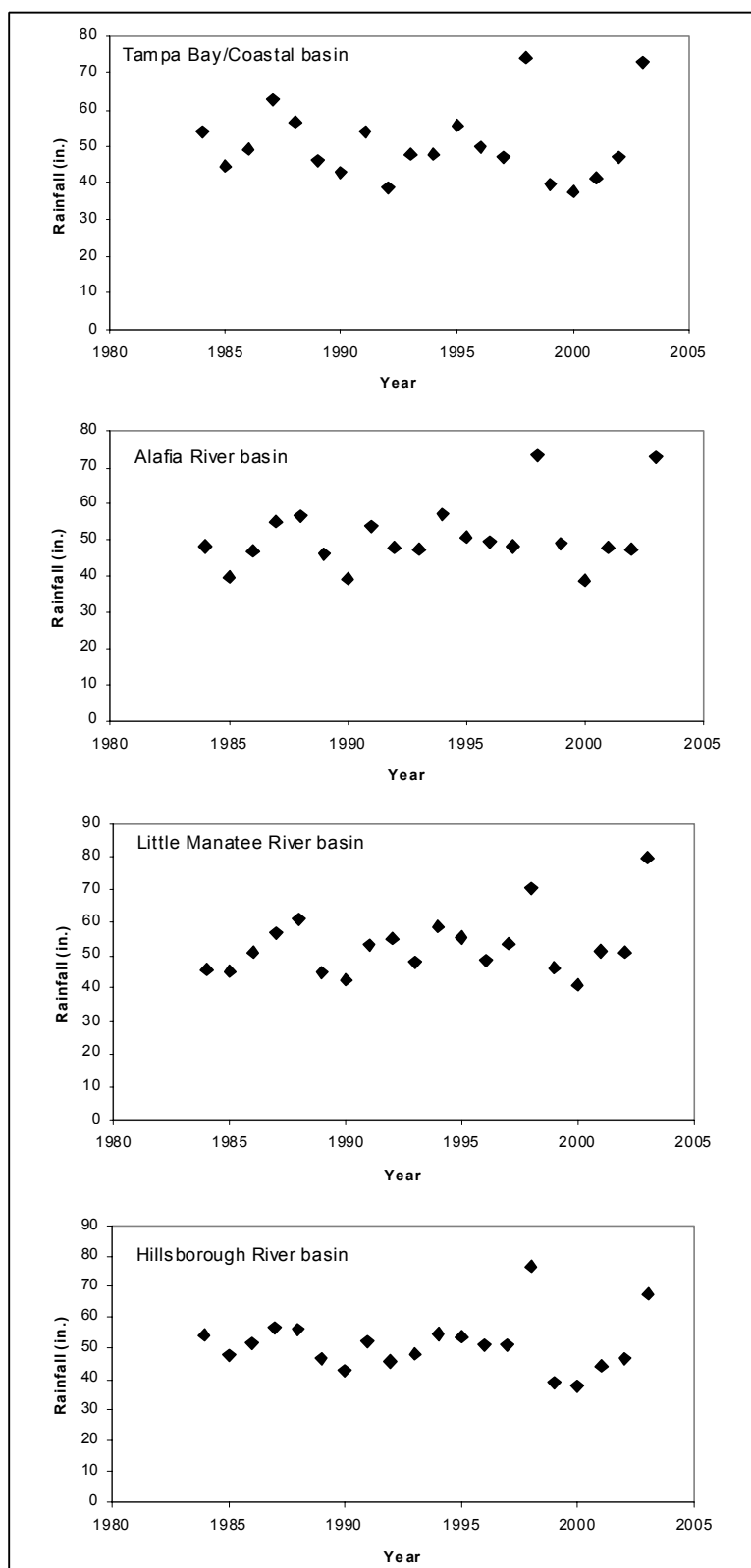


Figure 3. Scatterplots of annual basin rainfall versus year, water years 1984–2003.

Table 2. Associations between annual mean DN concentration (mg N/L) and two potential explanatory variables (inches of rainfall and year) at EPC monitoring stations during the years 1996 through 2002 and 1983 through 2002, estimated using stepwise regression

EPC STATION	Regression Equation	<i>p</i> value
1996–2002: 101 Double Branch at Hillsborough Ave.	—	> 0.10
102 Channel A at Hillsborough Ave.	$DIN = 0.060 + 0.015(\text{year})$	0.05
103 Rocky Creek at Hillsborough Ave.	$DIN = 0.32 + 0.015(\text{year})$	0.01
104 Sweetwater Creek at Memorial Pkwy	—	> 0.10
105 Hillsborough River at Rowlett Park Dr.	—	> 0.10
137 Hillsborough River at Columbus Dr.	—	> 0.10
109 Palm River at U.S. 41	—	> 0.10
133 Delaney Creek at U.S. 41	$DIN = 0.804 + 0.275(\text{year})$	0.02
74 Alafia River at U.S. 41	—	> 0.10
112 Little Manatee River at U.S. 41	$DIN = 0.06 + 0.002(\text{annual rainfall})$	0.02
1983–2002: 101 Double Branch at Hillsborough Ave.	$DIN = 0.181 - 0.004(\text{year})$	0.02
103 Rocky Creek at Hillsborough Ave.	$DIN = 0.666 - 0.025(\text{year})$	< 0.001
133 Delaney Creek at U.S. 41	$DIN = -3.05 + 0.47(\text{annual rainfall}) - 1.37(\text{year})$	0.003

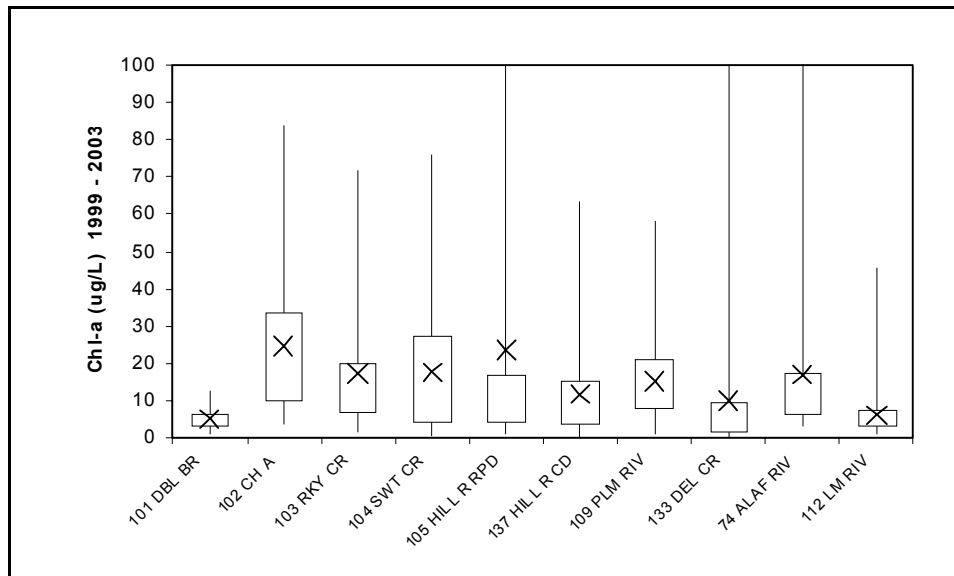


Figure 4. Chlorophyll-*a* boxplots, water years 1999–2003.

Chlorophyll-*a* trends, 1984–2003

We performed nonparametric correlation (Kendall tau) tests to identify potential trends in chl-*a* concentrations during the 20-year period 1984–2003 and the 10-year periods 1984–1993 and 1994–2003. Results of the analysis are summarized in Table 3. Over the entire 20-year period, significant ($p < 0.05$) reductions in chl-*a* concentration are evident at the Alafia River (sta. 74), Double Branch (sta. 101), and Palm River (sta. 109) sites. Marginally significant ($p < 0.10$) increases occurred at the Rocky Creek (sta. 103) and Sweetwater Creek (sta. 104) sites.

Dissolved Oxygen

The availability of dissolved oxygen (DO) plays an important role in determining aquatic habitat quality. Estuarine areas impacted by anthropogenic nutrient enrichment often show larger daily or seasonal variations in DO concentrations, due to more pronounced fluctuations in primary production and community respiration rates, than typically occur under pre-

development conditions (Day et al. 1989, Chapra 1997). Extended periods of low DO availability (concentrations < 4mg/L) are stressful to many organisms, and periods of hypoxia (DO concentrations < 2 mg/L) can be highly stressful or fatal to organisms that lack specific adaptations to deal with such conditions.

Table 3. Trend analysis (Kendall tau) of annual mean chlorophyll-*a* concentrations. (Significance levels: **** < 0.005; *** < 0.01; ** < 0.05; * < 0.10; - > 0.10)

EPC STATION	TIME PERIOD 1984–2003		TIME PERIOD 1984–1993		TIME PERIOD 1994–2003	
	Tau	Signif. level	Tau	Signif. level	Tau	Signif. level
101 Double Branch at Hillsborough Ave.	-0.47	****	–	–	–	–
102 Channel A at Hillsborough Ave.	–	–	–	–	–	–
103 Rocky Creek at Hillsborough Ave.	+0.27	*	–	–	–	–
104 Sweetwater Creek at Memorial Pkwy	+0.26	*	–	–	–	–
105 Hillsborough River at Rowlett Park Dr.	–	–	–	–	–	–
137 Hillsborough River at Columbus Dr.	–	–	–	–	-0.47	*
109 Palm River at U.S. 41	-0.42	**	–	–	–	–
74 Alafia River at U.S. 41	-0.33	**	-0.55	**	+0.47	*
133 Delaney Creek at U.S. 41	–	–	+0.51	*	–	--
112 Little Manatee River at U.S. 41	–	–	–	–	–	–

Mid-Depth DO Concentrations, 1999–2003

Boxplots summarizing mid-depth DO concentrations measured during the five-year period 1999 through 2002 are shown in Fig. 5. Mid-depth DO concentrations < 4 mg/L were measured during 25% or more of the sampling events at each monitoring site during the period. With the exception of the Little Manatee River station (sta. 112), mid-depth concentrations < 2 mg/L (indicative of hypoxic conditions) were also observed during at least one monthly sampling event at each site.

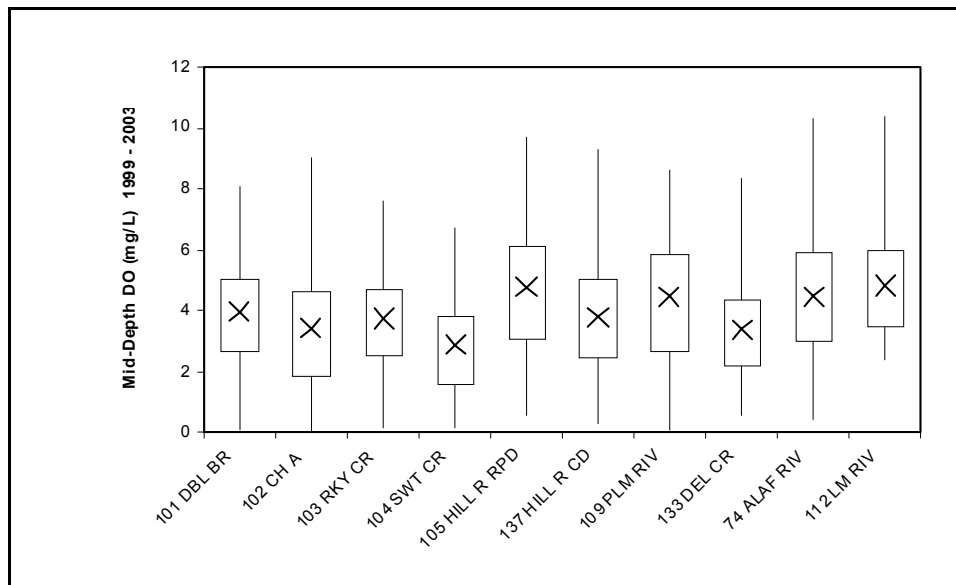


Figure 5. Mid-depth dissolved oxygen (DO) boxplots, water years 1999–2003.

Trends in the Frequency of Mid-depth DO Concentrations < 4 mg/L, 1984–2003

Nonparametric (Kendall tau) trend analysis detected increasing trends in the frequency of mid-depth DO concentrations < 4 mg/L at several sites during the 20-year period 1984 through 2003 (Table 4). Significant ($p < 0.05$) trends occurred at the Double Branch (sta. 101), Channel A (sta. 102), Hillsborough River at Rowlett Park Drive (sta. 105), Palm River (sta. 109), and Little Manatee River (sta. 112) sites. A marginally significant ($p < 0.10$) increasing trend occurred at the Alafia River (sta. 74) site. Shorter-term increasing trends were also found at a smaller subset of stations during the 1984–1993 and 1994–2003 periods (Table 4). These patterns indicate that the frequency of biologically stressful episodes caused by reduced mid-depth DO concentrations increased at 50% or more of the tidal stream stations monitored by EPC during the years 1984 through 2003.

Table 4. Trend analysis of annual frequency of mid-depth dissolved oxygen (DO) concentrations < 4 mg/L. (Significance levels: **** < 0.005; *** < 0.01; ** < 0.05; * < 0.10; – > 0.10)

EPC STATION	TIME PERIOD 1984–2003		TIME PERIOD 1984–1993		TIME PERIOD 1994–2003	
	Tau	Signif. level	Tau	Signif. level	Tau	Signif. level
101 Double Branch at Hillsborough Ave.	+ 0.46	**	–	–	–	–
102 Channel A at Hillsborough Ave.	+ 0.48	**	–	–	–	–
103 Rocky Creek at Hillsborough Ave.	–	–	–	–	+ 0.51	*
104 Sweetwater Creek at Memorial Pkwy	–	–	–	–	–	–
105 Hillsborough River at Rowlett Park Dr.	+ 0.39	**	+ 0.65	**	–	–
137 Hillsborough River at Columbus Dr.	–	–	+ 0.43	*	–	–
109 Palm River at U.S. 41	+ 0.36	**	+ 0.47	*	–	–
133 Delaney Creek at U.S. 41	--	–	–	–	–	–
74 Alafia River at U.S. 41	+ 0.35	*	–	–	–	–
112 Little Manatee River at U.S. 41	+ 0.44	**	–	–	–	–

Salinity

Salinity levels, 1999–2003

Box plots characterizing mid-depth salinity levels observed during the five-year period extending from 1999 through 2003 are shown in Fig. 6. Based on the interquartile ranges of monthly mid-depth measurements made during the period, salinity regimes at the 10 monitoring sites would be characterized as follows:

- Sta. 101 (Double Branch Creek at Hillsborough Avenue): oligohaline to mesohaline (0.5 to 18 ppt)
- Sta. 102 (Channel “A” at Hillsborough Avenue): mesohaline to polyhaline (5 to 30 ppt)
- Sta. 103 (Rocky Creek at Hillsborough Avenue): oligohaline to mesohaline
- Sta. 104 (Sweetwater Creek at Hillsborough Avenue): mesohaline to polyhaline
- Sta. 105 (Hillsborough River at Rowlett Park Drive): oligohaline to mesohaline
- Sta. 137 (Hillsborough River at Columbus Drive): mesohaline to polyhaline
- Sta. 109 (Palm River at U.S. Highway 41): polyhaline (18–30 ppt)
- Sta. 133 (Delaney Creek at U.S. Highway 41): oligohaline to mesohaline
- Sta. 74 (Alafia River at U.S. Highway 41): polyhaline
- Sta. 112 (Little Manatee River at U.S. Highway 41): mesohaline to polyhaline.

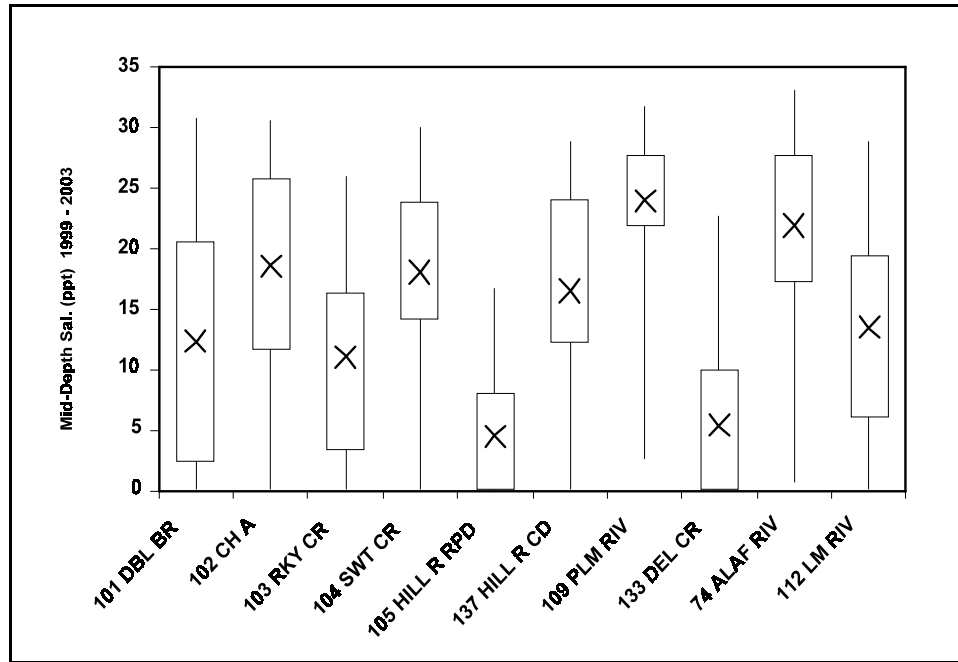


Figure 6. Mid-depth salinity boxplots, water years 1999–2003.

Freshwater Inflows, 1932–2003

The tidal reaches of rivers and streams are mixing areas, where higher-salinity coastal waters are combined with and diluted by freshwater runoff from the land. Salinity levels in these areas are strongly affected by variations in freshwater inflow. Previous studies have documented long-term changes in freshwater inflow patterns in three of Tampa Bay's larger tributaries (e.g., Flannery et al. 1991, Stoker et al. 1996). Significant reductions in annual freshwater discharge occurred in the downstream sections the Hillsborough River and Alafia River systems between the 1930s and early 1990s (Stoker et al. 1996), apparently in response to a combination of factors that include changing levels of human water use for municipal, agricultural and industrial purposes and variations in rainfall. In the Little Manatee River system during the same period, annual flows showed no significant trend but dry season flows increased significantly, apparently in response to agricultural irrigation practices in its watershed (Flannery et al. 1991).

The U.S. Geological Survey (USGS) has measured daily mean flows at a number of sites in these river basins since the 1930s. Based on nonparametric trend analysis (Table 5) the declining trends in annual discharge in the Hillsborough and Alafia rivers reported by Stoker et al. (1996), and the absence of trend in annual discharge in the Little Manatee River reported by Flannery et al. (1991), continue to be evident when the data and analyses are updated through 2003.

The nonparametric correlation analysis shown in Table 5 suggests that a large proportion of the year-to-year variation that has occurred since the 1930s in the volumes of freshwater discharged annually from the gaged portions of the Hillsborough and Alafia river basins can be explained by an empirical model containing two terms: annual rainfall and year. To examine this possibility, we used least-squares regression to fit a conceptual model of the form:

$$\text{annual discharge} = \beta_0 + \beta_1(\text{annual rainfall}) + \beta_2(\text{year})$$

where β_0 , β_1 , and β_2 are fitted regression coefficients. As with the DIN trend analyses discussed earlier, the rainfall data used in these analyses were obtained from the Southwest Florida Water Management District (SWFWMD). Annual discharge data were obtained from the USGS. Regressions were performed using both untransformed and log-transformed discharge and rainfall values, to determine which functional specification provided the highest R^2 value for each location.

Table 5. Trend and correlation analyses of annual streamflow and rainfall. (Significance levels: **** < 0.005; *** < 0.01; ** < 0.05; * < 0.10; - > 0.10)

RIVER BASIN	TIME PERIOD	FLOW TREND		RAINFALL TREND		CORRELATION BETWEEN ANNUAL FLOW AND ANNUAL RAINFALL	
		Tau	Signif. level	Tau	Signif. level	Tau	Signif. level
Hillsborough	1939–2003	-0.38	****	--	--	0.50	****
Alafia	1933–2003	-0.21	***	--	--	0.63	****
Little Manatee	1940–2003	--	--	--	--	0.66	****

For the Hillsborough River, the empirical model explaining the highest proportion (R^2) of the variability in annual discharge at the City of Tampa dam (USGS gage no. 023045000) took the form:

$$\text{annual discharge (cfs)} = -697.3 + 25.3(\text{annual rainfall [in.]}) - 6.5(\text{year})$$

($R^2 = 0.67$, $p < 0.0001$).

For the Alafia River at Lithia (USGS gage no. 02301500), the model providing the highest R^2 value took the form:

$$\text{annual discharge (cfs)} = -404.4 + 14.9(\text{annual rainfall [in.]}) - 1.0(\text{year})$$

($R^2 = 0.77$, $p < 0.0001$).

The fact that inclusion of the β_2 coefficient added significantly ($p < 0.05$) to the model's overall predictive value indicates that the relationship between discharge and rainfall changed over the period of record at both gaging stations, presumably reflecting the anthropogenic activities that have affected a number of aspects of the rainfall/runoff relationship in the two watersheds over the past several decades. Observed and model-predicted annual discharge values for the two sites are shown in Fig. 7.

Relationships Between Freshwater Inflow and Salinity, 1984–2003

For the years 1984 through 2003, salinity data collected by the EPC can be combined with USGS streamflow data to evaluate relationships between the two variables in the tidal sections of the Hillsborough, Alafia and Little Manatee rivers. Nonparametric correlation analysis indicates that the relationship between annual mean mid-depth salinity and annual gaged freshwater inflow is significant in each river system (Table 6). The response of salinity to variations in gaged flow is also inverse and highly nonlinear in each system (Fig. 8).

Given the strong relationships that currently exist between salinity and gaged freshwater inflow, it appears likely that the significant reductions in gaged flow that occurred in the downstream reaches of the Hillsborough and Alafia rivers between the 1930s and 2003—unless mitigated in some way by increased freshwater inflows from ungaged sub-basins that are not included in the USGS monitoring network—produced increasing salinity levels in the tidal reaches of those river systems. The increases in dry season streamflow

documented by Flannery et al. (1991) in the Little Manatee River have apparently not been sufficient to produce long-term trends in total annual discharge, but may have caused reductions in dry-season salinity in the tidal reach of that system.

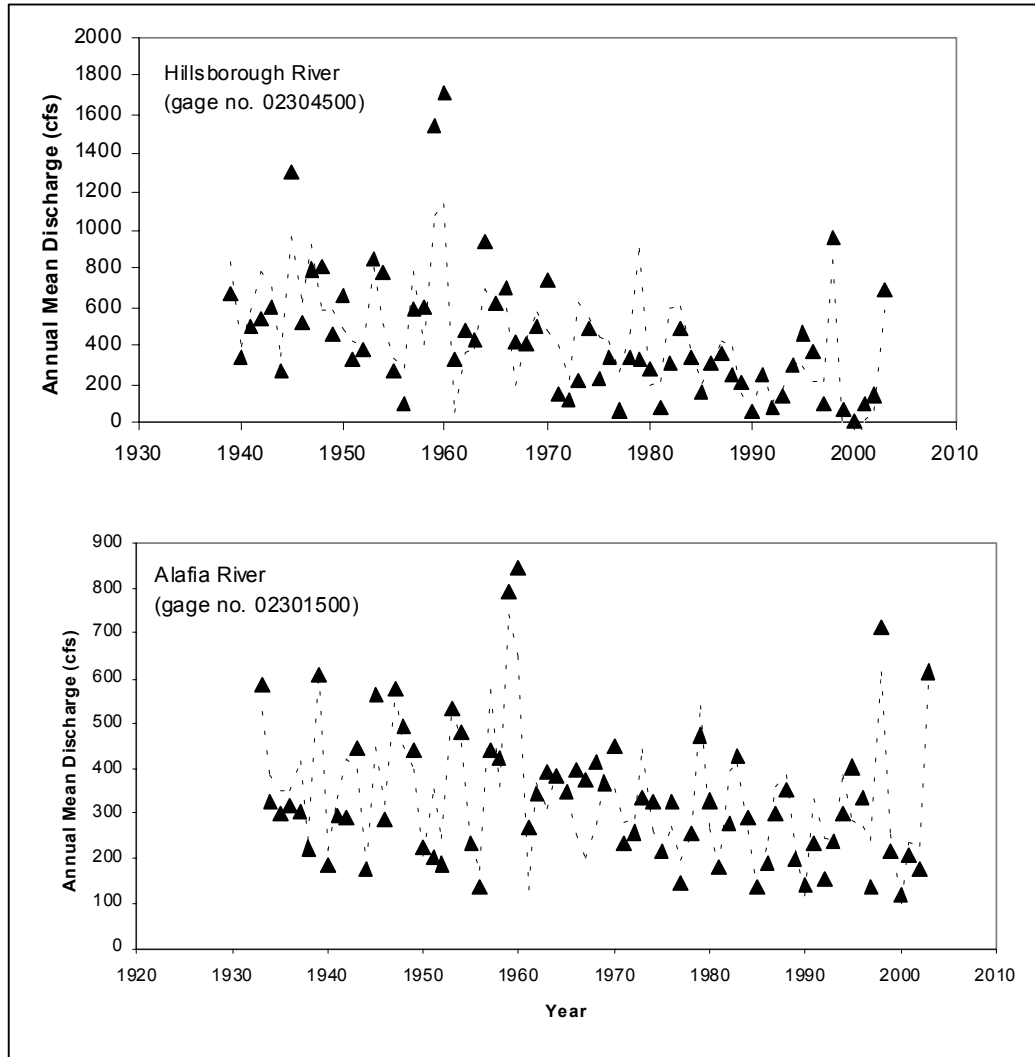


Figure 7. Measured (triangles) and predicted (dashed line) annual discharge at USGS gages in the lower Hillsborough River and Alafia River basins. Predicted values are based on stepwise regression, using annual rainfall and water year as explanatory variables. (Data sources: SWFWMD, USGS)

Table 6. Correlations between annual mean mid-depth salinity (ppt) and annual mean discharge (cfs). (Significance levels: **** < 0.005; *** < 0.01; ** < 0.05; * < 0.10; - > 0.10)

EPC STATION	TIME PERIOD	Tau	Signif. level
105 Hillsborough River at Rowlett Park Dr.	1984–2003	–0.79	****
74 Alafia River at U.S. 41	1984–2003	–0.59	****
112 Little Manatee River at U.S. 41	1984–2003	–0.56	****

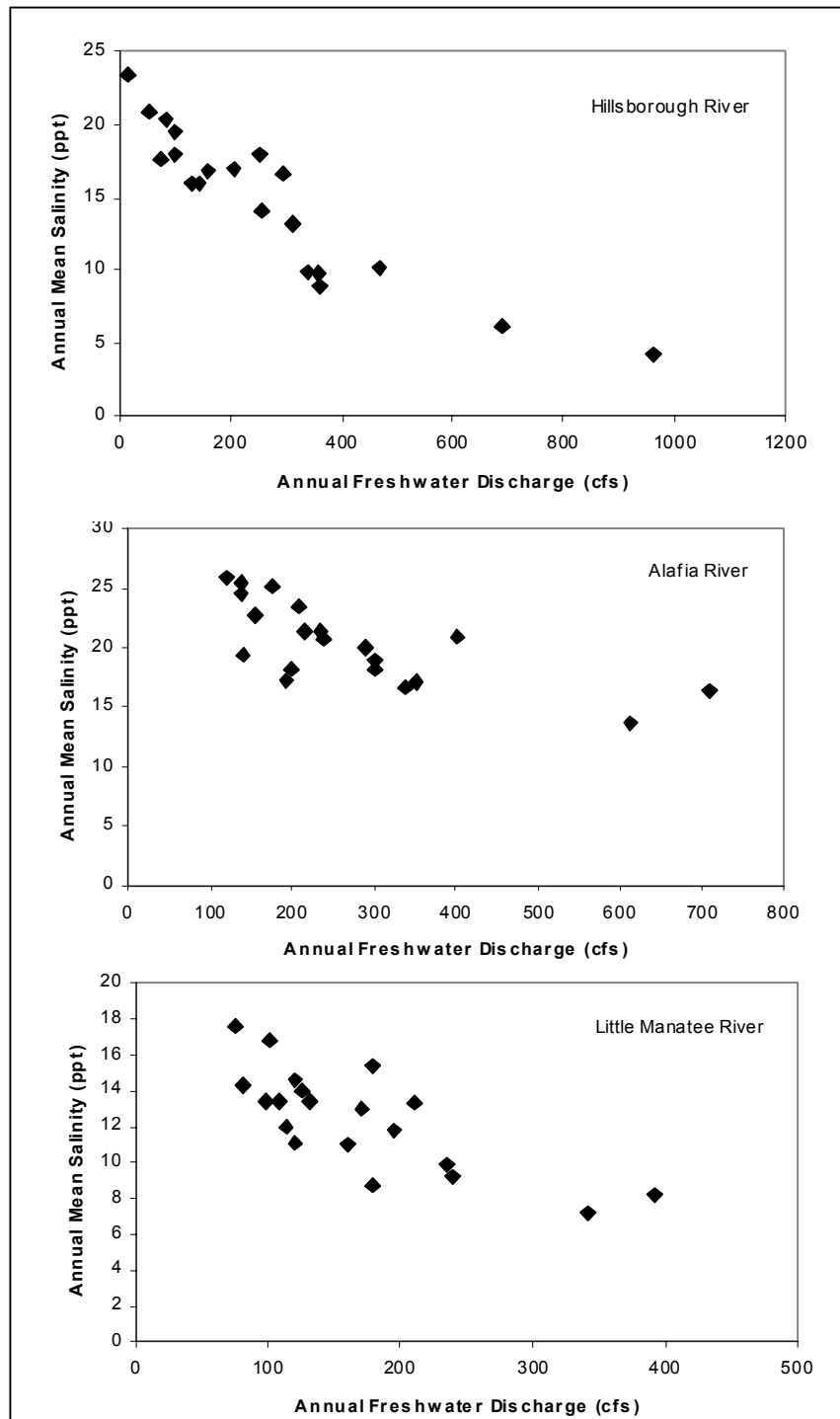


Figure 8. Scatterplots of annual mean mid-depth salinity and annual streamflow in the downstream reaches of the Hillsborough River, Alafia River and Little Manatee River, 1984–2003. (Streamflow data source: USGS)

Relationships Between Salinity and Rainfall, 1984–2003

Annual mean mid-depth salinity levels at the EPC monitoring stations were also highly correlated with annual rainfall during the 20-year period 1984–2003 (Table 7). Nonparametric trend analysis detected no significant trends in rainfall or salinity over the period.

Table 7. Correlations between annual mean mid-depth salinity (ppt) and annual basin rainfall (inches). (Significance levels: **** < 0.005; *** < 0.01; ** < 0.05; * < 0.10; - > 0.10)

EPC STATION	TIME PERIOD 1984–2003		TIME PERIOD 1984–1993		TIME PERIOD 1994–2003	
	Tau	Signif. level	Tau	Signif. level	Tau	Signif. level
101 Double Branch at Hillsborough Ave.	-0.77	****	-0.72	***	-0.82	****
102 Channel A at Hillsborough Ave.	-0.47	****	-0.44	*	-0.64	***
103 Rocky Creek at Hillsborough Ave.	-0.67	****	-0.56	**	-0.69	***
104 Sweetwater Creek at Memorial Pkwy	-0.56	****	-0.44	*	-0.69	***
105 Hillsborough River at Rowlett Park Dr.	-0.47	****	-0.50	*	-0.42	*
137 Hillsborough River at Columbus Dr.	-0.65	****	-0.78	****	-0.64	***
109 Palm River at U.S. 41	-0.53	****	-0.50	*	-0.56	**
133 Delaney Creek at U.S. 41	-0.43	**	–	–	-0.64	***
74 Alafia River at U.S. 41	-0.46	***	–	–	-0.82	****
112 Little Manatee River at U.S. 41	-0.49	****	-0.50	*	-0.51	**

Because freshwater discharges from some tributaries have shown long-term trends over the past several decades (e.g., Fig. 7) we also examined the possibility that relationships may exist between salinity, rainfall and year by using stepwise regression to fit a conceptual model of the form:

$$\text{annual mean mid-depth salinity} = \beta_0 + \beta_1(\text{annual rainfall}) + \beta_2(\text{year}),$$

where β_0 , β_1 , and β_2 are fitted regression coefficients. As above, regressions were performed using both untransformed and log-transformed salinity and rainfall values to identify the functions providing the highest R^2 value for each location.

The final regression equations generated using this approach are summarized in Table 8. As expected, significant inverse relationships were found at all stations between annual mean salinity and annual rainfall. In addition, significant ($p < 0.05$) or marginally significant ($p < 0.10$) multi-year salinity trends (β_2 values) were found at four sites. At stations 102 (Channel A) and 104 (Sweetwater Creek) the estimated β_2 values were negative, suggesting that once the effects of year-to-year variations in annual rainfall were included in the regression model annual mean salinities at these site trended downward during the period 1984 through 2003. At stations 74 (Alafia River) and 133 (Delaney Creek) the estimated β_2 values were positive, suggesting that annual mean mid-depth salinity levels increased over time at these stations once variations in annual rainfall were included in the model.

DISCUSSION

It appears that resource managers addressing water quality issues in the tidal reaches of these rivers and streams will face a number of issues in coming years. On a positive note, significant reductions in annual mean DIN concentrations occurred at five of the EPC monitoring sites during the period 1984–2003, presumably reflecting the concerted nitrogen load reduction effort (TBEP 1996) that has been underway in the Tampa Bay watershed since the early 1980s. On the other hand, however, DIN concentrations also increased significantly at three monitoring sites during the period 1994–2003, raising the possibility that the

effectiveness of nitrogen load reduction efforts may have peaked in some areas in the mid-1990s, and that nitrogen loads from those areas may have begun increasing once again during the 1994–2003 period.

Table 8. Regression models describing annual mean mid-depth salinity for the period 1984 through 2003 using two potential explanatory variables (rainfall and year). (Significance levels: **** < 0.005; *** < 0.01; ** < 0.05; * < 0.10; – > 0.10)

EPC STATION	REGRESSION MODEL	R ²	MODEL SIGNIF.
101 Double Branch at Hillsborough Ave.	$\log(\text{salinity}) = 4.35 - 0.04(\text{annual rainfall})$	0.78	****
102 Channel A at Hillsborough Ave.	$\text{salinity} = 40.25 - 0.32(\text{annual rainfall}) - 0.33(\text{year})$	0.79	****
103 Rocky Creek at Hillsborough Ave.	$\log(\text{salinity}) = 4.08 - 0.04(\text{annual rainfall})$	0.68	****
104 Sweetwater Creek at Memorial Pkwy	$\log(\text{salinity}) = 4.26 - 0.03(\text{annual rainfall}) - 0.01(\text{year})$	0.62	****
105 Hillsborough River at Rowlett Park Dr.	$\log(\text{salinity}) = 5.21 - 0.09(\text{annual rainfall})$	0.44	****
137 Hillsborough River at Columbus Dr.	$\log(\text{salinity}) = 4.84 - 0.04(\text{annual rainfall})$	0.79	****
109 Palm River at U.S. 41	$\log(\text{salinity}) = 3.79 - .13(\text{annual rainfall})$	0.76	****
133 Delaney Creek at U.S. 41	$\log(\text{salinity}) = 4.31 - 0.07(\text{annual rainfall}) + 0.04(\text{year})$	0.56	****
74 Alafia River at U.S. 41	$\text{salinity} = 31.51 - 0.29(\text{annual rainfall}) + 0.30(\text{year})$	0.62	****
112 Little Manatee River at U.S. 41	$\log(\text{salinity}) = 3.43 - .02(\text{annual rainfall})$	0.48	****

Other apparent water quality challenges include:

- Exceedances of the state's chl-*a* concentration guideline for estuarine waters (11 µg/L) at seven of EPC's 10 tidal stream monitoring sites during the years 1999 through 2003;
- The presence of mid-depth hypoxia at nine of the 10 sites during that period;
- Significant increases in the frequency of mid-depth DO concentrations < 4 mg/L at five of the sites during the years 1984 through 2003;
- Significant long-term reductions in gaged freshwater inflow to the tidal reaches of two major tributaries (Hillsborough River and Alafia River) between the 1930s and 2003, which may have caused changes in the salinity regimes occurring in the tidal reaches of those rivers; and
- Possible changes in salinity/rainfall relationships at four monitoring sites (Channel A, Sweetwater Creek, Alafia River, and Delaney Creek) during the period 1984–2003.

From a management perspective, salinity changes appear to present the most complex implications for the bay's living resources. In the tidal reaches of the Hillsborough and Alafia rivers, the reductions in annual freshwater inflows from gaged portions of these watersheds that have occurred since the 1930s have—unless mitigated by increased freshwater inflows from ungaged coastal sub-basins—presumably caused low-salinity habitats to shift in an upstream direction. Because the volumes of tidal streams in the Tampa Bay area tend to be largest at their mouths and become smaller upstream, upstream shifts in low salinity habitats are expected to lead, over time, to a reduction in the overall size of those habitats (Estevez et al. 1991). And in streams where dams or salinity barriers have been constructed within the tidal reach, upstream movement of higher salinity zones may cause some important low-salinity habitats to become severely compressed or lost altogether (Estevez et al. 1991).

Regression analyses performed on EPC monitoring data also detected possible trends in salinity/rainfall relationships in the tidal reaches of Channel A, Sweetwater Creek, Delaney Creek, and the Alafia River during the period 1984 through 2003. At the Channel A and Sweetwater Creek sites salinity levels per unit rainfall showed evidence of declining trends,

while at the Alafia River and Delaney Creek sites salinity levels per unit rainfall appeared to increase over time. These trends may be due to anthropogenic hydrologic impacts such as changing water use and point and nonpoint source discharge patterns.

The management implications of the chlorophyll-*a* and dissolved oxygen levels seen in the EPC monitoring data are difficult to determine. In the Tampa Bay area, and at statewide and national levels, estuarine water quality guidelines have been developed primarily for open-water areas. It is not clear whether these guidelines are directly applicable to tidal streams and rivers, which often have very different physical, chemical and biological attributes from the open waters of large coastal embayments.

When addressing issues affecting the open-water portions of Tampa Bay, local management efforts have made considerable progress over the past two decades using an approach based on the development of quantitative resource-based goals and clearly-defined strategies for reaching those goals. Applying this approach to the tidal reaches of Tampa Bay's tributaries—by developing resource-based goals and strategies addressing DIN, chlorophyll-*a*, dissolved oxygen and salinity, for example—would be a helpful next step for local resource managers.

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ASSESSING PINELLAS COUNTY WATER QUALITY MONITORING USING A THREE-TIERED MONITORING APPROACH

K. Levy & A. Squires

INTRODUCTION

From January 1991 through December 2002, the Pinellas County Department of Environmental Management (PCDEM) has monitored surface water quality within 45 of the County's 52 drainage basins, four lakes, and nine named receiving water bodies receiving discharge from County basins. The 1991–2002 monitoring program provided valuable data to support County watershed planning initiatives in accordance with State Water Policy (Chapter 62-40 FAC), the Pinellas County Comprehensive Plan, the Tampa Bay Estuary Program Comprehensive Conservation and Management Plan, and reporting requirements of Pinellas County's National Pollutant Discharge Elimination System (NPDES) permit (Squires and others 2003), however, the program design resulted in several limitations including large geographic data gaps, statistical bias from the site selection process which limited inferences to the location of the fixed station, complications associated with sampling tidal systems, and limited statistical estimation or trend analysis for the receiving water bodies.

To better assess water quality status and trends, provide basin loading estimates, and to expand the geographical range of the program, the PCDEM employed a three-tiered monitoring program in 2003. The first tier of the program is a coastal and open water body monitoring program that incorporates a probabilistic design that parallels the Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program (EMAP). A probabilistic approach includes randomly selected station locations where each site represents an equal but known proportion of the population of interest. This approach eliminates bias associated with site selection and allows for statistically defensible inferences of seasonal, annual and long-term water quality status and trends (Janicki Environmental 2003). The second tier of the program was designed to monitor water quality and flow in streams and creeks and to provide loading estimates to receiving water bodies. The third tier is focused on the development of basin specific storm event mean concentration (EMC) data and evaluation of best management practices (BMPs). The data collected from this program are used to evaluate stormwater improvement projects, to assess problem areas and to provide loading data to meet the County's NPDES permit requirements. This paper provides background information on the 1991–2002 surface water quality monitoring program and the development and objectives of the three-tiered monitoring approach implemented in 2003.

THE 1991–2002 WATER QUALITY MONITORING PROGRAM

From January 1991 through December 2002, the PCDEM monitored water quality at 136 fixed primary and secondary site locations (Figure 1). Most of the County's 52 basins (see Figure 2; basins 53–63 actually represent receiving water bodies) contained at least one fixed primary site at or near the terminal discharge from the basin. Secondary sites were generally selected to monitor discharge from tributaries or other sources, and were sampled less frequently. Primary and Secondary sites were located in marine waters, lakes, drainage channels, creeks, streams, and canals. In addition to the fixed sites, the department also sampled between 9 and 13 stations in basins 57 through 60 each year. These supplemental sites were randomly selected for the annual benthic monitoring program, also known as EMAP. Each year a new subset of locations used for the EMAP program were sampled for water quality parameters over a one-year period. New sites were chosen each year from the new EMAP site list and no sites were sampled for longer than one year. Parameters measured in situ included temperature, salinity, specific conductance, pH, and dissolved oxygen. Analyses of grab samples collected from the field included chlorophyll (a, b, c), nutrients (total Kjeldahl

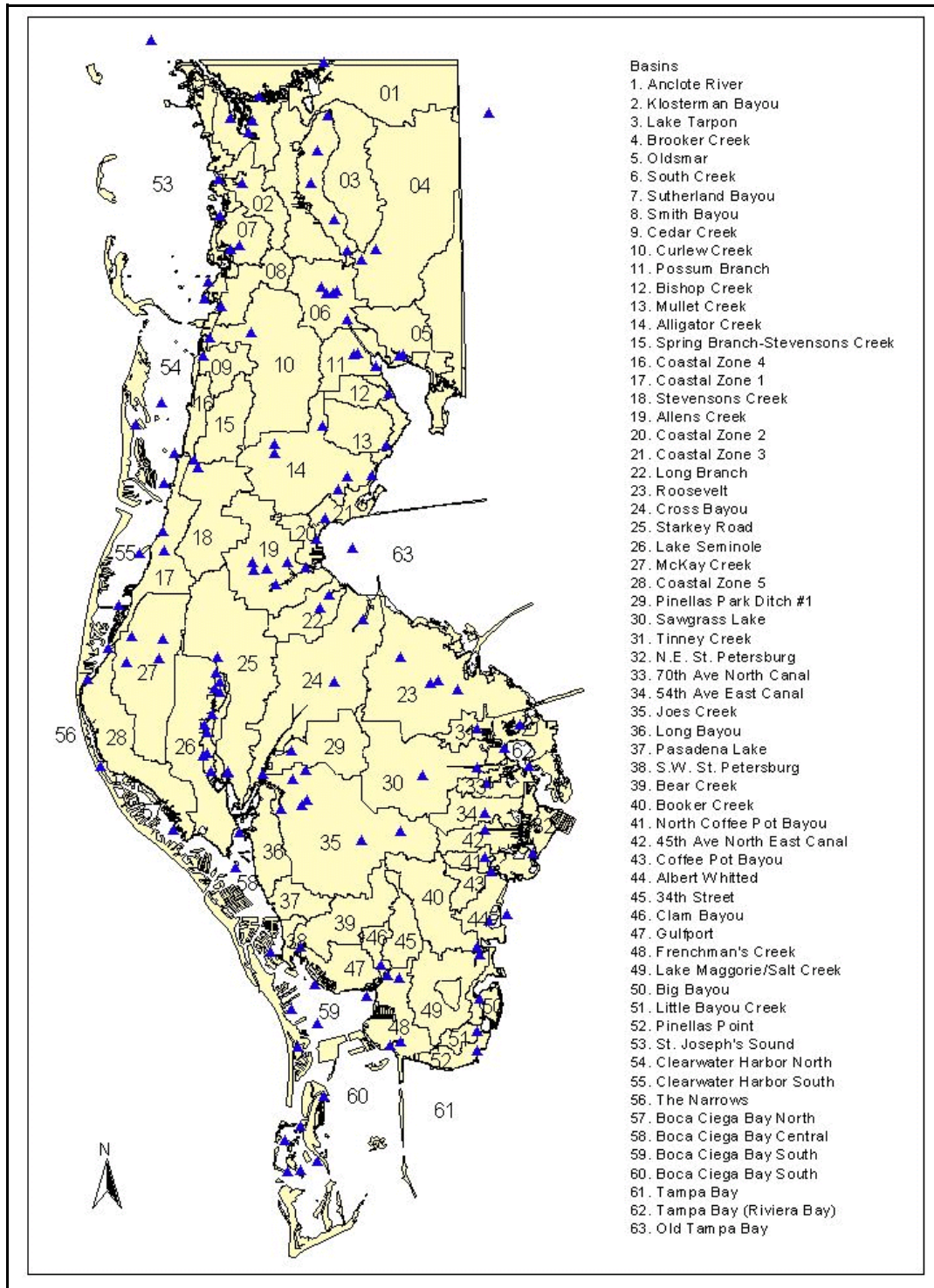


Figure 1. 1991–2002 water quality monitoring sites.

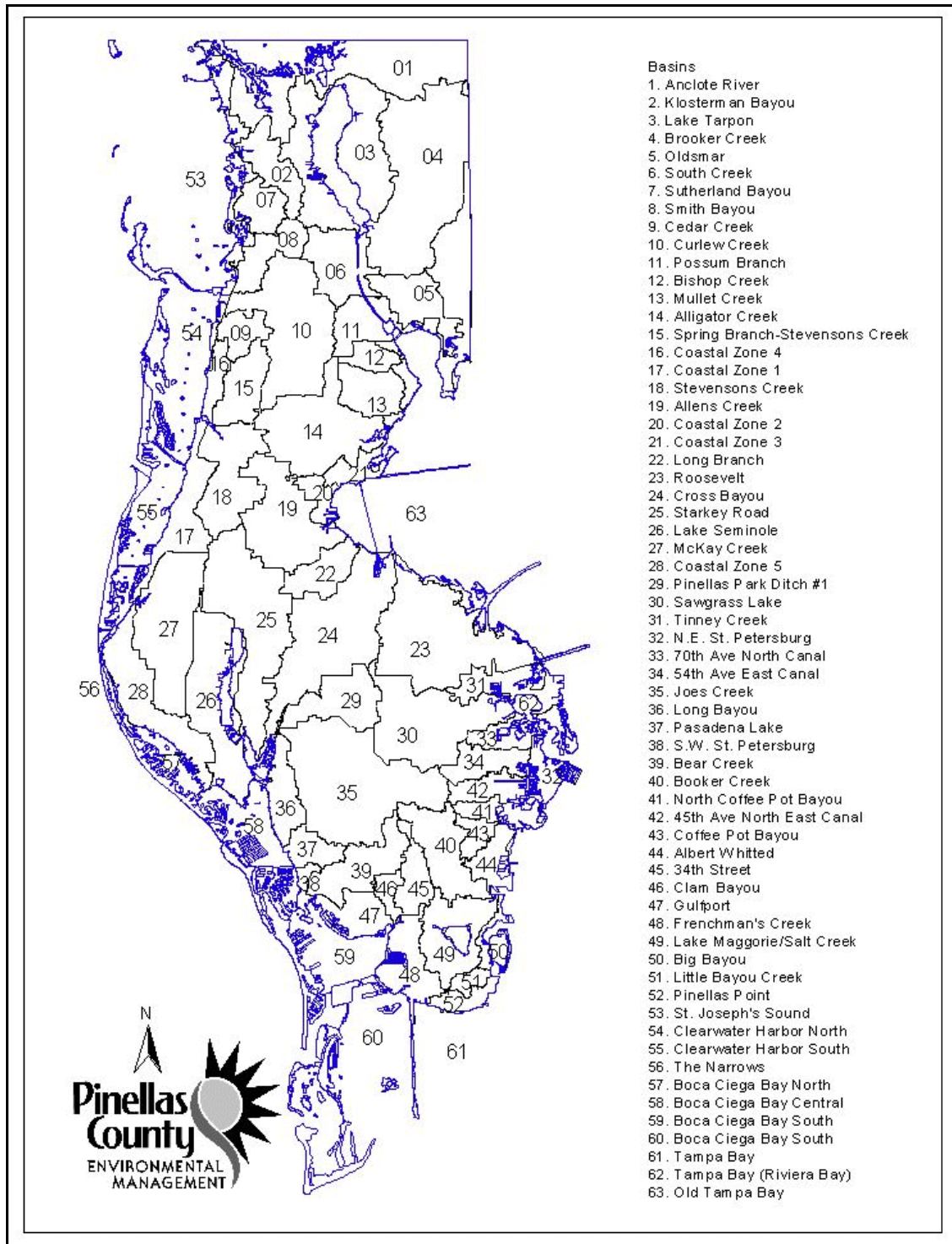


Figure 2. Pinellas County basins.

nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, and dissolved orthophosphorus), total suspended solids, and turbidity. Additional analytes tested over the 12-year period, depending upon site and time period, included five-day biochemical oxygen demand, nitrite nitrogen, chlorides, sulfate, and hardness (lakes), and fecal and total coliforms (1991–1996). A report summarizing spatial and temporal water quality trends by site, by basin and for the entire County for the 12-year period was completed in 2003 (Squires and others 2003).

THE THREE-TIERED MONITORING PROGRAM

Beginning in January 2003, a three-tiered monitoring program was implemented to provide better geographic coverage of County waters, basin loading estimates, and more statistically defensible results. The first tier of the monitoring program included a redesign of the open water body monitoring program by Janicki Environmental and PCDEM. The open water body monitoring program was designed to meet specific objectives including; NPDES permit obligations, status and trend reporting, prioritization of management efforts and identification of water quality problems and improvements. The approach of the open water body monitoring program is a probabilistic design that incorporates a parallel EPA EMAP-based element and a stratified-random sampling design element. To expand the geographic coverage of the program, the County was divided into 18 non-overlapping geographic reporting units or strata (see Figure 3). To apply the EMAP-based element, grid cells were overlaid on each of the 18 geographic reporting units and a random location was selected within each of the grids (see Figure 4). This allows estimates and confidence limits of the total surface area of various water quality conditions within strata to be estimated. The stratified-random element was integrated by collecting two random samples in each grid cell per year. This allows stratified-random sampling statistics to be applied to estimate population means and confidence limits for each stratum. By incorporating both design elements, the sampling probabilities of each sample collected can be calculated (Janicki Environmental 2003). *A Design of a Surface Water Quality Monitoring Program for Pinellas County, Florida* was completed in 2003 and includes specifics on the program implementation, data reporting methods, and analysis.

The second tier of the monitoring program was designed to monitor water quality within Pinellas County streams and creeks and to provide receiving water body loading estimates. Following the same sampling schedule as the open water body monitoring program, water quality and flow data are collected from 47 sites located in 22 County basins (see Figure 5). All sites were selected within the freshwater reaches of the stream or creek to avoid problems associated with sampling in tidal mixing zones. Water quality samples and flow measurements are collected at a variety of sites including box culverts, weirs, and open channels using a modification of the USGS method. The results from this program will be reported annually.

The third tier of the monitoring program was designed to determine basin and land-use specific EMCs and to assess the load efficiency of BMPs implemented throughout the County. Each location of interest is equipped with a mobile storm event monitoring system. The system consists of an area-velocity flow meter and sensor, a refrigerated sampler, a telephone modem with voice message capability for retrieval of stored data, a float and pulley level sensor, a tipping bucket rain gage and a multiprobe unit for measuring in situ conductivity, temperature, pH, dissolved oxygen and turbidity.

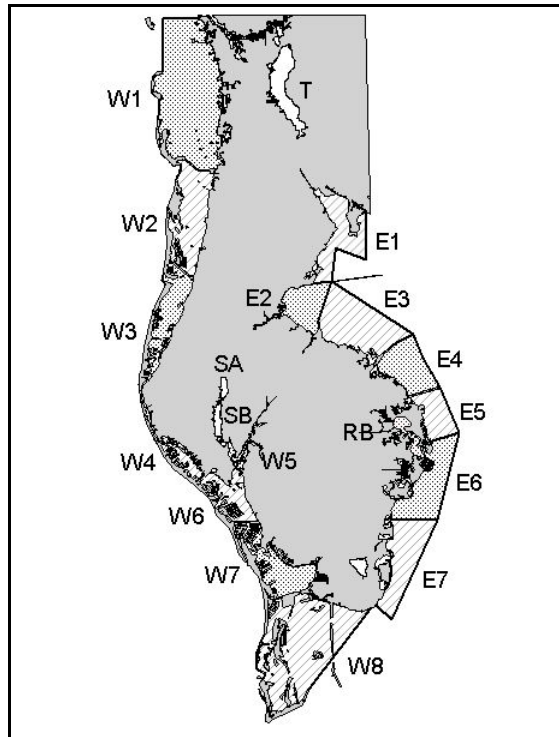


Figure 3. Geographic strata.

To estimate the EMC for a particular land-use or basin, the EMC is calculated by averaging the inflow and outflow concentrations for each storm over a designated time period (usually one year) by using the following formula (Rushton 2003):

$$\text{EMC efficiency (\%)} = [(\text{concentration in} - \text{concentration out}) / \text{concentration in}] \times 100$$

where: EMC = average event mean concentration from flow weighted samples
 concentration in = average of EMC at the inflow
 concentration out = average of EMC at outflow
 Concentrations are reported in mg/L or µg/L.

Estimates of BMP load efficiency are calculated by adding the individual storm events together for a given time period (usually one year) using the following formula (Rushton 2003):

$$\text{Load efficiency (\%)} = [(\text{SOL in} - \text{SOL out} / \text{SOL in})] \times 100$$

where: SOL in = the sum of loads at the inflow for a given period
 SOL out = the sum of loads measured at the out fall for a given time period
 Load efficiencies are reported in kg/yr or lbs/yr.

Currently, the storm event monitoring equipment is located in the Lake Seminole watershed shown in Figure 1 as Basin 26. The objectives of this project include the development of an EMC for low-density residential land-use in Pinellas County and an efficiency evaluation of two stormwater treatment ponds that were recently constructed to treat 67 acres of previously untreated development. Water quality samples are collected during storm events and base flow conditions. This project will take place over an 18-month period after which the systems

will be transported another location and land-use within the Lake Seminole watershed to develop additional EMCs.

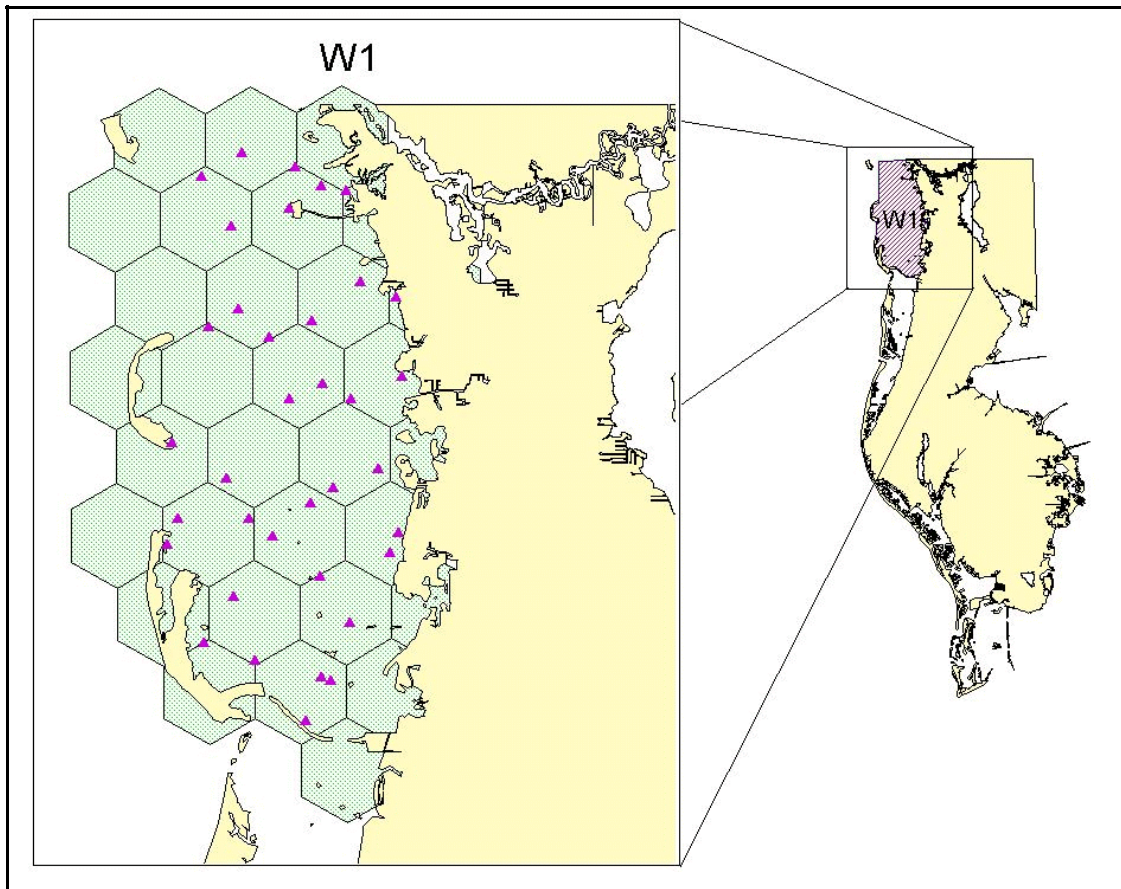


Figure 4. Stratum W1 with grid overlay and random site locations.

CONCLUSION

As discussed previously, the 1991–2002 water quality monitoring program provided valuable data to support local initiatives, however, the design resulted in several limitations that were improved upon in the re-design. The probabilistic monitoring program, the stream monitoring program and the BMP evaluation and EMC development program will help the County meet specific goals and objectives for surface water quality management including;

- NPDES permit obligations;
- Providing status and trends information;
- Providing a method of identifying water bodies that are not meeting their designated uses;
- Measuring long-term water quality responses to management efforts;
- Providing information to prioritize management efforts;
- Evaluation of water quality improvement projects;
- Estimating loads to receiving water bodies;
- Filling important data gaps; and
- Providing information to develop water quality targets for living resources.

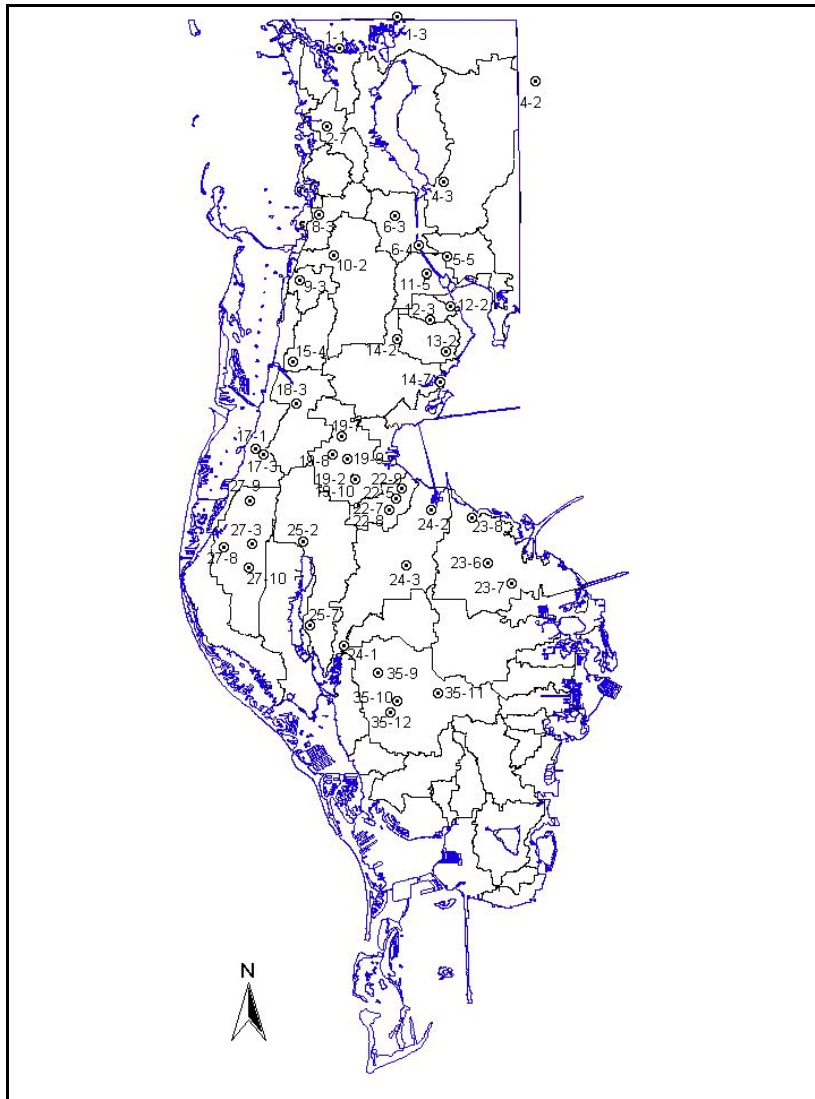


Figure 5. Stream water quality and flow monitoring sites.

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TAMPA BAY WATER'S HYDROBIOLOGICAL MONITORING PROGRAMS

R. McConnell, D. Robison & T. Janicki

ABSTRACT

The Master Water Plan for Tampa Bay Water, a regional water supply authority in west-central Florida, includes development of new surface water withdrawals from tributaries discharging to Hillsborough Bay, as well as a desalination facility located on the Bay. Although these projects were developed for water supply purposes and potential impacts involve the same major water body, different state rules and criteria apply to these projects: water use permits for river withdrawals and a NPDES industrial wastewater discharge permit for desalination. Both permits required development of estuarine monitoring programs that included hydrology/water quality, biota, and habitat/vegetation; critical indicators; and associated criteria such as parameters and sampling methods. The river withdrawal permits incorporated a probability-based stratified random design with some fixed stations; the desalination permit required a fixed station design with stratified random design for some elements. In addition, data collected by other agencies are incorporated into both programs. Some of the significant challenges in developing consistent monitoring approaches highlighted by these programs include: integrating data from programs with different objectives, scale, index periods; probabilistic vs. fixed-station design; standardized protocols for sampling and analysis within elements; and using recent and historical data from multiple programs to establish baseline conditions. This paper includes an overview of monitoring activities; more detailed information and monitoring results were provided in related papers and posters at BASIS 4.

BACKGROUND

After decades of increasing groundwater use in the Tampa Bay region, environmental impact (e.g., lowered lake levels and wetland stress) has become a significant concern in some areas. In addition to water conservation measures, new water supply sources must be developed to relieve environmental stress around regional groundwater facilities and meet increasing water demand for an ever-growing population. The Master Water Plan for Tampa Bay Water, a regional water supply authority in west-central Florida, includes new surface water withdrawals from three major tributaries, the Hillsborough River, the Tampa Bypass Canal (TBC), and the Alafia River, as well as a desalination facility on Hillsborough Bay, a segment of the Tampa Bay estuarine system (see Figure 1).

RIVER WITHDRAWALS

The TBC/Hillsborough River and the Alafia River projects are part of an integrated system, referred to as the Enhanced Surface Water System (ESWS) that includes the new Tampa Bay Regional Reservoir and is designed to manage and optimize withdrawals, conveyance, and storage of surface water supply (see Figure 2). Anticipated long-term annual average production from the ESSW is approximately 60 mgd including reservoir withdrawals, with the TBC/Hillsborough River system contributing about 75% and the Alafia River system contributing about 25%. To minimize hydrologic and ecological impacts and ensure that flows remain within the range of natural variability, water use permits (WUP) issued by the Southwest Florida Water Management District (SWFWMD) include withdrawal schedules that vary with available flows (i.e., withdrawals increase with increasing flows up to a maximum, no withdrawals below a designated low flow). In the future, Tampa Bay Water's new Regional Reservoir in southern Hillsborough County (anticipated on-line in 2005) will be used for supply during Florida's winter/spring dry season.

The first 66 million gallons per day (mgd) withdrawn from the surface water sources is treated at the new Tampa Bay Regional Water Treatment Plant and then pumped into the regional pipeline system. Amounts withdrawn that exceed 66 mgd will be pumped to the Regional Reservoir. Reservoir storage will improve the reliability and dependable yield of these surface water sources. During the dry season when water cannot be withdrawn from the surface water sources, up to 66 million gallons per day will be taken from the reservoir

to supply the water treatment plant. By the year 2008, surface water sources will provide nearly 30% of Tampa Bay Water's regional supply.

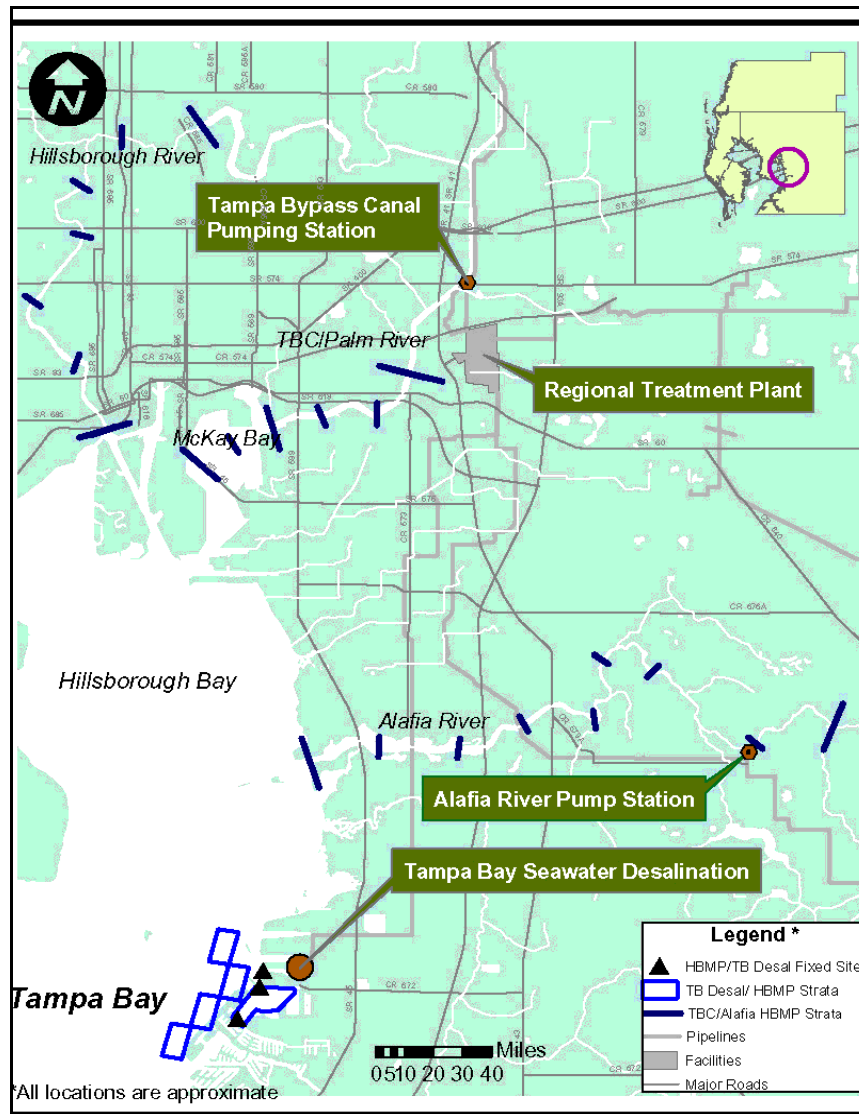


Figure 1. Location of Tampa Bay Water's surface water projects and hydrobiological monitoring programs.

Tampa Bypass Canal/Hillsborough River Water Supply Project

The TBC/Hillsborough River Water Supply Project involves withdrawals of seasonally available surface water from the TBC and the Hillsborough River for public supply use in the region. The project includes the diversion of a percentage of high flows from the Hillsborough River through an existing flood control structure (S-161 located in the Harney Canal) into the TBC. Diversion from the river, as well as flow originating from the TBC, is withdrawn at a single pumping facility located on the east side of the TBC adjacent to flood control Structure S-162. The pump station delivers water to the Tampa Bay Regional Water Treatment Plant and a re-pump station, located at the water treatment plant, will deliver excess capacity to the Regional Reservoir.

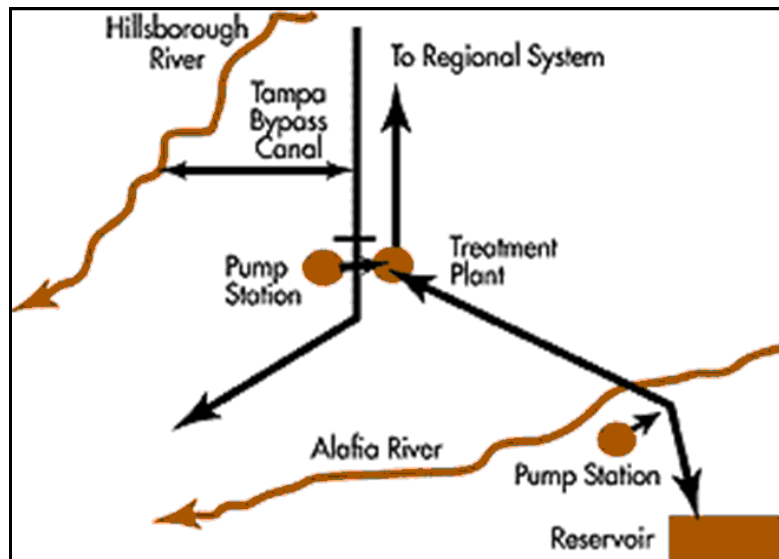


Figure 2. Tampa Bay Water's enhanced surface water system (schematic).

The permitted withdrawal schedules for both the TBC and the Hillsborough River components of this project (see Table 1) vary with available flows (i.e., withdrawals increase with increasing flows up to a permitted maximum); however, no water can be withdrawn below an established low flow limit at the existing control structures discharging to tidal waters. The maintenance of a minimum flow in surface waters is required under Florida law to ensure that aquatic ecosystems and recreational uses are not adversely affected by withdrawals. The Hillsborough River withdrawal schedule allows for the harvest of proportionately greater volumes of the high flows that occur during periods of heavy rainfall, between 65 and 647 mgd, but limits or prevents withdrawals from the low flows that occur during periods of drought. The TBC withdrawal schedule allows for the harvest of 80 % of the flow between 7 and 81 mgd.

The Alafia River Water Supply Project

The Alafia River Water Supply Project involves the withdrawal of seasonally available surface water from the Alafia River for public supply use in the region. The withdrawal location is the south side of the Alafia River at Bell Shoals Road, approximately 18 kilometers upstream from the mouth. The withdrawal schedule for the Alafia River project (see Table 1) was developed to minimize hydrologic and ecological impacts to the riverine system by not withdrawing water during low flow periods, and to ensure that flows remain within the range of natural variability. The minimum flow of 80 mgd corresponds to the 80th percentile, or the flow level that is exceeded 80 % of the time during an average year. Withdrawals occur only when the river flow is at 80 mgd or greater, at which time up to 10 % of the flow can be withdrawn. The maximum withdrawal quantity is 52 mgd. The estimated long-term annual average yield from this source is 17.5 mgd.

TBC/Alafia HBMP

Water Use Permits (WUPs) issued in 1999 by the SWFWMD for the Hillsborough River/Tampa Bypass Canal (TBC) and Alafia River Water Supply Projects specify withdrawal schedules that vary with available flows (i.e., less water is withdrawn at lower flows, no water is withdrawn below a designated minimum low flow) in order to minimize hydrologic and ecological impacts, and ensure that riverine flows remain within the range of natural variability. Each WUP also requires the development and implementation of a comprehensive

hydrobiological monitoring program (HBMP); due to the proximity and integrated nature of these water supply projects, a single unified HBMP was developed.

Table 1. Withdrawal Schedules for Tampa Bypass Canal / Hillsborough River and Alafia River Water Supply Projects				
Tampa Bypass Canal / Hillsborough River				
Discharge at HR Dam (cfs)		Diversions (cfs)		
Min	Max	Min	Max	
--	100	--	0	no diversion if flow <100
100	150	10	15	10% if flow >100
150	215	15	65	10-30% if flow >150
215	1001	65	300	30% if flow >215, to 300 max divert
Discharge at S-160 (cfs)		Withdrawal (cfs)		
Min	Max	Min	Max	
0	11	--	0	no withdrawal if flow <11
11	125	0	100	80% if flow >11, to 100 max withdraw
Alafia River at Bell Shoals Road (Intake)				
Flow at Bell Shoals (cfs)		Withdrawal (cfs)		
Min	Max	Min	Max	
--	124	--	0	no withdrawal if flow <124
124	804	12	80	10% if flow >124, to 80 max withdraw

WUP rules consider potential changes in salinity patterns and associated water quality constituents, biological communities, recreational use and aesthetics, but rules do not define “adversely impacted” or “significantly altered.” For this reason, a consensus-based focus group, consisting of consultant and university experts, representatives of federal, state, and local environmental agencies, and various environmental organizations was established to help design the HBMP, identify critical indicators, evaluate future monitoring data, and recommend appropriate management actions if required. Detailed information regarding design and implementation is provided in the design report and QAQC plan (see PBS&J 2000, 2002).

This HBMP utilizes a probability-based stratified random design with some fixed stations. Monitoring areas include the lower Hillsborough and Alafia Rivers, the TBC, McKay Bay, and Hillsborough Bay. Primary objectives are to characterize indicators within river segments (strata) and evaluate flow/parameter relationships; a key indicator is change in salinity zones. Sampling is extensive due to limited existing data in four reporting units: lower Hillsborough and Alafia Rivers, TBC/Palm River, and McKay Bay; data collected by others (e.g., the Environmental Protection Commission of Hillsborough County) are used for Hillsborough Bay. Water quality and biological monitoring are included; sampling frequency varies by element (see Table 2). TBC/Alafia HBMP field data collection began in April 2000; the TBC and Alafia River projects went on-line in August 2002 and February 2003, respectively.

Table 2. Summary of HBMP monitoring elements, objectives, and parameters			
Element	Objective(s)	Parameters	
		AR, PR, MB, HR	AB/HB
Hydrology / Water Quality	<u>Rivers:</u> Estimate daily freshwater flows, withdrawals, and water levels. Evaluate trends/changes in salinity regimes and relationships between water quality parameters and flow. <u>Desal:</u> Monitor potential effects of discharge on water quality in Hillsborough and Apollo Bays in accordance with water quality criteria.	Monthly: Hydrolab casts or grab samples: salinity, conductivity, temperature, DO, Secchi disk depth, chlorophyll-a, TOC, DOC, TSS, color; Daily: rainfall, flow measurements; Continuous recorders at six fixed stations: water level, salinity, conductivity, temperature and DO.	Bi-monthly: tidal-dependent Hydrolab casts, 72-hour continuous salinity, conductivity, temperature and DO measurement, grab samples for pH and chloride. Continuous recorders at three fixed stations: water level, salinity, conductivity, and temperature.
Benthic Invertebrates	<u>Rivers:</u> Estimate changes in species composition, abundance and/or distribution. <u>Desal:</u> Monitor potential effects of the discharge on benthic invertebrate communities in accordance with state biological integrity requirement.	Monthly sampling of infauna/epifauna, grain size and organic matter, in freshwater and estuarine strata. More intense sampling in wet season and most likely potential impact areas.	Quarterly sampling of infauna/epifauna, grain size and organic matter in estuarine strata. Sampling design focused on areas with most significant potential for change based on USF model.
Zooplankton and Larval Fishes	<u>Rivers:</u> Estimate changes in species composition, abundance and/or distribution.	Monthly oblique tow data are collected under contract with the University of South Florida.	Not applicable.
Adult and Juvenile Fishes	<u>Rivers:</u> Estimate changes in species composition, abundance and/or distribution within rivers. <u>Desal:</u> Evaluate changes in species composition, abundance and/or distribution in Hillsborough Bay relative to Tampa Bay.	Monthly trawl and seine data are collected under contract with the Florida Marine Research Institute.	Monthly trawl and seine data are collected in Hillsborough Bay by the Florida Marine Research Institute under the FIM Program.
Water Dependent Birds	<u>Rivers:</u> Evaluate changes in abundance and richness over time, and correlations with foraging habitat and changes in water quality or biological indicators.	Bimonthly surveys are conducted at three locations: Alafia Banks, ponds near the mouth of the Palm River, and upper McKay Bay.	Not applicable.
Habitat / Vegetation	<u>Rivers:</u> Estimate areal extent, relative abundance, and upstream/downstream shifts of vegetative communities. <u>Desal:</u> Monitor potential effects of the discharge on seagrass communities in accordance with state biological integrity requirement.	Annual linear shoreline and wetland polygon mapping, annual emergent and submerged aquatic vegetation survey by strata and fixed stations in the Alafia River.	Annual / bi-annual submerged aquatic vegetation survey performed by City of Tampa (transects) and SWFWMD (photo-interpretation).
Note: AR - Alafia River, PR - Palm River, MB - McKay Bay, HR - Hillsborough River, AB - Apollo Beach area, HB - Hillsborough Bay (secondary reporting unit).			

SEAWATER DESALINATION

The Tampa Bay Seawater Desalination facility (TB Desal) is co-located with Tampa Electric's Big Bend Power Station to allow the reverse osmosis concentrate to be diluted with Big Bend cooling water prior to discharge. Desal will withdraw approximately 44.5 mgd from cooling water intake, produce 25 mgd of product water, and discharge 19.5 mgd of backwash/concentrate water into cooling water tunnels for dilution prior to release into the discharge canal (see Figure 3). The total combined cooling withdrawal for the power plant cannot exceed 1.4 billion gpd. With all four Tampa Electric cooling units operating, concentrate dilution is 70:1; dilution will be more than 20:1 and 28:1, 99.6% and 95 % of the time, respectively.

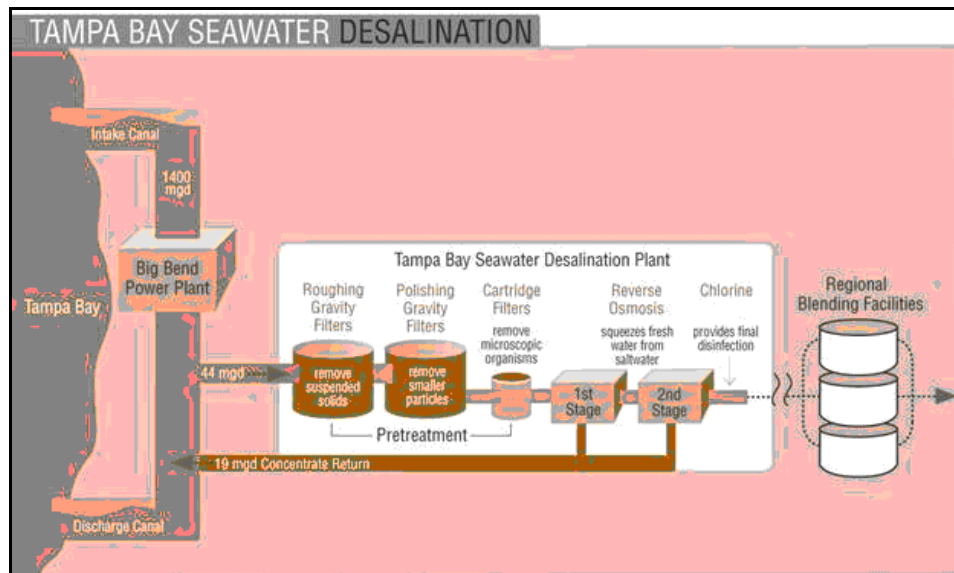


Figure 3. Tampa Bay seawater desalination facility (schematic).

Studies performed in support of the required discharge permit issued by the FDEP included assessments of biological and water quality data and extensive near- and far-field modeling of potential short-term, localized and long-term, and cumulative impacts. Based on model results, the maximum predicted worst-case salinity increase was 2.2–2.5 ppt short-term and very localized, with no build-up over time. Studies were reviewed by consultant and university experts, representatives of federal, state, and local environmental agencies, and various environmental organizations; model results were confirmed with independent models and data.

The state of Florida Industrial Wastewater Facility Permit (FL0186813-Major) issued in 2001 by the FDEP for the TB Desal facility requires compliance with state numeric standards (chloride and dissolved oxygen, intake compared to discharge) and biological integrity standard, and also project-specific model-based criteria for required dilution and maximum salinity. Permit limits and required simultaneous compliance for chloride, dilution, and salinity are more stringent than state standards.

TB Desal HBMP

The TB Desal industrial wastewater discharge permit specifies effluent limitations and monitoring requirements for the operation of the plant. The permit authorizes discharge from the desalination plant to the TECO Big Bend Power Station's cooling water discharge conduits, then to the TECO Big Bend discharge canal, and ultimately to Hillsborough Bay; discharges

are limited under the permit and require specific monitoring. Reported values, monitoring frequency, sample type and the sample point vary based on the effluent characteristic being measured.

Permit No. FL0186813 requires implementation of an HBMP under an FDEP-approved plan of study (POS). The POS includes four elements: water quality, benthos, seagrass, and fish; monitoring areas include the Apollo Beach area and Hillsborough Bay. Data are obtained from sampling activities performed on a bimonthly and quarterly basis, as well as data collected by other monitoring programs in the Hillsborough Bay area (see Table 2). Supplemental monitoring activities were also identified by Tampa Bay Water and Hillsborough County to enhance elements of the TB Desal HBMP. Detailed information regarding design and implementation is provided in the POS (Janicki Environmental 2002) and related documents.

This HBMP utilizes a fixed station design with stratified random design for some elements. Primary objectives are to ensure compliance with state numeric standards (chloride and dissolved oxygen, intake compared to discharge) and biological integrity standard, and also project-specific model-based criteria for required dilution and maximum salinity. Sampling includes power plant intake and discharge canals, Apollo Beach embayment, and near-field area; data collected by others are used for Hillsborough Bay.

Water quality monitoring is performed at three (3) fixed stations in the study area: the TECO Big Bend facility Intake and Discharge Canals, and the Apollo Beach Embayment. Fixed station monitoring includes: continuous salinity recorders, bimonthly 72-hour dissolved oxygen measurements, and bimonthly grab samples for select parameters. Additional water quality monitoring includes stratified random sampling and fixed location profiles. Biological field data collection includes benthic invertebrate sampling. TB Desal HBMP field data collection began in April 2002. The facility went on-line in 2003; initial production has been intermittent due to cost efficiency issues related to the pretreatment process.

DISCUSSION

Major goals for both HBMPs are to: provide early warning of potential changes to protect resources of concern from unacceptable adverse impacts, reflect the unique characteristics of each environmental resource area, and meet applicable permit requirements. Both HBMPs define monitoring elements including hydrology/water quality, biota, and habitat/vegetation; critical indicators; and associated criteria such as monitoring parameters and sampling methods. The key indicator for both is salinity change; additional primary indicators include benthos and plankton changes for the TBC/Alafia HBMP, and benthos changes for the TB Desal HBMP. Different monitoring index periods have been identified based on natural and operational conditions. For river withdrawals, late summer is critical due to salinity variation and the largest withdrawals; for seawater desalination, the winter dry season is critical due to highest Bay salinities and the lowest dilution.

Although different permitting rules and criteria apply to these projects, some of the potential impacts involve the same major water body (Hillsborough Bay). In addition, data collected by other monitoring programs (e.g., the Environmental Protection Commission of Hillsborough County) are incorporated into datasets used for both programs. Coordination of these HBMPs and incorporation of existing monitoring program data in particular has resulted in some significant challenges:

- Using recent and historical data from multiple programs to establish baseline.
- Integrating data from programs with different objectives, scale, index periods, and probabilistic vs. fixed-station designs.

- Using standardized protocols for sampling and analysis within elements.
- Logistics: timely data availability from others.

Sampling and analysis activities for both HBMPs have been standardized to the maximum extent possible. This helps to maximize use of dedicated equipment and staff, and allows some economy by using existing equipment and staff performing similar activities in the same geographic area. Sampling protocols are also standardized between other Bay monitoring programs where feasible which allows incorporation of outside data and facilitates use of HBMP data by other agencies.

HBMPs are important not only because they help to ensure that water resource projects will not have significant adverse impacts, but also because the comprehensive nature of these monitoring programs contributes to an understanding of the importance of freshwater inflows and effects associated with changes to flow regimes, and potential impacts of desalination. HBMP data are also being used for minimum flow and level (MFL) studies being conducted by the SWFWMD and research investigations conducted by the USF. Data will also be used in conjunction with ambient monitoring efforts by other local agencies, and will likely be used for evaluations of other system stressors such as total maximum daily loads or TMDLs.

These HBMPs will continue for the duration of the associated permits for surface water withdrawals or desalination. Detailed evaluations to further understanding of hydrologic and biologic conditions in these systems and potential impacts of water supply projects will continue as the monitoring databases expand.

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A HYDROBIOLOGICAL COMPARISON OF THE ALAFIA RIVER, THE HILLSBOROUGH RIVER, AND THE TAMPA BYPASS CANAL

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ABSTRACT

Water Use Permits issued to Tampa Bay Water for surface water withdrawals from the Alafia River, the Hillsborough River, and the Tampa Bypass Canal water supply projects specified the development of a Hydrobiological Monitoring Program (HBMP) to detect potential adverse impacts in these riverine estuaries and Hillsborough Bay. The HBMP employs a stratified random sampling design, and includes monitoring elements for hydrology, water quality, sediments, benthos, zooplankton, fish, birds and vegetation. The three affected water bodies are distinctly different in many ways. The lower Alafia River has no major impoundments and is relatively unimpacted by dredge and fill, urban runoff, or point source discharges. The Hillsborough River is highly urbanized, and is impounded for public water use. As a result, the lower river receives widely fluctuating freshwater inflows from releases over the dam, as well as substantial urban runoff. In addition, the lower Hillsborough River has been substantially impacted by dredge and fill activities. The Tampa Bypass Canal (TBC) is a deep-dredged and channelized man-made flood control conveyance for the Hillsborough River. The lower TBC receives very little freshwater inflow, except during the release of large volumes of floodwaters over the lowest control structure. In addition, the TBC receives effluent from a municipal wastewater treatment plant. These hydrologic and morphometric differences affect, and are reflected in, the biotic communities that reside and utilize these riverine estuaries. This paper presents a comparative summary of the hydrology, water quality, and biota of these three water bodies based on HBMP data collected between 2000 and 2002.

THE TAMPA BYPASS CANAL AND ALAFIA RIVER WATER SUPPLY PROJECTS

In their Master Water Plan, Tampa Bay Water, the regional water supply authority of the greater Tampa Bay area, identified the need to develop approximately 46 million gallons per day (mgd) of new water supplies for the region by year-end 2002 and an additional 41 mgd of new water by year-end 2007. In 1998, Tampa Bay Water completed feasibility studies addressing the use of excess surface water flows from the Alafia River, the Tampa Bypass Canal, and high flows from the Hillsborough River to supplement regional potable water supplies. These three surface water sources would be connected to a new 60 mgd regional water treatment facility and a proposed off-stream reservoir. This entire suite of facilities, including water sources, treatment facilities, and the reservoir, referred to as the *Enhanced Surface Water System*. As proposed, the system would function generally as depicted in Figure 1, and as described below:

- Surface waters would be withdrawn from one or more sources pursuant to the permitted withdrawal schedules.
- If less than 60 mgd were available from the combination of sources then all water withdrawn would be conveyed to the new regional water treatment facility for treatment and distribution.
- If more than 60 mgd were available from the combination of surface water sources, 60 mgd would be conveyed to the regional water treatment facilities, and the remainder of the permitted available supply would be conveyed to the off-stream reservoir in southeastern Hillsborough County for storage.

The water in storage would be used to supply the new regional water treatment facilities when less than 60 mgd were available directly from the surface water sources.

High flows from the Hillsborough River can be diverted to the Tampa Bypass Canal via the Harney Canal to supplement available water supplies in the Tampa Bypass Canal. Because of the interconnection between the two waterbodies, this water supply system was termed the Tampa Bypass Canal Water Supply Project. In March 1999, the Southwest Florida Water Management District (District) issued the final Water Use Permit for the Tampa Bypass Canal

Water Supply Project. In July 1999, the District issued the final Water Use Permit for the Alafia River Water Supply Project.

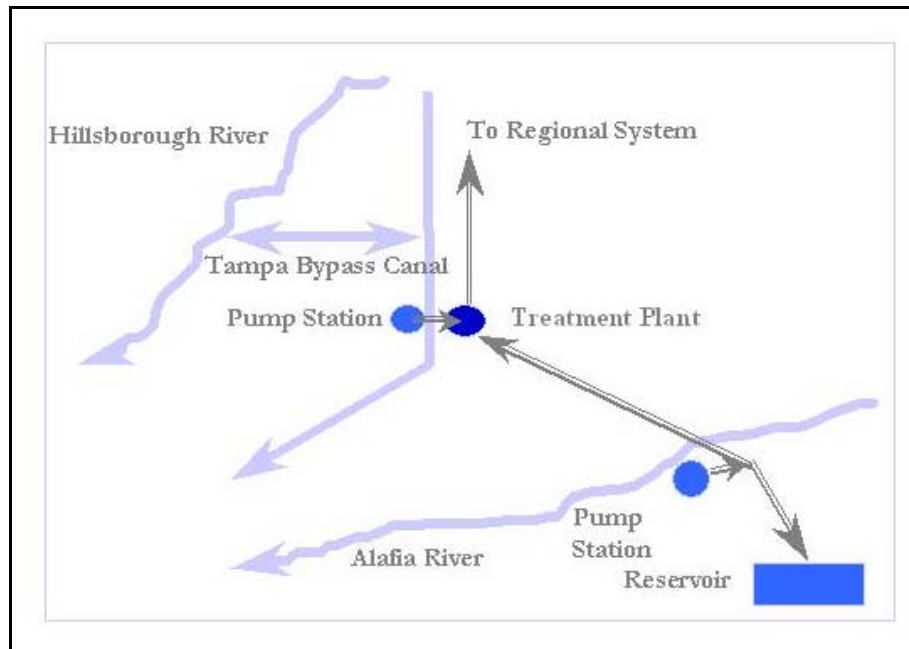


Figure 1. Schematic of the Enhanced Surface Water System (ESWS).

The estimated date for completion of the pumping and pipeline facilities for the Tampa Bypass Canal and Alafia River Water Supply Projects was the summer and fall of 2002, respectively; and production was scheduled to begin at these facilities in late 2002 or early 2003. These facilities and associated infrastructure were essentially completed on schedule, and the harvesting of surface waters from the Tampa Bypass Canal and Alafia River was initiated on August 30, 2002 and February 7, 2003, respectively.

Withdrawals from the Tampa Bypass Canal Water Supply Project are made from a single pump station in the middle pool, located immediately north of M. L. King Boulevard. Withdrawals are made on a flow based schedule with calculated flow at Structure 160 on the Tampa Bypass Canal, and calculated flow at Tampa Dam on the Hillsborough River, being the criteria used to determine how much water Tampa Bay Water is allowed to harvest at any point in time. Quantities from the Hillsborough River permitted for regional use are diverted through the existing flood control structure (S-161) on the Harney Canal into the middle pool of the Tampa Bypass Canal where they are withdrawn.

Withdrawals from the Alafia River are made from a single pump station on the Alafia River located just upstream of Bell Shoals Road. Withdrawals are made on a flow-based schedule with calculated river discharge at Bell Shoals Road being the criteria used to determine how much water Tampa Bay Water is allowed to harvest at any point in time. The permitted Alafia River surface water withdrawal schedule is shown in Figure 2.

THE HYDROBIOLOGICAL MONITORING PROGRAM

Development and implementation of comprehensive Hydrobiological Monitoring Programs (HBMPs) for both the Tampa Bypass Canal and Alafia Water Supply Projects were required as specific conditions of approval for their respective Water Use Permits. However, because

of the similar schedule for development and the close proximity of the two water supply projects, the District subsequently agreed that a single integrated HBMP could be jointly developed and implemented to simultaneously address the permit requirements for both projects. As specified in the permits, the primary areas within which monitoring and evaluation will be undertaken must include: the lower Alafia River downstream of Aldermans Ford Park to Hillsborough Bay; the Tampa Bypass Canal/Palm River below Structure 160; McKay Bay; and the lower reaches of the Hillsborough River from the Tampa Dam to Hillsborough Bay. As part of the Water Use Permit review process, by rule all applicants must demonstrate that the proposed withdrawals or water uses will not cause adverse environmental impacts to wetlands, lakes, streams, estuaries, fish and wildlife, or other natural resources.

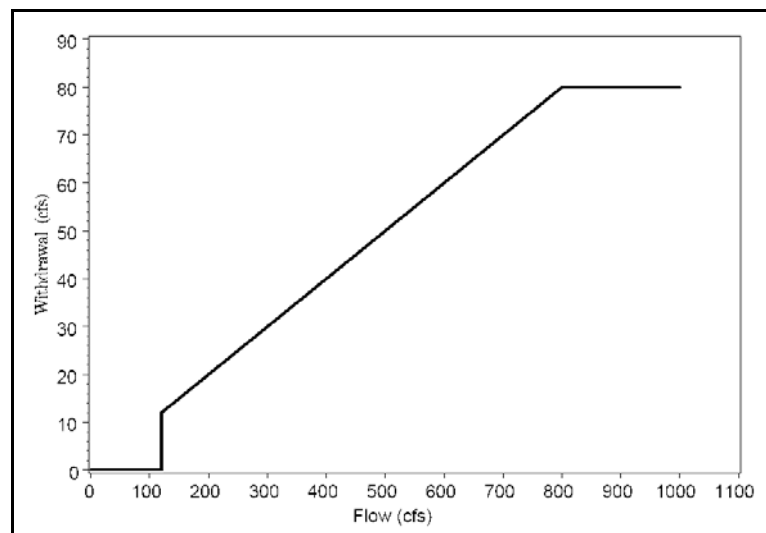


Figure 2. The permitted Alafia River surface water withdrawal schedule.

Given the technical complexity and political sensitivity of the projects, Tampa Bay Water elected to develop the HBMP design in an open public forum with input from representatives of regulatory and resource management agencies, and other stakeholders. A consensus-based process was subsequently developed and implemented for the HBMP design phase. This approach created a coordinated, interactive forum from which critical input was provided by a team of consultant and university experts, as well as representatives of federal, state, and local environmental regulatory and resource management agencies, and various environmental activist organizations.

In response to a solicitation of a broad range of potential stakeholders to participate in the HBMP design process, a core group of participants was identified. The HBMP Design Focus Group (Focus Group) included representatives from the following agencies:

- Tampa Bay Water
- Environmental Protection Commission of Hillsborough County
- Hillsborough County Water Team
- Pinellas County
- City of Tampa
- City of St. Petersburg
- Tampa Bay Estuary Program

- Tampa Bay Regional Planning Council
- Southwest Florida Water Management District
- Florida Department of Environmental Protection
- Florida Fish & Wildlife Conservation Commission
- University of South Florida College of Marine Science
- Florida Marine Research Institute
- National Audubon Society
- PBS&J Consultant Team

To solicit and incorporate input from the HBMP Focus Group members, a series of six workshops and progress meetings were conducted during the summer and fall of 1999. The consensus-based process allowed for the continuous review and oversight of the emerging HBMP design by all interested parties, resulting in a more robust technical design, and an enhanced level of interagency and intergovernmental communication. Consequently, consensus approval of the HBMP design was achieved in a greatly accelerated time frame. The final HBMP design was described in the document entitled *Tampa Bypass Canal/Alafia River Water Supply Projects Hydrobiological Monitoring Program—Final Report* (PBS&J, 1999). The HBMP design was subsequently approved by the Tampa Bay Water Board of Directors for implementation in December 1999.

As set forth in the District's Basis for Review for water use permitting, the minimal goal of the HBMP is to generate information at an appropriate scale and resolution to determine if the permitted water supply projects are in compliance with applicable District rules for water use. Accordingly, the programmatic goal of the HBMP was articulated by the Focus Group as follows:

The goal of the HBMP is to ensure that, following the implementation of the permitted surface water withdrawals, flows in the Tampa Bypass Canal, Hillsborough River and Alafia River do not deviate from the normal rate and range of fluctuation to the extent that:

- Water quality, vegetation, and animal populations are adversely impacted in streams and estuaries;
- Salinity distributions in tidal streams and estuaries are significantly altered as a result of withdrawals; or
- Recreational use or aesthetic qualities of the resource are adversely impacted.

The Focus Group concluded that any potential impacts from the permitted surface water withdrawals would likely first be manifested in the river systems where surface water withdrawals will take place, and possibly Hillsborough Bay. Therefore, the potentially affected waterbodies were defined to include: the lower reaches of the Alafia River (AR); the Tampa Bypass Canal/Palm River (PR); McKay Bay (MB); and the tidal or lower Hillsborough River (HR). These geographic areas of concern, or study areas, were subsequently termed as reporting units.

The HBMP defines three monitoring program elements including hydrology/water quality, biota, and habitat/vegetation. For each program element a list of critical indicators was specified. Indicators are units of measure that describe the status of the statistical populations or subpopulations of interest, usually in response to some environmental stressor. Table 1 lists the critical indicators identified for each of the HBMP elements, and their application to the four primary reporting units.

HBMP Element	Critical Indicators	AR	PR	MB	HR	HB
Hydrology/Water Quality	Freshwater Withdrawals	X	X		X	
	Streamflow	X	X		X	
	Water Level	X	X	X	X	
	Salinity	X	X	X	X	X
	Conductivity	X	X	X	X	
	Temperature	X	X	X	X	X
	Dissolved Oxygen	X	X	X	X	X
	Secchi Disk Depth	X	X	X	X	X
	Chlorophyll-a	X	X	X	X	X
	Color	X	X	X		X
	Total Organic Carbon	X	X	X		
	Dissolved Organic Carbon	X	X	X		
	Total Suspended Solids	X				X
Biota	Benthic Macroinvertebrate Infauna	X	X	X	X	X
	Benthic Macroinvertebrate Epifauna	X	X	X	X	X
	Ichthyoplankton and Zooplankton	X	X	X	X	
	Adult and Juvenile Fishes	X	X	X	X	X
	Water-Dependent Birds	X	X	X		
Vegetation/Habitat	Emergent Aquatic Vegetation	X	X	X	X	
	Submerged Aquatic Vegetation	X				
	Sediment Grain Size	X	X	X	X	
	Sediment Organic Matter	X	X	X	X	

Two sampling designs were considered for application on the HBMP: probability sampling, and non-probability sampling. Probability sampling requires that each possible sample has a known and equal probability of selection, and the places and/or times to be sampled are selected using a random process. Employing this approach requires a definition of the set of distinct samples that the program is capable of collecting with respect to a specific population. Non-probability sampling, on the other hand, typically involves sampling a restricted portion of a population that is readily accessible (e.g., fixed station sampling of salinity from a bridge), or the selection of “typical” or “representative” sample units that are close to the sampler’s perception of the average of the target population (e.g., sampling only in the middle of a river channel to the exclusion of the channel sides).

A probability sampling approach allows for inferences to be drawn about the target populations (e.g., fish abundance in the lower Alafia River), as well as a variety of subpopulations (e.g., fish abundance in a particular segment of the lower Alafia River, during a particular season) if those subpopulations, or strata, are designed into the sampling approach. For practical purposes, strata refer to spatial and/or temporal partitions across which the sampling effort is distributed in order to characterize subpopulations. The use of strata within a sampling design enhances the power to detect differences because it optimizes the design based on the natural variability of the indicators being measured. Incorporating strata into the sampling design and randomly selecting sampling locations across the various strata is referred to as a stratified random sampling approach.

The Focus Group considered the ability to characterize the status of, and draw inferences about, the various critical indicators in particular reporting unit segments, during particular time periods, to be critical to evaluating potential impacts. Therefore, after considering the merits of both probability and non-probability sampling designs, it was concluded that a

probability-based design was best suited to meet most of the programmatic goals and objectives of the HBMP. A probability-based sampling design was considered to be most appropriate for discerning spatial and temporal variability in the abundance and distribution of water quality constituents (e.g., salinity, dissolved oxygen) and biological populations (e.g., benthos, plankton, fish) within the potentially affected waterbodies. It should, however, be noted that certain other data needs were identified that could best be addressed using a non-probability sampling approach (e.g., fixed station measurements of water level and bird populations). Several fixed stations for salinity, water level, and dissolved oxygen were also included.

The theory of stratified sampling deals with properties of population estimates derived from stratified samples, and with the optimal number of samples needed to obtain a level of precision and statistical power adequate to meet defined monitoring objectives. In consideration of these factors, a spatial and temporal stratification scheme for the primary reporting units was adopted, and the minimum number of samples needed to estimate the status of the various indicators within the defined spatial and temporal strata of interest was determined.

The HBMP was implemented in April 2000, and has been ongoing since. In addition to providing important compliance monitoring information that addresses the requirements of the respective Water Use Permits, the HBMP is the first comprehensive hydrologic, water quality, and biological monitoring program focused on the characterization of status and trends in three of major tributaries to Tampa Bay. Information derived from the HBMP has been widely disseminated and used by multiple regulatory and management agencies and research organizations for a variety of applications and purposes.

The remainder of this paper presents a summary of period of record data collected by others, and HBMP data collected through 2002, with the objective of comparing and contrasting pre-withdrawals hydrologic and biological conditions in the lower Alafia River, the lower Hillsborough River, and the tidal Tampa Bypass Canal (Palm River).

COMPARISON OF THE HBMP REPORTING UNITS

The Alafia River, the Hillsborough River, and the Tampa Bypass Canal constitute three of the five most important tributaries to Tampa Bay with respect to the annual volume of freshwater inflow, the other two being the Manatee River and the Little Manatee River. These three tributaries, however, represent a gradient of anthropogenic impact with the Alafia being the least impacted and the Tampa Bypass Canal being the most impacted. Past and ongoing anthropogenic impacts to these systems include dredge and fill, point and non-point source discharges, impoundment, and freshwater withdrawals. The relative effects of these anthropogenic impacts on the hydrology and biology of these three tributaries have been characterized by the HBMP.

The Alafia River is the least impacted of the HBMP reporting units. There are no major impoundments on the river, and the only major surface water withdrawal is that permitted to Tampa Bay Water. Upstream of the permitted withdrawal point at Bell Shoals Road, the South Prong of the river has been heavily impacted by past phosphate strip mining, and there has been a history of wastewater spills from upstream clay settling ponds. Land uses in the lower river watershed are mostly rural in nature, with low density residential being the most predominant. There has been relatively little dredge and fill in the river and its riparian wetlands except near the mouth of the river where the dredging of a ship channel and turning basin for the old Gardinier (now Cargill) phosphate processing facility extends from

Hillsborough Bay up to the U.S. 41 bridge. The past discharge of spoil material in this area resulted in the loss of substantial acreage of emergent tidal wetlands. The tidal river segment of the Alafia River is approximately 16 km in length.

The Hillsborough River was first dammed in 1898 to provide a salt barrier, and in 1924 a hydroelectric facility was constructed. The existing Tampa Dam was constructed in 1945 to create the Hillsborough River reservoir, to provide the primary potable water supply for the City of Tampa. The tidal Hillsborough River below the Tampa Dam is approximately 16 km in length with a watershed area of about 11,400 acres. Land uses in the tidal river watershed are predominantly urban, and approximately 76% of the tidal river shoreline has been hardened to provide seawalls and bulkheads for residential, commercial, and industrial development. As a result very little of the historic riparian wetlands remain. In addition, the tidal river is a major drainage conveyance for urban runoff, with over 114 major storm water outfalls discharging to it. Most of these non-point source discharges were constructed prior to federal and state requirements for storm water treatment. The tidal river also receives freshwater inflows from Sulphur Springs, an artesian spring with a mean annual discharge of 40 cfs.

The lower Tampa Bypass Canal (TBC) is the most impacted of the HBMP reporting units. The TBC was constructed between 1966 and 1982 as a flood control project with the objective of diverting flood flows from the upper Hillsborough River around the City of Tampa. The tidal segment was dredged along the historic stream channel of the Palm River, and the dredged channel exceeds 8 m in depth upstream of confluence with McKay Bay. Native riparian vegetation communities associated with the historic Palm River and its watershed were largely filled by dredge spoil during the construction of the TBC. Freshwater inflows to the tidal segment are controlled at Structure 160 (S-160) located approximately 7 km from the confluence with McKay Bay. There is an existing 3 mgd domestic wastewater discharge just downstream of S-160.

McKay Bay is a small shallow tidal embayment at the terminus of the lower TBC. Prior to the extensive dredging and filling that took place in and around the Port of Tampa beginning in the early 1900s, there was no distinct dividing line separating McKay Bay from the rest of Hillsborough Bay. However, after the construction of the 22nd Street causeway and bridge in 1927, and the filling of Hooker Point and Port Sutton, McKay became a semi-enclosed water body. Like the TBC, McKay Bay has been impacted by dredge and fill, and only remnants of the native emergent tidal wetlands now remain.

Freshwater Flows

Figures 3, 4 and 5 show box and whisker plots of monthly flows for the period of record in the Alafia River at Lithia, the Hillsborough River at the Tampa Dam, and the TBC at S-160, respectively. These plots indicate that the Alafia River exhibits the typical seasonal flow distribution of west central Florida rivers, with greatest flows occurring during the wet season months of June through October following the spring dry season low flows. Similarly, the Hillsborough River exhibits the typical seasonal flow pattern, however, mean monthly flows are lower than the Alafia, and very low to zero flows are common during the months of April through June. In contrast, the seasonal flow pattern in the TBC is virtually non-existent, and mean monthly flows for all months are less than 200 cfs.

Figures 6, 7, and 8 show daily flows for the period of record in the Alafia River at Lithia, the Hillsborough River at the Tampa Dam, and the TBC at S-160, respectively. These plots indicate that the Alafia River exhibits continuous flows with both seasonal and annual flow

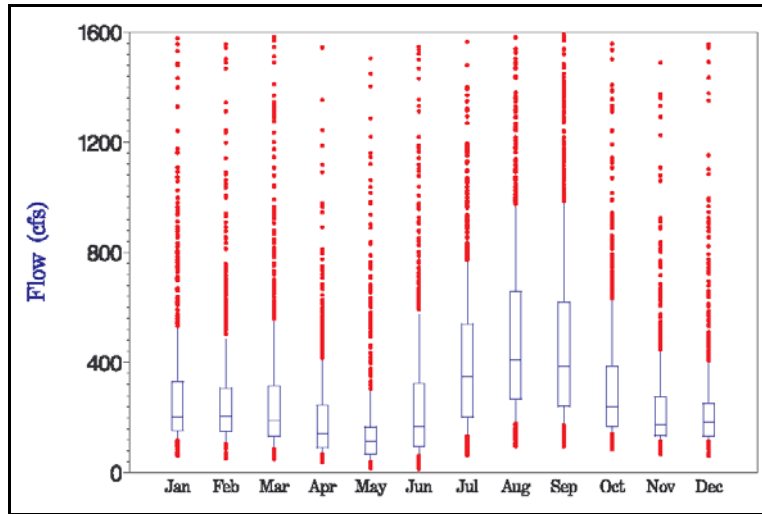


Figure 3. Monthly flows in the lower Alafia River at Lithia (1975–2002).

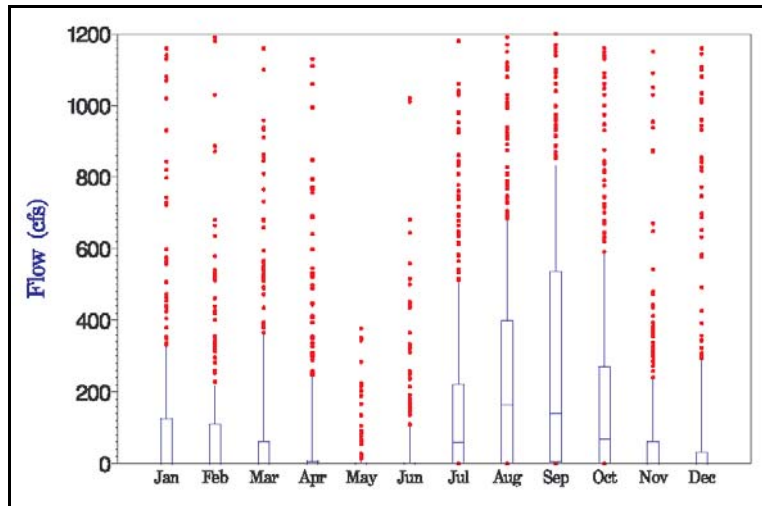


Figure 4. Monthly flows in the Hillsborough River at Tampa Dam (1999–2002).

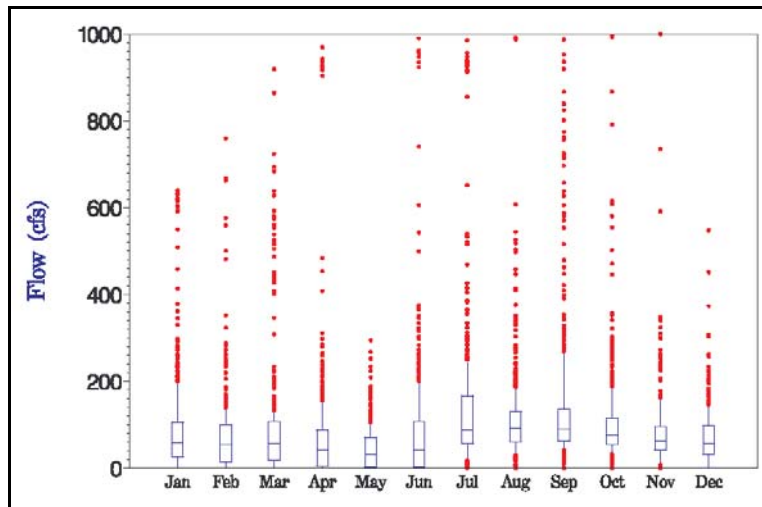


Figure 5. Monthly flows in the Tampa Bypass Canal at S-160 (1983–2002).

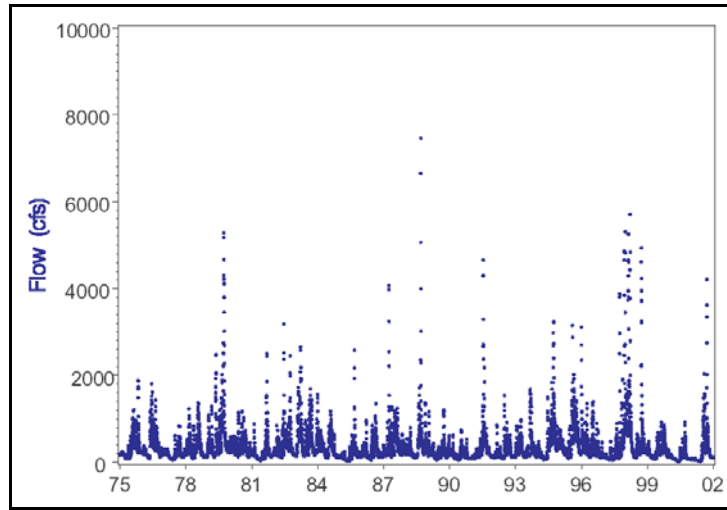


Figure 6. Daily flows in the lower Alafia River at Lithia (1975–2002).

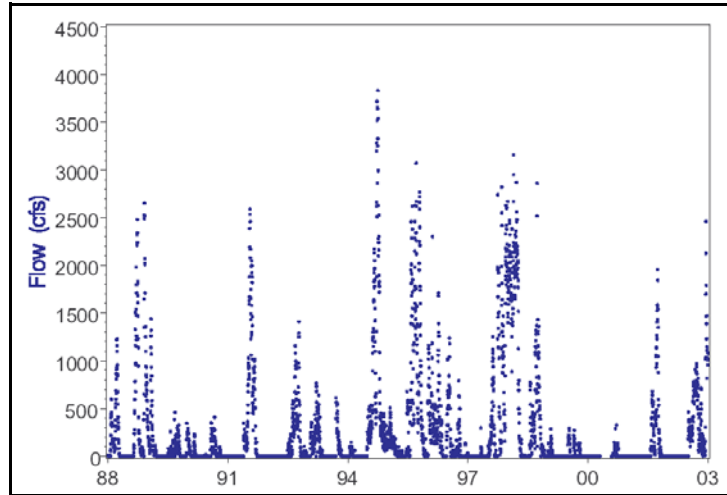


Figure 7. Daily flows in the lower Hillsborough River at Tampa Dam (1988–2003).

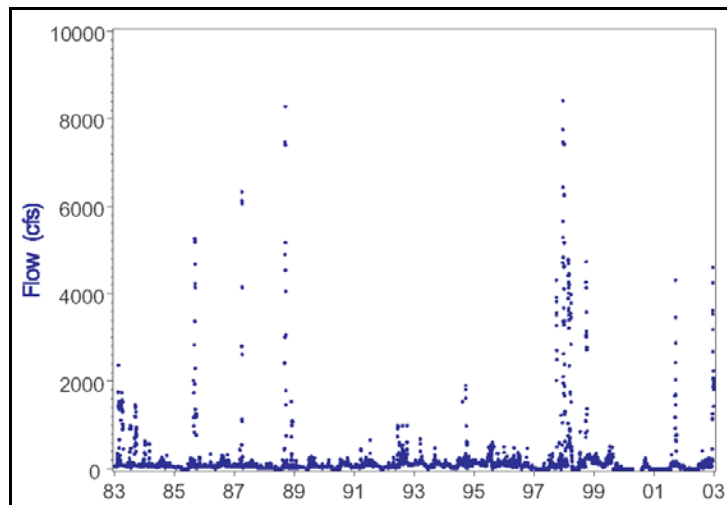


Figure 8. Daily flows at the Tampa Bypass Canal at S-160 (1983–2002).

periodicity, with summer and winter ENSO high flows approaching and occasionally exceeding 6,000 cfs. In contrast, the Hillsborough River exhibits many periods of very low or zero flows, punctuated by periodic wet season and winter ENSO high flows approaching and exceeding 3,000 cfs. The TBC exhibits very low but continuous flows punctuated by infrequent very high flows exceeding 6,000 cfs. Such high flows are controlled flood flow diversions following exceptionally high rainfall volumes associated with tropical storms and ENSO events.

Salinity

Figures 9, 10, and 11 show box and whisker plots for period of record and HBMP surface salinity data for the Alafia River, the Hillsborough River, and the TBC, respectively. These plots indicate that the Alafia River exhibits a spatial salinity gradient typical of river estuaries, with salinities decreasing upstream from the mouth. Mean salinities at mouth range between 20–25 ppt, while mean salinity values decrease to near zero at river kilometer 17 (measured upstream from the mouth). The Hillsborough River also exhibits a less pronounced salinity gradient moving upstream from the mouth; however, minimum mean salinity values at the Tampa Dam are approximately 5 ppt, with freshwater conditions only being attained during periods of high flow. The TBC, on the other hand, exhibits virtually no spatial salinity gradient, with mean salinity values of about 25 ppt from the mouth up to S-160.

Dissolved Oxygen

Figures 12, 13, and 14 show scatter plots for HBMP bottom dissolved oxygen (DO) data for the Alafia River, the Hillsborough River, and the TBC, respectively. These plots indicate that the Alafia River usually exhibits a healthy oxygen environment, with the vast majority of the measured concentrations equal to or greater than the state standard of 5 mg/l. Worth noting is the periodic hypoxia that occurs between river kilometers 2 and 13, as well as the occasional very high DO concentrations measured near river kilometer 2. Periodic density stratification and algal blooms are responsible for these anomalies. Comparatively, the Hillsborough River exhibits a less healthy oxygen environment with many measured values at or below the State standard, and widespread periodic hypoxia. The TBC exhibits the most unhealthy oxygen environment with the majority of values at or below the State standard of 5 mg/l, and many zero DO measurements, indicating hypoxic and anoxic conditions ranging from just upstream of the mouth to S-160. The dredged depth of the TBC and relatively poor circulation appear to contribute significantly to these conditions.

Sediments

Figures 15, 16, and 17 are histograms of HBMP sediment data (percent fines and organic matter) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that percent fines and percent organic matter reach peaks in the Alafia River between river kilometers 4 and 8. In the Hillsborough River the percent fines and percent organic matter reach peaks further upstream between river kilometers 7 and 11, with another smaller peak between river kilometers 3 and 4. Furthermore, the percent organic matter is generally higher than in the Alafia. In contrast, mineral fine-grained sediments dominate the deep dredged TBC, with percent fines ranging from 50 to greater than 90 percent, a far greater proportion of fines than in the Alafia or Hillsborough. Fine-grained mineral sediments appear to be remnants of the TBC channel dredging.

Emergent Aquatic Vegetation (EAV)

Figures 18, 19, and 20 are histograms of HBMP emergent aquatic vegetation data (hectares per 100-meter interval) by river kilometer for the Alafia River, the Hillsborough River, and the

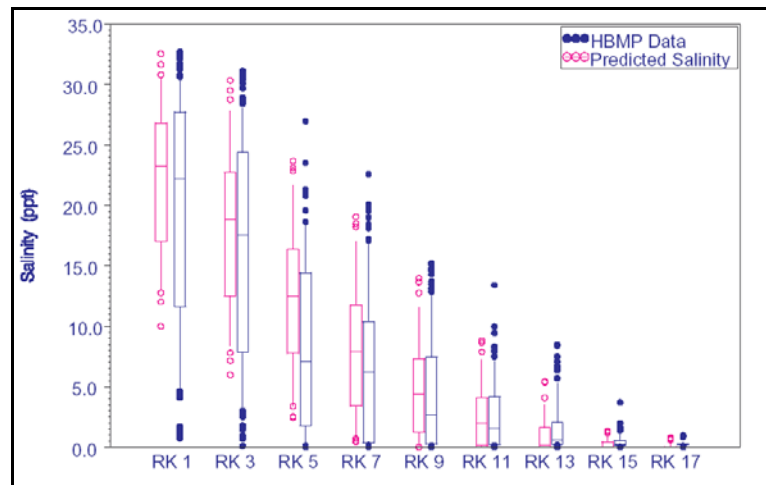


Figure 9. Surface salinity in the lower Alafia River.

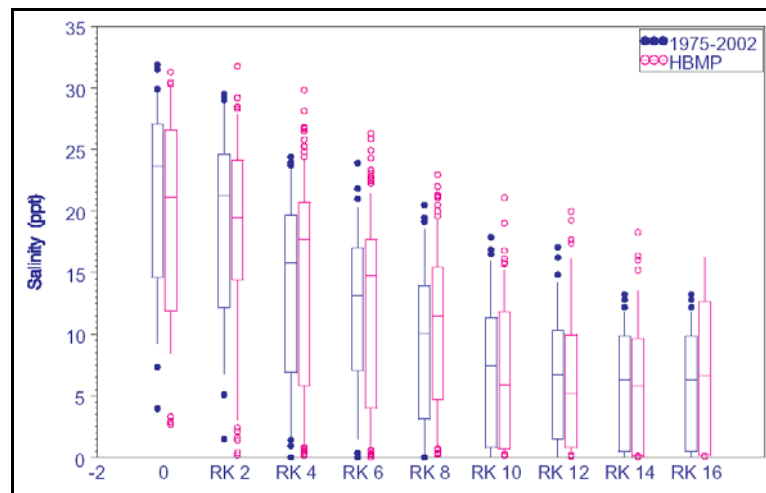


Figure 10. Surface salinity in the lower Hillsborough River.

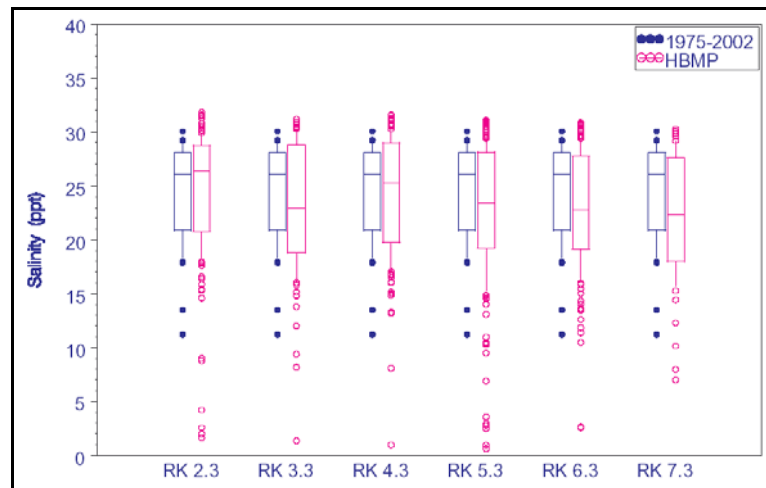


Figure 11. Surface salinity in the Tampa Bypass Canal.

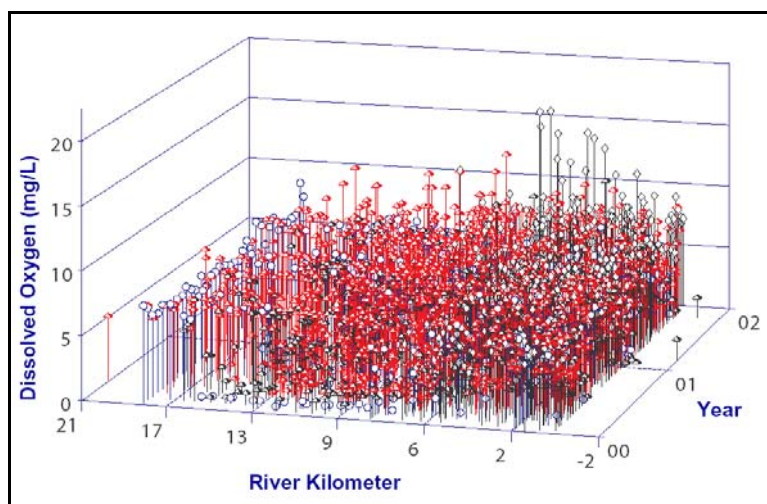


Figure 12. Bottom dissolved oxygen in the lower Alafia River.

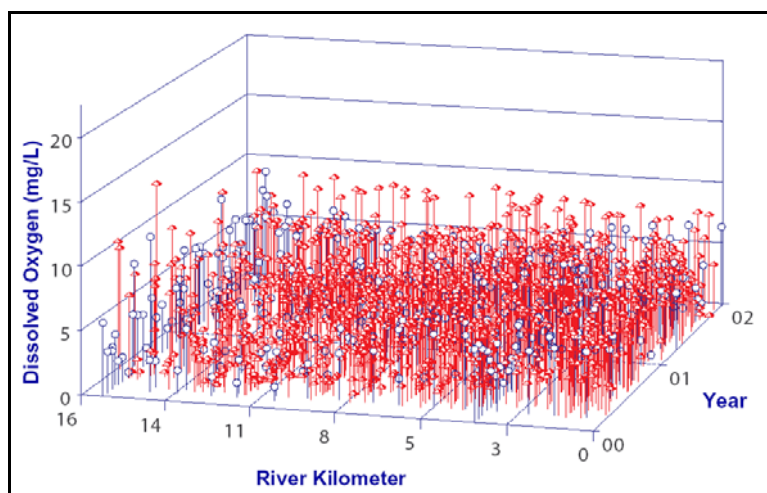


Figure 13. Bottom dissolved oxygen in the lower Hillsborough River.

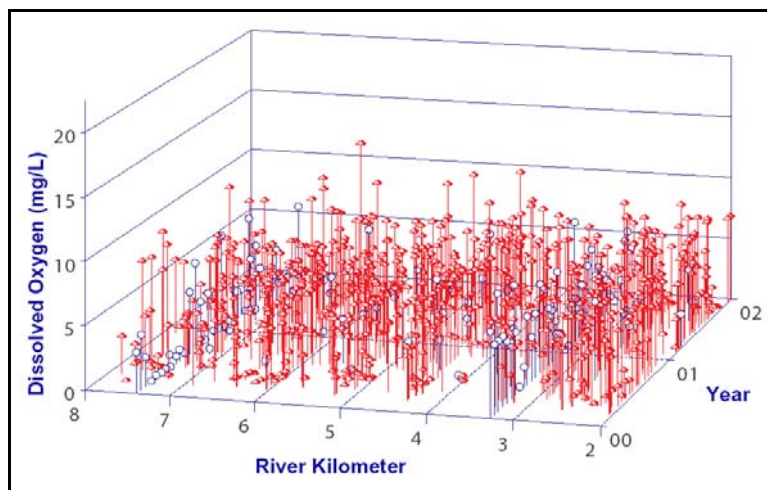


Figure 14. Bottom dissolved oxygen in the Tampa Bypass Canal.

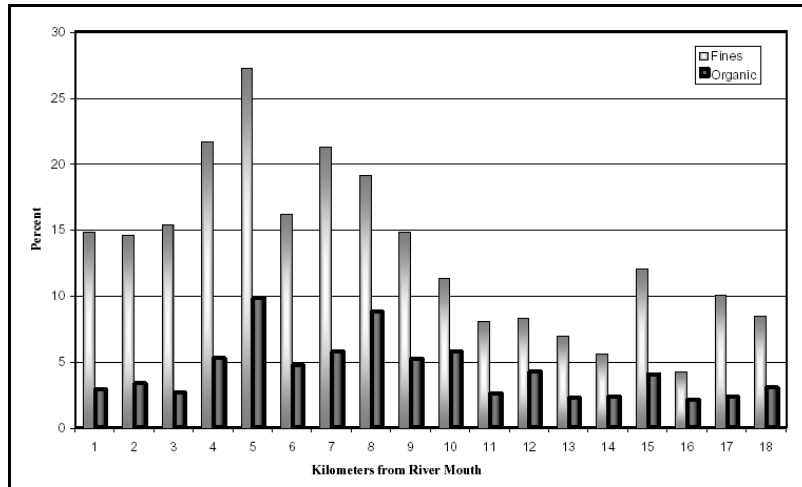


Figure 15. Sediment fines and organic matter in the lower Alafia River.

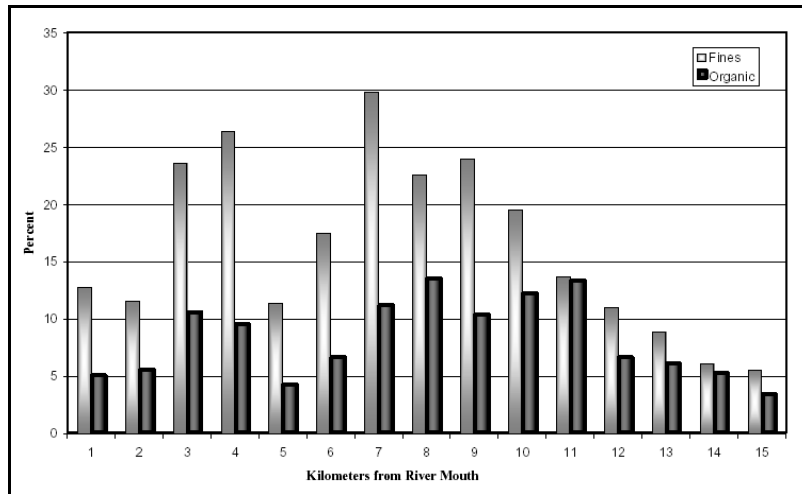


Figure 16. Sediment fines and organic matter in the lower Hillsborough River.

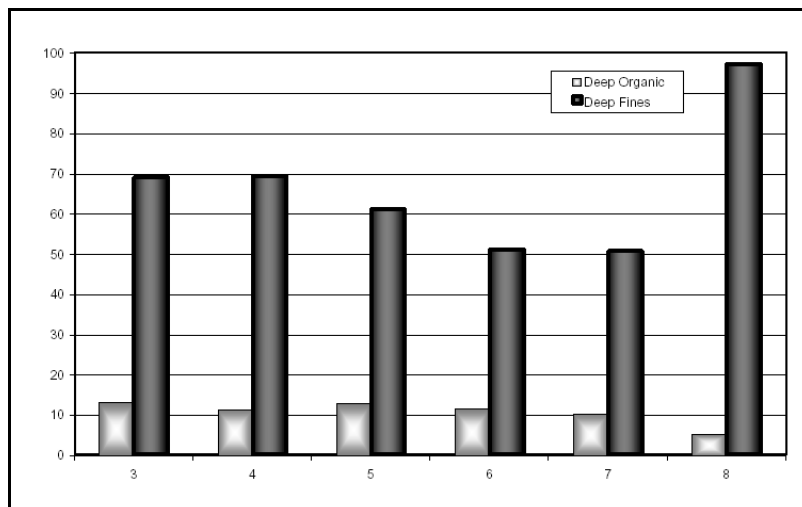


Figure 17. Sediment fines and organic matter in the Tampa Bypass Canal.

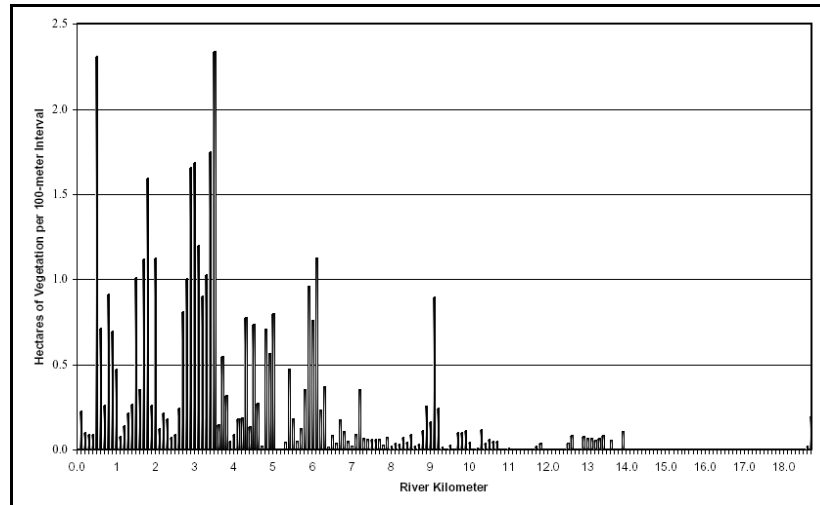


Figure 18. Emergent aquatic vegetation in the lower Alafia River.

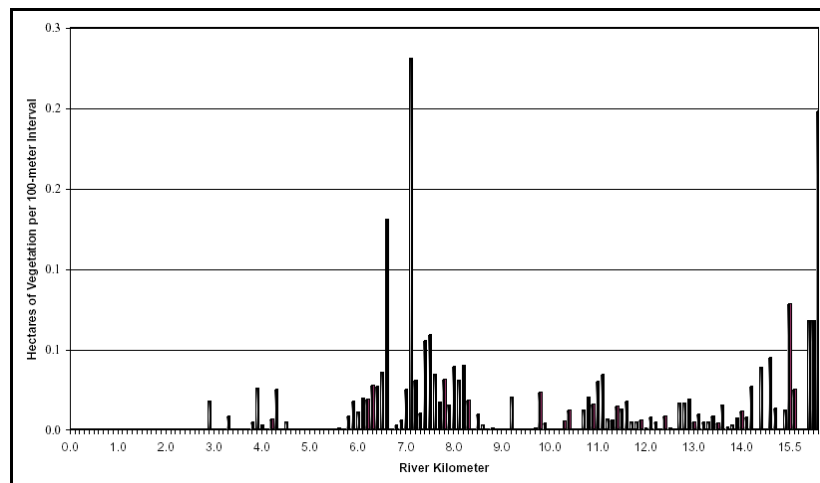


Figure 19. Emergent aquatic vegetation in the lower Hillsborough River.

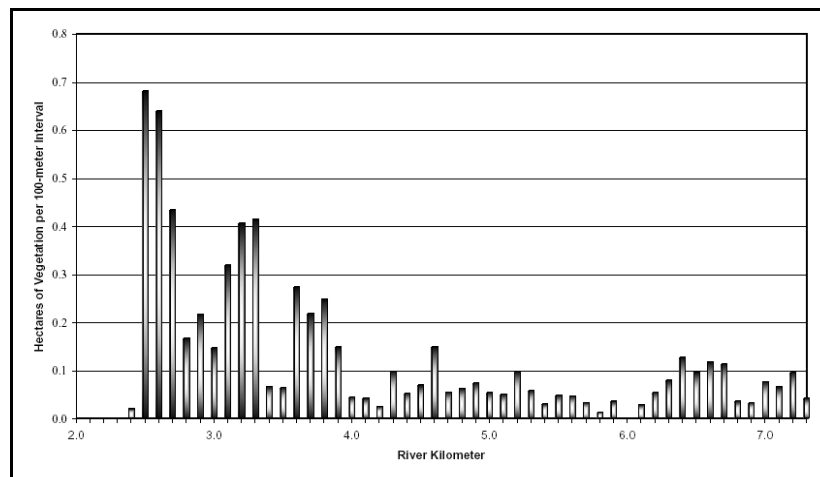


Figure 20. Emergent aquatic vegetation in the Tampa Bypass Canal.

TBC, respectively. These histograms indicate that the vast majority of emergent aquatic vegetation in the Alafia River occurs from the mouth up to river kilometer 6. This vegetation is predominantly mangroves near the mouth, transitioning to *Juncus roemerianus* marshes and then to tidal freshwater marshes. Upstream of about river kilometer 6 the river profile becomes much more incised and relatively little riparian wetlands exist. Comparatively, the Hillsborough River has far less area of emergent aquatic vegetation than the Alafia. The mouth of the Hillsborough is virtually entirely hardened where the river flows through downtown Tampa. Small clusters of fringing tidal marshes exist between river kilometers 6 and 8, and small tidal freshwater marshes exist in the vicinity of Rowlett Park just downstream of the Tampa Dam. The TBC has more emergent aquatic vegetation than the Hillsborough, but substantially less than the Alafia. Most of the emergent aquatic vegetation in the TBC is mangroves near the mouth extending up to river kilometer 4, while small fringing tidal marshes occur further upstream to S-160.

Benthic Invertebrates

Figures 21, 22, and 23 are histograms of HBMP benthic invertebrate density data (mean number of individuals/m²) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that in both the Alafia and Hillsborough Rivers, benthic invertebrate densities are generally comparable, and are greatest in the lower reaches and decrease moving upstream. In the TBC, however, benthic invertebrate densities in the deep dredged channel are more than an order of magnitude lower than in the other two reporting units, and densities decline to near zero in the upper reaches near S-160. These extremely low benthic invertebrate densities are likely due to the poor oxygen environment that exists in the deep dredged TBC. Benthic invertebrate densities in the shallower shoreline areas are generally comparable to the Alafia and the Hillsborough Rivers.

Figures 24, 25, and 26 are histograms of HBMP benthic invertebrate species diversity data (mean number of taxa/sample) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that benthic invertebrate diversity is highest in the Alafia River and only slightly lower in the Hillsborough River. In addition, in both reporting units diversity is greatest in the lower reaches and decreases moving upstream. In the TBC, this pattern is also observed in the shallower shoreline areas, however, in the deep dredged channel benthic invertebrate densities are substantially lower than in the Alafia and the Hillsborough Rivers, declining to less than three taxa per sample in the upper reaches near S-160.

Zooplankton and Ichthyoplankton

Figures 27, 28, and 29 are histograms of HBMP zooplankton (including both invertebrate zooplankton and ichthyoplankton) density data (mean number of individuals/m³) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that zooplankton densities are highest in the TBC and lowest in the Alafia River. Furthermore, in the Alafia and TBC peak zooplankton densities occur at the mouth, whereas in the Hillsborough peak densities occur in the middle and upper reaches.

Figures 30, 31, and 32 are histograms of HBMP zooplankton (including both invertebrate zooplankton and ichthyoplankton) diversity data (mean number of taxa/m³) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that zooplankton diversity is greatest in the Alafia River, and generally comparable between the Hillsborough River and the TBC. Furthermore, in all three reporting units zooplankton diversity is greatest near the mouth and decreases moving upstream.

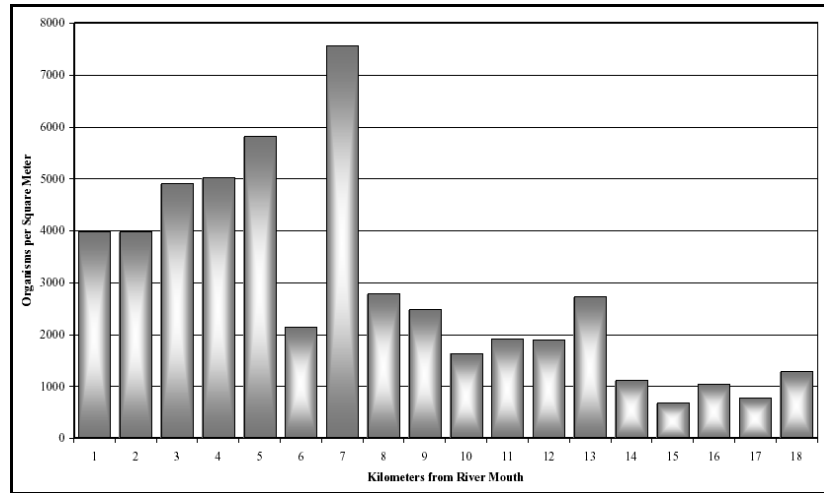


Figure 21. Benthic invertebrate density in the lower Alafia River.

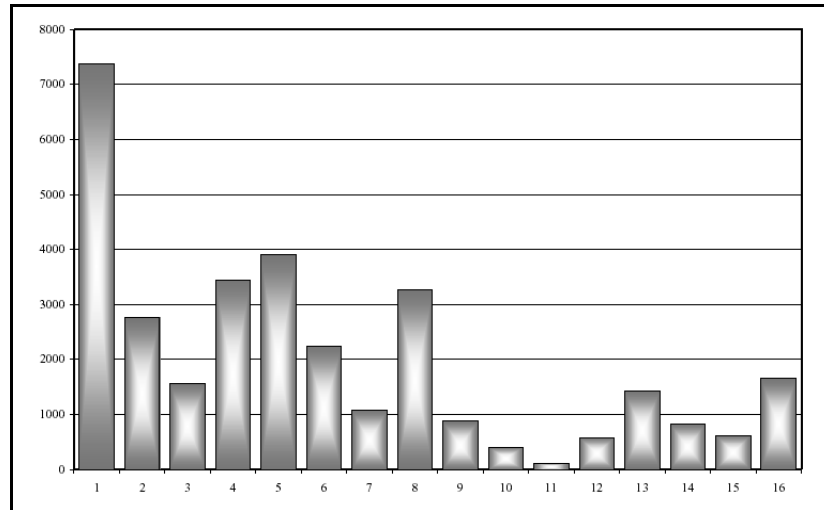


Figure 22. Benthic invertebrate density in the lower Hillsborough River.

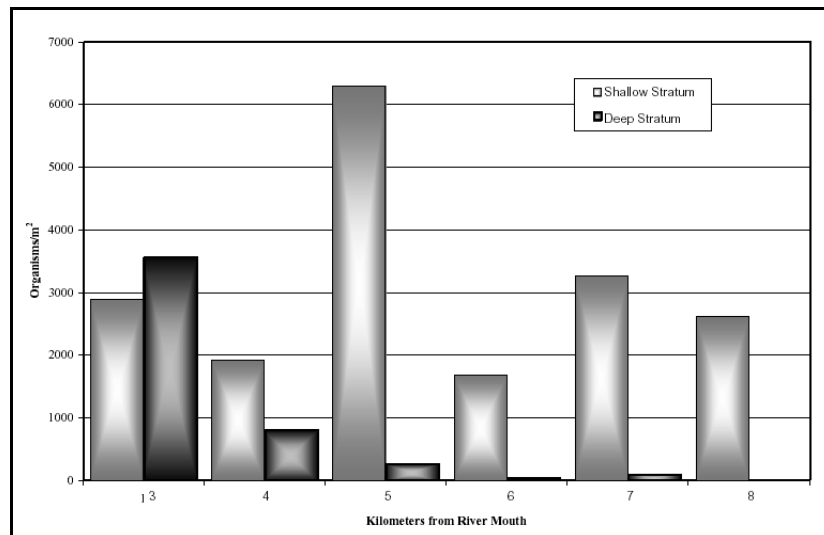


Figure 23. Benthic invertebrate density in the Tampa Bypass Canal.

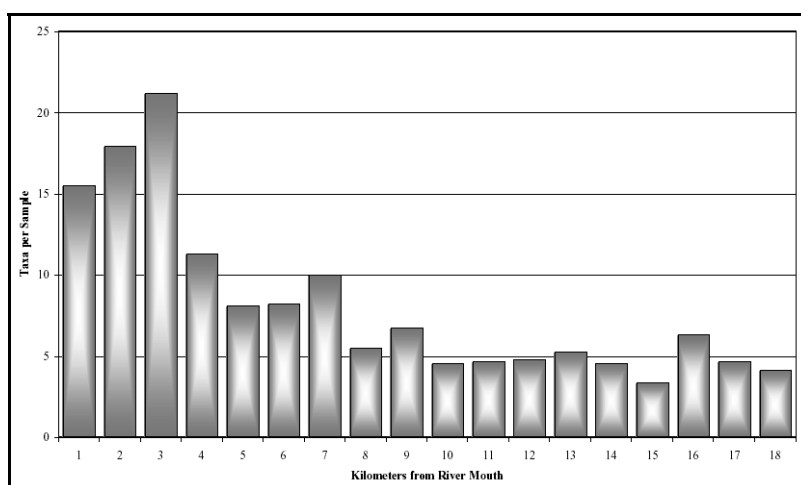


Figure 24. Benthic invertebrate diversity in the lower Alafia River.

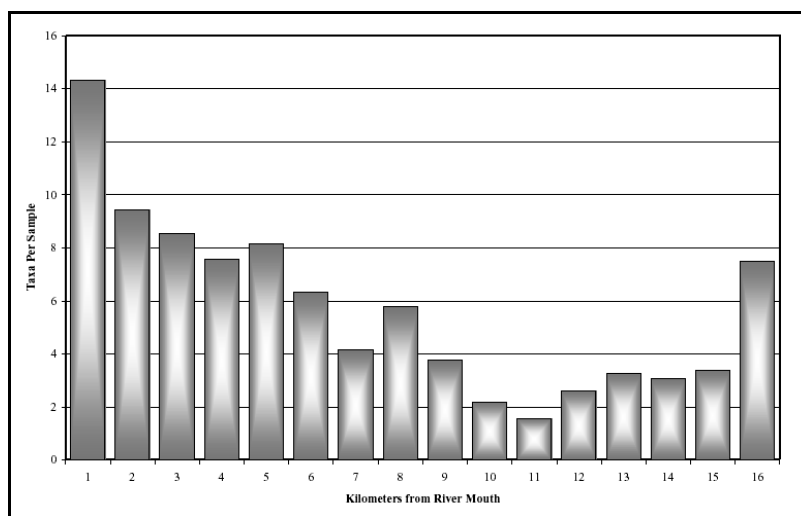


Figure 25. Benthic invertebrate diversity in the lower Hillsborough River.

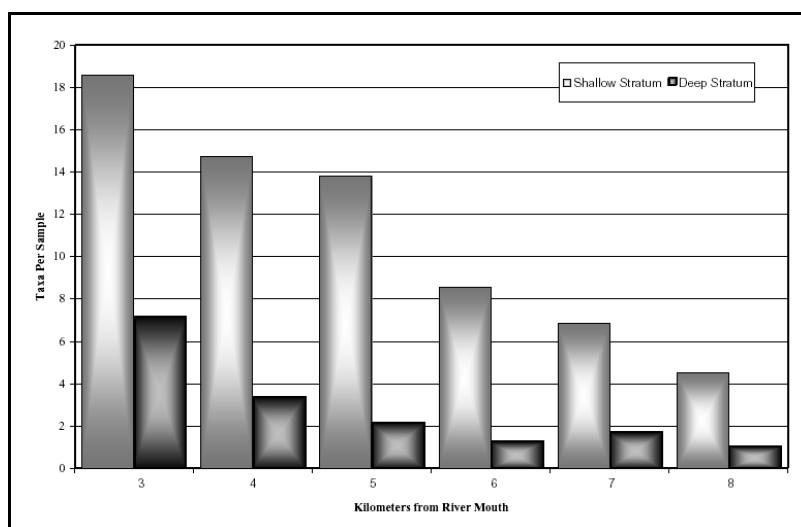


Figure 26. Benthic invertebrate diversity in the Tampa Bypass Canal.

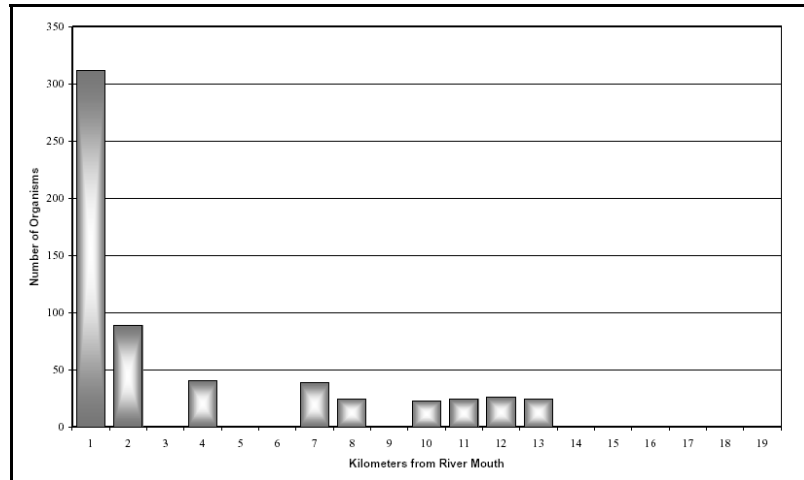


Figure 27. Zooplankton density in the lower Alafia River.

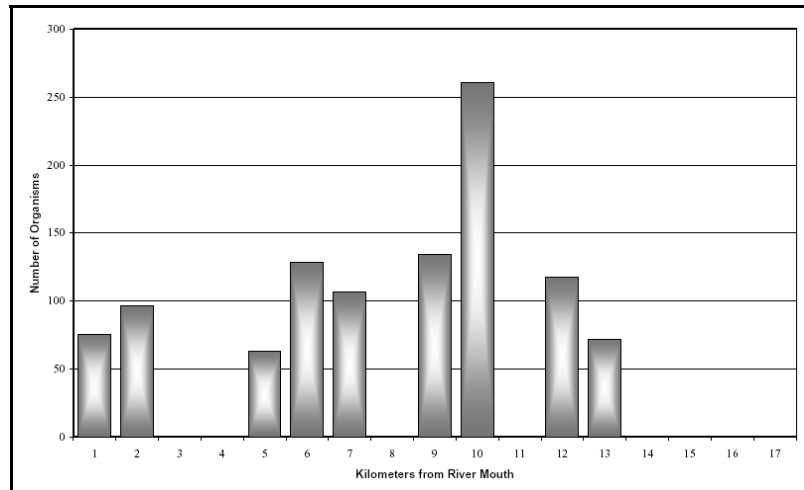


Figure 28. Zooplankton density in the lower Hillsborough River.

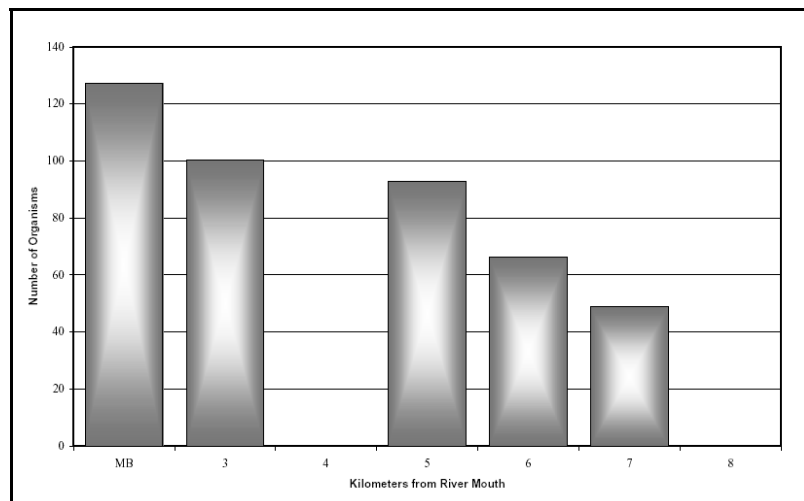


Figure 29. Zooplankton density in the Tampa Bypass Canal.

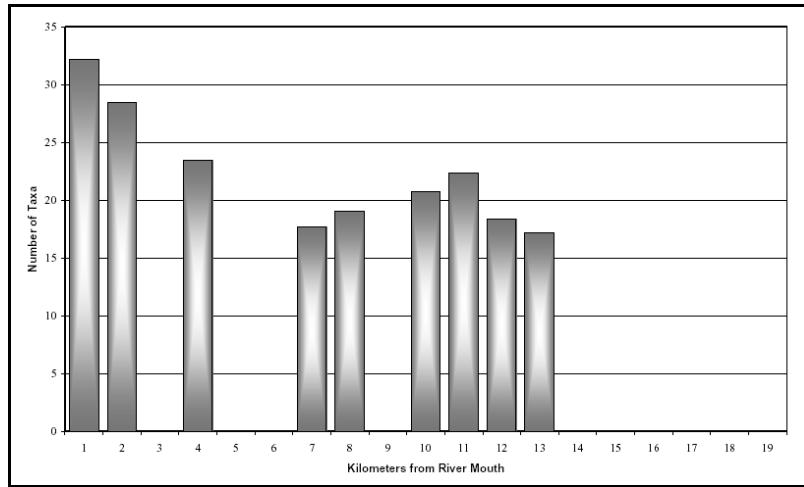


Figure 30. Zooplankton diversity in the lower Alafia River.

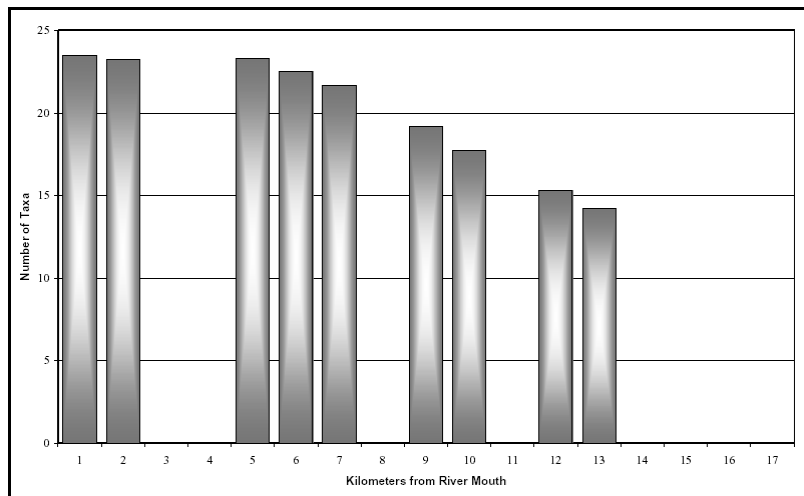


Figure 31. Zooplankton diversity in the lower Hillsborough River.

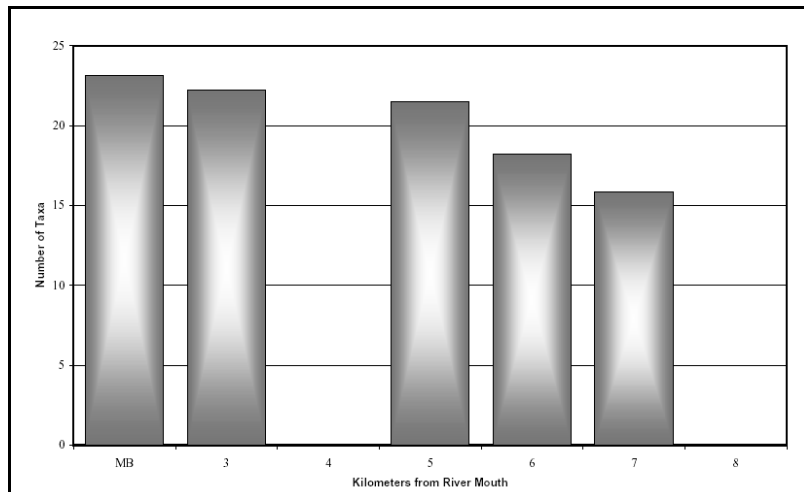


Figure 32. Zooplankton diversity in the Tampa Bypass Canal.

Fish

Figures 33, 34, and 35 are histograms of HBMP fish density data (mean number of individuals per seine net sample) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that fish densities are highest in the TBC and lowest in the Alafia River. Furthermore, in the Alafia River peak fish densities occur in the lower reaches (distinctly at river kilometer 4), whereas in the Hillsborough River and TBC peak densities generally occur in the middle and upper reaches, respectively. In the TBC very high numbers of a few species (e.g., *Anchoa spp.*, *Menidia spp.*) were typically encountered.

Figures 36, 37, and 38 are histograms of HBMP fish diversity data (mean number of individuals per seine net sample) by river kilometer for the Alafia River, the Hillsborough River, and the TBC, respectively. These histograms indicate that fish diversities are highest in the Alafia River and lowest in the TBC. Furthermore, in the Alafia River fish diversity is greatest near the mouth and decreases moving upstream, whereas in the Hillsborough River and the TBC fish diversity is relatively even throughout all reaches.

SUMMARY

Table 2 provides a comparative summary of the hydrologic, water quality, and biological characteristics of the tidal Alafia River, Hillsborough River, and Tampa Bypass Canal. These three water bodies represent a wide range of physical and hydrologic alteration, and this range of anthropogenic disturbance is proportionally reflected in the hydrology, water quality, and biology of these systems. Future regulatory decisions affecting these systems—including Minimum Flows and Levels, Water Use, NPDES, and Total Maximum Daily Loads—should be based on both their existing conditions as well as their potential for restoration.

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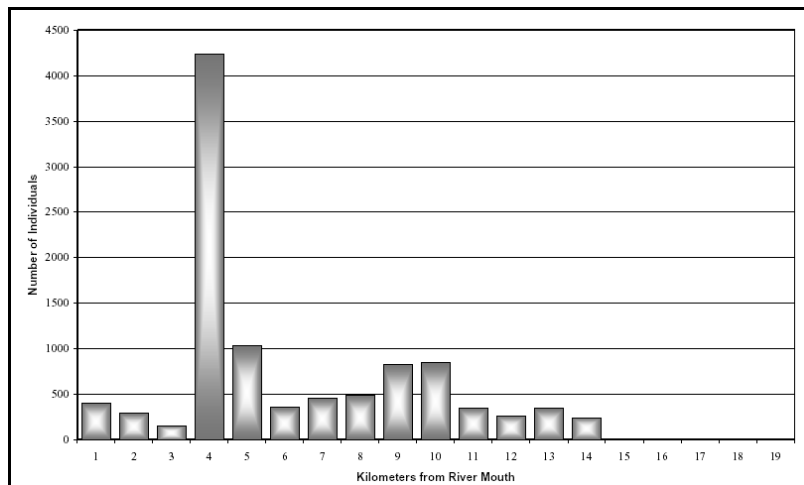


Figure 33. Fish density in the lower Alafia River.

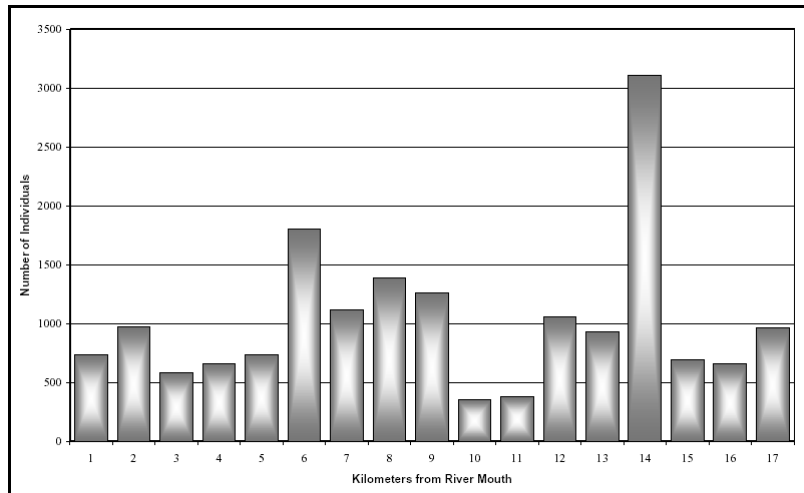


Figure 34. Fish density in the lower Hillsborough River.

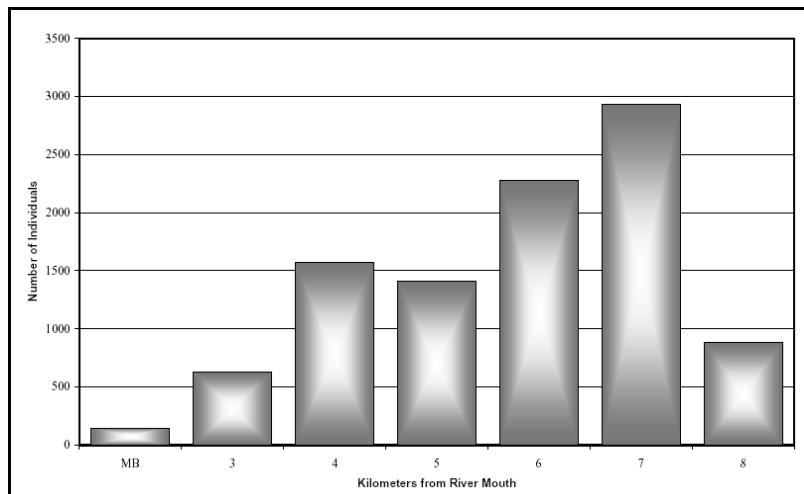


Figure 35. Fish density in the Tampa Bypass Canal.

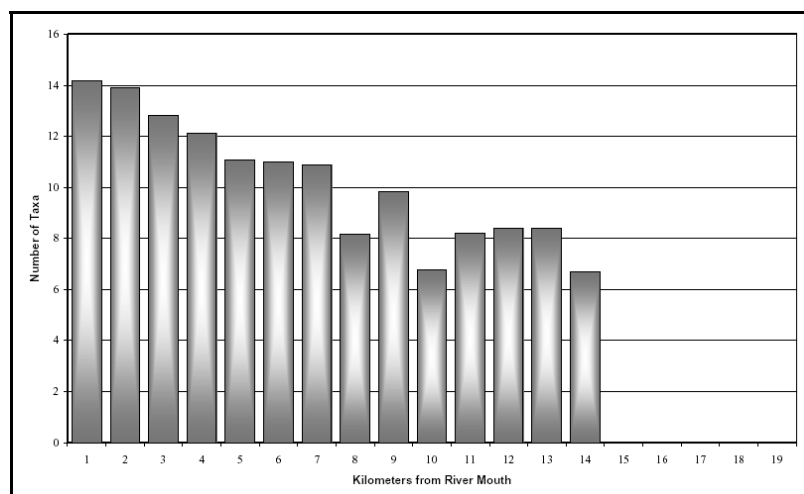


Figure 36. Fish diversity in the lower Alafia River.

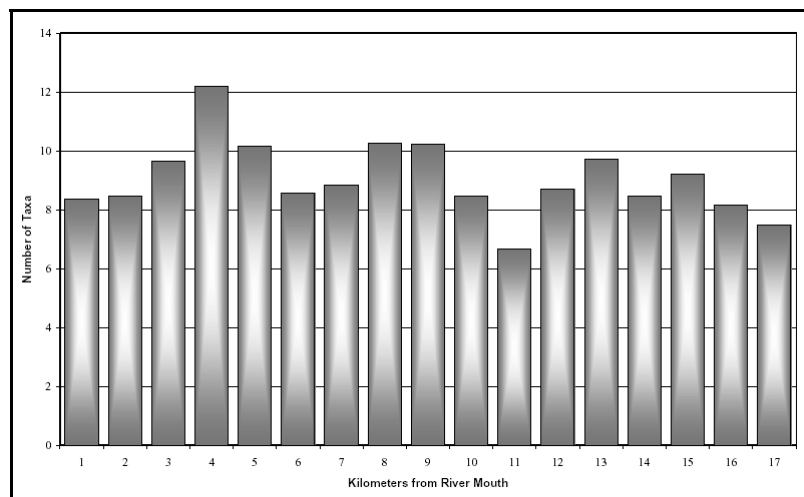


Figure 37. Fish diversity in the lower Hillsborough River.

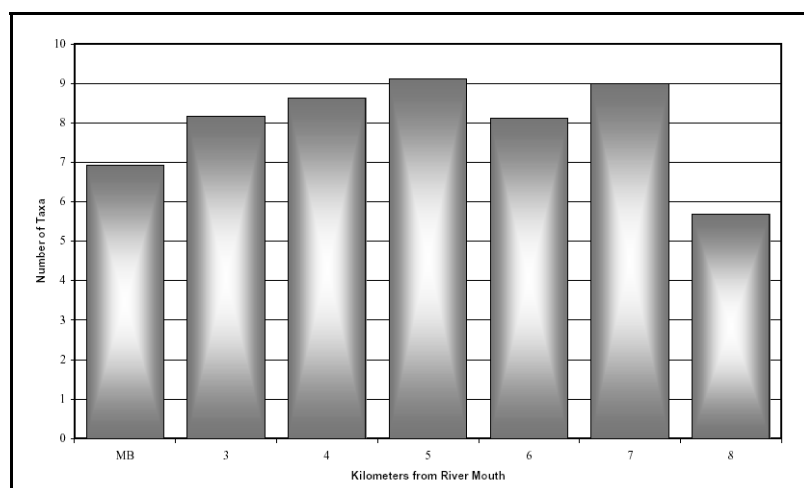


Figure 38. Fish diversity in the Tampa Bypass Canal.

Table 2. Summary hydrobiological comparison of the Alafia River, the Hillsborough River, and the Tampa Bypass Canal.								
Reporting Unit	Freshwater Inflow	Salinity	Dissolved Oxygen	Sediments	Emergent Vegetation	Benthic Invertebrates	Zooplankton	Fish
Alafia River	Typical seasonal flow pattern; periodic flood flows	Typical gradient from 25-30 ppt at mouth to 0 ppt at RKm 16	Usually above 5 mg/l; periodic hypoxia in mid-reaches	Moderate fines and organics; peak in lower reaches (RKm 5)	Highest area of tidal EAV; greatest in lower reaches	Highest diversity and density; peaks in lower reaches	Highest diversity and lowest density; peak in lower reaches	Highest diversity and lowest density; peak in lower reaches
Hillsborough River	Seasonal periods of very low or no flow; periodic flood flows	Lesser gradient with 25-30 ppt at mouth to 5-10 ppt at the dam	Frequently below 5 mg/l; occasional hypoxia	Higher fines and organics; peak in middle reaches (RKm 8)	Lowest area of tidal EAV; greatest in middle reaches	Moderate diversity and density; peak in lower reaches	Moderate diversity and density; peak in middle reaches	Moderate diversity and density; peak in middle reaches
Tampa Bypass Canal	Very low or no flow year round; periodic extreme flood flows	Little or no gradient with 25-30 ppt from mouth to S-160	Usually below 5 mg/l; persistent hypoxia in deep areas	Highest fines (50-90%) and organics; peak in upper reaches (S-160)	Moderate area of tidal EAV; greatest in lower reaches	Lowest diversity and density; deep areas are depauperate	Lowest diversity and highest density; peak in lower reaches	Lowest diversity and highest density; peak in upper reaches



A REVISED INTEGRATED HYDROLOGIC MODEL FOR WATER SUPPLY MANAGEMENT IN THE TAMPA BAY REGION

E. Hosseinipour

ABSTRACT

Tampa Bay Water, Florida's largest wholesale water supplier, has pioneered development, application and implementation of a unique integrated surface-ground water simulation model in concert with an optimization program (S-O) to operate multi-wellfield water supply facilities in west-central Florida. These wellfields are operated as an integrated system using this set of simulation-optimization models giving priority to minimization of environmental impact while reliably meeting demands. This management program called the Optimized Regional Operations Plan (OROP) has been in effect since January 1999 and is used to produce a priority production schedule for 150 wells in 12 inter-connected facilities on a bi-weekly basis. The OROP database is updated as data become available from various sources including the agency's environmental and hydrological monitoring programs, the national weather service rainfall stations, and water production information some of which are automatically relayed through a SCADA system.

The main components of the Integrated Surface and Ground Water (ISGW) modeling programs (HSPF and MODFLOW), soon to be revised in a new package called Integrated Hydrologic Model (IHM) are public domain, have been tested, and have gained wide-spread acceptance within the water resources/environmental community. However, a substantial portion of the computer codes that communicate information between the two main models are independently developed and tested. The application of the integrated model in the unique hydrologic conditions of west-central Florida that include high and quick-changing water table profiles, numerous environmental features such as wetlands and surface water bodies, a very variable rainfall pattern, high and spatially variable ET which depends to a large extent on changes in Depth To Water Table conditions provide major challenges as far as operational use of the model is concerned. Various applications of the model over the course of three years revealed that although the model predictions may be reasonable for long term regional water resource assessments, the short term response especially during the extreme hydrologic conditions (wet/dry season) are questionable. The re-make of the model was predicated to resolve issues such as appropriateness of model conceptualization for the given physical settings, site-specific processes to be considered, and the preferred methodology to represent these processes, interpretation of results from a "well-calibrated" model, as well as other technical and institutional issues. Figure 1 shows the facilities currently included in the OROP as well as others that will be included later when infrastructure capabilities are in place.

This paper will briefly present the predecessor model and discuss the logics that led to the re-make of the integrated model. Specifically, we will describe the expected application scenarios for the model and discuss the approach of presenting the contentious theoretical issues via a peer review of the model and an uncertainty analysis of its parameters.

INTRODUCTION

As stated above after a three-year application experience with ISGW, we identified certain deficiencies in the model as far as OROP requirements were concerned. In order to overcome the issues identified with ISGW, we decided it is best to have an independent review of ISGW such that the prospective revisions would have the approval of experts in the field. We developed an RFP with the objective of "reviewing scientific and technical data and methodologies used in the development of the ISGW version CNTB121, and to provide comment and critique as to the adequacy and appropriateness of the model development and its applications in light of the intended purposes for Tampa Bay Water's use of the model." This review focused on three main areas: the surface and groundwater engines (MODFLOW and HSPF) codes modifications and conceptualization; the linkage codes; and the evapotranspiration methodology adopted in ISGW. In addition, there was a desire to address other related areas such as: the implications of a loosely coupled model to simulate the hydrologic behavior of the area; the convergence between the two models and the impact of having limited feedback from MODFLOW to HSPF; application of sophisticated models on a regional scale where adequate data may not be available; and how much testing and verification ISGW has gone through. The foremost question was whether the conceptual

model developed for the study area is adequate. Questions related to appropriate representation of stratigraphy, water balances, boundary conditions, surface water flows, aquifer stresses were posed and asked to respond via thorough review of the conceptual model and input data sets. Model implementation issues such as grid size, time step, convergence criteria, and mass balance errors and calibration methodology were also to be addressed. One of the main interests was whether the model could predict short-term responses on the system due to imposed stresses. Is the model capable of producing correct Unit Response Matrices (URMs) at the control points used in OROP? Major tasks in the Scientific Review included:

- Assessment of the model conceptualization
- Assessment of the application of algorithms that represent the conceptual model
- Interpretation of data and assessment of model input parameters
- Critique of the model calibration process and results
- Analysis and interpretation of model output as to the adequacy for intended purpose

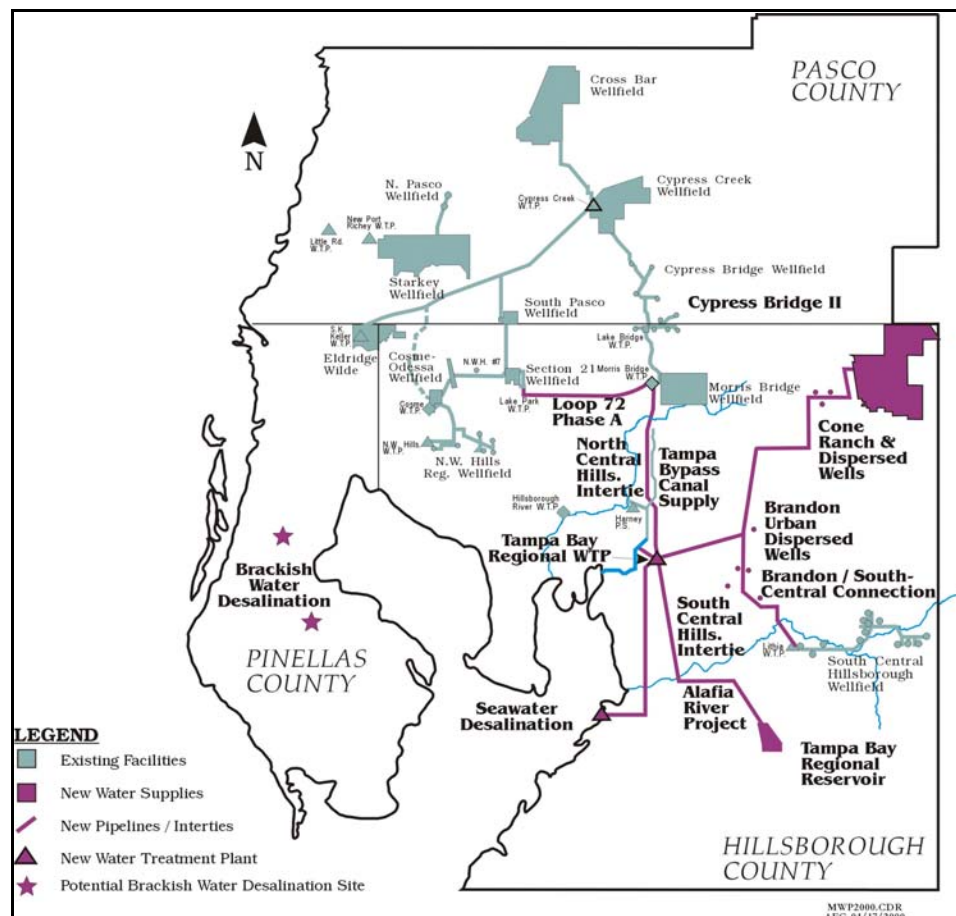


Figure 1. Present and future interconnected facilities of Tampa Bay Water.

Although the model was previously reviewed by the regulatory agency there was no formal report and controversy remained on a number of issues. The goals of this review were to find a reasonable balance between addressing purely academic concerns and meeting the practical needs of Tampa Bay Water. To this end the following were expected from the peer review:

- Determine whether the methodologies implemented in ISGW/CNTB 121 were scientifically reasonable by evaluating the model assumptions, theoretical basis and the application scenarios.
- Review the procedures and analysis used in developing and applying quantitative measures such as data reduction to construct the model.
- If any of the methods used deem not to be appropriate then enumerate and describe the deficiencies and evaluate the associated errors; can the deficiencies be remedied, and if not identify alternative methodologies that are scientifically reasonable and defensible.
- If the methods used are reasonable but there are other more robust and preferred approaches then identify those and develop a quantitative assessment of relative strengths and weaknesses and the benefits expected from the recommended preferred approach.
- An assessment of the practicality for the implementation of the preferred methods and the operational burden relative to expected performance should also be explained and justified.

In light of the importance of the Integrated Hydrologic modeling to the management of water resources in the Tampa Bay Region, the establishment of the scientific credibility of the model is crucial. This is because we are applying the state of are technologies in water management (optimization, ANN, etc.) along with emerging advances in the hydrology of shallow water table to ensure that the most robust methods are used in the management of natural resources of the region. In a surface water model we are interested in the following features of the model:

- Areal precipitation distribution
- Surface runoff routing characteristics
- Simulation time step and accuracy predicted results
- Evapotranspiration process hierarchy and variations with land uses
- Land use and its impact on hydrologic processes
- Vadose zone processes as it relates to high water table conditions
- Eco-hydrology of wetlands/lakes as it relates to regional water balance and ecosystem health
- Ease in linkage with a groundwater model
- Public acceptability

In a groundwater model we are specifically interested in following features:

- Ability to handle dewatering/rewetting process
- Capability and/or adaptability to handle variable specific yield
- Capability to accommodate various surface water features (streams, lakes, wetlands)
- Ease in linkage with a surface water hydrology model
- Public acceptability

Integrated Model Application at Tampa Bay Water

The integrated model (ISGW) has been used in a number of applications by Tampa Bay Water staff. Future model applications are likely to expand. For model revision and calibration purposes, it was important to take into consideration current and future uses of the enhanced model. This section summarizes envisioned application of the model by Tampa Bay Water and others in the region. The integrated model (ISGW) is currently being used by Tampa Bay Water as a tool in Optimized Regional Operations Plan (OROP) and other applications in

support of mitigation and permitting. Future applications of the model by Tampa Bay Water and the Southwest Florida Water Management District (SWFWMD) will encompass the following areas:

1. **Optimized Regional Operations Plan (OROP):** Tampa Bay Water will use the integrated model for managing water supply sources that includes 12 wellfields. The revised integrated model (IHM) will be used to generate unit response matrices (URMs). These applications involve simulating hydrologic conditions (water levels in aquifers and streams for short and long term periods) 2, 4, 13, and 52 weeks. Accurate URMs calculations are required regardless of the climatic conditions, but it is more critical to provide accurate URMs for dry conditions. In summary the following uses of the model are envisioned in support of OROP:
 - A. Short-term water level prediction every 2 weeks or more frequent
 - B. Longer-term water level prediction every quarter for rule curve development
 - C. Generation of fairly accurate URMs that are used as inputs in the OROP
2. **Water Resource Evaluation Tool:** The integrated model will be used to evaluate the environmental and hydrologic impacts of water withdrawals. It is expected that the revised and enhanced model will be used for this application by both agencies. This application requires accurate model predictions on a monthly/seasonal basis and over longer time periods beyond one year. Accurate predictions under dry conditions are of particular interest.
3. **Water Supply Plans:** There are interests to use the model in the development of regional water supply plans. This application requires running the model for long time periods in the order of 5–10 years to assess various water withdrawal scenarios and their impacts on the surrounding ecosystem. The ecosystems of interests include isolated and interconnected wetlands, lakes, streams, and receiving surface water features (such as Tampa Bay).
4. **Surface Water Evaluation and Surface Water Withdrawal for Water Supply:** Future applications of the model by Tampa Bay Water will include seasonal water diversion from Hillsborough River, Tampa Bypass Canal (TBC), and Alafia River. This will require a dynamic flow routing module (e.g., HEC-RAS) to be added (linked) to the surface component (HSPF) of the integrated model. These applications will require the surface water component of the model to provide accurate predictions of stream flow rates and water levels for short time periods (hourly, daily).
5. **Groundwater Withdrawal Reduction/Water Level Recovery:** Total groundwater pumping from the 11 central-system wellfields by Tampa Bay Water is scheduled to decrease from 158 MGD to 121 MGD by early 2003. Further reduction to 90 MGD is required by 2008. Other water sources (off stream Reservoir, Hillsborough River, Tampa Bypass Canal [TBC] and Alafia River, and desalinated water) will be used to satisfy the reduction of groundwater resources. The integrated model will be used to assess different reduction scenarios in regard to water level recovery in the surficial aquifer and wetlands (timing and spatial distribution) to support decision-making associated with the distribution of pumpage reductions among various wellfields, and environmental mitigation requirements. This requires accurate predictions under a variety of pumping conditions. Temporal scales of these assessments are most likely seasonal to yearly and beyond, to be delineated later.

6. Impacts of Conjunctive Use: Water withdrawal from one source (e.g., surface water versus groundwater or water pumped from a sink hole) may impact other sources in the vicinity. For example, we have used the model to evaluate the impact of pumping from the Morris Bridge Sink on the nearby wellfield and the Canal System.
7. Minimum Flows and Levels (MFL): SWFWMD may be interested to apply the model to evaluate MFL in the streams and aquifer in support of their mission. The Southwest Florida Water Management District manages water and water-related resources within its boundaries, which encompass approximately 10,000 square miles. Central to the mission of the agency is maintaining the balance between the water needs of current and future users while protecting and maintaining the natural systems that provide the region with its existing and future water supply. The Governing Board of SWFWMD directs a wide-range of programs, initiatives, and actions. These programs include flood control, regulatory programs, water conservation, education, and supportive data collection and analysis efforts.
8. Wetland Rehydration Design and Assessment: Although detailed conceptual designs of this type of application has not been fully explored yet, Tampa Bay Water envisions application of the enhanced integrated model for assessment of the wetland rehydration and recovery using reclaimed water, surface runoff, ditch blocks, or other structural means.

Background

Tampa Bay Water owns thirteen groundwater supply systems, which are operated in accordance with permits issued by SWFWMD. Twelve of these wellfields are operated as an integrated system giving priority to minimization of environmental impacts while cost effectively meeting demands. To further reinforce the plan for operating the regional wellfields as an integrated system, on December 15, 1998, SWFWMD issued a Consolidated Water Use Permit (WUP 2011771.00) to Tampa Bay Water for the eleven central wellfields. These eleven wellfields have supplied approximately 60% of the drinking water for the region in the past few years.

The integrated hydrologic model ISGW has been an integral part of several major activities at Tampa Bay Water since 1997. In addition to being used as a tool in the Optimized Regional Operations Plan (OROP) for short-term and long-term simulation runs, ISGW has been used for water resource planning and development activities, compliance with consolidated water use permits, development of response coefficients due to incremental pumping stresses, recovery analysis, and mitigation of impacted ecologic features. At the present time, ISGW is the only functional tool available for regional simulation of the complete hydrologic regime in the Tampa Bay region.

A scientific, peer-review of ISGW was completed in May 2001 (West Consultants et al.) and a parameter uncertainty analysis (Phase II) of the CNTB 121 application of ISGW was completed in June 2001 (Waterstone, Inc. et al.). Based on the results from the peer-review and uncertainty analysis, and the experience of the staff of Tampa Bay Water and SWFWMD in various applications of ISGW, several revisions and/or enhancements to ISGW were proposed. In addition, review of prior model applications showed a need to refine the conceptual model of the physical system for both surface water and ground water.

Integrated Hydrologic Modeling in the Tampa Bay Region

Beginning in 1993, ground-water modeling in the Northern Tampa Bay area began to change from the traditional approach of single-regime modeling of the ground-water system, to an integrated surface/ground-water modeling approach. This effort led to the development of an integrated surface/ground-water model, now commonly referred to as the ISGW model, through consulting services provided by SDI Environmental Services, Inc. (SDI). Since 1993, the ISGW model has undergone numerous revisions and re-conceptualizations as the application of the model expanded and as understanding of the hydrologic system improved.

In March 1997, SDI completed the report “Water Resource Evaluation and Integrated Hydrologic Model of the Central Northern Tampa Bay Region.” This model, referred to as the ISGW/CNTB model, was developed for use as an analysis tool to assess hydrological issues related to water resource and wellfield management in the Central Northern Tampa Bay area. The CNTB area includes the 11 wellfields under the Consolidated Water Use Permit. Since spring 2000, Tampa Bay Water has been using Run 121 of the ISGW/CNTB model for operation of the wellfields and compliance with Consolidated Water Use Permit conditions.

In August 1998, SWFWMD initiated a review of an earlier version (ISGW/CNTB 90) of the model. SWFWMD formed a technical advisory committee (TAC) to review the model. The TAC was composed of SWFWMD staff, representatives from the University of South Florida, Tampa Bay Water and SDI. The review process ended in April 1999 and the TAC recommended several refinements to the ISGW/CNTB model. Although a final report was not published regarding the findings and recommendations of the CNTB 90 TAC most of the recommended revisions by the TAC were implemented by Tampa Bay Water via consulting services by SDI during 1999. These revisions are included in the ISGW/CNTB 121 version of the model code. Some of the recommendations of the TAC required further evaluation prior to implementation.

Parallel to the continued development of the ISGW/CNTB 121 model, SDI has developed the ISGW/Cone Ranch model. This model incorporates a larger area than the original CNTB model and incorporates the more complex hydrogeologic system found in northeastern Hillsborough County. Code changes were also implemented in the ISGW/Cone Ranch version of the model.

Scientific Review Process and Recommendations

Through consideration of the ongoing and evolving needs of Tampa Bay Water with regard to the ISGW model as well as the issues raised by the TAC, a detailed independent scientific review by a team of consultants was performed on the ISGW/CNTB 121 code and associated model application. A final report on the review was completed in May 2001 (West Consultants et al.). Simultaneously an uncertainty/sensitivity analysis of ISGW parameters was conducted by another group of consultants and a final report prepared by June 2001 (Water Stone Inc.). Based on the recommendations of the scientific review and uncertainty/sensitivity analysis studies and the experiences of the Tampa Bay Water staff in applying the ISGW model in the past three years, and in association with SWFWMD staff, a scope of work with specific tasks was developed to revise the ISGW/CNTB 121 to better serve the needs of both agencies in the future

The current version of ISGW (ISGW/CNTB 121) uses HSPF V10 and MODFLOW 1983. One or more of the ISGW executable components (i.e., HSPF, MODFLOW, inter-processor codes) is not compatible with Windows 2000 operating system. HSPF V12 and MODFLOW 96 are implemented in the new IHM. All of the inter-processor codes of IHM are new and revised

vertical processes concept for the unsaturated zone is adopted that considers soil moisture front movement in association with depth to water table conditions that has proved to be crucial in the area. The following elements were incorporated in the revised Integrated model IHM: (a) Scenario configuration database with interface; (b) Process control executable; (c) Transaction engine executable. The interface for the scenario configuration database is used to specify global parameters for an execution (scenario) of IHM, such as simulation length, integration time step length, MODFLOW in concert with HSPF or individual model runs, etc. The process control executable reads the scenario database, provides cycling logic for IHM components, and runs the application. The transaction engine sequentially calls HSPF, MODFLOW, and IHM inter-processor codes as directed by the process control executable. Most of the pre- and post-processing for the surface water component of the model are based on HSPF capabilities built in the EPA's BASIN package while Groundwater Vista serves as the pre- and post-processing interface for the groundwater component of IHM. It is likely that in the future stand alone pre- and post-processing package will be developed exclusively for IHM.

Revision of Evapotranspiration Algorithm

A revised formulation and/or hierarchy for simulation of ET within the vadose and saturated groundwater profiles are implemented in the IHM. Simulation of ET from interception and depression storages was deemed acceptable within the current ISGW model. The Scientific Review report describes the following concerns with other aspects of ISGW ET algorithm:

- Pre-allocation of ET partitioning (surface water vs. ground water ET)
- Spatially-uniform extraction of ground water ET within a basin
- Applying different PET rate to open water and land areas
- Modification of PET by land cover for ground water ET (e.g., plant ET coefficients)
- Calculation of availability of water from LZS for ET
- ET extraction for water above land
- Field capacity and porosity calculations
- Hierarchy of ET extraction
- Others that may not have been described above

ISGW currently uses a hierarchy like that of HSPF where ET from saturated ground water is removed before ET from the vadose zone. An alternative hierarchy, suggested by the ISGW technical advisory committee of SWFWMD, reverses the order of ET extraction for saturated ground water and vadose zone. Much of the hierarchy debate is related to the magnitude of capillary fringe in west-central Florida soils. More importantly, the magnitude of upward flux from the water table into the portion of the vadose zone that is active in ET processes is debated. In either hierarchy, the concerns raised in the Scientific Review were to be addressed and resolved in the IHM. If any of the concerns in the scientific review report cannot be resolved adequately, provide defensible justification and flexibility for later refinement as new developments in the future could facilitate the resolution of the subject matter. Data requirements for the algorithms should be readily available for west-central Florida. Sample data sets for HSPF, MODFLOW, and inter-processor codes will be developed to test the package to assure proper behavior. Consideration should be given to the conceptual approach for hierarchy option(s) used, in other integrated models.

Multiple Land Segments in Surface Model Basins

Depth to water table influences infiltration, runoff, ET, and recharge processes. Depth to water table also influences the location of plant and tree communities. Runoff can be generated through an infiltration-excess or a saturation-excess process. Most of the runoff

generated in regions with near-surface water table is through saturation-excess. The area where near-surface water table conditions persist varies seasonally and has been referred to as variable saturation areas (VSA). Differences in seasonal timing and volume of runoff generated from infiltration-excess compared to saturation-excess can be significant. Differences in runoff translate into differences in ET and recharge. Spatial variability in components of the water budget can be better simulated when land areas that have more homogenous physical and hydraulic properties are aggregated in a model element.

IHM implements the capability to simulate multiple land segments within a model sub-basin in the surface water hydrology component (HSPF). Multiple pervious land segments (PERLND) and at least an impervious land segment (IMPLND) are included in each sub-basin. The basis for various land segments is similarity in land use/cover, depth to water table, or other factors dominating the hydrologic and hydraulic behavior in west-central Florida. Each land segment within IHM sub-basin is comprised of an aggregation of many discrete, unconnected land areas. Imperviousness and irrigation flux are incorporated into the conceptual model for multiple land segments within individual basins. Irrigation flux can significantly modify the antecedent soil moisture, affecting the water balance of the irrigated area. Area corrections are included in IHM flux transfers between HSPF and MODFLOW due to the differences in basin area for disparate discretization schemes. This approach facilitated Cell-by-Cell Distribution of Recharge and Ground-Water ET.

One-Day Integration Time Step and Ground-Water Stress Period

ISGW used a one-week integration time interval between HSPF and MODFLOW and a fixed daily time step for groundwater simulation and fixed hourly time step for surface water simulations. The time step length of MODFLOW is an input in the IHM and can vary depending on a particular need. This provision helps to reduce the effect of time lag introduced through the indirect coupling of the surface and ground water flow processes, especially for short-term simulations. The indirect coupling impacts the stream-aquifer interactions due to the one-week lag that translates into stream flow simulation results being out of phase with the observed data. Lag time in the integration time step also affects ET fluxes from the vadose zone and saturated ground water.

Technical and User Manuals

Existing documentation of ISGW is in the form of project reports. This form of model documentation is not adequate as either a manual of development procedures or a user manual for guiding application development. That is, unless a person has a relatively long association with the modeling package the learning curve is long and arduous. IHM now has a user's manual, a theory/technical manual and an application guide manual that help a user to gain familiarity with the model quickly and facilitate model set and execution. The IHM manuals are viewed as an extension of the manuals for HSPF and MODFLOW. References are made to specific sections of the manuals of the component models (HSPF and MODFLOW) for a user who may be interested in expanded discussion of a specific topic. IHM manuals concentrate on explaining how HSPF and MODFLOW work together with the inter-processor codes to simulate the entire water budget. The technical manual includes an explanation of conceptual information and the application of the concepts into code language. The user manual includes guidance on applying IHM field problems. Procedures used to develop various pieces of codes, to construct input time series such as rainfall, pump package, PET are fully explained and appropriate references provided. The documentations will also serve as living guides for users of IHM should there be a need for modification and expansion of sections within individual document.

CONCLUSIONS

IHM is an improvement over ISGW since the vadose zone processes implemented are more physically based. It also links the infiltration from both rainfall and irrigation as input to the upper Boundary Condition (soil surface) and addresses both infiltration excess runoff (Horton theory–soil surface BC limitation) and saturation excess runoff (subsurface boundary limitation). In west central Florida region with minor exceptions (urban and industrial land uses) plants and crops are the larger players in the hydrologic cycles than runoff/stream flow components. One of these mechanisms often is dominant depending on a site's climate and soil hydraulic regime. For humid conditions with relatively lower rates of rainfall (irrigation input) the soil may saturate below when downward unsaturated flow is limited by some restrictive subsoil later/conditions. In other site-specific conditions, topography, soil depth (depth to water table), soil horizonation (different intermittent soil horizons), and soil hydraulic regime are major players. Of the two mechanisms of infiltration control (subsurface or saturation excess vs. surface or infiltration excess) the former may be dominant in the region and must be considered in order to have a proper water balance. Added to this complexity in our application of integrated modeling is the fact that appropriate choice of methodologies is often dictated by regulatory agencies and paucity of hydrologic data.

Model calibration process to evaluate the uniqueness and accuracy of calibrated model parameters was a crucial goal of the project. An examination of sensitivity of the model to assess the reliability of calibration results and the uncertainty of calibrated parameters were also a goal. Addressing quality and clustering of calibration data was also important. The aim was to make sure that calibration targets are selected to sufficiently cover appropriate regions and time periods.

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NEAR-TERM FORECASTING OF SURFACE WATER SUPPLIES FROM THE HILLSBOROUGH RIVER AND TAMPA BYPASS CANAL SYSTEM

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INTRODUCTION

Tampa Bay Water, the largest wholesale water supplier in Florida, serves more than two million residents in the Tampa Bay region through its member governments in Hillsborough, Pasco, and Pinellas Counties (the Tri-County Region), as well as the cities of New Port Richey, St. Petersburg, and Tampa. Wellfields historically have supplied approximately 60 percent of the Tampa Bay region's drinking water. Tampa Bay Water holds a Southwest Florida Water Management District (SWFWMD) Consolidated Water Use Permit (WUP 2011771.00, December 15, 1998) that governs the operation of 11 of its wellfields. Because this WUP includes a schedule that requires reductions in average annual wellfield pumping, Tampa Bay Water developed a Master Water Supply Plan to develop alternative source supplies including surface water.

This report describes the development of a suite of computer modeling tools to forecast daily flows at key locations along the Hillsborough River and Tampa Bypass Canal (TBC). The forecasted flows will be used to estimate the availability of surface water for operational planning purposes. Because Tampa Bay Water manages its water supply system proactively by planning the operation of its entire system for one week in advance, the Hillsborough River/Tampa Bypass Canal Flow Generation and Hydraulic Routing Model (HR/TBC model) was developed to produce forecasts for a seven-day period into the future.

WATERSHED DESCRIPTION

The Hillsborough River basin covers approximately 650 square miles and is supplied by several major tributaries and springs including Cypress Creek, Trout Creek, Blackwater Creek, and Crystal Springs. The United States Geological Survey (USGS) measures stream flow at a number of locations in the watershed including Trout Creek, Cypress Creek, Morris Bridge, Zephyrhills, and the Tampa Dam (see Figure 1). The basin consists primarily of large, flat areas, with many wetlands, that drain to the Hillsborough River during wet weather. Before reaching Tampa Bay, the Hillsborough River enters the Hillsborough River Reservoir (reservoir), which has served as a water supply source for the City of Tampa since the 1920s.

The basin is quite complex in its lower reaches, and includes a number of flow control structures and canals, including the TBC (see Figure 2). The TBC was constructed during the 1970s by the U.S. Army Corps of Engineers (USACE), primarily to provide flood control for the densely developed lower portion of the watershed in Tampa. During periods of exceptional flooding, water can be retained upstream of structure S-155 in a flood detention area and can be diverted to the TBC. More commonly, diversions from the river into the canal occur further downstream via structure S-161 on the Harney Canal. All excess TBC water is discharged into the Palm River via structure S-160. Both the Tampa Dam and structure S-160 provide saltwater barriers, preventing saltwater from moving upstream.

The TBC historically has been delineated into three "pools," the boundaries of which are defined by the structure that forms the backwater in each pool. The upper pool is upstream of S-159; the middle pool is upstream of S-162 (and includes the Harney Canal); and the lower pool is upstream of S-160 (see Figure 2).

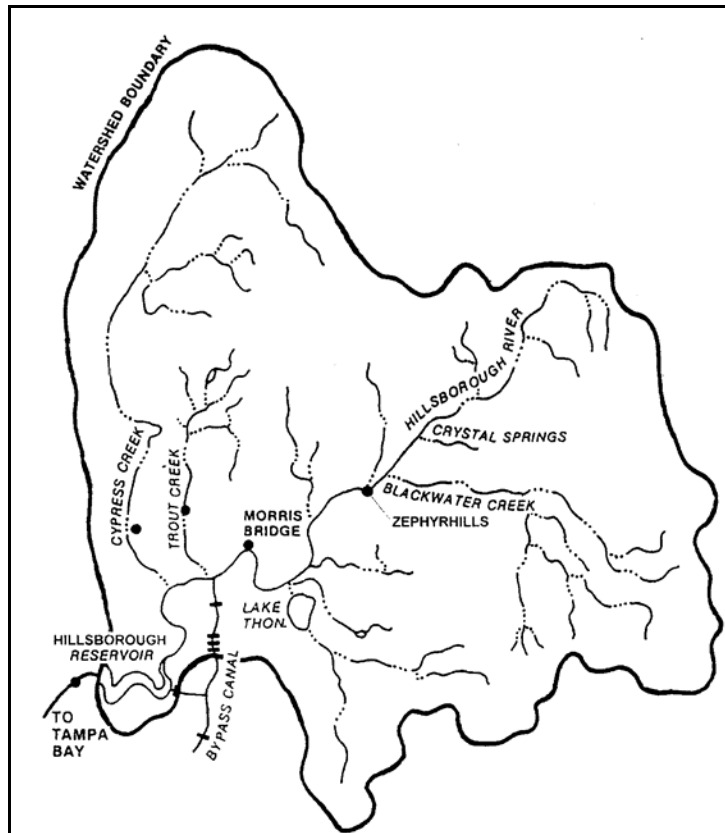


Figure 1. Hillsborough River basin.

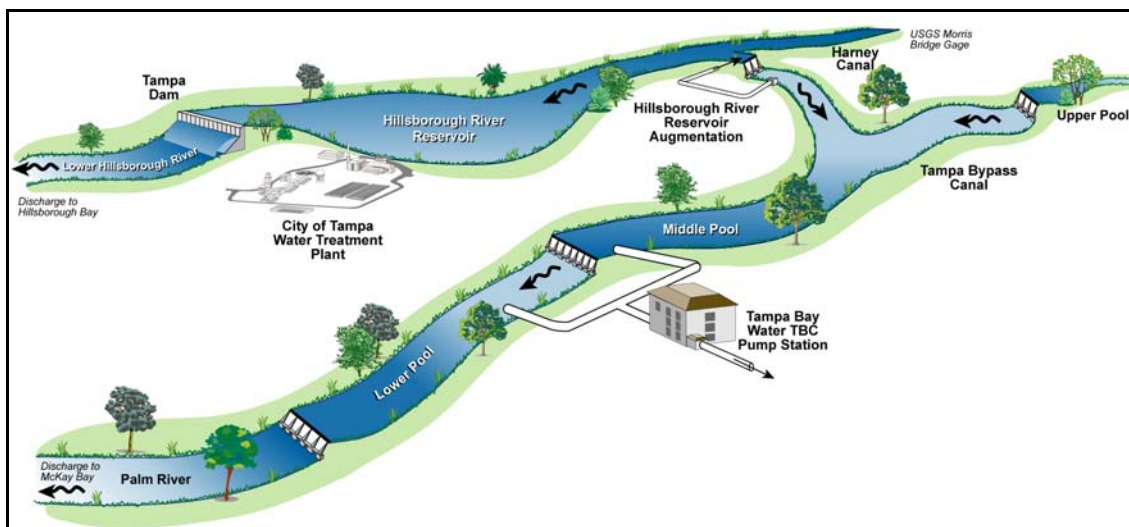


Figure 2. Lower Hillsborough River.

The TBC also has a significant impact on local groundwater flow patterns. The canal is hydraulically connected to the aquifer, and groundwater inflow provides baseflow to the middle and lower pools of the TBC. In the upper pool of the canal, stormwater runoff can recharge the groundwater system.

The complete HR/TBC model package includes several flow generation models and a hydraulic routing model. The flow generation models provide stream flow predictions for each of the major tributary streams at gauged locations. These include Cypress Creek, Trout Creek, and the main stem of the Hillsborough River (Morris Bridge and Zephyrhills gauges). The HR/TBC model tributary areas are defined as follows:

Upper Basin

- Cypress Creek—Cypress Creek watershed above USGS Gauge No. 02303800
- Trout Creek – Trout Creek watershed above USGS Gauge No. 02303350
- Upper Hillsborough River – Hillsborough River watershed above Zephyrhills (USGS Gauge No. 02303000)

Middle Basin:

- Hillsborough River watershed above Morris Bridge (USGS Gauge No. 02303330) and below Zephyrhills

Lower Basin:

- Hillsborough River upstream of Tampa Dam (USGS Gauge No. 02304500) and downstream of Morris Bridge
- TBC upstream of S-160 (not a USGS gauging site)

The hydraulic routing models route the flows generated by the flow generation models (at Cypress Creek, Trout Creek and the Hillsborough River at Morris Bridge) through the lower Hillsborough, including transfers from the Hillsborough River to the TBC via Harney Canal, and through the TBC. The hydraulic routing models also account for local groundwater and stormwater inflow occurring downstream of the flow generation model domains and above the Tampa Dam and structure S-160. Operation of the structures located in the lower Hillsborough River is also included in the hydraulic routing model.

BASIN CHARACTERIZATION

To facilitate the development of the models a project-oriented database was constructed. This database utilized existing information available from public sources. No single data repository exists for all water data pertinent to this project. In addition, most sources do not maintain data sets for the entire period of record of interest for this study (September 1, 1988, through July 31, 2002). Data sources included Tampa Bay Water, SWFWMD, USGS, and the National Oceanic and Atmospheric Administration (NOAA).

For development of the Lower Basin hydrodynamic model additional data were needed regarding the geometry of the river and TBC, as well as details relating to the design and operation of the structures. The following sources provided the bulk of this information:

- Hillsborough River cross sections: Hillsborough County Public Works Department's SWMM Model
- Watersheds in the Lower Basin: Hillsborough County Public Works Department's Hillsborough River Watershed Management Plan
- As-Built Drawing of the Tampa Dam: City of Tampa
- As-Built Drawings of the TBC: SWFWMD (USACE)

- Operation of Structures: City of Tampa, Tampa Bay Water, and SWFWMD
- Historical Diversions and Withdrawals: Coordinated by Tampa Bay Water

Previous reports were obtained that studied flow, groundwater seepage, or any other relevant facet about the system. Interviews were conducted with the operator of the Tampa Dam, and SWFWMD staff to confirm the manner of operation of flow control gates on the structures. Additional field surveying or data collection was deemed unnecessary for development of the model.

FLOW FORECASTS FOR UPPER AND MIDDLE BASINS

The Lower Basin routing model requires the input of daily forecasted flows for the upcoming week from Cypress Creek, Trout Creek, and Morris Bridge. The final approach chosen to forecast these flow rates utilized artificial neural network models (ANNs). Approximately 14 years of data was used to train, validate, and test each ANN. For any date D , the flow forecasting objective was to be able to forecast flow rates at Cypress Creek, Trout Creek, and Morris Bridge at dates $D + 1$, $D + 2$, ..., $D + 7$. This required seven ANNs; one for each day's forecast. Similarly at Zephyrhills, three ANNs were developed for dates $D + 1$, $D + 2$, and $D + 3$.

Because the Zephyrhills gauge is located upstream of the Morris Bridge gauge, the flow rates at these two locations were determined to be highly correlated. Analysis indicated an approximate three-day wave front travel time from the gauge at Zephyrhills to the gauge at Morris Bridge. Therefore, the most recent three days of history at Zephyrhills was determined to be important input for forecasting the next three days of flow at Morris Bridge. Similarly, forecasted flow rates at Zephyrhills for three days into the future were used as input into the Morris Bridge ANNs to improve the Morris Bridge predictions.

The forecasts were conducted in two stages for each gauge. First, an average flow rate for the forecast period was predicted (that is, a seven-day average flow rate for Cypress Creek, Trout Creek, and Morris Bridge; and a three-day average flow rate for Zephyrhills). Then this value was used as input into the daily ANNs. There was a separate ANN for each forecast day. For example, Cypress Creek had eight ANN models: the seven-day average flow, day one, day two, day three, day four, day five, day six, and day seven. ANNs were developed similarly for the other gauges, except that Zephyrhills had models for a period of only three days.

The developed ANNs provided reasonably accurate daily forecasts for seven days into the future, although after day three the accuracy diminishes rapidly. Because ANN models generally assume that recent historic patterns are valid in the near future, regular evaluation of this assumption will be necessary.

Example ANN Modeling

An example of the ANN modeling is presented for only Cypress Creek. Except for the duration of the forecast period, specific data available within each drainage sub-basin, and other minor input details, the process was the same for each gauge and the results were very similar.

Available data were reviewed and selected based on their representativeness of various hydrologic processes (e.g., lake water levels give an indication of long-term drought). Historical data utilized in the Cypress Creek included; flow rates for Cypress Creek at Worthington Gardens and near Sulphur Springs, area precipitation, surface water levels, and ground water levels. Additionally, the historically noted seven-day averaged flow rates,

the 52-week lagged seven-day averaged flow rate, and the seven-day median flow for Cypress Creek Springs were included as input.

Figure 3 presents the results from the weekly average flow rate model. In the scatter plot, the ANN-forecast flow rate was plotted against the observed flow rate for each seven-day period. The entire historical record was included in the plots, which means that the data pairs from the training set, the validation set, and the testing set all are included. Also shown is the least squares linear fit of the observed versus the forecasted rates (thicker line) and the line on which the forecasted values equal the observed values (thinner line). The results illustrate that the seven-day average forecasts are quite accurate. Thus, including these forecasts as input for the training of the daily ANNs proved beneficial to their accuracy.

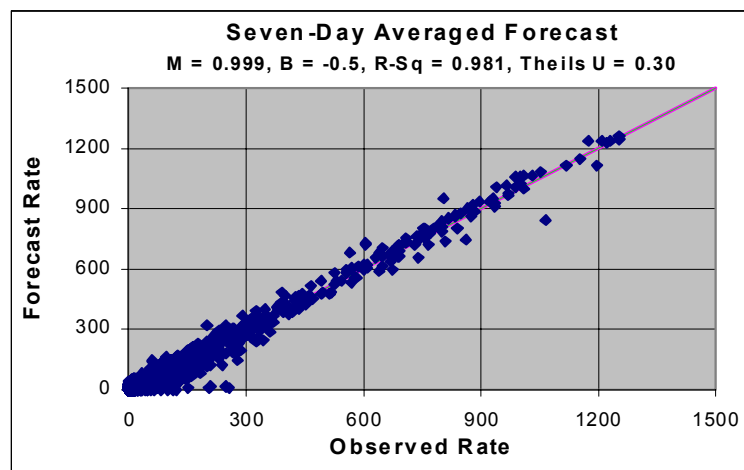


Figure 3. Seven-day averaged forecast at Cypress Creek.

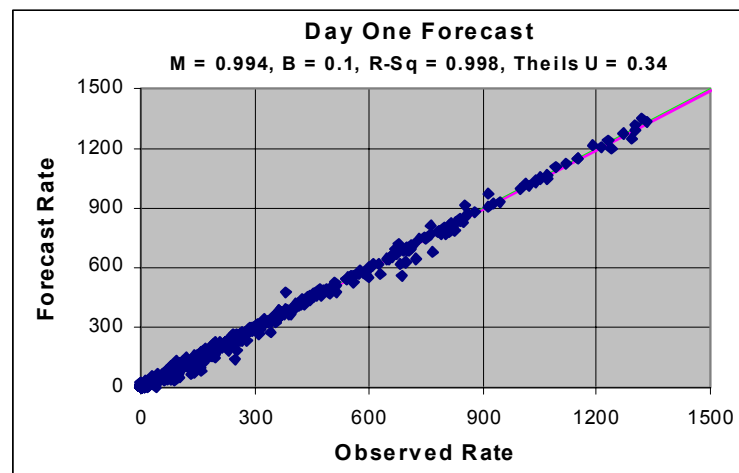


Figure 4. Day one forecast at Cypress Creek.

Separate ANNs were constructed for each forecasted day out to seven days into the future. The daily ANNs utilized input as described above and also included; daily observations over the previous few days, the historically noted daily median flow rate at Cypress Creek, and the seven-day average flow. The forecast for day one in the future was excellent (Figure 4). Even though the forecast accuracy diminishes the farther into the future the forecasts are made, the forecasts out to day seven are all reasonable.

These results were similar to the ANN results at Zephyrhills (albeit for three days) and Morris Bridge. The results were more variable at Trout Creek, however, which was attributed to the smaller sub-basin (more variable flow) and the lack of upstream flow monitoring. The Trout Creek sub-basin generally produces a small proportion of the total flow into the Lower Basin, so these forecasts typically have only a slight impact.

HYDRODYNAMIC MODELING OF THE LOWER BASIN

The HR/TBC model for the Lower Basin was developed using, HEC-RAS 3.0, to establish flow rates and water surface elevations at the Tampa Dam and structures S-160, S-161, and S-162. The overall configuration of the routing model is illustrated in Figure 2.

Procedures outside of HEC-RAS were developed to estimate the necessary boundary conditions. Boundary conditions input into the HEC-RAS model come from:

- Upper and Middle Basin flow forecasts utilizing the ANN models, as described previously. This is the primary flow contribution.
- Groundwater baseflow using a spreadsheet application and observed groundwater levels. This flow contribution is considered a small net effect in the Hillsborough River when compared to the flow range of interest (100 to 1,000 cfs) and was not included at this time. The baseflow in the TBC was included as part of the spring flow.
- Spring flow in the TBC, based on recent observed data.
- Local runoff predictions using NOAA forecasts of future precipitation and a spreadsheet application. The area of the watershed contributing to local runoff is approximately 59 square miles (mi²), or approximately 9 percent of the total watershed draining to the Tampa Dam. These flows could be high on a given day, but the forecasts will be highly variable. Only larger storms contribute significant runoff.
- City of Tampa withdrawals from the reservoir based on historical use and anticipated future changes to the City's use pattern because of the ASR system.

Other inflow components include the direct precipitation onto the water surfaces and evaporation. These two features were not added at this time, but could easily be included into the model.

The geomorphology input data for HEC-RAS includes connectivity information for the stream segments, cross section coordinates, distances between the cross sections, Manning's roughness coefficients, and hydraulic structure information for all of the flood control structures and bridges. Because of the complexity of the lower basin, the model was split into separate applications: one for the Hillsborough River and one for the TBC.

The Hillsborough River model extends from the Tampa Dam to the Morris Bridge gauge, and includes Cow House Creek. The TBC model extends from just downstream of S-160 to S-159 and includes the Harney Canal downstream of S-161. The upper pool of the TBC was added as a lateral inflow boundary condition to Cow House Creek (S-163), since the gates of S-159 are normally kept in the closed position and the gates of S-163 are normally kept in the open position.

The cross section data for the Hillsborough River were based on Hillsborough County's SWMM model of the Hillsborough River basin. USACE (provided by SWFWMD) as-built drawings were utilized extensively to obtain cross section data for the TBC. Bridge information was not readily obtainable, so surrogate geometry data (i.e., typical pier spacing based on older drawings) were used for bridges. Bridges did not restrict flow in the range of interest.

The primary purpose of the TBC structures and the Tampa Dam is flood control. However, the main objective of this project was to develop tools for Tampa Bay Water's use to forecast water supply availability during normal to low flow conditions when only the slide gates of the TBC would be in operation to maintain water levels at target elevations. Furthermore, the Tampa Dam is normally operated manually to try to maintain target pool elevations, which may vary seasonally. This model was set up primarily for flow simulations generally between 100 cfs and 1,000 cfs through the Tampa Dam; however, the model seems to accurately depict the system when inflow is up to 1,200 cfs at the Morris Bridge gauge. Because HEC-RAS has no options available to model slide gates, the Navigation Dam option was used at structures to maintain target elevations. Therefore, structure boundary conditions require setting target pool elevations for each simulation. Generally, these elevations do not vary to a great degree, but some seasonal targets exist for the Tampa Dam and at S-162.

HEC-RAS simulations were conducted using observed USGS data for the upstream inflow at the three main tributaries, observed S-161 diversions, observed City of Tampa withdrawals, plus the observed Tampa Bay Water withdrawals during the last year. Groundwater contributions and local runoff were estimated using local data and the procedures described previously. The simulations were conducted for the purpose of adjusting model parameters until the model results reasonably replicated observed responses of the system.

The hydrodynamic model operates as expected. Figure 5 illustrates daily observed stage vs. daily simulated stage for the Hillsborough River at the Tampa Dam for the same time period. The daily difference in modeled flow through the Tampa Dam when compared to the observed data was sometimes high; however, the model generally simulated flow trends with reasonable accuracy. Uncertainties associated with the daily operating protocol for the Tampa Dam affect the model predictions of flow through the dam. For example, observed flow differences in the range of several hundreds of cfs or stage elevation changes within 0.2 ft can alter simulated flow and stage results on any given day. When the modeled target elevation matched the observed data, the simulated and observed flows typically were within 100 cfs of each other. However, dam releases on a given day could vary by up to 300 to 400 cfs because of increased inflow from rainfall events. Since allowed diversions are only a fraction (10 to 30 percent) of the flow through the dam when the flow is greater than 100 cfs, variations of flow through the dam do not directly translate to similar results for withdrawals.

The large flow spike near the end of the example simulation shown in Figure 5 is a result of runoff. This spike did not occur in the observed data, although there was a small increase in flow. The rainfall estimate was based on one gauge in the Lower Basin, so it may have been an isolated storm. Simulations were conducted with and without the addition of runoff. The simulation results for daily flows were not much different in the flow range of interest when runoff was included, but runoff was retained in the HR/TBC model.

FORECASTING ACCURACY

The final models combine both the upstream tributary forecasts (ANNs) and the hydrodynamic model simulations (HEC-RAS). Each component was developed and tested independently. However, the operation of the complete HR/TBC model was verified with the individual components implemented simultaneously. To verify operation of the complete model, potentially available water withdrawals were determined by applying the WUP rules to stage and flow predictions from the complete HR/TBC model. These

predicted withdrawals were then compared to withdrawals determined by applying the WUP rules to observed stage and flow data.

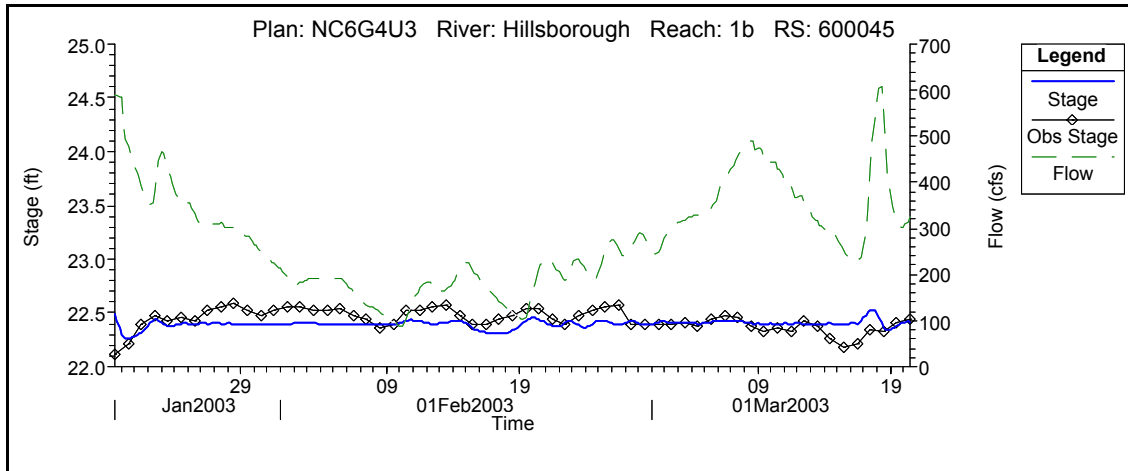


Figure 5. Observed vs. simulated stage upstream of Tampa Dam with surface runoff.

The prediction accuracy for the potential water diversions from the Hillsborough River was determined by computing the withdrawals using observed flow data, and then comparing similar predictions made using forecasted data. This process provided an estimate of the accuracy of the HR/TBC model's primary forecast components (i.e., the tributary flow generation models and the hydraulic routing model). Groundwater baseflow and local runoff was held constant for both scenarios because no data exists to confirm these values. Ultimately, the accuracy of the entire process will need to be monitored with actual use of the overall application.

Ten cases were selected to illustrate the accuracy of the model. Each case constitutes a seven-day period of time and a corresponding forecast, conducted on a Wednesday. These 10 cases were selected when flow through the Tampa Dam was in the range between 100 and 1,000 cfs (since this is of most interest when applying the model), and when sufficient data were available to compare the results. The dam is operated somewhat differently now (since about mid-2002) than it was during the historical period of record. The water level in the reservoir generally is kept at a more consistent and higher elevation than it was in the past. The historical observed flow rates through the dam perhaps varied more than they would now, increasing the variability in the simulations.

Considering all of the inputs to the combined model and given the operator's control of the water levels at the dam, the overall predictions were considered reasonable. Figure 6 summarizes the relationship between flow through the Tampa Dam predicted by forecasted flow and the observed flow. As the trend line indicates, flows were overestimated when the seven-day flow volume was less than approximately 4,000 cfs-d and underestimated when the seven-day flow volume was above this value. These results indicated that a good statistical fit existed between the two approaches (flow through the dam as predicted by observed inflow, and flow through the dam as predicted by forecasted inflow). The deviation present in some examples, however, illustrates that re-forecasting flows may be necessary when a large deviation occurs after only two or three days into the week.

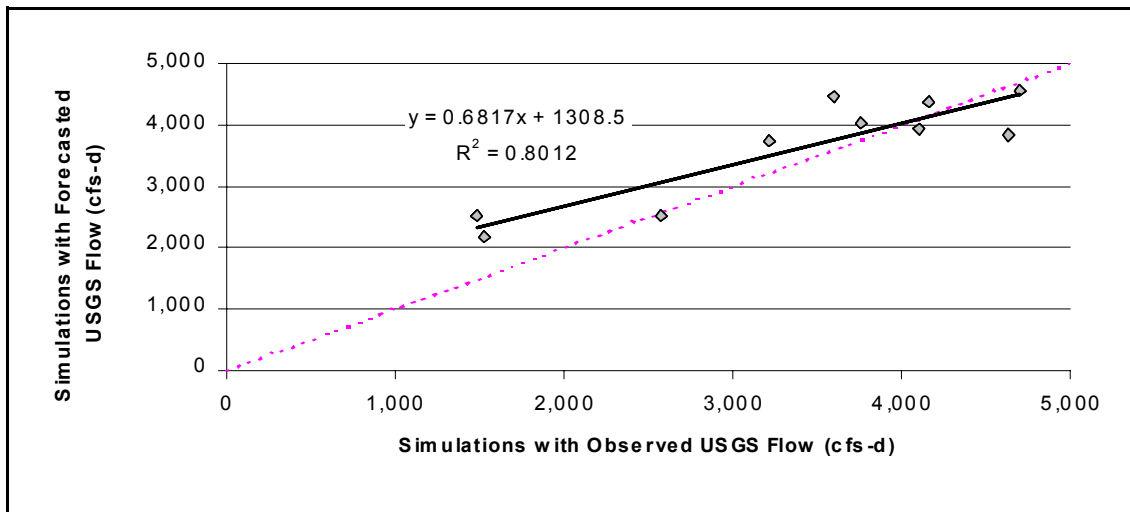


Figure 6. Flow through dam predictions with forecasted flow versus observed USGS flow.

While Figure 6 provides a comparison of flow through the dam, actual diversions for water supply are only a fraction of this flow. Furthermore, this fraction varies with the flow rate (between 0.10 and 0.30). The simulated flow through the dam must be used to estimate diversions through S-161 by applying the WUP rules. Figure 7 provides a comparison of the potential diversions at S-161 between the simulations conducted with the observed and forecasted flow rates. Except for one model run, the total volume that was diverted for each case was very similar. Therefore, this comparison indicates that the amount of water that was forecasted available for water supply was similar between the two scenarios (using observed inflow to the Lower Basin vs. forecasted inflow).

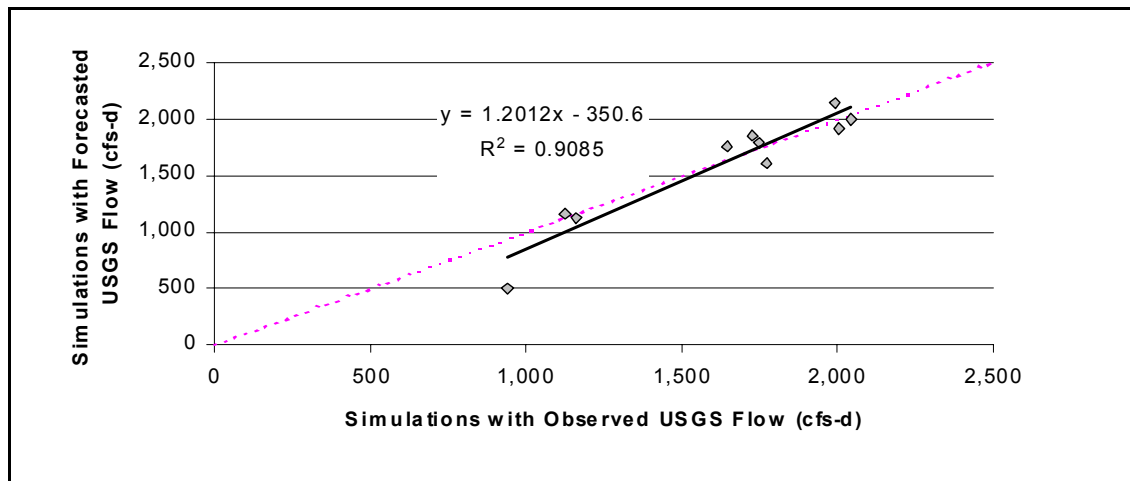


Figure 7. Diversions through S-161 computed for forecasted flow versus observed USGS flow.

A test of the validation of the TBC portion of the HR/TBC model was not conducted because of data limitations during the calibration period. Sparse data of sufficient quality were available since Tampa Bay Water only began monitoring flows through the flood control structures in September 2002. A review of these data indicated that spring flow dominated the overall flow in the TBC. Therefore, the prediction of the spring flow will mostly affect the accuracy of the projections. This issue needs further evaluation as additional flow data are collected and experience in operating the system is gained.

Overall, the HR/TBC model suite provides a good tool to assist in forecasting and managing surface water supply source from the HR/TBC. After additional experience with operating the model and improved knowledge of the system dynamics is gained, model parameters may be adjusted to improve the accuracy of model-predicted hydraulic responses (i.e., flows and stages). Maintaining a record of predictions as well as the actual observed flow will allow future diagnostic evaluations of the model's performance.

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AN INTEGRATED OBSERVING AND MODELING SYSTEM FOR TAMPA BAY

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INTRODUCTION

The USF College of Marine Science is developing an integrated circulation, wave, sediment transport, and water quality model. The model system ingests real-time observations of the physical forcing functions for Tampa Bay to produce three-dimensional fields of circulation, temperature, salinity, wave spectra, sediment resuspension and transport, turbidity, primary production, chlorophyll, nutrients, dissolved oxygen, and other biogeochemical quantities. The need for a detailed three-dimensional integrated water quality model has become apparent in Tampa Bay management issues. The integrated model development is well underway. The hydrodynamic model is fully operational in either a nowcast-forecast mode or a hindcast mode and is described on our web site (<http://ompl.marine.usf.edu/TBmodel>). The wave and sediment transport component of the model has been implemented (Shi et al., 2002) and is being tested against observations made in December 2001 and January 2002 and in May through August 2002. The water quality model code has been obtained and is being adapted to the other components of the Tampa Bay model system in collaboration with Ray Pribble and Tony Janicki of Janicki Environmental. The integrated model has been and will continue to be calibrated and validated against extensive observational data available for Tampa Bay collected by the Tampa Bay Estuary Program (TBEP), the Environmental Protection Commission of Hillsborough County (EPCHC), the US Geological Survey, and others. The integrated model provides a management tool that can be used to evaluate the bay ecosystem response to severe storms or to seasonal and interannual changes in fresh water input, as well as to changes due to human impacts, such as river withdrawals, nutrient loading, changing land use patterns, or alterations in bay bathymetry. The model system has been used to support management decisions in several environmental issues affecting the bay. For example, the model was used to simulate the trajectory of the discharges from the Piney Point phosphate plant that have occurred since October of 2001 for the Florida Department of Environmental Protection (Figure 1) and to evaluate changes in salinity and estuarine residence time in the Palm River and McKay Bay for the Southwest Florida Water Management District (Figure 2).

REAL-TIME OBSERVATIONS

The origin of real-time ocean observations in west Florida dates back to 1990 when the Tampa Bay Physical Oceanographic Real-Time System (PORTS; see <http://ompl.marine.usf.edu/PORTS/>) was implemented and to 1993 when preliminary measurements began on the continental shelf under a USGS/USF cooperative agreement, followed by further developments supported by Minerals Management Service and the Office of Naval Research. The Coastal Ocean Monitoring and Prediction System (COMPS) for real time data from a network of offshore buoys and coastal stations began in 1997 with State of Florida support, and we continue to operate this through the present time in conjunction with other agency grants. COMPS program data and model products are reported on the Internet at <http://comps.marine.usf.edu>.

The Tampa Bay Physical Oceanographic Real-Time System (TB-PORTS) is a marine information acquisition and dissemination technology developed by the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) in collaboration with the local maritime community and the University of South Florida College of Marine Science.

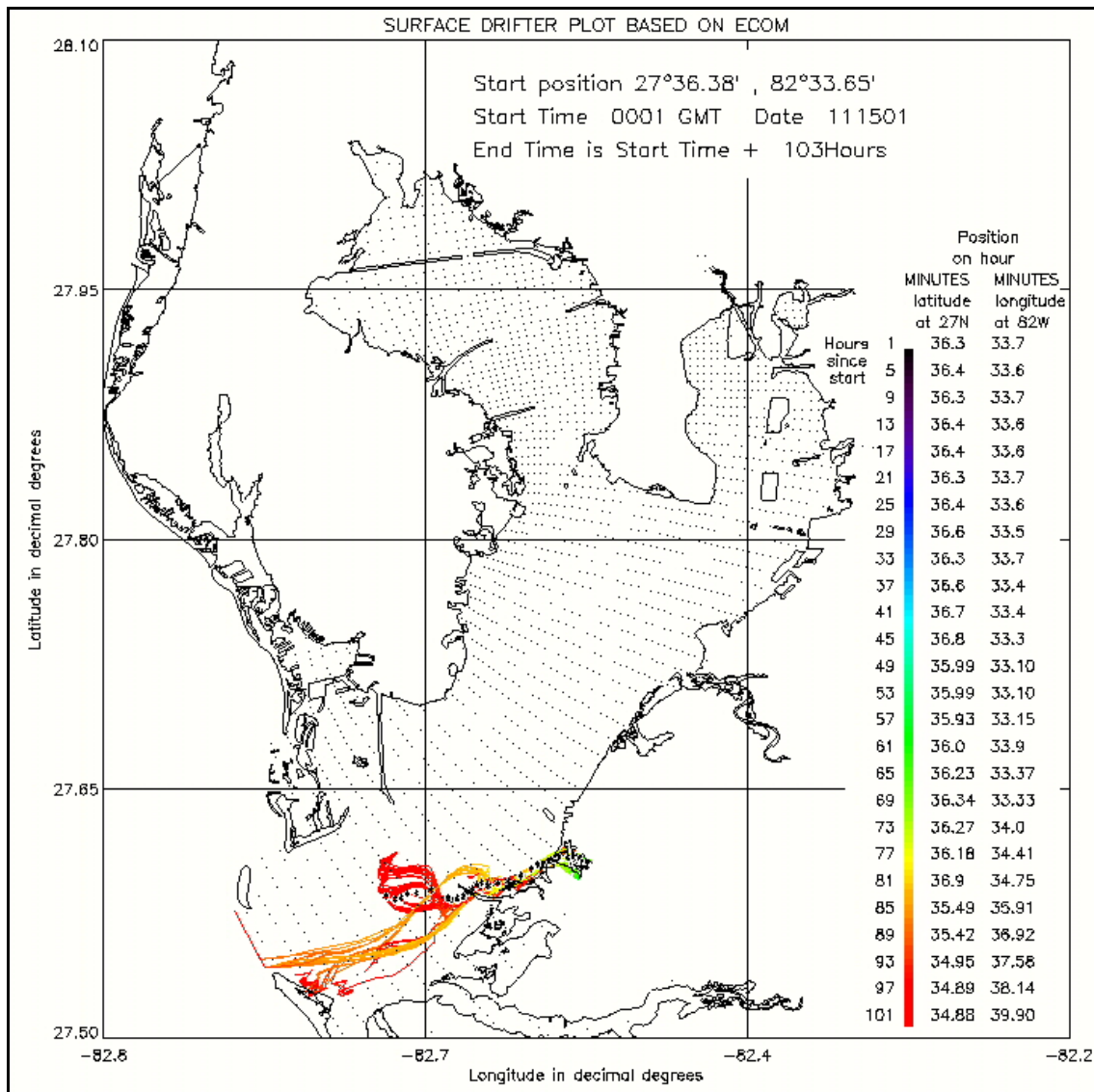


Figure 1. Simulated trajectory of the discharge plume from the Piney Point phosphate plant into Bishops Harbor. Color is time in hours past 0 UTC on November 15, 2001 (color scale to right). The centroid of all particles is indicated by the black symbols and the position is given in latitude and longitude in the columns to the far right. No particles exit Bishops Harbor for the first 75 hours. After this time, two groups of particles exit Bishops Harbor and are transported toward the southwest. The first group of particles quickly leaves Tampa Bay through Southwest Passage within 90 hours. The second group recirculates within the bay and is trapped to the south of the Skyway Bridge and just north of Anna Maria Island.

The goals of TB-PORTS are to improve navigational safety and to protect the environment by providing more accurate water level, current, and meteorological data for Tampa Bay. TB-PORTS is operated by the Greater Tampa Bay Marine Advisory Council-PORTS, Inc. (GTBMAC-PORTS) through cooperative agreements with the NOAA National Ocean Service and with the University of South Florida. GTBMAC-PORTS has agreements with local contractors to provide routine operations and maintenance on the system. Tampa Bay PORTS is funded by local and state agencies and is housed in the USF College of Marine Science. NOS provides operational data quality assurance/quality control and technical support. TB-PORTS

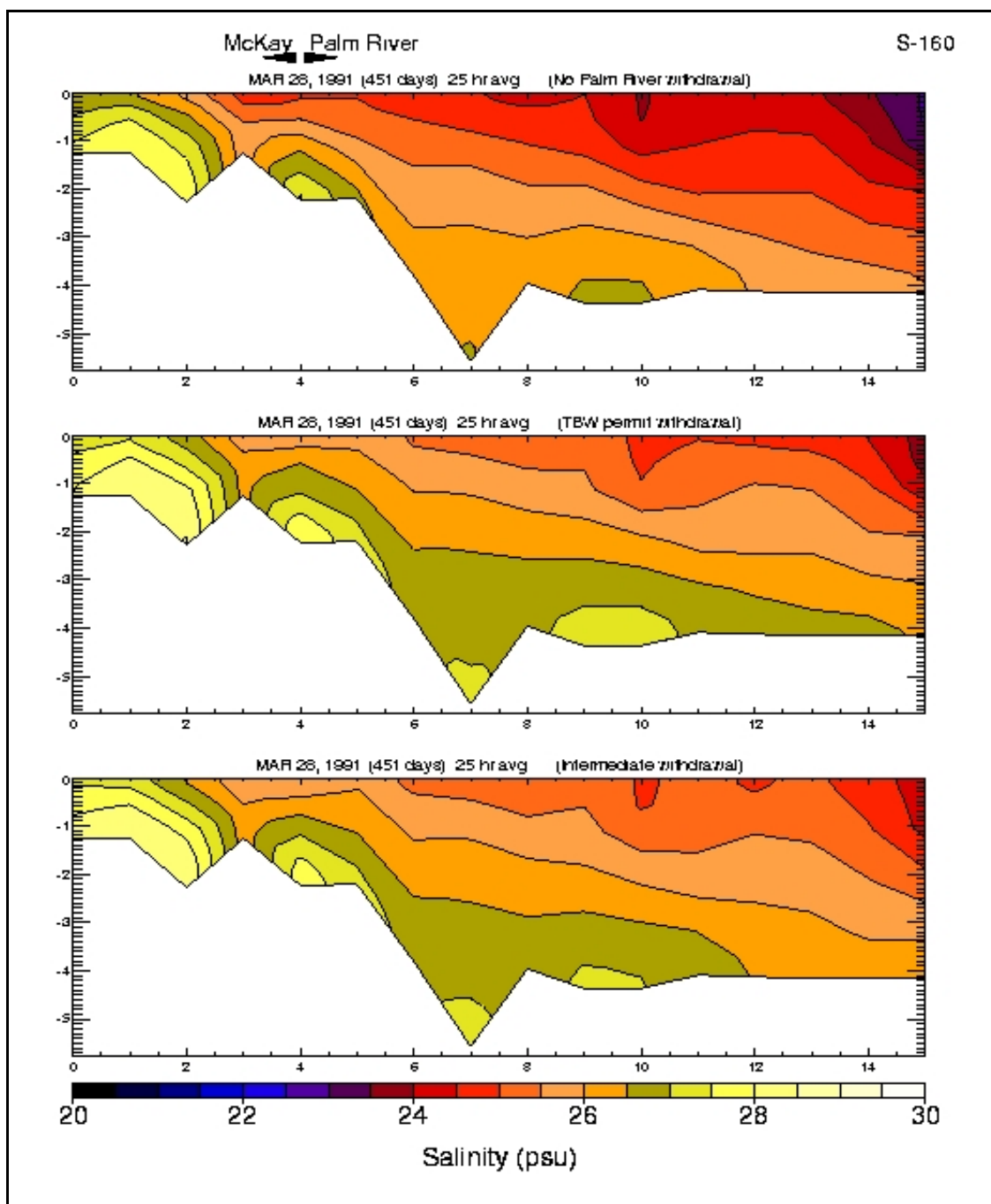


Figure 2. Salinity in McKay Bay and Palm River for the baseline case (top), the Tampa Bay Water permitted withdrawal (middle), and an intermediate withdrawal case (bottom). The vertical axis is depth in meters and the horizontal axis is distance along the section. Structure 160 is at the far right of the figure and the 22nd St. Causway is at the far left edge. Both withdrawal cases show salinities elevated by 0.5 to 1 psu (or part per thousand) throughout the water column.

integrates real-time current, water level, temperature, wave, visibility, and wind measurements collected every six minutes at multiple locations in Tampa Bay. Because the bay's tides and currents are influenced strongly by nontidal forces such as winds and river flow, TB-PORTS provides important real-time information to both recreational boaters and professional pilots navigating in Tampa Bay. TB-PORTS has been in continuous operation

since 1992. Information from TB-PORTS is used routinely by shipping interests and environmental managers. Statistics on ship groundings in US harbors show that the number of groundings has decreased by 60 % since TB-PORTS became operational. TB-PORTS data are valuable in mitigation of hazardous material spills and in permitting and monitoring of waste water discharges and fresh water diversions in the bay.

TB-PORTS monitors water level and wind speed and direction at four sites (CSX-Rockport (water level) and Howard Curran Waste Water Treatment Plant (winds) in the Port of Tampa; Old Port Tampa, Port Manatee, and Port of St. Petersburg), current speed and direction in the main ship channel at the Sunshine Skyway Bridge, at the entrance to the Port Manatee Channel, and at the entrance to Old Port Tampa, and wind speed and direction, air temperature, and barometric pressure at a USCG range marker (Cut-C lower back range) 3 nm NE of the Sunshine Skyway Bridge center span. In addition, two COMPS sites monitor water level and wind speed and direction at the north end of Egmont Key and Anna Maria Island at the mouth of the bay.

CIRCULATION MODEL

The circulation model has been under development at USF since 1990. It is a three-dimensional time-dependent model of the hydrodynamics of circulation in Tampa Bay (Galperin et al., 1992a,b; Vincent, et al., 1997, 2000), based upon an advanced version of the Princeton Ocean Model (Blumberg and Mellor, 1987). 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. 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; surface wind stress, precipitation, and evaporation. 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, Apalachicola Bay, Florida Bay, the lower Mississippi River and adjacent continental shelf, the west Florida shelf, and the New York Bight. The present version of the Tampa Bay model uses a 70-by-100 horizontal curvilinear grid (Figure 3) with 11 sigma levels in the vertical (Figure 4). Boundary conditions for the Tampa Bay model are provided by the PORTS and COMPS data stream. The model is automatically updated every 12 minutes to provide a “nowcast” of present conditions in the bay. Every 4 hours, a 25 hour forecast is performed using winds from the National Weather Service ETA model and water levels at the mouth of the bay extrapolated from present observations and forecasts of offshore conditions. Model nowcast and forecast fields are presented in graphical format and can be viewed on the OMPL Web site (<http://ompl.marine.usf.edu/TBmodel>) and can be obtained via a DODS (Distributed Ocean Data System) server. The DODS interface to the model fields was designed in collaboration with the NOAA HAZMAT office to assist in hazardous material spill response and contingency planning. At this writing, the nowcast/forecast system is offline for re-tooling to harden the system for NOAA-sanctioned operational use.

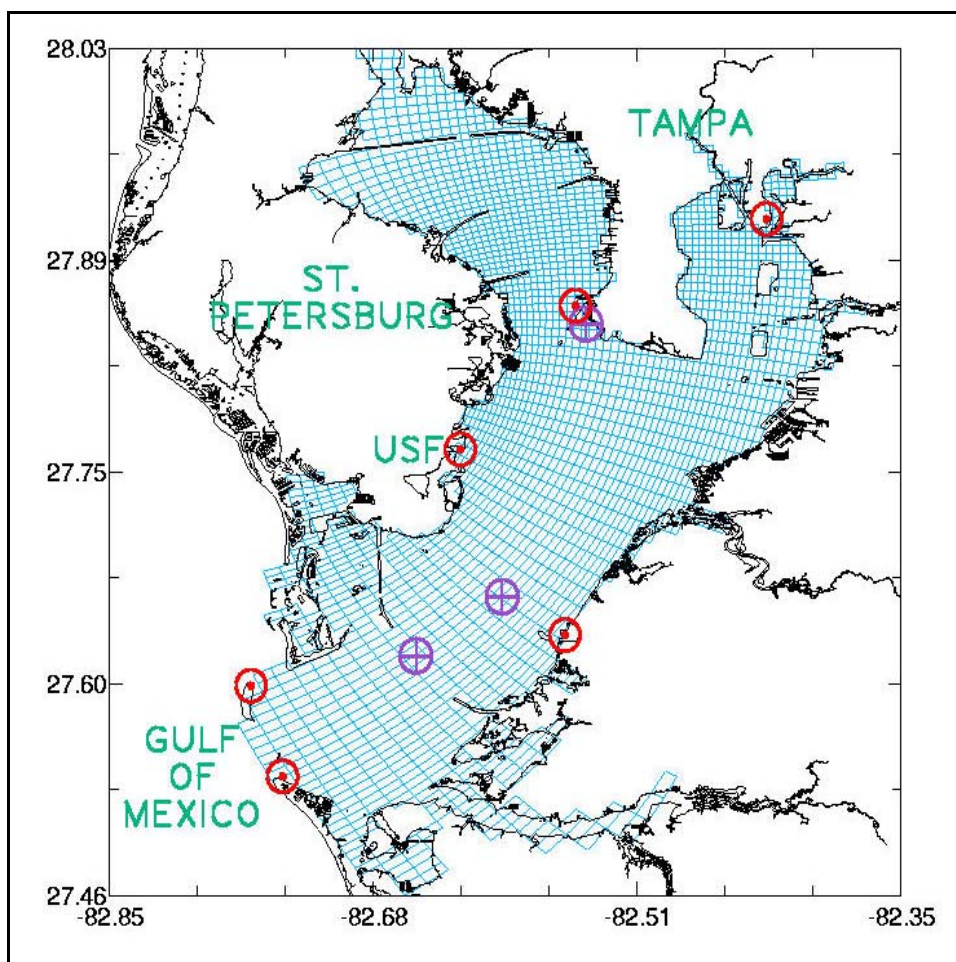


Figure 3: 70 x 100 horizontal curvilinear orthogonal grid with Tampa Bay PORTS and COMPS observing sites. Red circles/dots indicate water level/wind sites and purple circles/crosses indicate current/wind sites.

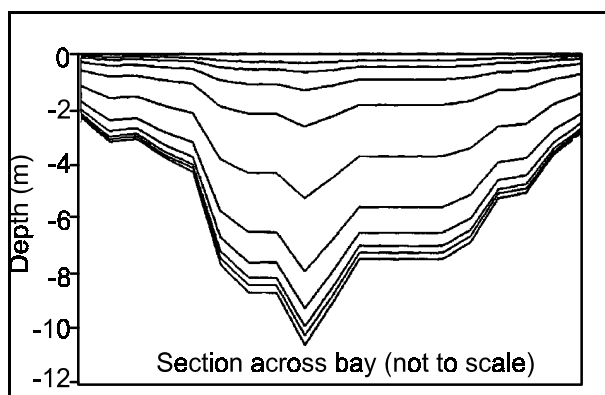


Figure 4: typical cross section of 11 sigma layers in the vertical dimension

TRAJECTORY MODEL

The hydrodynamic model output velocity fields drive a trajectory model to predict the movement of hazardous material spills or persons or objects in the water in Tampa Bay. Trajectories are treated as a cloud of a large number of Lagrangian particles, each modeled by a first order Markov process using instantaneous velocities from the hydrodynamic model and a dispersion coefficient calibrated using observed drifter tracks. Trajectory predictions have been verified by a limited number of GPS and radio-tracked drifters. The information on contaminant distribution from the trajectory model can be ingested into the Florida Marine Research Institute's Marine Spill Assessment and Response System (FMSAS), a GIS-based spill mitigation tool. The predicted distribution of contaminant from the spill model forms a layer in the FMSAS database and can be used as a template to cut through the resources-at-risk data layers to arrive at an inventory of resources exposed. Predicted trajectories can be generated in real-time via a web-based form that is linked to the USCG Area Contingency Plan for emergency response or for search and rescue.

RESIDENCE TIME

Estuarine residence time is estimated by seeding each model grid cell with large numbers of particles or with a passive tracer, as described above for the trajectory module (Burwell et al., 2000). The e-folding time for particle concentration is computed in each grid cell under a variety of boundary conditions observed in the bay (Figure 5). The resulting residence times vary widely in space and time. Residence time is most sensitive to variations in wind forcing and to variations in fresh water input.

WIRELESS DATA DELIVERY

Information from the real-time observations or model output and on the predicted distribution of passive particles (for hazardous material spills or search and rescue efforts) can be delivered in real-time to harbor pilots, shipping agents, resource managers, or others in the field using GSM/GPRS wireless internet technology. Global System for Mobile Communications (GSM) is an emerging international standard for digital cellular communications. Under the GSM standard, General Packet Radio Service (GPRS) enabled networks offer 'always-on', higher capacity, Internet-based content and packet-based data services. Using the wireless communications link, the remote computer can access the predicted spill trajectory or other model or observational products using standard web browsers.

In addition, the wireless delivery technology can be implemented through our collaboration with L-3 Communications, the developer of the Tampa Bay Vessel Information and Positioning System (see http://www.l-3ar.com/marketing/MAR001_030103.htm). L-3 provides a wireless wide area network in the Tampa Bay region and has the capability to transmit real-time data from Tampa Bay PORTS along with navigational information to the harbor pilots and other maritime interests via carry-on units in use in Tampa Bay (Husick, 1999).

WAVE MODEL

The SWAN wave model is coupled to the circulation model and computes wave spectra at each model grid cell under observed wind conditions and modeled water velocity (Shi et al., 2002). Wind stress forcing and bathymetry for the wave model are the same as that used for the hydrodynamic model. Bed stresses are computed as a superposition of stresses due to wave orbital velocity and those computed by the hydrodynamic model. The information on bed stresses are combined with data on sediment type, compiled by USGS, to compute sediment resuspension. The velocity field from the hydrodynamic model is combined with the

information on sediment resuspension and settling velocity to compute sediment transport. Turbidity and nutrient flux due to sediment resuspension will provide input to the water quality model component.

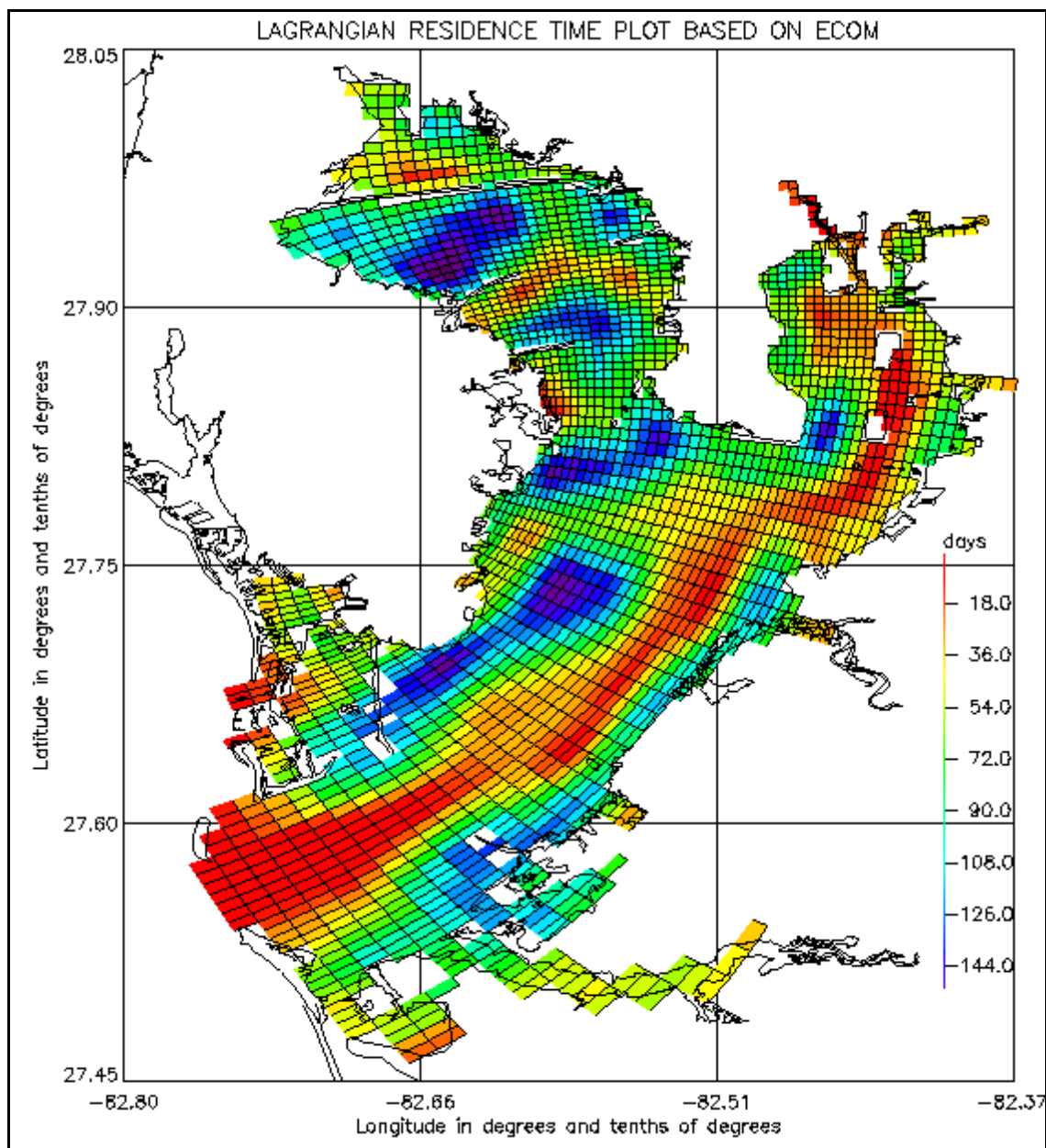


Figure 5. Residence time based on the Lagrangian particle trajectory method for boundary conditions observed during the fall and winter of 1997-98. Color represents e-folding time in days, or the time required for the number of particles in a grid cell to decrease by 65%. Residence times in Lower Tampa Bay and in areas adjacent to the main channels are 10 to 20 days or less, while on shoals and in areas restricted by causeways, they exceed 140 days.

During December 2001 and January 2002, four Sea Bird Electronics SeaGauge wave and tide recorders were deployed in Tampa Bay in each major bay segment. Since May 2002, a SeaGauge has been continuously deployed at a site in middle Tampa Bay as a component of the Bay Regional Atmospheric Chemistry Experiment (BRACE; see <http://ompl.marine>).

usf.edu/BRACE). Preliminary analyses of these wave data show good agreement with modeled wave spectra at each site.

WATER QUALITY MODEL

Development is underway of the water quality component of the model system by Ray Pribble and Tony Janicki of Janicki Environmental. The water quality module takes information from the circulation and wave components and data on nutrient loading to compute primary production, chlorophyll, turbidity, nutrients, dissolved oxygen, and other biogeochemical quantities. The water quality model code has been obtained and is being integrated with the other model components. A new, higher resolution model grid is being developed to better resolve the main channels and important sub-basins of the bay, like the McKay Bay-Palm River system. In the integrated model, waves, sediment resuspension and transport, and water quality variables are computed on the same grid as used by the three-dimensional hydrodynamic circulation model. The water quality component utilizes the EFDC code developed by John Hamrick, formerly of Virginia Institute of Marine Science and now of Tetra-Tech. Much of this model was developed with EPA funding and is considered the state-of-the-art in water quality modeling. The EFDC model is now being adapted to the other model components. Data from EPCHC, TBEP, BRACE, and the US Geological Survey are being used for model calibration/validation and to set the boundary conditions for nutrient loading of the bay. The integrated model should be operational within the next few months. Continued model development, calibration/validation, and application to specific problems of concern will take place during the next year.

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EXPORT OF ATMOSPHERICALLY DERIVED NITROGEN IN THE TAMPA BAY WATERSHED

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ABSTRACT

Earlier estimates—notably that of Pribble et al. (2003)—of the retention of atmospherically derived nitrogen (N) within the Tampa Bay watershed appear low based on comparison with other estuaries in the eastern US, thus leading to an apparent overestimate of the relative contributions of atmospheric deposition to the N budget for the bay itself. Since detailed mass balance information is lacking on individual components of N fluxes exported from the watershed, a geochemical tracer approach was used to estimate the extent that atmospheric inputs are retained. Two key assumptions are inherent in the analysis: (1) the tracer for atmospheric deposition is conservative (no sources other than atmospheric deposition contribute significantly to riverine fluxes of the tracer, nor are there significant sinks for the tracer within the watershed other than surface runoff and groundwater recharge); and (2) the only source of nitrogen is atmospheric deposition. This approach thus defines a minimum degree of N retention.

Cl^- appears to be a reasonable, conservative tracer to predict expected TN concentrations (in the absence of sources other than atmospheric deposition and assuming no other inputs) provided that the data are appropriately screened. Screening criteria include calcium enrichment and Cl^- concentrations exceeding expected values based on likely runoff volumes and atmospheric inputs. Two data sets were used for analysis—NASQAN data for 22 streams in north through central Florida, and monitoring data for 96 surface water stations within Tampa Bay and its watershed collected by the Environmental Protection Commission of Hillsborough County. Atmospheric deposition ion ratios were developed based on wet deposition measured at selected NADP monitoring sites and dry deposition estimates developed by Poor et al. (2004).

R_N based on estimates of background Cl^- for Tampa Bay range from 0.817 to 0.923 (i.e., 82 to 92%). The best estimate is 0.860, with 95% LCL and UCL of 0.827 and 0.893, respectively. Using an N retention coefficient of 0.860, the Pribble et al. (2003) estimate of the contribution of atmospheric deposition to total N loads to Tampa Bay for 1995 is reduced from 56% to 33%.

INTRODUCTION

Beginning in the 1950s, Tampa Bay began to experience a progressive decline in the submerged aquatic vegetation (SAV) in response to cultural eutrophication. Very low N:P ratios since at least the mid-1970s (when systematic monitoring of water quality in the Bay began in earnest) suggest nitrogen limitation, and recent restoration efforts have focused on reducing nitrogen inputs to reduce algal productivity, improve water clarity and induce recolonization by SAV. As part of the restoration effort, considerable attention has been directed towards elucidating the contributions of atmospheric deposition to N cycling in Tampa Bay and its watershed. Resolving this question has two basic components. First, although wet deposition contributions of inorganic nitrogen are fairly straightforward to characterize, the contributions from dry deposition are not well understood. Second is the question of how much of the atmospheric deposition flux is retained by the landscape, and how much is exported to the estuary (i.e., indirect contributions compared to direct contributions to the estuary. The former question is the subject of the paper by Poor et al. (this volume); the latter is the subject of this research.

The contribution of indirect inputs of atmospheric N to estuaries depends on several factors in addition to the actual atmospheric flux. The size of the watershed relative to the surface area of the receiving estuary can have an obvious impact simply because of the greater degree of hydraulic loading to the estuary. Other factors such as land use and surficial geology can have a profound influence as well. For example, inorganic N export in forested watersheds is related to hydrology, land use, and vegetation type which may mask the relationship between atmospheric inputs and outputs (Campbell et al. 2004). Urbanization affects runoff volumes by increasing the amount of impermeable surface, thus leading to greater export

rates of atmospherically deposited N. Apart from directly increasing N inputs to the watershed, urbanization and agricultural land uses can also enhance export of atmospheric N by increasing the degree of N saturation in soils of both land use types because of the additional inputs of N as fertilizer or as animal feed.

Based on data compiled by Castro and Driscoll (2002), the indirect contribution of atmospheric N to the total N load (direct atmospheric plus all watershed inputs, including indirect N) generally appears to be less than 20% for estuaries along the eastern coast of the United States. In contrast, Pribble et al. (2003) estimated that the indirect atmospheric N contribution to Tampa Bay was approximately 37%, nearly two times higher than the estimates for any of the 10 watersheds studied by Castro and Driscoll. This large difference appears to be more a function of the assumptions used in the analysis by Pribble et al. rather than due to differences in atmospheric loadings. For example, Pribble et al. systematically overestimated the atmospheric contribution (J_{atm}) to measured surface water fluxes (J_{surf}) in individual catchments by assuming that the only N inputs to the watershed were from atmospheric deposition and fertilizer applied to both agricultural and urban land uses, while other land uses were assumed to receive only atmospheric N. The degree of N retention of atmospheric deposition was then calculated based on the ratio of the estimated N input from these two sources compared to the total N output in surface water.

A sufficiently detailed N budget for Tampa Bay is not available to resolve more accurately the indirect atmospheric contributions of N to Tampa Bay. As a result, the objective of this study of this study is to infer indirect contributions of atmospheric N to Tampa Bay using ion ratios to track atmospheric fluxes and compare inputs to outputs to determine the degree of retention. In brief, the degree of N enrichment or depletion in surface water relative to atmospheric inputs is estimated by using a suitable tracer to normalize the data for evaporative concentration:

$$N_{exp} = (N_{atm}/Cl_{atm}) \times Cl_{surface} \quad (1)$$

where N_{exp} is the expected concentration of total nitrogen in surface water, N_{atm} and Cl_{atm} are the concentrations of N and Cl in rainfall, respectively, and $Cl_{surface}$ is the concentration of Cl in surface water. Rainfall concentrations are based on both wet and dry deposition fluxes, and N_{atm} is the summation of the deposition fluxes of all inorganic species (e.g., NO_3^- and NH_4^+). The fraction of atmospheric N retained by the watershed, R_N , is then calculated as:

$$R_N = 1 - (N_{obs}/N_{exp}) \quad (2)$$

METHODS

The efficacy of the ion tracer approach lies in the validity of the underlying assumptions. There are two key assumptions to the approach: the first is that the tracer (Cl) used to normalize N concentrations for evaporative-concentration effects is conservative—*i.e.*, it has no sources other than atmospheric deposition nor does it undergo any biogeochemical reactions that would alter its concentrations in streams or rivers. The second key assumption is that all the nitrogen measured in the surface water of interest has no sources other than atmospheric deposition. Although there are approximately 96 routine water quality monitoring stations maintained by Environmental Protection Commission of Hillsborough County (EPCHC), virtually all of these reflect to some extent cultural disturbance and anthropogenic inputs of nutrients from within their contributing catchments. As a result, assuming the validity of the tracer assumption, the calculated retention coefficient R_N defines a minimum degree of N retention within the Tampa Bay watershed.

Because of the potential bias using monitoring data from the Tampa Bay watershed, data were obtained for 22 Gulf coast streams and rivers in northern and central Florida from the USGS NASQAN network. Among the watersheds selected are several where, based on landuse data (ca. 1987), watershed disturbance should be comparatively small. Data from the EPCHC water quality monitoring network also were obtained with the objective of coupling the results from the NASQAN data analysis with data from contributing watersheds to Tampa Bay to better infer R_N . Monitoring data from 1985 through 2002 were obtained for the full suite of surface water stations monitored by EPCHC.

Wet deposition inputs for NO_3^- and NH_4^+ for different watersheds were based on regional monitoring of major ions conducted by National Atmospheric Deposition Program (NADP; Figure 1). Regional fluxes were computed by assigning each NADP site to a geographic subregion and calculating the annual average. Three regions were established: the panhandle and north Florida (NADP sites FL14 and GA09), north central Florida (sites FL03 and FL05) and Tampa Bay (site FL41). Annual wet deposition fluxes for inorganic N and Cl were used to compute on average TN:Cl ratio for wet deposition for all the Florida NADP sites (except for Kennedy Space Center) and the Okefenokee swamp site in Georgia (GA09) for the period 1990 through 2002 (Table 1).



Figure 1. Map showing NADP sites in Florida and southern Georgia used to estimate wet deposition fluxes of N. North regions includes sites FL14 and GA09; north central region includes FL03 and FL05; and Tampa Bay (Verna Well Field) includes site FL41.

Table 1. Average Ion fluxes in wet deposition by region, 1990–2002 (kg/ha). Inorganic N fluxes expressed as N. Data from NADP (<http://nadp.sws.uiuc.edu>).

REGION	Ca	NO ₃ ⁻ + NH ₄ ⁺	Cl	Ppt (cm)
North	0.89	2.95	5.87	135.6
North Central	1.16	3.07	6.25	122.0
Verna Well Field	1.57	3.56	7.71	140.2

Dry deposition fluxes were based on basin-wide calculations conducted by Poor et al. (in review). These calculations were derived from concentrations of Ca²⁺, Cl⁻, HNO₃, HONO, NO_x, NO₃⁻, HCl, NH₃, and NH₄⁺ measured in ambient air at both a rural and urban location within the Tampa Bay watershed, and spatially variable deposition velocities calculated with the CALMET/CALPUFF modeling system. The inferred dry deposition fluxes for Tampa Bay were then used to compute wet:dry deposition ratios for Ca²⁺, NO₃⁻, NH₄⁺, and Cl⁻, which in turn were used to estimate the dry deposition fluxes for each species in north and northcentral Florida (*i.e.*, assuming constant ratios across the regions). The resultant total deposition fluxes were then used to compute ion ratios relative to Cl⁻ in atmospheric deposition.

RESULTS

Cl⁻ has been used effectively as a tracer to quantitatively evaluate retention of various major ions derived from atmospheric deposition, including NO₃⁻ and NH₄⁺, in seepage lakes in Florida (Pollman et al. 1991; Pollman and Canfield, 1991), and several streams in the southern Blue Ridge Province (Elwood et al. 1991). When applied to coastal rivers and streams in Florida, however, care must be taken to ensure that other sources of Cl⁻ do not confound the analysis. There are two key inputs of additional Cl⁻ of major concern: discharge of water from the Floridan aquifer and, in intertidal areas, exchange with seawater. When atmospheric deposition is the only source influencing streamwater concentrations, increasing Cl⁻ concentrations owing to evapotranspiration should be accompanied by increasing N concentrations. Conversely, because both seawater and groundwater derived from the Floridan aquifer often are depleted in N¹, stream and river reaches receiving these inputs are expected to show declining N concentrations as these additional hydrologic inputs essentially dilute ambient N concentrations while raising Cl⁻ concentrations at the same time.

Total N concentrations plotted as a function of Cl⁻ concentrations are shown for the NASQAN streams in Figure 2. Compared with these concentrations is a line depicting expected N concentrations based on atmospheric deposition derived from Eqn. (1) and TN:Cl ratio of 0.826 in total deposition. In addition, the plot also shows the range of expected streamwater Cl⁻ concentrations derived from atmospheric deposition, corrected for evaporative concentration. Evaporative concentration was calculated based on annual precipitation fluxes and assuming that net runoff of 25 to 76 cm/yr typical for northern Florida (Palmer, 1984) reflects evaporative losses only:

$$Cl_{bkgmd} = (Cl_{VWM} / R) \times P \quad (3)$$

where Cl_{bkgmd} is the predicted streamwater concentration, Cl_{VWM} is the annual volume-weighted mean concentration of Cl⁻ in atmospheric deposition (wet + dry), P is the annual precipitation depth, and R is the annual runoff volume. Cl_{VWM} is calculated as follows:

$$Cl_{VWM} = J_{Cl} \times (10 / P) \quad (4)$$

¹ In regions such as the lower Suwannee River basin where dairy farming has impacted groundwater concentrations of NO₃⁻, this generalization is not always true.

where J_{Cl} is the total (wet + dry flux of chloride) calculated on an annual basis, and is derived from the annual NADP wet flux coupled with Poor's dry deposition flux and calculated dry:wet ratio for 2002.

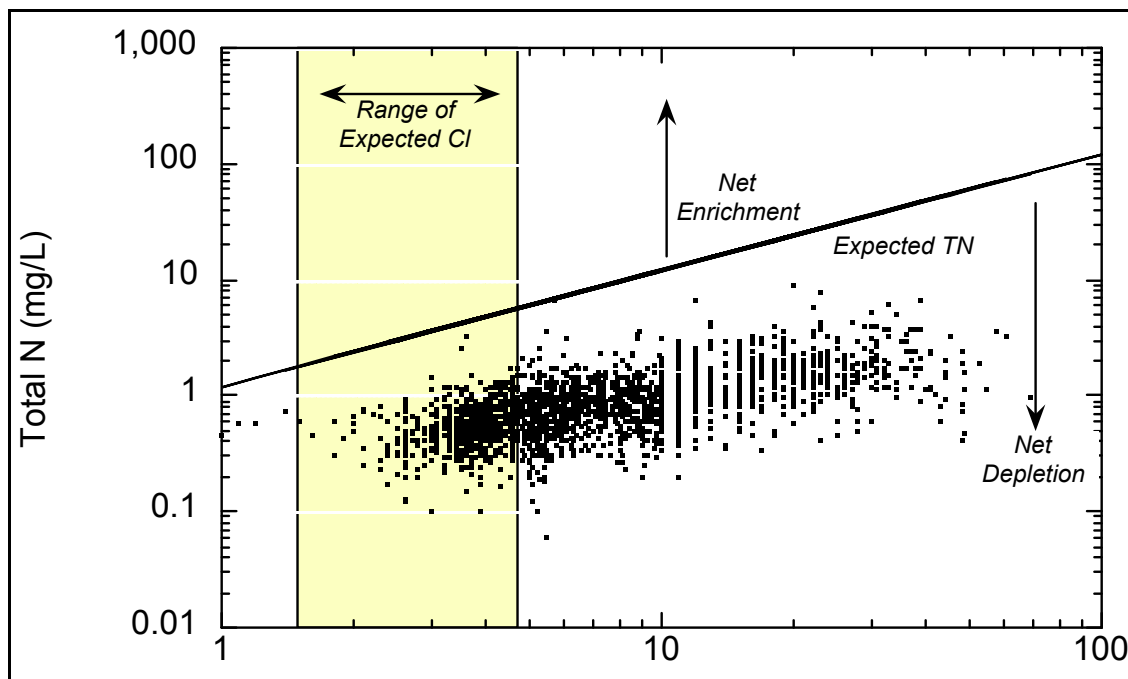


Figure 2. Plot of total N concentrations in selected NASQAN streams and rivers as a function of Cl. Shown on the plot is the line depicting expected total N as a function of Cl, and the likely range of expected Cl concentrations (Cl_{bgmtd}) assuming only atmospheric inputs corrected for evapotranspiration (see text).

Figure 2 illustrates several important points. First, with the exception of only two data points, all the observed data indicate net depletion of total N. Second, a relatively minor fraction of the observed data has Cl^- within the expected range for atmospheric inputs alone. Third, the slope of the TN: Cl^- relationship appears to show a downward shift, particularly at Cl^- concentrations above 30 mg/L, that may be indicative of dilution from groundwater.

Because the Floridan aquifer consists of principally limestone with some dolomite (Heath and Conover, 1981), Ca^{2+} was used as a tracer to identify samples influenced by calcium carbonate weathering (and thus potentially influenced by discharge from the Floridan aquifer). The total atmospheric deposition ratio of Ca^{2+} to Cl^- based on the wet and dry fluxes estimated for the Tampa Bay watershed is 0.208; thus samples from the NASQAN streams with Ca:Cl higher than 0.2 were excluded from further analysis. Only four streams from the original 22 stream data set included observations with Ca:Cl below 0.2: Blackwater River, Perdido River, Ochlocknee River, and Sopchoppy River. Samples from the Ochlocknee were further excluded because Cl^- concentrations were greatly elevated (average concentration for low Ca:Cl was approximately 46 mg/L) compared to expected concentrations of ca. 1.5 to 4.8 mg/L.

The average value for R_N calculated for NASQAN streams with low Ca:Cl and average Cl^- concentrations within the expected background range is 0.867 ± 0.011 . R_N for the Ca-enriched group was somewhat higher, averaging 0.891 ± 0.008 . R_N values also were computed for EPCHC stations screened to remove obvious influences of intertidal seawater inputs. Based

on an analysis of the cumulative frequency distribution of specific conductance, EPCHC data with mid-depth specific conductance concentrations greater than 550 mS were excluded from further consideration. Average R_N for the reduced set EPCHC samples (41 stations, total $n = 4,318$) was 0.930 ± 0.006 .

Despite screening for direct marine inputs, R_N for the reduced set of EPCHC samples is still likely biased high. The concentration of Cl_{bkgmd} ranges from 3.0 to 5.9 mg/L, based on characteristic runoff volumes of 25 to 51 cm in the Tampa Bay watershed (Kenner, 1966). Virtually all of the Cl^- concentrations in the reduced EPCHC data set exceed the upper estimate for Cl_{bkgmd} (only 3 out of 4,318 observations had $Cl^- \leq 5.9$ mg/L) and are likely influenced by groundwater inputs. As a result, R_N for both the NASQAN and EPCHC data sets were combined to develop an inferential model for predicting R_N for appropriate concentrations of Cl_{bkgmd} .

Figure 3 plots the relationship between R_N and Cl^- for the NASQAN 22 stream data set coupled with the EPCHC low conductivity data set. The following logarithmic model was fitted to the data:

$$R_N = 0.82255 + 0.03437 \times \ln(Cl) \quad (r^2 = 0.5839; p < 0.0001) \quad (5)$$

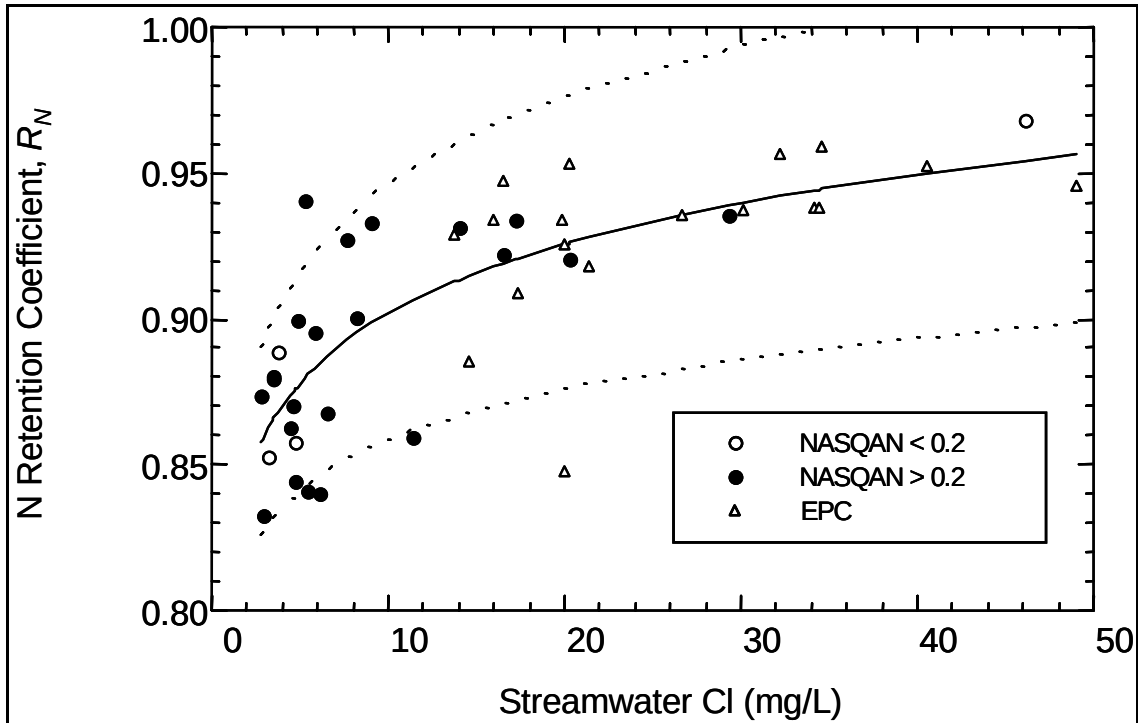


Figure 3. Plot of R_N vs. streamwater Cl^- concentrations for NASQAN 22 stream and low conductivity EPC data sets. The curves show results from fitting R_N as a linear function of log-transformed Cl^- concentrations and the upper and lower 95% confidence intervals for individual predicted values.

Corrected R_N including upper and lower 95 % confidence limits, were then calculated from the model for the EPCHC streams based on the expected concentrations in Cl_{bkgmd} . The best (i.e., assuming that runoff on average approximates the midpoint of the expected range of 25 to 76 cm) corrected value for R_N for the EPCHC low conductivity samples was 0.860 (Table 2), which agrees extremely well with the average value for the low Ca:Cl NASQAN streams (excluding the Ochlocknee River). The upper and lower limits for R_N are 0.817 and 0.923. The revised estimates for R_N for the Tampa Bay watershed are more consistent with the estimates of Castro and Driscoll (2002) for coastal rivers along the eastern United States (Figure 4). Applying this revised value for R_N to the mass balance data developed by Pribble et al. (2003) results in a reduction in the estimate of the relative contribution of atmospheric deposition to the N budget for Tampa Bay from 56% to 33%.

Table 2. Predicted corrected values for R_N in low conductivity EPC streams as a function of expected Cl_{bkgmd} concentrations. Annual runoff values derived from Kenner (1966) for the Tampa Bay watershed. R_N values including upper and lower 95 % confidence limits on individually predicted values calculated from Equation (5).

ANNUAL RUNOFF (cm)	Cl_{bkgmd}	R_N	LCL R_N	UCL R_N
25.4	5.93	0.884	0.845	0.923
50.8	2.96	0.860	0.827	0.893
76.2	1.98	0.846	0.817	0.876

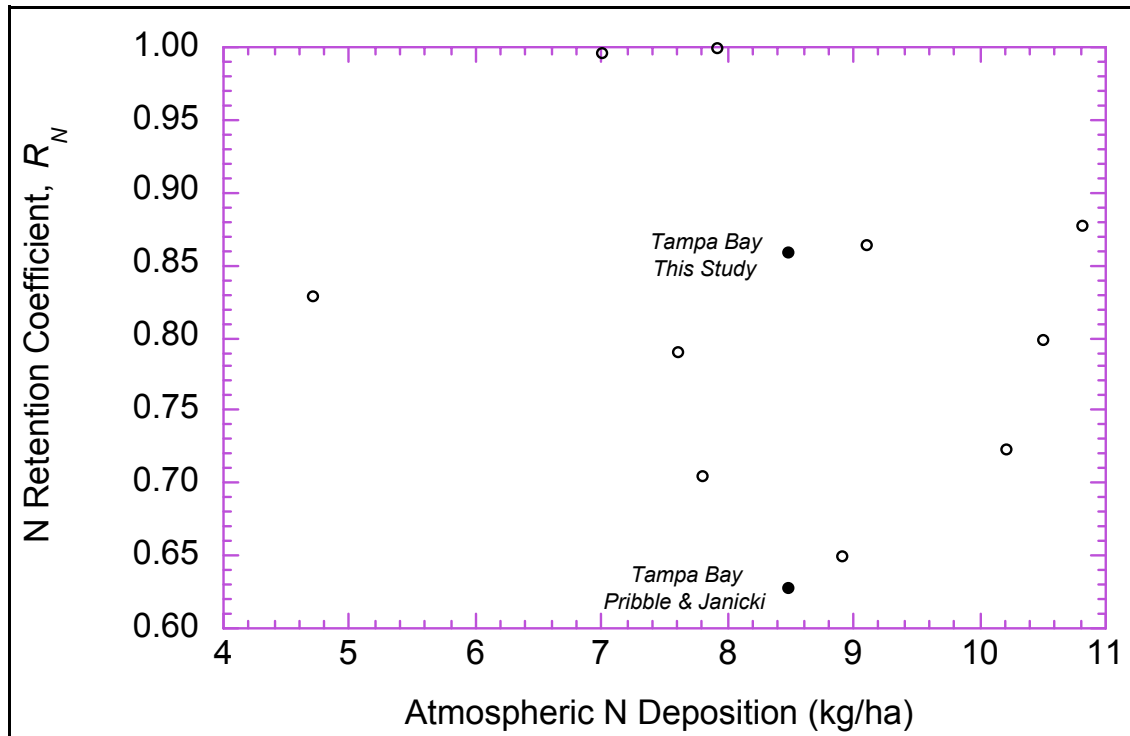


Figure 4. Comparison of watershed retention (R_N) of atmospheric N deposited to the watershed for 10 estuaries in the eastern United States with estimates for Tampa Bay from Pribble et al. (2003) and this study. Estuary data from Castro and Driscoll (2002); the Pribble et al. estimate for Tampa Bay is for 1995.

Our estimates for both R_N and the relative contribution of atmospheric deposition to the overall N budget of Tampa Bay also agree well with other studies. Howarth (1998) estimates that only 20% of the anthropogenic inputs of N to estuaries draining into the North Atlantic actually is exported to the ocean; the remaining 80% is either retained within the watershed or is remobilized to the atmosphere via denitrification. Excluding the Gulf of Mexico, the contribution of atmospheric deposition to total nitrogen loads in estuaries in the US is estimate to vary from approximately 10 to 40% (Paerl et al. 2002). Whitall and Paerl (2001) estimated that the atmospheric deposition contribution to the Neuse River estuary in North Carolina is most likely ca. 24%, with a range of 15 to 51% that reflects uncertainties in estimates of N retention as a function of land use. Using estimated atmospheric inputs derived from NADP wet deposition and CASTNET dry deposition monitoring in conjunction with land use information developed by USGS, Pollman and Roy (2002) estimated that atmospheric deposition contributes only ca. < 0.5 to ca. 1 kg/ha to the total flux of N in north Florida and panhandle streams compared to estimated inputs approximating 4 kg/ha. The total flux of N from the Tampa Bay watershed also compares well with yields from undisturbed tropical watersheds. Based on data compiled by Pribble et al. (2003), the watershed yield for N from the Tampa Bay watershed in 1995 was 6.79 kg/ha, which lies well within the estimate of N yields of 5.08 ± 2.71 kg/ha-yr for undisturbed tropical watersheds (Lewis et al. 1999).

CONCLUSIONS

Earlier estimates of the retention of atmospherically derived N within the watershed appear low based on comparison with other estuaries in the eastern US. As a result, we used Cl^- as a tracer for atmospheric inputs of nitrogen to estimate the extent that atmospheric inputs are retained. Cl^- appears to be a reasonable, conservative tracer to predict expected TN concentrations (in the absence of sources other atmospheric deposition and assuming no other inputs) provided that the data are appropriately screened. Screening criteria include calcium enrichment and Cl^- concentrations exceeding expected values based on likely runoff volumes and atmospheric inputs. R_N based on estimates of background Cl^- for Tampa Bay range from 0.817 to 0.923 (i.e., 82 to 92%). The best estimate is for R_N is 0.860, with 95% LCL and UCL of 0.827 and 0.893, respectively. This agrees well with an average value of 0.867 estimated from the NASQAN data base considering only screened data. Using an N retention coefficient of 0.860, the Pribble et al. (2003) estimate of the relative contribution of atmospheric deposition to total N loads to Tampa Bay for 1995 is reduced from 56% to 33%.

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SOURCE ATTRIBUTION FOR THE ATMOSPHERIC DEPOSITION OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) TO TAMPA BAY

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ABSTRACT

Sampling of 16 USEPA priority polycyclic aromatic hydrocarbons (PAHs) at the Gandy Bridge monitoring site between May and August 2002 provided preliminary ambient air concentrations and dry deposition rates for Tampa Bay. Poor et al. (2004) estimated a total (gas + particle) dry deposition flux including naphthalene of $10 \mu\text{g m}^{-2} \text{d}^{-1}$, assuming a unidirectional flux of these compounds from air to water. Predominantly gas-phase naphthalene, phenanthrene, fluorene, fluoranthene, acenaphthene and pyrene had concentrations that were consistently higher than concentrations of the remaining ten PAHs, which suggests a local source of PAH emissions due to the relatively short residence times of these compounds in the atmosphere. Average daily ΣPAH concentrations were correlated with collocated SO_2 concentrations ($r = 0.74$). A comparison of the ratio of PAH to fluorene concentrations for concentrations observed at the Gandy Bridge site and for concentrations measured in the emissions from coal-fired boilers were in reasonable agreement. The results offer tentative evidence that one or more of the PAH sources impacting the Gandy Bridge site on a few days in summer of 2002 was a local combustion source, and possibly a coal-fired power plant.

INTRODUCTION

The incomplete combustion of fossil fuels releases to the atmosphere polycyclic aromatic hydrocarbons (PAHs). Of the more than 100 known PAHs, the USEPA has focused their research efforts on 16 “priority” PAHs, so named because of their toxicity and environmental prevalence (Table 1). Of the 16 priority PAHs, all but three (acenaphthylene, acenaphthene, and fluorene) caused genotoxicity in *Salmonella typhimurium* bacteria (ATSDR, 1995). Benz(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-c,d)pyrene are classified by the USEPA as probable human carcinogens (ATSDR, 1995). The presence of PAHs in Hillsborough Bay, Cross Bayou Harbor and Bayboro Harbor sediments at concentrations that exceed 1000 ppb pose a threat to aquatic species (TBEP, 1999).

Sources of PAHs to the sediments include their direct spills or discharge, storm water run-off, and atmospheric deposition to Tampa Bay. PAHs distributed in the environment are from reservoirs of fossil fuels and from the combustion or metabolism of fossil fuels by natural and human-assisted processes (Soclo, et al., 2000). Burning of fossil fuels, for example, occurs in virtually every human endeavor: transportation, power production, manufacturing, agriculture and recreation. Our study has as its goals to better characterize the PAH exchange between the atmosphere and estuary, and to identify atmospheric sources of PAHs that contribute to this exchange. Poor et al. (2004) estimated the atmospheric deposition rates of PAHs to Tampa Bay. We present in this paper the PAH concentrations from bayside ambient air monitoring and explore the relationships among the PAH species for clues on source attribution.

MATERIALS AND METHODS

A high capacity integrated organic gas and particle sampler (HiC-IOGAPS; Model 3000DB, URG Corp., Chapel Hill, NC), described by Swartz et al. (2003), was installed on the seawall at an atmospheric deposition monitoring site near the eastern end of the Gandy Bridge, Tampa, and adjacent to Tampa Bay, Florida (27.89N, 82.54W). The inlet height was 2 m above the sea wall. The sampler consisted of an inverted open-pipe Teflon-coated inlet, a Teflon-coated cyclone with a $2.5 \mu\text{m}$ cut-point at 91 L min^{-1} , two 8-channel denuders and a filter pack in series (Figure 1). The filter pack included a 90-mm quartz (Pallflex) filter to collect organic aerosol, followed by three subsequent 90-mm XAD-4 impregnated quartz (Pallflex) filters to trap semi-volatile organic compounds that degassed from filters. The XAD-4

coated denuders and XAD-4 impregnated filters were prepared in the USEPA Office of Research and Development National Exposure Research Laboratory, Research Triangle Park, NC, by the procedure of Gundel, et al. (1995) in March 2002, and delivered to Tampa, FL, with the HiC-IOGAPS in April 2002. Typical collection times were 24 hours, beginning at 0700 Eastern Standard Time. Flow rates were computer controlled and calibrated with a NIST-traceable laminar flow element prior to deployment. Samples were collected between May and August 2002. Refer to Poor, et al. (2004) for details on sample handling and laboratory analyses. PAH gas and particle concentrations are summarized in Tables 1 and 2.



Figure 1. HiC-IOGAPS installed at the seawall near the eastern end of the Gandy Bridge, Tampa, Florida.

RESULTS AND DISCUSSION

One common technique for source attribution of PAHs is to correlate wind and temperature observations with ambient air concentration data. For example, Odabasi et al. (1999) plotted separately the gas-phase and particle-phase concentration data for each day of observation at a Chicago, IL monitoring site. They found that the gas-phase concentrations increased with temperature and the particle-phase concentrations. These relationships suggest that the gas-phase concentration has as a source the increased volatilization of PAHs from surfaces like roads, soils, vegetation, and carbon-containing aerosols. As another example, Cortes, et al. (2000) showed that at Sturgeon Point, a Great Lakes Integrated Atmosphere Deposition Network site located near Lake Erie, wind blowing from the direction of urban Buffalo, NY (20 km northwest), elevated PAH concentrations by factor of 3 or more than for wind arriving at the site from across Lake Erie. Table 3 summarizes the average daily meteorological

conditions for 6 of the 7 days of data,¹ and Figure 2 shows the air mass back trajectories for those same days.

Table 1. PAH gas concentrations (ng m⁻¹).

PAH	5/30/02	5/31/02	6/1/02	6/7/02	6/13/02	6/25/02	7/1/02
Naphthalene	103.85	85.91	75.77	36.07	39.71	70.72	45.87
Acenaphthylene	0.51	0.41	0.00	0.09	0.00	0.19	0.24
Acenaphthene	5.57	6.69	2.24	2.91	3.31	4.60	2.60
Fluorene	8.88	8.92	6.16	5.23	5.00	5.23	3.77
Phenanthrene	17.79	20.92	11.29	10.03	11.17	11.23	9.94
Anthracene	0.39	0.43	0.03	0.15	0.72	0.32	0.89
Fluoranthene	5.48	5.99	4.98	3.90	5.00	5.00	3.23
Pyrene	1.89	2.25	1.28	1.19	1.71	2.12	1.54
Benzo(a)anthracene	0.13	0.08	0.00	0.01	0.01	0.02	0.01
Chrysene	0.90	1.19	0.26	0.17	0.27	0.25	0.12
Benzo(b)fluoranthene	0.07	0.02	0.08	0.06	0.09	0.05	0.02
Benzo(k)fluoranthene	0.02	0.01	0.01	0.00	0.01	0.01	0.01
Benzo(a)pyrene	0.05	0.02	0.00	0.00	0.00	0.00	0.00
Indeno(1,2,3-c,d)pyrene	0.08	0.04	0.00	0.00	0.00	0.00	0.00
Dibenz(a,h)anthracene	0.06	0.03	0.00	0.00	0.00	0.00	0.00
Benzo(g,h,i)perylene	0.07	0.05	0.02	0.01	0.02	0.04	0.03
Σ Gaseous PAHs	146	133	102	60	67	100	68

Table 2. PAH particle concentrations (ng m⁻¹).

PAH	5/30/02	5/31/02	6/1/02	6/7/02	6/13/02	6/25/02	7/1/02
Naphthalene	7.48	48.21	16.17	18.45	12.89	19.24	91.76
Acenaphthylene	0.00	0.00	0.00	0.01	0.00	0.00	0.04
Acenaphthene	0.27	0.26	0.12	0.28	0.25	0.25	0.50
Fluorene	0.23	0.23	0.12	0.26	0.34	0.22	0.34
Phenanthrene	2.18	2.34	2.01	1.56	3.07	2.57	3.86
Anthracene	0.04	0.05	0.04	0.05	0.07	0.07	0.10
Fluoranthene	1.16	0.82	0.72	0.53	1.08	1.09	2.35
Pyrene	0.60	0.48	0.40	0.29	0.60	0.55	1.61
Benzo(a)anthracene	0.03	0.02	0.01	0.01	0.01	0.01	0.01
Chrysene	0.05	0.06	0.03	0.03	0.04	0.04	0.03
Benzo(b)fluoranthene	0.05	0.07	0.02	0.03	0.00	0.00	0.06
Benzo(k)fluoranthene	0.01	0.02	0.00	0.00	0.00	0.00	0.02
Benzo(a)pyrene	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Indeno(1,2,3-c,d)pyrene	0.03	0.05	0.01	0.02	0.00	0.02	0.00
Dibenz(a,h)anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzo(g,h,i)perylene	0.05	0.06	0.01	0.03	0.01	0.03	0.18
Σ Particle PAHs	12	53	20	22	18	24	101

We expected that ΣPAH concentrations would be lowest with the arrival of a marine air mass, as previous research showed that a marine air mass from the Gulf of Mexico or Cuba had significantly lower ambient air and rainwater concentrations of aged combustion products nitrate and sulfate (Smith, 2002; Earls, 2001). For this limited dataset, however, we saw that the highest (5/31/02) and the lowest ΣPAH (6/13/02) occurred with a marine air mass (Fig. 2), and for similar average surface meteorology (Table 3). Hourly winds (not shown) indicated a steady westerly flow for 5/31/02 but a land-sea breeze effect for 6/13/02, which

¹ Sampling begun on 6/7/02 lasted for 48 hours; thus daily averages and 24-hour trajectories for this date were not comparable.

was not evident in air mass trajectory (Fig. 2). Thus, an urban plume from Pinellas County may have contributed more to the PAH concentrations on 5/31/02 than on 6/13/02. The average temperatures were not more than 1°C different across the sampling days (Table 3), so trends in the Σ PAH concentrations cannot be explained by temperature effects such as evaporation.

Table 3. Summary of average daily meteorological observations made at the Tampa International Airport (27.96N, 82.53W) (NCDC, 2004).

Observation	5/30/02	5/31/02	6/1/02	6/13/02	6/25/02	7/1/02
Temperature (°C)	28	27	27	28	27	27
Dew Point (°C)	21	20	22	23	23	22
Avg Wind Speed (m/s)	2.6	2.7	3.1	2.7	1.8	1.8
Res Wind Speed (m/s)	0.8	0.9	1.6	2.2	0.4	0.2
Res Wind Direction (deg)	290	260	290	260	150	240
Rainfall (mm)	0	0	0	0.5	5.8	35

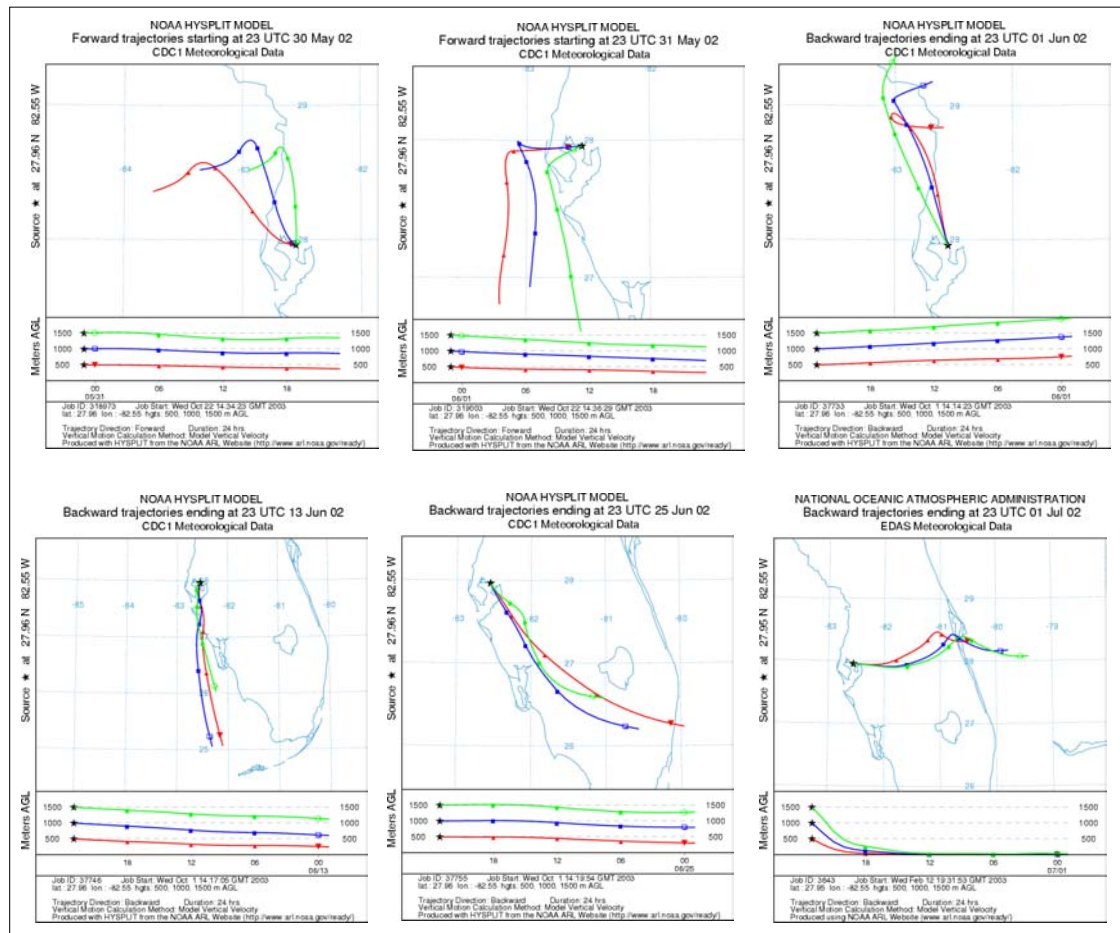


Figure 2. The 24-hour backward air mass trajectories for 1800 EST on June 1, June 13, June 25, July 1, July 31 and August 6, 2002. The three levels shown are 500 m (triangles), 1000 m (squares) and 1500 m (circles) (Draxler and Rolph 2003; Rolph 2003).

In general, the Σ PAH particle concentrations decreased with average wind speed ($r = 0.5$), a trend that suggests dilution of a plume rather than re-suspension of PAH-bearing road dust. No remarkable trend was seen for Σ PAH gas concentrations, and this can be explained as follows: if the PAH source were local, higher wind speeds would tend to dilute the PAH plume but reduce the extent of PAH photolysis as the PAH is transported to the receptor—effects that counteract each other.

Another oft-used technique for source attribution is to compare the ratios of a PAH species within a sample with similar ratios made at an emission source. Ignored by this approach is the fact that PAHs undergo photolytic and chemical reactions in the atmosphere that change their mass distributions. For example, the atmospheric lifetime of gaseous 2- and 3-ring PAHs that react with OH radicals, is less than one day (Brubaker and Hites, 1998). Photolysis rates of PAHs found as particles depend upon the substrate. PAHs adsorbed to silica gel, alumina, or fly ash have atmospheric lifetimes from less than one hour to over 200 hours; PAHs absorbed in carbon black can survive photolysis for more than 1000 hours (Behymer and Hites, 1985). Thus, this ratio approach will be appropriate only for significant sources proximate to the bay.

Khalili et al. (1995) measured not only the ambient air PAH concentrations but the PAH concentrations from major sources in the Chicago area: coke ovens, heavy duty diesel engines, gasoline engines, and wood combustion. They compared the benzo(e)pyrene to benzo(a)pyrene ratio for both the source and receptor concentrations to apportion the receptor concentrations to these sources. They found from these sources that the 2- and 3-ring PAHs dominate the PAH concentrations, and that the 6-ring PAHs were detected only in highway tunnel, gasoline engine and diesel engine samples. We did not measure benzo(e)pyrene but can use the published data from Khalili et al. (1995) to find the ratio of chrysene to the 4-, 5- and 6-ring PAHs (Table 4). Our sampling method was more efficient at capturing the 2- and 3-ring (and most likely the 4-ring) compounds than the method described by Khalili et al. (1995), thus we do not expect these ratios to be the same. The ratios seen at Gandy Bridge are the most similar to those reported for emissions from a coke oven (Table 4).

Table 4. Mass ratios of 4-, 5- and 6-ring PAHs to chrysene observed at Gandy Bridge monitoring site and for source emissions obtained from Khalili et al. (1995).

PAH	Gandy Bridge	Coke Oven	Diesel	Tunnel	Gasoline	Wood
Fluoranthene	18.87	6.01	0.56	1.50	1.58	2.92
Pyrene	7.95	3.83	0.34	2.48	2.54	3.05
Benzo(a)anthracene	0.10	0.52	1.74	1.16	0.21	0.57
Chrysene	1.00	1.00	1.00	1.00	1.00	1.00
Benzo(b)fluoranthene	0.28	0.32	0.96	0.56	1.16	0.71
Benzo(k)fluoranthene	0.05	0.54	0.68	0.53	0.90	1.36
Benzo(a)pyrene	0.02	0.36	2.11	0.80	0.95	6.19
Indeno(1,2,3-c,d)pyrene	0.06	0.07	1.74	0.26	0.00	0.00
Dibenz(a,h)anthracene	0.01	0.00	1.19	0.19	0.00	0.00
Benzo(g,h,i)perylene	0.32	0.05	0.76	0.22	0.32	0.00

Yet another approach is to examine the correlations or covariances between the PAH species to identify possible source “fingerprints.” This approach comes in many forms, from a simple Pearson product correlation matrix to multiple linear regressions to principal component

analysis. Typical co-pollutants such as NO_x, SO₂, etc. can help confirm sources (Table 5). For example, we show in Figure 3 a linear model fit to the data by least squares regression to explain the average daily ΣPAH and NO₂ concentrations from SO₂ concentrations measured at the Gandy Bridge site; the correlations were $r=0.74$ and $r=0.92$, respectively. These correlations suggest that ΣPAH and NO₂ sources also emit SO₂.

Table 5. Average daily pollutant concentrations.

POLLUTANT	5/30/02	5/31/02	6/1/02	6/13/02	6/25/02	7/1/02
NO (ppb)	7	8	5	1	5	9
NO ₂ (ppb)	9	11	12	5	6	10
SO ₂ (ppb)	9	9	10	4	4	10
PM _{2.5} (mg m ⁻³)	9	11	12	10	9	8
PM ₁₀ (mg m ⁻³)	20	20	20	16	17	17

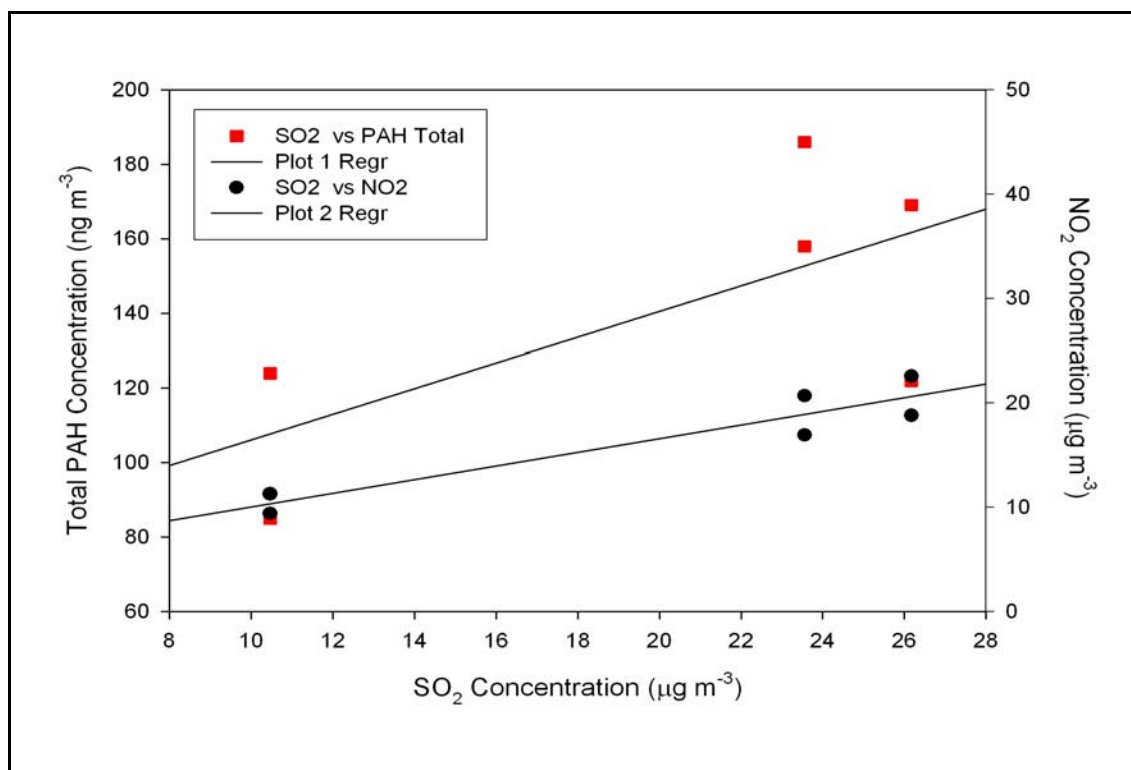


Figure 3. Fit of a linear model by a least squares regression to explain the dependence of atmospheric ΣPAH and NO₂ concentrations on SO₂ concentrations.

The largest SO₂ sources near Tampa Bay are coal- and oil-fired utilities (Batten et al. 2003). We found from USEPA (1998) the composite PAH emission factors for bituminous controlled coal combustion (lb PAH/ton fuel) and fuel oil (lb PAH/10³ gal fuel), and from these factors calculated the PAH to fluorene ratio (Table 6). Fluorene was chosen over chrysene because of its longer atmospheric lifetime (Brubaker and Hites, 1998; Behymer and Hites, 1985).

Comparing the observed ratio at the Gandy Bridge site with the ratio for coal combustion revealed a surprising agreement for most of the PAHs.

Table 6. Mass ratios of PAHs to fluorene observed at the Gandy Bridge monitoring site and based on average emission factors from USEPA, 1998.

PAH	Gandy Bridge	Coal Combustion	Fuel Oil Combustion
Naphthalene	15.9	14.3	253
Acenaphthylene	0.03	0.27	0.06
Acenaphthene	0.67	0.56	4.72
Fluorene	1.00	1.00	1.00
Phenanthrene	2.50	2.97	2.35
Anthracene	0.09	0.23	0.27
Fluoranthene	0.97	0.78	1.08
Pyrene	0.40	0.36	0.95
Benzo(a)anthracene	0.01	0.09	0.90
Chrysene	0.07	0.11	0.53
Benzo(a)pyrene	0.002	0.042	ND
Indeno(1,2,3-c,d)pyrene	0.004	0.067	0.48
Dibenz(a,h)anthracene	0.001	ND	0.37
Benzo(g,h,i)perylene	0.02	0.03	0.51

ND – no data. Benzo(b)fluoranthene and benzo(k)fluoranthene were not reported separately in the USEPA (1998) document.

CONCLUSION

We make an inference here that is based on a small data set and should be considered as a preliminary hypothesis rather than a definitive conclusion. The results offer evidence that one or more of the PAH sources impacting the Gandy Bridge site on a few days in summer of 2002 was a local combustion source, possibly a coal-fired power plant.

ACKNOWLEDGMENTS

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FACILITATING ADAPTIVE MONITORING FOR SCIENTIFIC INVESTIGATIONS THROUGH QUALITY ASSURANCE AND DATA MANAGEMENT

D. Bishop & C. Anastasiou

ABSTRACT

Adaptive monitoring can be effectively utilized in scientific investigations to account for changing or unanticipated variations in the conditions under study. Intensive project design and research can anticipate much of the variability encountered in scientific investigations, but planning for continued re-assessment and adaptivity allows investigators to more fully address unanticipated influences. In order to facilitate adaptive monitoring, comprehensive quality assurance and data management procedures must be in place at the onset of the investigation and implemented periodically as the investigation progresses. The resulting data can then be utilized to make modifications or address inadequacies in project design or implementation. This reliance on data in adaptive monitoring emphasizes the importance of quality assurance and data management in scientific investigations.

A case study of the Old Tampa Bay Intensive Water Quality Monitoring Program is used to illustrate the importance of quality assurance and data management in the adaptive monitoring of the multi-agency collaborative investigation. The Tampa Bay Estuary Program, SWFWMD, Florida Fish and Wildlife Conservation Commission, City of Tampa, and Pinellas County have implemented an intense water quality assessment of Old Tampa Bay for determining the causes of recent declines in seagrass coverage. The investigation has involved four agencies individually collecting water chemistry and site condition data in four delineated quadrants of Old Tampa Bay. Project planning incorporated detailed quality assurance and standard operating procedures that decreased sampling variability and assured that data could be utilized periodically to make necessary monitoring modifications.

ADAPTIVE MONITORING

Natural ecological systems are the sum total of community assemblages and the affects of global, regional, and local processes that are often neither completely understood nor entirely predictable. Scientists and managers are challenged to monitor these dynamic conditions with fiscal, regulatory, and sociological limitations. Since these dynamic systems can be highly variable over time and space (Michener 1997), it is inherently difficult to precisely define monitoring protocol at the onset of the monitoring program that will adequately address the conditions affecting the system.

A standard approach to scientific investigations often involves formulating rigid monitoring protocol during project planning that is maintained to project completion. A more adaptive approach to monitoring follows similar project methodology, but allows for periodic review and potential modification of project objectives and protocol as evolving experiments. A functional project design, implementation, and monitoring program are necessary to provide project direction. But by periodically assessing and evaluating the project, managers and scientist can effectively adapt to changing site conditions without the confines of an extended predefined monitoring protocol.

PROJECT DESIGN AND PLANNING

Budget and statistical considerations are central components of project planning for most scientific investigations. For a monitoring project to produce serviceable results, data must be collected according to a valid scientific and statistical design and be cost-effective (Caughlan 2001). While it is often cost-prohibitive to monitor all parameters of interest for indefinite periods of time, statistical analysis based on existing or preliminary data during the planning process can ensure representative and cost-effective monitoring results.

Planning for adaptive monitoring can also be beneficial in insuring cost-effective implementation by enabling scientists to modify protocol and pursue unanticipated features in a system. Intensive project design and preliminary research can anticipate much of the

dynamic variability encountered in scientific investigations, but adhering to rigid monitoring protocol may force scientists to ignore potential project conclusions. An adaptive monitoring program allows scientists to address pertinent variables that were not accounted for during initial project planning.

The largest portion of project costs are expended on data collection elements while proper time or funding are typically not allocated for quality assurance and data management. Failure to plan for quality assurance and data management can have significant consequences if environmental management decisions are based on potentially unreliable data (Batley 1999).

QUALITY ASSURANCE AND DATA MANAGEMENT

In order to facilitate adaptive monitoring for scientific investigations, comprehensive quality assurance and data management procedures must be in place at the onset of the investigation and maintained concurrently as the project progresses. Quality assurance refers to the activities undertaken to ensure the representativeness and integrity of samples, and the accuracy and reliability of data required to make project decisions (Ibe 1995). Data management is an integral component of scientific investigations and encompasses a broad spectrum of activities including database design, data compilation, processing, metadata, and archiving (Michener 1997).

Quality assurance and data management are often not considered until field sampling has completed, and is then not provided proper time and budget allocations. By delaying these components until project completion, scientists may fail to detect inadequacies in the monitoring program until all funds are depleted. Adhering to strict quality assurance and data management as the project progresses allows scientists to detect monitoring inadequacies and alter protocol to ensure that collected data are reliable, statistically relevant, and complete. The resulting data can then be utilized to make modifications or address inadequacies in project design or implementation.

CASE STUDY: OLD TAMPA BAY INTENSIVE WATER QUALITY MONITORING

Project Summary

The Tampa Bay Estuary Program, SWFWMD, City of Tampa, Florida Fish and Wildlife Conservation Commission, and Pinellas County implemented an intensive water quality assessment of Old Tampa Bay. The focus of the collaborative effort was to determine if water quality conditions are consistent with observed seagrass distribution and lack of recovery in Old Tampa Bay (see Figure 1). Monitoring included collecting monthly water chemistry and site condition data at stratified random stations for 2002 and 2003 in four quadrants of Old Tampa Bay (see Figure 2).

Project Planning and Design

Project planning and design were conducted by participating agency staff with the goals of detecting differences between stable and lost seagrass, shallow and deep areas, and shallow East and shallow West areas. Sample size and duration of the investigation were selected based on project budget constraints and statistical power analysis of existing ambient chlorophyll data from Tampa Bay. Specific attention was paid to not over sampling and maintaining cost-efficiency. A detailed standard operating procedure was developed and then thoroughly reviewed by participating agencies to ensure proper staff training.

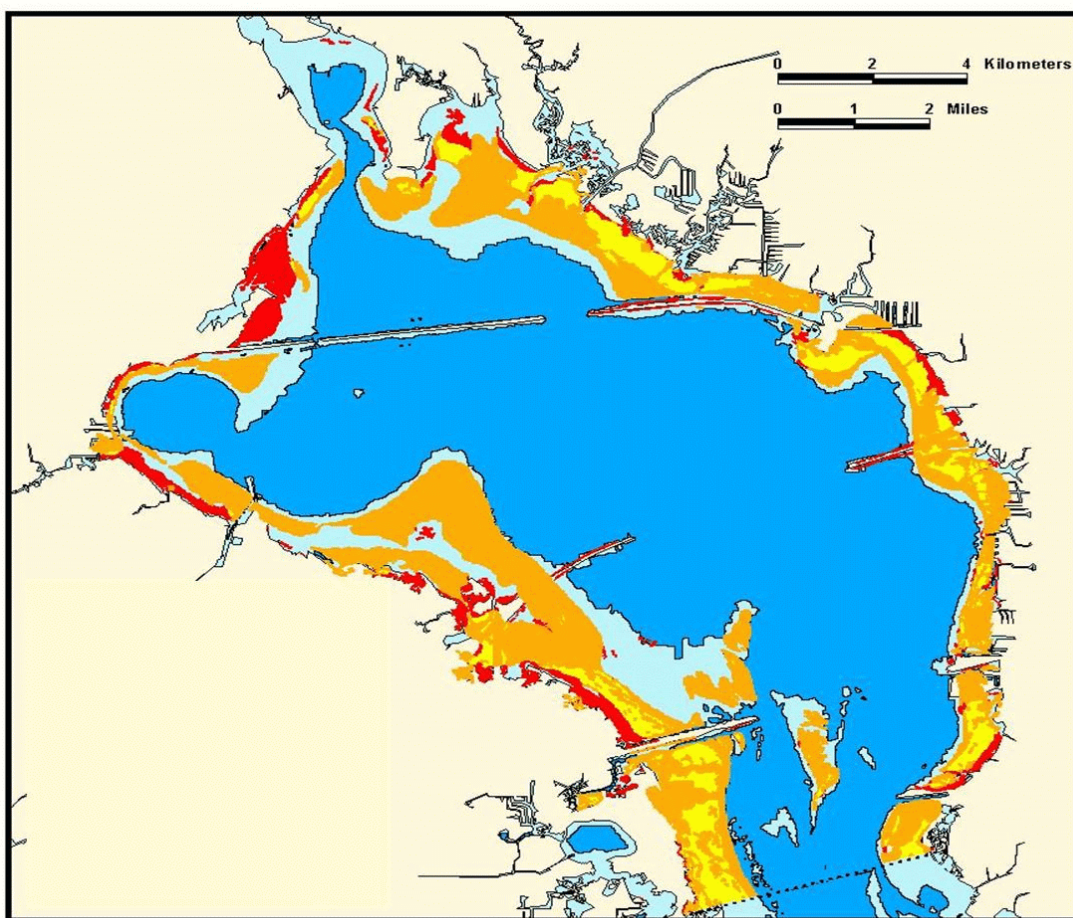


Figure 1. Old Tampa Bay project focus area and biological strata distribution.

Quality Assurance and Data Management

For each sampling event, a replicate and a field blank sample were collected by all four groups as a check of repeatability and sampling contamination for laboratory and field sampling protocols. The number of replicate and blank samples totaled approximately 16% of the samples collected for the entire project. Independent field audits were also conducted to ensure that sampling procedures were consistent among field crews. The data management for this project was performed internally by the SWIM Program as the project progressed and data were available for review soon after the final sampling month for each year. Strict protocols were established to ensure that all data were thoroughly reviewed and quality assurance checks completed prior to the release of the data files. Qualified data files were stored in FDEP GWIS3 Data Base format and uploaded to STORET via the SIMM Module. Following the compilation of field and laboratory data into a central database, the data were exported to a Quality Assurance Event Check program that tests for blank values exceeding the PQL for any parameter. The program also compares replicate and original parameter values then reports value comparisons that exceed a 20% relative percent difference. A complete project outlier check is also performed that compares all past project events to the present event. From this check, outliers for each parameter throughout the duration of the project are revealed. Values that fall under any of these categories are documented and investigated. Investigations may include consulting the laboratory manager for extraneous lab values, questioning of field staff, or inspection of field sheet comments for a questionable issue. Problems and conclusions of these investigations are

documented for entry into the Quality Assurance report. Any extraneous values that have not been resolved through investigation are flagged in the database with various data value qualifiers.

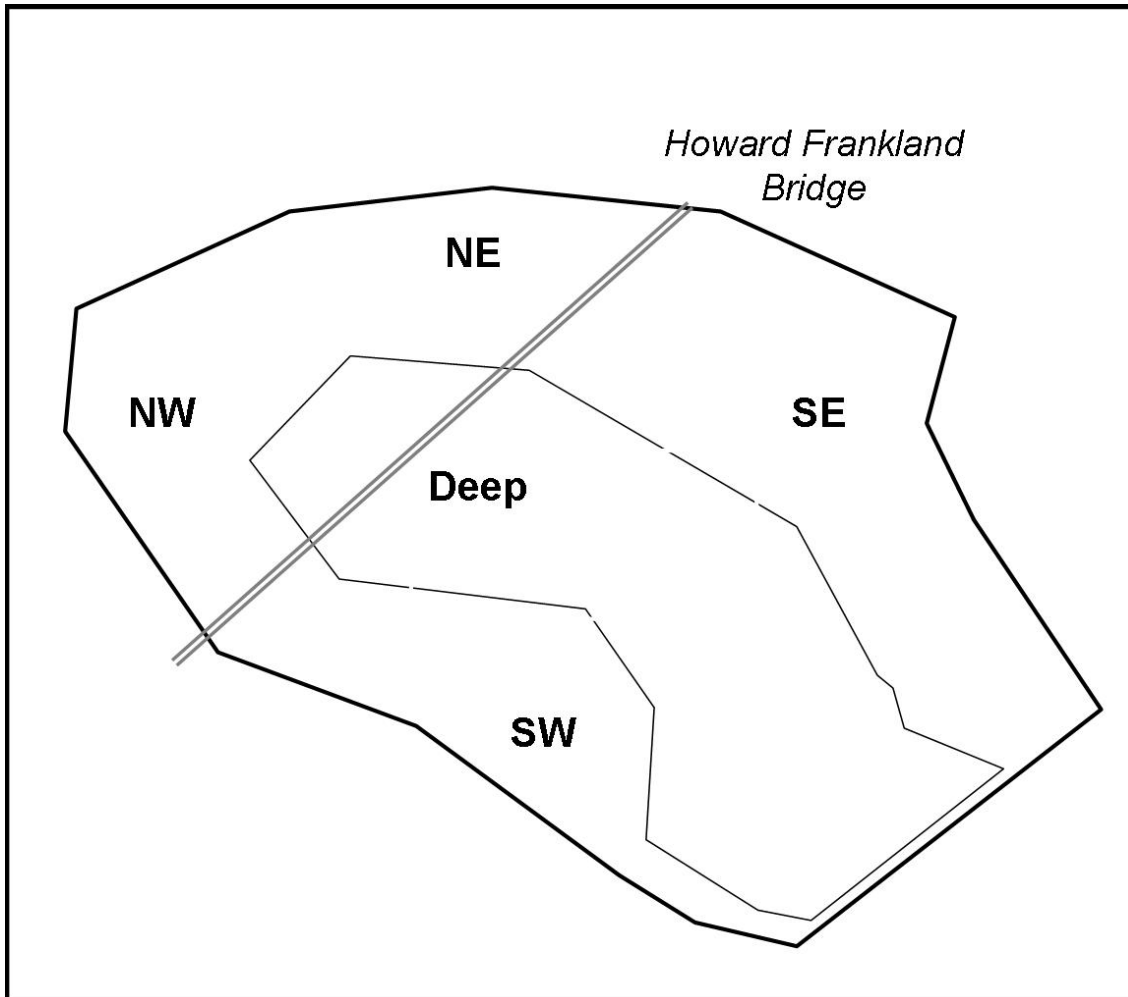


Figure 2. Old Tampa Bay project physical strata delineation.

ADAPTIVE MONITORING IN PRACTICE

The reliability and availability of the data during the project enabled participants to review and modify monitoring protocol. Modifications were implemented after project staff review during periodic project meetings. Examples include:

- After the first year of data collection, the statistical power of the shallow vs. deep test was reassessed to determine if more deep samples should be added in the second year when more funding became available. The power test was conducted using a nonparametric test (Kruskal-Wallis Test) on year one data for shallow and deep sites. This analysis indicated that existing sample size would be sufficient to detect significant differences between shallow and deep stations and reinforced the power analysis that was conducted during the project design phase.
- In April and May of 2002, chlorophyll b levels were below the PQL for most

monitoring sites. Project staff determined that sample volume should be increased from 1.0L to 3.0L in order to obtain more reliable chlorophyll data. Increasing the sample volume had minimal affect on reducing PQL occurrences in 2002 (see Table 1), but the modification in monitoring protocol has ensured greater precision and accuracy of the chlorophyll b data during analysis.

- A central indicator of interest for the monitoring program was light attenuation through the water column. The initial project monitoring protocol calculated light attenuation coefficients from two underwater PAR sensors separated vertically by 0.5 m. These methods have inherent limitations in shallow waters less than 1.5 m that can be overcome by calculating beam attenuation coefficients from samples using a laboratory transmissometer. After recognizing that light attenuation could not be analyzed in many of the shallow sites and with the acquisition of laboratory transmissometers by participating agencies, monitoring protocol was modified to include transmittance samples. While beam attenuation coefficients cannot be directly substituted for light attenuation coefficients, the monitoring protocol modification has provided a viable alternative when light attenuation cannot be measured (Anastasiou, 2003).

Table 1. Old Tampa Bay project percent of chlorophyll b data below PQL per month in 2002 and 2003.

	2002	2003
April	64%	66%
May	40%	10%
June	10%	0%
July	2%	0%

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ABSTRACTS
Session 3: WATER AND SEDIMENT QUALITY, WATER QUANTITY,
and ATMOSPHERIC DEPOSITION

PRESENTATIONS

A Comparison of Water Quality and the Factors That Influence Water Quality in the Segments That Comprise Tampa Bay. A. Janicki (Janicki Environmental, Inc), J.O.R. Johansson (City of Tampa Bay Study Group), A. Squires (Pinellas Co. Dept. of Environmental Mgt.), R. Boler (Environmental Protection Commission of Hillsborough Co.), R. Brown (Dept. of Environmental Mgt., Manatee Co.).

Effects of Entrainment and Temperature Increase on Phytoplankton: a Novel Use of HPLC Pigment Analyses and Particle Size Analysis. J. Culter, J. M. Sprinkle, G. Kirkpatrick (Mote Marine Laboratory). In 1998 a quarterly study was initiated to determine if phytoplankton were sensitive to the effects of entrainment and temperature increases, at the Tampa Electric Company Big Bend facility. Methods for determination of effects included; high pressure liquid chromatography pigment analysis, multisizer particle size analysis, Coulter LS laser particle size analysis, and total suspended solids.

In May and September there was a decrease in concentration of chlorophyll *a*, peridinin and fucoxanthin from intake to discharge, likely due to physical disruption of cells during plant passage. Some pigments decreased from intake to discharge and other pigments showed no marked decrease from intake to discharge suggesting that a large portion of the phytoplankton population makes it through the plant intact, even in the worst case. Passage through the plant in warm months affected portions of the phytoplankton community in discharge water by as much as 50%, but these impacts were not carried through to the open bay, indicating rapid recovery. In cold months the warmer water may enhance the growth of some components of the phytoplankton community by 50 to 400% over the control site. Nutrient availability could not be ruled out as a contributing factor to this enhanced growth within north Apollo Bay.

None of the shifts in phytoplankton were extreme, primary production in the vicinity of the plant was not dramatically altered. No algal classes present at one site were completely eliminated at another and there were no order of magnitude increases or decreases in pigments or particle sizes. Study sponsored by Tampa Electric Company. [jculter@mote.org]

Developing Nutrient Loading Limits for Bishop Harbor from the Former Piney Point Phosphate Facility. K. Hackett, A. Janicki, J. R. Pribble, D. Wade (Janicki Environmental, Inc.). Bishop Harbor is a shallow water embayment situated on the southern bank of Tampa Bay. On February 1, 2001, Piney Point Phosphates, Inc., notified the Florida Department of Environmental Protection (FDEP) that it is was no longer able to maintain the Piney Point phosphate mining facility and the untreated acidic process wastewater stored at the site. The potential adverse impacts resulting from a spill of untreated wastewater on Bishop Harbor are substantial. Therefore, FDEP has been examining wastewater treatment and discharge scenarios in order to reduce impacts on Bishop Harbor. Discharge of the treated wastewater will cause an increase in nitrogen load and chlorophyll *a* concentration to Bishop Harbor. To establish a target for chlorophyll *a* concentrations in Bishop Harbor, nearby Terra Ceia Bay was used as a reference. The mean chlorophyll *a* concentration for Terra Ceia Bay between 1989 and 1998 was 7.8 µg/l. Based on regression models fit with observed data, a chlorophyll *a* concentration of 7.8 µg/l in Bishop Harbor was consistent with an ammonia nitrogen concentration of 0.37 mg/l in Bishop Harbor and an ammonia load from the Piney Point discharge canal of 140 kg ammonia nitrogen/day. We utilized a two-dimensional, laterally averaged, hydrodynamic and water quality model, CE-QUAL-W2, to predict long-term effects of this interim loading limit on Bishop Harbor water quality. The mean annual chlorophyll *a* concentration derived from this one-year mechanistic model simulation was 6.6 µg/l, which agrees favorably with the chlorophyll *a* target of 7.8 µg/l. [khackett@janickienviro.com]

Sediment Quality Issues in Tampa Bay. S. Grabe (Env. Protection Commission of Hillsborough Co.), D. Wade (Janicki Environmental, Inc), D. McDonald (McDonald Environmental, LLD). The purpose of this paper is to synthesize the existing information on sediment quality in Tampa Bay, and provide an overview of the empirical linkages that have been developed between sediment quality and benthic community characteristics. These linkages have been developed specifically for Tampa Bay, and for Tampa Bay in the context of the estuaries in the Gulf Coast region.

The identification and remedial treatment of contaminated sediments are among the priorities for Tampa Bay managers. The bay is subject to the input of chemical contaminants including metals (cadmium, chromium, copper, lead, mercury, and zinc), organochlorine pesticides (chlordane, DDT, dieldrin, and endrin), and the organic chemicals, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). However, the

overall benthic condition of the bay is good, and low dissolved oxygen conditions and elevated contaminants are typically found in a few “hot spots.”

A large body of field observations has been collected from the historical to current period, and linkages have been developed between sediment quality and benthic community characteristics. Over the past seven years, the Tampa Bay Estuary Program (TBEP) partners and a national advisory group have worked cooperatively on the implementation of a probabilistic benthic monitoring program and a set of narrative and numerical sediment quality targets for sediment quality. The Tampa Bay Estuary program is using this information to support the sediment quality target setting process. One promising approach that is under consideration is to apply this information to set sediment quality targets based on the estimated geographic extent of healthy and degraded habitats, and to track the magnitude and trends of the extents annually. [David_Wade@janickienvironmental.com]

Development of a Benthic Quality Index For Use as a Management Tool in Establishing and Monitoring Sediment Quality Targets for the Tampa Bay Estuary. K.J. Malloy, D. Wade, A. Janicki (Janicki Environmental, Inc), S. Grabe (Environmental Protection Commission of Hillsborough Co.). Sediment quality is an indicator of the health of an estuary. The Comprehensive Conservation and Management Plan for the Tampa Bay Estuary Program requires the development and monitoring of sediment quality targets throughout the bay. Benthic invertebrates can be used as biological indicators to indirectly assess the condition of estuarine sediments. A Benthic Quality Index (BQI) was developed for use as a management tool for determining sediment condition in Tampa Bay. Benthic data were collected with a Young-modified Van Veen grab sampler during 1993-2002. Sampling was restricted to a late summer index period to eliminate seasonality as a confounding factor. Stepwise and linear discriminant analyses were used in index development. The metrics proven to be the best discriminators of healthy and degraded sediment conditions were proportion of expected diversity, Bivalve proportion and Capitellid Proportion. The BQI serves as a scientifically valid and ecologically relevant management tool for establishing sediment quality targets and monitoring sediment quality bay-wide. [kmalloy@janickienvironmental.com]

Benthic Nutrient Fluxes in Tampa Bay. P. Carlson, L. Yarbrow, D. Saindon, A. Ketron, H. Arnold (FWC Fla. Marine Research Inst.). Efforts to manage nitrogen levels in Tampa Bay depend on accurate estimates of nitrogen inputs, exports, and internal transformations for the Bay. However, existing nitrogen budgets for Tampa Bay have not included estimates for benthic nitrogen fluxes because only a few measurements have been made in Tampa Bay. This omission is serious because benthic nutrient fluxes are potentially very large and might affect the entire water column. In some estuaries, nitrogen is recycled between water column and sediments, effectively amplifying the effect of external nitrogen loads on estuarine water quality. However, other studies have shown that the sediment processes of denitrification and burial can enhance water quality by exporting or sequestering nitrogen from the water column. Our study is measuring diffusive fluxes of nitrogen and phosphorus species between sediments and water column in Tampa Bay. Every three months, we collect four replicate cores from muddy and sandy sites in each of four Bay segments (Old Tampa Bay, Hillsborough Bay, Middle Tampa Bay and Lower Tampa Bay) for measurement of diffusive nutrient fluxes and potential denitrification rates. Core incubations were performed in October 2002, February 2003, and May 2003, and additional incubations will be done in August and October 2003. For preliminary estimates, nutrient fluxes measured at these eight intensive-study sites will be extrapolated to the entire Bay on the basis of sediment grain size and organic content data. If this study indicates that benthic nutrient fluxes warrant additional measurements, a more intensive series of *in situ* measurements is planned. [Paul.Carlson@fwc.state.fl.us]

Hydrodynamic and Hydrologic Characteristics of Tampa Bay. M.E. Luther, S.D. Meyers (Univ. of So. Fla. College of Marine Science), M.S. Flannery, X. Chen, M. Heyl (SW Fla. Water Mgt. District). This paper will compare changes in the characteristics of freshwater inflows to the hydrodynamics of the bay. More specifically, it will look at issues affecting inflows, such as long-term trends, groundwater relationships, and changes in seasonal and inter-annual variations and spatial distributions of flows. Changes in inflow affect the hydrodynamics of different areas of the bay in different ways, altering the residual salinity distribution and resulting circulation and residence times, with possible effects on ecology. There are major unknowns in the fresh water input to the bay. Only a fraction of the bay's inflow is gaged and a large proportion of the inflow is direct rainfall. Much of the inflow must be extrapolated from a few stream gages and precipitation gages. Trends in flows in major streams may be due to climate or to human impacts. Seasonal variability in fresh water inflow is modulated by large scale climate fluctuations, like El Niño, with resulting changes in bay salinity and residual circulation. Potential anthropogenic factors affecting stream flow include increased municipal withdrawals, agricultural runoff, increased urbanization, and mining in some areas. The groundwater contribution to bay inflow is largely unknown. Effects of changes in groundwater use may be local or may increase stream flow or direct groundwater flow to the bay. One important aspect of estuarine response

to inflow is the distinction between near field and far field effects, as many of the important oligohaline and mesohaline habitats are upstream of the tributary mouths. These effects are being studied using numerical models of the bay and of the tributaries. [luther@marine.usf.edu]

Ecological Criteria for the Determination of Minimum Freshwater Inflows for the Alafia River Estuary. M.S. Flannery, M.G. Heyl, X. Chen, (Southwest Florida Water Mgt. District), E. Peebles (USF College of Marine Science), D. Wade (Janicki Environmental, Inc), E. Estevez (Mote Marine Laboratory, A Janicki (Janicki Environmental, Inc), J. Culter (Mote Marine Laboratory). The Southwest Florida Water Management District will adopt minimum flow regulations for the Alafia River estuary during 2004. Minimum flows are defined in Florida Statutes as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area". Minimum flows for the Alafia River estuary were determined using the District's percent-of-flow method, which simulates the effects of different percentage reductions of freshwater inflows on a daily basis. A hydrodynamic model and regression analyses were used to evaluate changes in salinity distributions in the estuary that would result from a range of freshwater withdrawals. These results were compared to the distributions and salinity relations of riverine wetlands, benthic infauna and mollusks, including oysters, which are concentrated 1 to 4 km above the river mouth. Significant relationships were found between freshwater inflow and the distribution and abundance of the early life stages of several fishes and invertebrate prey species that occur in the water column. An important factor on the Alafia is the highly enriched nutrient status of the river. The responses of phytoplankton abundance and hypoxia to freshwater inflow differed among reaches of the tidal river, due to gradients in available nutrients, light penetration, and mixing times along the length of the tidal river that resulted from changes in freshwater inflows. [sid.flannery@swfwmd.state.fl.us]

Summary of Atmospheric Deposition Studies and Loading Results in Tampa Bay, Florida. R. Pribble (Janicki Environmental, Inc.), N. Poor (USF College of Public Health). Over the last 10 years, there has been emerging recognition of the influence of atmospheric deposition on estuarine systems. This influence was first noticed in terms of nitrogen loading. Atmospheric deposition also accounts for loadings of metals, including mercury, and PCBs, PAHs, and pesticides. Initial estimates suggested that deposition directly to the surface of the bay accounted for 30% of the nitrogen and phosphorus loadings to the bay. To improve this estimate, the Tampa Bay Atmospheric Deposition Study (TBADS) was initiated in spring 1995. Atmospheric deposition is estimated from both wet deposition (rainfall) collected using a wet bucket, and dry deposition (gaseous constituent interaction and dust fallout) estimated from atmospheric concentrations and modeled deposition velocities. Concentrations are obtained using an annular denuder system. Loading estimates derived from these data suggest a contribution of 780 tons/yr nitrogen directly to the bay from the atmosphere during 1996–2001, of which about 60% is ammonia nitrogen. Passive sampling devices for ammonia in Tampa around Hillsborough Bay showed that effects from industrial and wastewater treatment emissions of ammonia are typically limited to the local area. Atmospheric deposition accounts for less than 5% of the total mercury, arsenic, chromium, and lead loading to the bay, but 10% or more of the loadings of cadmium, zinc, copper, and iron. Monitoring of PCBs, PAHs, and pesticides found that concentrations of PCBs were below detection limits, PAH deposition was less than typically found in larger cities, and only the pesticides chlordane and endosulfan were found in detectable concentrations. [rpribble@janickienviromental.com]

POSTERS

Using Percent Transmittance for Calculating Light Attenuation in Clear Shallow Waters: a Case Study in Old Tampa Bay. C.J. Anastasiou (SW Fla. Water Mgt. Dist., Univ. So. Fla. College of Marine Sci.), R. Johansson, W. Avery (City of Tampa, Bay Study Group). Light attenuation coefficients are often calculated from measurements taken with a Secchi disk and underwater PAR sensors. These methods have inherent limitations in clear shallow waters that can be overcome with a transmissometer. Typically, Secchi disk and PAR do not work well in waters less than 1.5 m. With a transmissometer, measurements can be taken, *in-situ*, in water depths as shallow as 10 cm. In addition, it can be used in the laboratory on field-collected samples taken at any depth. We used transmittance, at a wavelength of 660 nm, to calculate a beam attenuation coefficient, which is a function of the amount of particulate matter and of colored dissolved organic matter (CDOM). By filtering samples in the laboratory and comparing filtered samples versus unfiltered samples, we were able to separate attenuation due to particulate matter and attenuation due to CDOM. Caution should be exercised, however, when using beam attenuation coefficients to develop optical models because transmittance is beam specific and does not take into account the behavior of light at other wavelengths. Furthermore, the beam attenuation coefficient is not directly comparable to attenuation coefficients derived from either Secchi disk or PAR and should not be thought of as a replacement but rather as a supplement to existing methods. However, where other methods may not be appropriate, such as in clear shallow waters, using a transmissometer can be a viable alternative. We use data

collected during the summer 2003 Old Tampa Bay intensive water quality monitoring campaign as a case study. [Chris.Anastasiou@swfwmd.state.fl.us]

The Decline and Fall of Bishop Harbor. G. Blanchard, S. Browning (Manatee Co. Environmental Management Dept.). Bishop Harbor is a shallow, mangrove-lined, coastal embayment on the eastern side of Middle Tampa Bay. Since 2001, multiple releases of partially-treated gypsum stack process water from the defunct Piney Point Fertilizer plant deemed necessary to insure the integrity of the gypsum stack dikes have transformed the Harbor through massive inputs of nutrients. Ammonia-nitrogen is the predominate nutrient delivered by the releases. At the point where the discharge enters the head of the harbor, ammonia-nitrogen levels reached 3.03 mg/l and chlorophyll-a concentrations reached 285 mg/m³. Water quality in the Harbor prior to the first emergency discharge in October 2001 (mean monthly ammonia-nitrogen 0.04 mg/l; mean monthly chlorophyll-a 5.90 mg/m³) was similar to that in observed in Middle Tampa Bay outside the Harbor mouth. Although average annual ammonia-nitrogen levels declined in 2002 to almost pre-discharge levels, average annual chlorophyll-a levels remained elevated (average annual chlorophyll-a 7.24 mg/m³). A second series of emergency releases began in January 2003. During this period, harbor average annual chlorophyll-a levels reached 14.02 mg/m³. Limiting nutrient loads from the facility to 308 pounds ammonia-nitrogen per day (15-day average) is intended to stabilize chlorophyll-a at a target value of 7.8 mg/m³. [greg.blanchard@co.manatee.fl.us]

Determination of Organic Nitrogen Compounds in Atmospheric Aerosols. S.M. Calderón (Chemical Engineering School, Universidad de Los Andes, Venezuela), S.W. Campbell (Chemical Engineering Dept., Univ. of So. Fla.), N.D. Poor (College of Public Health, Univ. of So. Fla.). Recent studies have confirmed that nitrogen-enriched atmospheric particles can contribute substantially to the nitrogen saturation phenomenon that affects terrestrial and aquatic systems, atmosphere-biosphere nutrient cycling, atmospheric chemistry and air quality. Considering that recent research showed that dissolved organic nitrogen (DON) in precipitation samples represents a significant input of nitrogen from the atmospheric deposition process over Tampa Bay, the determination of the Water Dissolved Organic Nitrogen (WSON) fraction present in particulate matter collected at the Gandy Bridge site in Tampa is proposed. Fine and coarse mode particles will be collected using a Dichotomous Sequential Air Sampler in order to estimate the contribution of the two main modes of size distribution to the total nitrogen flux from atmospheric deposition. A characterization and estimation of the concentration of free and combined amino compounds will be done to identify possible terrestrial or aquatic sources. A new approach for the preparation of aqueous extracts of the samples for WSON determination will be tested. This will be focused on the isolation of organic from inorganic compounds and the separation of organics in three chemically different fractions according their hydrophobicity, thereby diminishing the negative bias introduced by organics in ion measurements, as well as decreasing the complexity of the mixture to be characterized. Characteristics of the possible species in each fraction according their solubility will average to define pseudo-components that will be considered as single compounds in the future application of a thermodynamic model for atmospheric aerosols. [scaldero@eng.usf.edu]

Satellite Remote Sensing and Characterization of Tampa Bay Waters: Challenges, Possibilities, Prospects. T. Clayton (USGS Ctr. for Coastal & Watershed Studies), C. Hu, Z. Chen, F. Muller-Harger (Univ. of So. Fla. Inst. for Marine Remote Sensing), J. Brock (USGS Ctr. for Coastal & Watershed Studies). An optimal approach to estuarine characterization and monitoring combines automated, real-time *in situ* sensing with spatial wide-field-of-view/synoptic sensing. With respect to the latter, small, shallow estuaries such as Tampa Bay pose a particular challenge. Satellite sensors designed primarily for terrestrial applications are characterized by infrequent revisit times, spectral wavebands that are few in number and broad in width, and sensitivity and dynamic range inadequate for aquatic applications. Ocean color sensors offer a more appropriate spectral design plus better spatial coverage and revisit frequencies, but spatial resolution is coarse relative to the scale of many coastal features. Optically shallow submerged environments offer the additional challenge of deconvolving radiance contributions from the atmosphere, water column, and benthos.

The Moderate Resolution Imaging Spectroradiometer (MODIS) offers new capabilities for estuarine characterization: ~ 2x/day revisit frequency, an extensive suite of wavebands for ocean-color applications and atmospheric correction, plus selected bands with spatial resolution as fine as 250 m. Since March 2003, MODIS images have been generated for the Tampa Bay region (<http://modis.marine.usf.edu/products/tampabay/qc.html>). A significant challenge will be the removal of atmospheric contributions and accurate retrieval of at-surface radiances that can be used to estimate the optical contributions of benthic and water-column constituents. A particular focus will be the spatial and temporal variability of patterns associated with sediment resuspension and transport within Tampa Bay, and an exploration of their relation to environmental forcing functions (e.g., winds, tides, precipitation) and consequences (e.g., benthic light supply). Associated fieldwork for algorithm development and groundtruthing will begin in October 2003. [tclayton@usgs.gov]

Dissolved Oxygen Monitoring in the Real and Variable World, a Case Study of Spatial and Temporal Variance.

J. K. Culter, J.M. Sprinkle (Mote Marine Laboratory). Technological advances in marine instrumentation have enabled the collection of large in situ data sets relevant to environmental studies. Dissolved oxygen (DO) is one such parameter with relevance to management issues. The collection of near continuous dissolved oxygen by the use of logging instrumentation presents special problems for quality control and data interpretation. Instrument fouling, electronic drift and between instrument differences are important considerations for interpretation of data collected with instrument deployments. Instrument limits and error must also be taken into consideration for issues of water quality compliance. Data collected as part of intensive dissolved oxygen studies conducted at the TECO Big Bend facility over the period of several years are presented. The studies clearly illustrated that single point measurements of dissolved oxygen are not adequate for the characterization of the DO regime within a specified water body. Spatial variance in DO can be pronounced in both the horizontal and vertical (depth) planes. Temporal variance can also be pronounced both on diurnal cycles and over periods as short as minutes. Spatial and temporal variance within 'natural' waters can often violate the state standard for dissolved oxygen. Sediment structure is also an important consideration when monitoring near bottom DO, as release of hydrogen sulfide from anoxic sediments can poison the DO probe. Issues related to calibration and maintenance are also discussed. Data provided in this presentation made possible through the courtesy of Tampa Electric Company. [jculter@mote.org]

Submarine Ground Water Discharge to Feather Sound, Tampa Bay, Florida.

E. Davis, J.B. Martin (Univ. of Fla. Dept. of Geology), P.W. Swarzenski (USGS Ctr. for Coastal Geology). Submarine ground water discharge (SGD) has been variously defined as the total flux of water across the sediment-water interface regardless of its origin, or alternatively, as the flux of meteoric water from continental aquifers that extend offshore. The magnitude of SGD commonly is 1 to 2 orders of magnitude greater when measured directly (e.g. using seepage meters or radioisotope tracers) than when calculated on the basis of hydrologic models. A similar discrepancy occurs in Feather Sound in Tampa Bay; seepage meter measurements in April 2002 indicate that seepage velocity, on average, could be as great as 7.3 cm/day, but a flow net analysis and mass balance calculations indicate seepage velocity of only 0.05 to 0.08 cm/day, respectively. Measurements of Cl concentrations made in April and August 2002 indicate that overlying Bay water mix with the pore waters to depths ranging from ~ 54 cm to ~ 182 cm. Assuming that the observed change in Cl concentrations results from two end-member mixing (e.g. overlying Bay water and the pore waters) over the 112-day period between the sampling events, calculations of mixing between Bay and pore waters indicate that seepage velocities would be between 0.29 cm/day and 0.48 cm/day. For mixing to cause the seepage velocities measured with seepage meters, mixing would have to occur within 1.5 to 13.4 days. Regardless of the rate, mixing could provide an important source of nutrients to the Bay water by increasing oxidation of the detrital organic matter. [geodavis@ufl.edu]

Quaternary Stratigraphy, Sedimentation and Ecosystem History of Tampa Bay.

N.T. Edgar (USGS Ctr. for Coastal & Watershed Studies), T.M. Cronin (USGS Reston, VA), P.W. Swarzenski, W.J. Greenwood (USGS Ctr. for Coastal & Watershed Studies), D.A. Willard (USGS Reston, VA), G.L. Wingard, G.R. Brooks, R. Larson, D.W. Hastings (Eckerd College), B.P. Flower, A.C. Hine, D.J. Hollander, S.D. Locker, B.C. Suthard (Univ. of So. Fla. College of Marine Science), D.S. Jones (Fla. Museum of Natural History), J. Wehmiller (Univ. of Delaware Dept. of Geology). Physical, geochemical and micropaleontological evidence from sediment cores were used to reconstruct the sedimentary, ecosystem, and sea-level history of central and northern Tampa Bay (Safety Harbor region) focusing on ecosystem impacts during the past century. Using ^{14}C and ^{210}Pb dating, pollen stratigraphy, and amino acid racemization for chronology, three major Quaternary stratigraphic units were recognized: a marine unit most likely equivalent to the last interglacial period (Marine Isotope Stage 5), a lacustrine unit representing the last glacial maximum and deglacial interval (~ 21–11 ka), and an estuarine unit deposited during the late Holocene (3ka–recent). The uppermost < 0.5 to 1.0 m of Holocene sediments were deposited during the past century and can be identified by the stratigraphic appearance of *Casuarina* pollen and by ^{210}Pb dating. *Casuarina*, the Australian pine, was introduced into the area about 1880–1920 and is a useful marker to date and correlate 20th century sediments from Tampa Bay and south Florida. Preliminary study of salinity sensitive ostracode and foraminiferal species from the cores indicates a decrease in mean salinity during the past few centuries, coincident with pollen evidence for changes in terrestrial vegetation. Decreasing salinity might be caused by climatically-driven increases in runoff, changes in sea-level, bay geometry and circulation, anthropogenic land-use activities, or a combination of these factors. Temporal patterns of geochemical (Mg/Ca ratios, $^{18}\text{O}/^{16}\text{O}$ ratios) proxies of salinity and temperature, and organic biomarkers indicating carbon source also will be discussed. [tcronin@usgs.gov]

Distribution of Select Wastewater Compounds in Surface Water and Bottom Sediments in Hillsborough Bay, Florida.

M. Fernandez (USGS Ctr. for Coastal and Watershed Studies). In November 2002, a synoptic survey was conducted for the purpose of determining the distribution of select wastewater compounds in bottom sediments

and the water column of Hillsborough Bay, Florida. Surface water samples were collected at twelve sites within the bay; bottom sediment samples were collected at six of the sites. One water sample was collected at the outfall of the City of Tampa's Howard F. Curren Advanced Wastewater Treatment. Both surface water and sediment samples were analyzed for 75 compounds commonly found in effluent, including herbicides, polycyclic aromatic hydrocarbons, flame-retardants, and sterols.

Among the surface water samples, there were ten sites with detectable compounds; none were present at concentrations exceeding their reportable limits. The compounds most often present at these sites were sterols from human or warm-blooded animal sources. Other common compounds included: tributyl phosphate (anti-foaming agent and fire retardant), atrazine (herbicide), 3-beta-coprostanol (carnivore fecal indicator), and cholesterol (fecal indicator). The eight surface water samples were also tested for 17-beta-estradiol, a biogenic endocrine disruptor. The 17-beta-estradiol, analyzed with a highly selective immunoassay method with a detection limit of 1.5 parts-per-trillion (ppt), was present at all eight sites with concentrations in the range of 1.6 to 3.1 ppt throughout Hillsborough Bay. Preliminary data for the six sediment samples indicate the presence of polycyclic aromatic hydrocarbons including benzo(a)pyrene (carcinogenic compound), and 3-beta-coprostanol, cholesterol, and beta-sitosterol (plant sterol). [mfernand@usgs.gov]

Preliminary Findings on the Distribution of Polycyclic Aromatic Hydrocarbons in Bottom Sediment of the Alafia River-Kitchen Bay, Feather Sound, Pinellas Point, and Terra Ceia Areas of Tampa Bay, Florida. M. Fernandez (USGS Ctr. for Coastal & Watershed Studies, St. Petersburg), S. Robb (USGS Gulf Breeze, FL), K. Doan, J. Stephans (USGS Ctr. for Coastal & Watershed Studies, St. Petersburg), S. Grabe (Hillsborough Co. Env. Protection Commission). In June 2002, bottom sediment sediments were collected at four study sites along the tidally-affected shoreline in Tampa Bay, Florida: Alafia River-Kitchen Bay, Feather Sound, Pinellas Point, and Terra Ceia. Thirty sampling sites were selected using a randomly stratified sampling method. Sediment samples were analyzed for total organic carbon (TOC) and selected polycyclic aromatic hydrocarbons (PAHs). Total organic carbon was measured with a combustion method. PAHs for 16 carcinogenic compounds were determined using immunoassay analyses.

Total PAH concentrations ranged from 13 to 876 parts-per-billion (ppb). All values were well below the Florida Department of Environmental Protection effects-based Sediment Quality Assessment Guidelines's Threshold Effects Level (TEL) of 1,684 ppb. The TEL represents the upper limit of the range of sediment-contaminant concentrations dominated by no adverse biological effects. Normalization of PAH by TOC for all the sites ranged from about 24 to 1622 micrograms PAH per gram ($\mu\text{g}_{\text{PAH}}/\text{g}_{\text{TOC}}$). TOC-normalized PAH concentrations can be used to compare the relative potential impact on benthic organisms at different sites. The range of the TOC-normalized PAH concentrations for the four study areas are: Alafia River-Kitchen Bay: 7.7 and 113.5 $\text{mg}_{\text{PAH}}/\text{g}_{\text{TOC}}$; Feather Sound: 2.4 and 94.0 $\text{mg}_{\text{PAH}}/\text{g}_{\text{TOC}}$; Pinellas Point: 13.0 and 162.2 $\text{mg}_{\text{PAH}}/\text{g}_{\text{TOC}}$; and Terra Ceia: 3.6 and 21.7 $\text{mg}_{\text{PAH}}/\text{g}_{\text{TOC}}$. Based on these findings, the Terra Ceia study area appears to be the least impacted, followed by Feather Sound, Alafia River-Kitchen Bay, and Pinellas Point. [mfernand@usgs.gov]

Nearshore Distribution of Organic Carbon, Percent Silt/Clay, and Total Polycyclic Aromatic Hydrocarbons in Tampa Bay, Florida. M. Fernandez, K. Smith (USGS Ctr. for Coastal & Watershed Studies), S. Grabe (Hillsborough Co. Env. Protection Commission), P. Swarzenski (USGS St. Petersburg). Most seagrasses in Tampa Bay occur within 0.5 km of the shoreline. This study is designed to investigate the distribution of organic carbon (OC), polycyclic aromatic hydrocarbons (PAH), and percent sand, silt, and clay in bottom sediments (%SSC) within that corridor of Tampa Bay. In June 2003 the U.S. Geological Survey (USGS) collected 350 randomized bottom sediment samples from within the corridor with 50 percent being in areas where seagrasses have been reported and 50 percent in areas where seagrasses have been reported absent. Approximately 70 more samples in the Bay system were collected by Hillsborough, Manatee, and Pinellas Counties under the auspices of the Tampa Bay Estuary Program.

The data will be graphically represented on a map showing the spatial distribution of organic carbon and percent sand, silt, and clay (%SSC). In combination with complementary data sets, these data will be used to investigate relations between: historical and present-day grain-size distributions; organic carbon content and sediment size; and seagrass densities and %SSC, OC, and OC-normalized PAH concentrations. [mfernand@usgs.gov]

High-resolution Bathymetric Mapping for Tampa Bay. M. Hansen, G. Peery (USGS Ctr. for Coastal and Watershed Studies). Regional scale and high-resolution bathymetric mapping will be performed in Tampa Bay to provide the physical context, background, and baseline information for all other research, monitoring, and modeling activities. In addition, bathymetric data provides critical information for the development of circulation,

hydrologic, sediment transport, and water quality components of an integrated numerical model for predicting the system-wide impact of natural and anthropogenic changes in Tampa Bay. Bathymetric mapping will be linked to wetland and seagrass distribution data, and groundwater data to understand the impacts and links between groundwater movement, elevation change, and habitat distribution and health.

The USGS has developed a high-resolution bathymetric system developed specifically for mapping shallow features in estuarine environments and near shore zones. This boat-based system utilizes precision sonar and GPS equipment to provide $\pm 8\text{cm}$ vertical accuracy. The project plan for the USGS Tampa Bay Study is to update the bathymetry maps for all of Tampa Bay. To date, approximately one-third of Tampa Bay has been mapped with the boat-based system. Beginning in the summer of 2003, the plan is to utilize NASA's EAARL airborne bathymetric lidar system to map the shallow and nearshore regions of Tampa Bay. Utilizing the same GPS technology, the EAARL system also provides $\pm 8\text{cm}$ vertical accuracy. The advantage of the lidar system is that it will provide a complete mosaic of the shallow and environmentally sensitive regions that cannot be effectively mapped with the boat-based system. Combining data acquired with both systems will provide high-resolution information on a regional scale to support ongoing science activities in Tampa Bay. [mhansen@usgs.gov]

A Multi-proxy, Multi-species Approach to Determine Changes in Water Temperature and Salinity of Tampa Bay over the past 21,000 Years. T.A. Hollweg, D.W. Hastings (Eckerd College), B.P. Flower (Univ. of So. Fla. College of Marine Science), N.T. Edgar (USGS Ctr. for Coastal & Watershed Studies), T.M. Cronin (USGS, Reston, VA), T. Quinn (Univ. of So. Fla. College of Marine Science), G. Brooks, A. Runyan (Eckerd College). A paleoclimate reconstruction of Tampa Bay, Florida has been established from geochemical analyses of calcareous microfossils from an 11.1-m piston core collected aboard the R/V *Marion Dufresne* in July 2002. Changes in sea level have strongly influenced the evolution of Tampa Bay from an open marine system during the last interglacial, to a lacustrine one ($\sim 21\text{--}11\text{ ka BP}$) and finally to the present day marginal marine system (3 ka BP –present).

Geochemical analyses, including Mg/Ca, Sr/Ca, and oxygen isotopes, were conducted on the shells of two non-marine ostracode species, *Candona annae* and *Limnocythere floridensis*, during the lacustrine period. Mg/Ca and Sr/Ca ratios in ostracode shells are indicators of past water temperature, salinity, and/or chemical composition of the water. Changes in oxygen isotope ratios reflect changes in water temperature and evaporation-precipitation processes.

Down core data indicate that both Mg/Ca and Sr/Ca ratios for both ostracode species show parallel trends. The main feature in the data set is that, starting at 14.1 ka BP to $\sim 12\text{ ka BP}$, Mg/Ca and Sr/Ca ratios increase by 70% . Assuming that water temperature is the primary control on Mg incorporation this is equivalent to a warming of 4°C . Oxygen isotope values show a decrease of -2.0‰ over this period. Assuming that 1.0‰ of this change is due to changes in ice volume, this is equivalent to a warming of 4.7°C . Our multi-proxy approach reveals a major warming trend and possibly a significant increase in salinity within the deglacial interval.

Existing ostracode temperature calibrations for brackish water ostracodes are being revised so these conclusions should be viewed as preliminary. We can state that this multi-proxy, multi-species approach shows considerable promise in the determination of how water temperature, water chemistry and salinity have changed in Tampa Bay over the last glacial-interglacial cycle. [hastindw@eckerd.edu]

An Approach to Defining Baseline Conditions in Alafia River, Hillsborough River, and Tampa Bypass Canal. A. Janicki, D. Wade (Janicki Environmental), R. McConnell (Tampa Bay Water). Water Use Permits issued to Tampa Bay Water for surface water withdrawals from the Alafia River, Hillsborough River, and the Tampa Bay Bypass Canal water supply projects specified the development of a Hydrobiological Monitoring Program (HBMP) to detect potential adverse impacts to the riverine estuaries and Hillsborough Bay. The HBMP was implemented in spring 2000 to collect baseline data prior to initiation of new surface water withdrawals in the fall of 2002. Analysis of potential changes in the spatial and temporal patterns in water quality, including salinity, and the biota in response to surface water withdrawals is a critical element of the HBMP. Ideally, a long time series of pre-operational data, that includes data from a wide range of meteorological conditions, would be available for comparison. Water quality data from Hillsborough Bay provide such a time series that extends from the mid-1970s to the present. Unfortunately, no such time series of data exists in any of the rivers of concern. We have developed an empirical approach to develop a baseline that defines the variability in salinity spatially and temporally in the rivers. The models developed allow defensible hindcasts of salinity based on such factors as river flow, longitudinal location on the river, water depth, and background salinity in Hillsborough Bay. We have also developed methods for statistical comparison of the spatial and temporal distributions in salinity in baseline period to observations made after withdrawals from the rivers commenced. [janickienv@aol.com]

Activity of Deep-burrowing Ghost Shrimp in Tampa Bay Influences Sediment Characteristics. P.L. Klerks, D.L. Felder (Dept. of Biology, Univ. of Louisiana at Lafayette), P. Swarzenski (USGS Ctr. for Coastal and Watershed Studies). Ghost shrimp are abundant bioturbators in Gulf coast estuaries. They can modify water and sediment characteristics by constructing extensive burrows, ejecting sediment from their burrows, and exchanging water between their burrows and the overlying water column. We investigated the influence that ghost shrimp have on Tampa Bay sediment characteristics, by: 1) determining the abundance of ghost shrimp species, 2) comparing sediment organic content, sediment silt/clay content and metal (Zn, Cd) concentrations between sediment away from burrows, sediment constituting the burrow-walls, and sediment ejected by the shrimp, and 3) quantifying the rate of sediment ejection (by the shrimp) from the burrows. This was done at four sites: Alafia River, Ballast Point, Gandy Bridge, and Feather Sound. Three species of ghost shrimp were encountered in Tampa Bay, and densities at the sites investigated averaged 33/m². The sediment making up the burrow walls was always finer (i.e. higher silt/clay content), higher in organic content and higher in Zn and Cd levels than surface sediment collected away from burrows. These differences were substantial (generally two-fold). The sediment actively ejected from the ghost shrimp burrows tended to have characteristics intermediate to the burrow wall and surface sediment. The amount of ejected material was significant (e.g. ejected at a rate of 1200 g dry wt./m²/d at one site). Taken together, this means that the abundant ghost shrimp in Tampa Bay significantly affect sediment characteristics, both by their construction of extensive burrows and by their ejection of sediment from the burrows onto the sediment surface. [pswarzen@usgs.gov]

Hydrobiological Monitoring for Surface Water Withdrawals. R. McConnell (Tampa Bay Water), D. Robison (PBS&J, Tampa), A. Janicki (Janicki Environmental). After decades of increasing groundwater use in the Tampa Bay region, adverse hydrologic impacts such as lowered lake levels and wetland stress have become a significant concern. Tampa Bay Water, the regional water supply authority, adopted a Master Water Plan in 1997 that identified surface waters—including the Alafia River, the Hillsborough River, and the Tampa Bypass Canal—as new water supply sources. The harvesting of surface waters has, however, raised new concerns regarding potential adverse impacts to estuarine ecosystems and recreational uses of the affected water bodies. Water Use Permits issued for the surface water supply projects specified the development of a Hydrobiological Monitoring Program (HBMP) to detect potential adverse impacts resulting from freshwater withdrawals. The HBMP employs a stratified random sampling design, and includes monitoring elements for hydrology, water quality, sediments, benthos, zooplankton, fish, birds and vegetation. The HBMP also defines a process by which adverse impacts can be determined, and includes a hierarchy of management responses to detected hydrobiological changes. The HBMP was implemented in spring 2000 to collect baseline data prior to initiation of new surface water withdrawals in the fall of 2002. The primary objectives of the HBMP are to detect changes in salinity patterns and estuarine biota resulting from the permitted surface water withdrawals, and to distinguish such changes from the natural variability that occurs in the affected tidal rivers. This paper provides an overview of the program design, sampling methods and data evaluation approaches. [mcconnell@tampabaywater.com]

A High Resolution Subsurface Resistivity Investigation of Tampa Bay. J. Meunier (USGS Center for Coastal & Watershed Studies), P. Swarzenski (USGS, Reston, VA). Multi-channel streaming DC resistivity was utilized to map the subsurface resistivity distribution in shallow sediments of Tampa Bay. The subsurface resistivity fields were examined with extremely detailed multidimensional saltwater/freshwater interface contours to delineate submarine groundwater plumes. Upon examination of the resistivity fields in the shallow coastal sediments, subsurface freshened groundwater plumes are widely evident, especially towards the northern reaches of the Bay. Resistivity data further suggest that submarine groundwater discharge of these brackish plumes could be more extensive than previously thought. Even during periods of diminished precipitation, brackish groundwater is widespread in the sediments below Tampa Bay. There appears to be a predictable freshening of this submarine groundwater closest to shore. Large dispersed plumes of subsurface discharge are notably prevalent in non-tidal river inlet areas. The enormous set of datum generated using this continuous-resistivity profiling technique demonstrates the viability of this emerging technology for future large-scale groundwater-surface water surveys. [jmeunier@usgs.gov]

Light Attenuation by Nonchlorophyll Suspended Matter in Tampa Bay. R.L. Miller (USGS Ctr. for Coastal and Watershed Studies). One factor that can hinder the restoration of seagrass meadows is a lack of sufficient light for photosynthesis. In the past, approximately one half (54%) of the light attenuation in Tampa Bay was due to the presence of suspended matter not directly associated with chlorophyll-a which was called nonchlorophyll suspended matter (NSM) by McPherson and Miller (1994). The current project is attempting to identify the nature of the suspended matter attenuating light.

Microphotography, thermogravimetric analysis (TGA), wavelength dispersive x-ray fluorescence, chemical analysis, and light profile measurements are being used to investigate the nature of suspended matter that causes

light attenuation in Tampa Bay. Preliminary data suggest that high attenuation by suspended matter in Old Tampa Bay is associated with the high concentrations of suspended aluminum and silicon and sometimes with abundant zooplankton or phytoplankton.

The addition of 5% hydrochloric acid to unfiltered water samples in a stirred cell resulted in reductions of the attenuation of a light beam by 16% and 8% in samples from Feather Sound and a platform north of Feathers Sound. Such reductions may be due to degradation of pigments or cells or to the dissolution of particulate carbonates. The majority of the attenuation was unaffected by the acid for these two samples suggesting that materials other than carbonates and chlorophyll are responsible for most of the light attenuation.

A Comparison of the Hydrology and Water Quality of the Alafia River, Hillsborough River, and the Tampa Bypass Canal. R. Montgomery (PBS&J Tampa), A. Janicki (Janicki Environmental), R. McConnell (Tampa Bay Water). The Alafia River/Tampa Bypass Canal Hydrobiological Monitoring Program documents rainfall, flow, salinity distributions, and other water quality characteristics in the Alafia and Hillsborough Rivers and the Tampa Bypass Canal. The primary objective of the HBMP is to determine both the magnitude, and temporal and spatial aspects of potential adverse impacts within each of these riverine estuarine systems and Hillsborough Bay. In conjunction with the ongoing analyses of HBMP monitoring data, historical hydrologic and water quality data have been gathered and analyzed for different baseline periods established for each of the riverine systems. The primary purpose of these analyses was to determine baseline conditions with which future comparisons can be made of HBMP data gathered following the initiation of freshwater withdrawals. The analyses of hydrologic information for each of the three baseline reference periods included determinations of both monthly and long-term rainfall and flow patterns, as well as analyses of the long-term relationships between rainfall and surface flows within each system. Both the spatial and temporal patterns of available water quality data for a number of data sources were investigated, and determinations were conducted of the spatial variations in the relationships between flow and ambient water quality measurements within each of the three riverine estuarine systems. This paper presents a summary comparison of the hydrology and water quality in the estuarine segments of the Alafia and Hillsborough Rivers, and the Tampa Bypass Canal. [rtmontgomery @pbsj.com]

A Comparison of the Fish Communities of Alafia River, Hillsborough River, and the Tampa Bypass Canal. E. Peebles (Univ. of So. Fla. Dept. of Marine Science), D. Robison (PBS&J Tampa), R. McConnell (Tampa Bay Water). A significant part of Tampa Bay Water's Hydro-biological Monitoring Program (HBMP) focuses on fish responses to changes in freshwater inflow from estuarine tributaries that are used for water supply. Fishes and macrozooplankton throughout the tidal portions of the Alafia and Hillsborough Rivers, and the Tampa Bypass Canal (TBC), are being surveyed on a monthly basis using plankton nets, seines and otter trawls. Data from the first three years of this ongoing study have identified distinct differences in the fish and zooplankton communities of the three tidal rivers. The Hillsborough River has the largest watershed of the three, but a dam in its lower reaches causes freshwater inflows to the estuary to be largely intermittent. When inflows cease, the planktonic fish and invertebrate fauna tends to be replaced by gelatinous predators (hydromedusae and ctenophores). The TBC is also impounded, and has the smallest watershed and the lowest levels of natural inflow. Gelatinous predators are most abundant in this system and fishes are least abundant. The Alafia River is unimpounded, and has the most stable inflow hydrograph. Fishes are most abundant and gelatinous predators are least abundant in this estuarine system. In general, the HBMP data identify a positive association between the magnitude and stability of the inflow hydrograph and fish and zooplankton abundance. In contrast, gelatinous predators demonstrate a negative association with inflow magnitude and stability. These positive and negative responses may be mediated by freshwater inflow's effect on residence times, the availability of food resources, or the distribution of hypoxic waters. [epeeble@seas.marine.usf.edu]

A Characterization of Impaired Surface Waters in the Tampa Bay Basin. K. Petrus, C. Burger, Z. Shelley, D. Tyler (Fla. Dept. of Env. Protection, Bureau of Watershed Management). As part of the State of Florida's Total Maximum Daily Load Program, the Department of Environmental Protection is performing surface water monitoring and gathering supplemental information on surface waters in the Tampa Bay area. The focus of the Department's monitoring and assessment effort has been on impaired coastal tributaries to Tampa Bay that include Long Branch, Lower Sweetwater Creek, and Delaney Creek. The Department's monitoring initiative entails routine and intensive data collection to assess surface water conditions throughout each impaired waterbody to support TMDL development. The intensive surveys include monitoring surface water quality and water quantity throughout each watershed during a three to four day period. Supplemental information is also being collected, e.g. pollutant loadings, channel morphology and aquatic macrophyte coverage, to gain an understanding of the abiotic and biotic factors that are influencing water quality. The presentation will provide a characterization of

the impaired surface waters and their watersheds, which is a critical step in determining the appropriate approach for TMDL development. [kevin.petrus@dep.state.fl.us]

Empirical Approaches to Quantifying Salinity Responses to Freshwater Inflows in Tampa Bay Tributaries.

X. Qi, D.L. Wade, A.J. Janicki (Janicki Environmental), M.S. Flannery (SW Fla. Water Mgt. District). For a variety of reasons, interest in the physical and biological responses to freshwater inflows in tidal rivers and estuaries in the Tampa Bay region has grown in the past decade. Watershed alterations, urban growth patterns, consumptive uses of surface water have contributed to changes in freshwater flows. One of the important responses to these changes has been changes in the magnitude, geographic distribution, and timing of salinity patterns in tidal rivers.

The authors have developed a set of analytical empirical approaches to quantifying salinity responses to freshwater inflows in the tributaries of Tampa Bay and the surrounding region. The driving factors in these relationships include freshwater inflow, antecedent flow conditions, ambient bay salinities, rainfall, and geographic distance from freshwater sources. The approaches have allowed unbiased estimation, and have proven to be robust to prediction error.

These analytical approaches have been applied for management purposes for estuaries and tributaries in the Tampa Bay and Charlotte Harbor watersheds. They have been used to hindcast historical salinities, and to describe baseline salinity conditions in an unbiased fashion. [David_Wade@janickienviromental.com]

A Comparison Of Habitats In The Alafia River, Hillsborough River, and The Tampa Bypass Canal.

D. Robison, R. Woithe (PBS&J Tampa), R. McConnell (Tampa Bay Water). The Alafia River/Tampa Bypass Canal Hydrobiological Monitoring Program documents emergent vegetation, submerged vegetation, and sediment composition in the Alafia and Hillsborough Rivers and the Tampa Bypass Canal. Vegetation is mapped once a year during the fall and winter. Sediment samples are collected in association with benthic macroinvertebrate samples. More than 300 sediment samples a year are collected from the three rivers combined. Percent fines and percent organic composition of sediments increase moving downstream from about 11 km on both the Hillsborough and Alafia Rivers. Above 11 km the percent fines and percent organic matter in the sediments is consistently low on both rivers. These values reach a peak around kilometer 4 on the Alafia. The majority of the vegetation of the Alafia River is located below kilometer 7. The largest areas of vegetation on the Alafia and the needlerush and mangrove swamps are found below the I-75 bridge. Above this point, vegetation is limited to narrow, fringe stands of cattail and needlerush. The Hillsborough River is quite different. The river banks near the mouth of the Hillsborough are hardened and dredge. As a result, the largest areas of wetland vegetation on the Hillsborough River tend to be the freshwater marshes just below the Hillsborough dam. Conversely, the banks near the mouth of the Bypass are the only areas in this water body that are not hardened, therefore the majority of vegetation on the Bypass canal is associated with the mangrove swamps that also fringe McKay Bay. [derobison@pbsj.com]

A Siliciclastic-Infilled Sedimentary Basin Within a Large Carbonate Platform, Tampa Bay, Florida.

B.C. Suthard, Al.C. Hine, S.D. Locker (Univ. of So. Fla. College of Marine Science), D.S. Duncan (Eckerd College), R.A. Morton, M.E. Hansen, N.T. Edgar (USGS Ctr. for Coastal and Watershed Studies). A seismic stratigraphic framework based on over 800 km of seismic reflection data collected within Tampa Bay and approximately 200 boreholes in and around the estuary shows three subsurface regions. In the north-central portion of the bay there is an east-west subsurface trough in the Miocene limestone that reaches depths of 30 m below the seafloor. Clinoforms within the trough prograde from the south and east and borehole data indicate that these clinoforms are siliciclastic sediments. South of the trough in the center of Tampa Bay there is a carbonate bedrock high. This area is characterized by less than two meters of siliciclastic sediment as well as small-scale karst features (10s m in width and relief). In the southern portion of the Bay the seismic reflection data shows the Miocene limestone has large-scale warping and large-scale karst features (100s m in width and 30 + m in relief) creating another deep basin filled by siliciclastics from the south and the east.

The sedimentary basin underlying the modern estuary reveals that accommodation space can form within a carbonate platform and may be filled by remobilized siliciclastics. Based upon the age of the underlying limestones and recent work by others, we propose that the Tampa Basin was filled during multiple Late Neogene and Quaternary sea-level fluctuations. Additionally, we speculate that the observed karst and sag-and-warp deformation indicate spatially selective subsurface collapse initiated by deep-seated dissolution produced by focused hydrologic processes. Overlying stratigraphic units subsided as a result, creating a surficial topographic low. [bsuthard@seas.marine.usf.edu]

A Proposed Schematic That Describes Anticipated Contaminant Sources into Tampa Bay. P.W. Swarzenski, M. Fernandez (USGS Ctr. for Coastal and Regional Marine Studies). A three-tiered flowchart has been developed to illustrate potential input pathways for water-borne and atmospherically derived contaminants into Tampa Bay. The flowchart addresses: 1) anthropogenic sources, 2) anticipated inputs and types of contaminants, and 3) existing water quality monitoring programs. The first tier identifies nine principal anthropogenic sources: domestic wastewater, industrial and small business waste, boatyard/ship building, atmospheric deposition, runoff (non-point source), storm sewers (point source), groundwater migration, mining, and discharge from ditches, streams, and rivers. The input of these contaminants to Tampa Bay can occur directly (atmospheric deposition, point sources), as well as from surface water runoff and groundwater-surface water exchange. The second-tier identifies potential classes of contaminants that may discharge into Tampa Bay. The proposed contaminant classification scheme emphasizes both human (e.g., personal care products) and animal pharmaceuticals, (e.g., aquaculture). Finally, a third-tier identifies existing state and federal monitoring programs, the agencies involved in enforcement of standards and management, as well as research agencies. Such an approach illustrates the ecosystem-wide interdependence between sound science and management in Tampa Bay. [mfernand@usgs.gov]

Groundwater-Surface Water Exchange In Tampa Bay: Results From A Geophysical and Geochemical Survey. P.W. Swarzenski (USGS Ctr. for Coastal and Regional Marine Studies), J. Martin (Univ. of Fla. Dept. of Geology), M. Baskaran (Wayne State Univ. Dept. of Geology). The reversible exchange of ground water from the Floridan aquifer system or the surficial aquifer to Tampa Bay bottom waters is controlled foremost by hydraulic head gradients between these water bodies, as well as by hydrogeologic constraints such as hydraulic conductivity and thickness of the overburden deposits. Superimposed on such physical hydrogeologic characteristics are effects of climate change and our own increasing demands on groundwater reserves. Saltwater intrusion can consequently occur wherever the potentiometric surface of a coastal aquifer falls below sea level. Similarly, groundwater also has the potential to be discharged as submarine groundwater when the potentiometric surface lies above sea level. Estimates suggest that just under $200,000 \text{ m}^3 \text{ d}^{-1}$ of groundwater discharge into Tampa Bay, which is roughly 20% of the combined surface water runoff. Considering that the underlying geologic framework controls this upward ground water flux, the northern reaches of Tampa Bay are most likely influenced by such additions.

To quantify this exchange of water across the sediment/water interface in Tampa Bay, we developed two field techniques—a geochemical survey of select isotopic tracers and trace elements measured in interstitial pore fluids, as well as a novel geophysical technique using streaming resistivity measurements. Multi-port piezometers and Lee-type seep meters were used to collect interstitial waters from discrete sediment depth intervals and were analyzed for such constituents as radium isotopes, $^{87}\text{Sr}/^{86}\text{Sr}$, Cl⁻, nutrients, and trace elements (U, V, Mo, Ba, Sr, Fe, Mn). Pore water results indicate that the reversible exchange across the sediment-water interface involves mostly recycled seawater at four sites and appears to be tidally driven. Similarly, an interpretation of the streaming resistivity data confirms large subsurface freshened water masses, particularly in northern Tampa Bay. [pswarzen@usgs.gov]

Guided Surface Vehicles as a Deployment Platform. P.G. Wenner, R.J. Bell (Univ. of So. Fla. College of Marine Science), M.L. Hall (Univ. of So. Fla. Ctr. for Ocean Technology), E.T. Steimle (Univ. of So. Fla. Env. Science & Policy). The monitoring of waterways for chemical species is hampered by the spatial and temporal restrictions inherent in gathering discrete samples and transporting them to a laboratory for testing. The development of in-situ instrumentation now makes possible the collection of real-time data, and with the incorporation of remotely operated vehicles a much greater data density on both a temporal and spatial scale is achieved.

Guided surface vehicles are finding a niche in coastal and estuarine systems as a tool for rapid and cost effective deployment platforms. One advantage is their use in high traffic areas, such as channels and ports. An on-board wireless computer interface provides continuous data and video feedback as well as an interface to control instrumentation deployed with the vehicle at distance greater than ½ mile. In this poster we will show data collected using a GSV provided by ENG Concepts. An underwater mass spectrometer was deployed to monitor the surface waters of a hyper-eutrophied lake in urban St. Petersburg for the purpose of detecting, in real-time, changes in the concentration of dissolved gases. The GSVs have also been used as a teaching tool to increase student involvement in the environmental sciences and as a platform for testing prototype instrumentation developed at USF. [esteimle@seas.marine.usf.edu]

PM₁₀ Size Distribution at for Peri-Urban Site in Tampa Bay. M.M. Williams, N. Poor (Univ. of So. Fla. College of Public Health). The influx of anthropogenic air toxins has negatively impacted the ecological resources of the Tampa Bay area. The results of this study will help assess the atmospheric deposition rates of metals based on the size speciation of particulate matter (PM₁₀) at a peri-urban site. Two methods will be used to obtain particulate

matter, a PM₁₀ dichotomous sampler and two PM₁₀ MOUDI samplers. The samplers will be collocated on the site. The study will be run over a 14-day period on a 24-hour cycle. PTFE 47mm diameter filters will be pre-weighed, post-weighed and extracted of ions following the sampling period. [mwillia2@hsc.usf.edu]

A Comparison Of The Benthic Invertebrate Communities In The Alafia River, Hillsborough River, and The Tampa Bypass Canal. R. Woithe (PBS&J Tampa), D. Wade (Janicki Environmental), R. McConnell (Tampa Bay Water), A. Peery (PBS&J Tampa). The Alafia River/Tampa Bypass Canal Hydrobiological Monitoring Program includes and benthic macroinvertebrate sampling element for the Alafia and Hillsborough Rivers and the Tampa Bypass Canal. The three rivers are sampled monthly using a random stratified design. Each year the program collects 200 samples in the lower 18 km of the Alafia, 144 samples in the lower 16 km of the Hillsborough, 60 samples in the lower 5 km of the Bypass Canal, and 60 samples in McKay Bay downstream of the Bypass Canal. The composition of benthic macroinvertebrates in the Bypass Canal is similar to that of McKay Bay. The shallow areas along the side of the Bypass Canal are most similar. The composition benthic invertebrates in the Hillsborough and Alafia Rivers are similar with some notable exceptions. Fresh water taxa were predominate in the Alafia River above Buckhorn Springs and kilometer 13. Drought conditions during the study period allowed brackish conditions to occur in the upstream portion of the Hillsborough and the benthic composition during this period reflects this. There is also a large group of estuarine and marine species that appear to be confined to the lower 4 km of the Alafia River. This same group of species appears in the Hillsborough River though their upstream limits are less defined. In general, taxa per sample and organisms per sample were greatest at the mouth of both rivers and steadily decreased with distance from the river mouth. [rdwoithe@pbsj.com]

Tampa Bay Water's Seawater Desalination Monitoring. R. Woithe (PBS&J Tampa), A. Janicki (Janicki Environmental), R. McConnell (Tampa Bay Water). Tampa Bay Water's Master Water Plan comprises a variety of alternative water supplies, including a seawater desalination plant located on Tampa Bay that began operating in early 2003. While desalination has been used in other areas of the world, it is a relatively new drinking water source in this area. Given the uncertainties associated with the initial application of seawater desalination in the area, concerns arose regarding the potential environmental effects of such an operation on Tampa Bay. One of the specific concerns expressed was what the expected changes in bay salinity would be upon discharge of the desalination concentrate that is characterized primarily by its elevated salinity. In response to those concerns and to the requirements set forth in the effluent discharge permit, Tampa Bay Water has designed and implemented a monitoring program to identify and assess environmental change (water quality, benthos, fish, and seagrasses) in the area most likely to be affected by the discharge of the desalination concentrate.

We will present an overview of the desalination plant operation and discharge, the predicted salinity changes due to the concentrate discharge, the monitoring program design, and some of the data analysis approaches that are being taken to quantify and assess any observed environmental changes. Results for the initial post-operational period will be reviewed and discussed. [JanickiEnv@aol.com]

Application of a Remote Instrumentation Platform to Estuarine Monitoring. B. Bendis (AMJ Equipment Corp.), T. Trader (FWC Fla. Marine Research Inst.), M. Previte (YSI/Sontek), D. Millie (FWC Fla. Marine Research Inst.). Water quality monitoring programs typically rely on intrusive spot-sampling, an approach that excludes most of the high-frequency variability in aquatic ecosystems. To address this deficiency, many programs now incorporate continuously recording instrumentation to supplement their conventional sampling. The St. Johns River in NE FL has experienced harmful algal blooms as well as fish kills and fish disease events in recent years. The natural variability and multiple anthropogenic influences within this ecosystem produce an array of acute stresses that require high-frequency sampling. In order to address these issues, we have deployed MARVIN, a floating platform with continuously recording instrumentation in the Trout River, a tributary of the St. Johns. A data logger/control module provides control of sampling events as well as data storage and transmission via cell phone or GOES-satellite. Flow-through instrumentation samples water for relative fluorescence, nutrients, and physical/chemical parameters. A volumetric water sampler obtains samples for analyses and verification. A meteorological package, PAR sensors and an underwater current meter are also included on this monitoring platform. High-resolution water quality data collected by in-situ instruments provide detailed information from tidal influences to changes in ecosystem metabolism. The data has also been applied to the development of Total Maximum Daily Loads (TMDLs) for the St. Johns River, thereby providing a management use for this type of data. [bbendis@amjequipment.com]

Hurricane Storm Surge Simulations for Florida's Tampa Bay Region. R. Weisberg, L. Zheng (Univ. of So. Fla. College of Marine Science). A high resolution, coastal ocean model with flooding and drying capabilities is used along with a merged bathymetric/topographic data set to simulate storm surges for the Tampa Bay region. Results are given for prototypical, category 2 and 4 hurricanes that approach the shore from the west, making landfall at Indian Rocks Beach. We show maps of flooding and time series of elevations at specific points, including the causeways for the four bridges that span the bay relative to mean sea level. Tides are additive to these. Also, the effects of wind-waves are not included, and these can add significantly to the storm surges shown. [Weisberg@marine.usf.edu]



**THE MATURATION AND FUTURE OF HABITAT RESTORATION PROGRAMS
FOR THE TAMPA BAY (FLORIDA) ESTUARINE ECOSYSTEM
—EXECUTIVE SUMMARY—**

B. Henningsen

Historical Perspective

Previous summaries of habitat restoration for Tampa Bay (Florida) have been detailed in both the 1992 BASIS 2 and 1997 BASIS 3 proceedings. This paper represents an update of programs and progress concerning the restoration of coastal ecosystems for Tampa Bay (1971–2002). Degradation and destruction of the bay's coastal habitats have been well documented, quantifying thousands of hectares of impacts to all components of the coastal ecosystem. For example, estimated losses of intertidal wetlands range up to 4423 ha with estimated losses of submerged vegetated wetlands ranging as high as 25,220 ha. In response to public and governmental awareness of declining habitat availability and quality, efforts were begun in the 1970s to begin the restoration of coastal ecosystems and improve water quality for the bay. Coastal ecosystem restoration of Tampa Bay is a critical component of bay management plans drafted by the Surface Water Improvement and Management (SWIM) Program of the Southwest Florida Water Management District and of the federal Tampa Bay National Estuary Program (TBNEP, now the Tampa Bay Estuary Program [TBEP]). Both management plans have used the planning process of normative forecasting, with the TBNEP plan projecting a 100-year timeframe. TBNEP goals include the restoration of ~809 ha of wetland habitats, with particular emphasis on oligohaline systems and "restoring the balance" (restoring lost habitats in direct proportion to their 1950 historical percentages). The SWIM Program is a 1987 state mandated program funded with public tax dollars.

Restoration Strategies

Proposed project sites have been identified via: 1) listings compiled by SWIM, TBNEP, and environmental consultants; 2) nominated by local governments, environmental organizations, or individuals. Final site selections were/are made after consideration of various factors: parcel ownership (public vs private), parcel size, permissibility, access, habitat complexity/diversity after restoration, cost/benefit ratios, availability of cooperator(s), location, public visibility. While preliminary restoration projects through the 1980s focused almost solely on intertidal wetlands for the estuary, maturation of restoration programs for the bay have resulted in projects targeting the ecosystem: subtidal, intertidal, transitional, freshwater wetland, and upland habitats.

Early projects consisted of small, simple marsh plantings (< 0.4 ha), but most current efforts represent sophisticated interdisciplinary projects that embrace the strategy of establishing habitat mosaics (ecosystem restoration) using the "restoring the balance" approach. Projects provide various habitats important for a multitude of wildlife species, maximizing habitat diversities and complexities. Over time, project designs have become increasingly complex, providing such habitats as: undulating shorelines, coves, shallow as well as deeper subtidal habitats, oyster bar substrates, braided tidal channels/creeks, semi-isolated brackish ponds, subtidal refugia "holes," complementary freshwater wetlands that overflow through intertidal marshes to open water lagoons. In addition, designs since the early 1990s increasingly emphasize high marsh components in anticipation of sea level rise over the next century. Assuming that sea level is rising (as data indicates) and will continue to rise, the additional acreage of high marsh provides the opportunity for habitats to transition up-slope as sea level rise occurs. If sea level rise does not reach predicted levels and habitats do not need to transition up-slope, then the ecosystem is still provided with valuable, productive high marsh communities.

As practicable and appropriate, projects also often help restore sheetflow and polish (i.e., cleanse) stormwaters. Restoration of the proper timing and distribution of freshwater inputs to the estuary via sheetflow (among other water delivery mechanisms) is recognized as an important element contributing to proper, natural ecological processes of the estuary. Redressing sheetflow of stormwater runoff is but one element of managing stormwater runoff, a topic not addressed by this paper but of great importance to the estuary. Suffice to say, that existing and proposed stormwater treatment projects performed by SWIM and many local governments are critical components for improvements in the bay's water quality and habitat values.

Several other goals can be and often are being simultaneously met by projects using restored freshwater and estuarine wetlands to help remove sediments and pollutants from stormwaters. These goals include: 1) stormwaters contribute to the hydration of freshwater wetlands; 2) enhanced nursery functions of estuarine habitats via the establishment of salinity gradients/lower salinities in the estuary and/or restored tidal lagoons/channels/creeks (i.e., resulting from freshwater inputs from watershed runoff and/or freshwater wetlands overflowing through brackish wetlands to estuarine open waters); 3) improved water quality for the bay.

Also of note is the increased use of artificial reefs to enhance and increase habitat complexity within restoration projects. Imaginative use of "materials of opportunity" (i.e., the "moo principle") has resulted in carefully constructed artificial reefs within tidal lagoons of restoration projects; "moo" reef materials typically represent materials that otherwise are considered refuse but which possess attributes which can be utilized to create multi-functional artificial reefs. Donated and recycled reef materials include such materials as: concrete culverts, blocks, pilings, and bridge handrails, PVC and fiberglass pipes, plastic and fiberglass packing panels (originally designed for use in power plant scrubbers), limestone boulders. By hand and heavy equipment, reefs are being carefully assembled in series of "reef pods" that meet the requirements of good artificial reefs: 1) relief off the bottom; 2) flow-through characteristics; 3) structure complexity providing numerous differing macro- and mini-habitats associated with ledges, cavities/holes/"caves", substrates, etc. Field observations and some baseline monitoring indicate that these artificial reefs are providing valuable productive habitat and feeding areas for various assemblages of benthic algae and invertebrates as well as benthic and nektonic fishes.

Up to an estimated 95 % of historic upland plant communities within one mile of the bay's shoreline are no longer present, being converted for urban development, agricultural uses, or mining operations. In addition, for non-urban areas, secondary succession has resulted in uplands often being dominated by non-native vegetation, a poor substitute for historic habitat values that existed when the plant communities were comprised of native flora. As such, upland restoration and proper management are important for the overall rehabilitation and functioning of the Tampa Bay estuarine ecosystem.

As part of the ecosystem continuum, increasingly, coastal brackish and freshwater wetland communities are being restored in concert with adjoining upland communities. While some projects provide only small acreages of fringing uplands surrounding the wetlands, other large-scale restoration opportunities currently or (when completed) will provide hundreds of acres of coastal uplands (e.g., projects associated with Cockroach Bay, Wolf Branch Creek, Terra Ceia, Bishop Harbor). Various herbaceous and forested habitats are being restored, as feasible, to historic conditions. Coastal pine flatwoods along Tampa Bay have been significantly reduced from historic acreages; as such, restoration of pine flatwoods is a

priority, although sometimes not feasible due to proximity to human development (i.e., regular controlled burns may or may not be feasible in some areas, a management tool necessary to properly maintain pine flatwoods). Other upland habitats being restored include hardwood forests, hammocks, and prairies. Various restoration strategies, species assemblages, plant distributions, non-native plant control measures, and experimental restoration techniques are being used for upland restoration efforts.

Since 1992, a series of two experimental test plots and five restoration projects have yielded promising results of using recycled shredded exotic plant and yard waste (grass, leaves, shrubs, trees) as a tool for large-scale coastal upland restoration. During 1992–2004, experiments and restoration projects (0.4–60.3 ha) using 10–38 cm depths of mulch indicate the technique has significant benefits for upland restoration projects. It suppresses nuisance and non-native plant growth, giving preferred installed native plants a competitive edge. It also increases nutrient levels and organic matter for plant growth, stabilizes soil temperatures and moisture content, and promotes greater plant survivorship and growth rates vs plants in unmulched areas. The technique appears most appropriate for the restoration of hardwood/hammock habitats and for mixed hardwood/pine uplands but is not recommended for pine flatwoods.

Lastly, restoration projects are often on public lands that are either public parks or nature preserves available for public use. As such, project designs are often multi-functional, in that they not only provide valuable coastal habitats but also incorporate features compatible with low impact human use (e.g., canoe/kayak launches, observation mounds [doubling as restored uplands], educational kiosks/signs, etc.).

Tampa Bay restoration projects are often regarded as “state of the art,” with experimental restoration techniques being frequently explored to push the science of restoration ecology. Regional, national, and international groups of scientists, resource managers, and policy makers annually visit various Tampa Bay restoration sites to learn about techniques, designs, strategies, costs, problems, and solutions concerning the bay’s restoration.

Restoration Project Summaries

Significant progress has been made toward meeting long range habitat goals for the bay. During the 32-year period of 1971–2002, at least 102 non-mitigation restoration projects have been performed for the bay for a total of 403 ha, of which 51 are SWIM projects (356 ha, 88.3% of all habitats restored, 1989–2002); the other 51 restoration projects have been performed by various government entities, and in some cases, private enterprises. Project sizes have ranged from 0.00081 to 73.2 ha, with majority of the projects smaller than 12.1 ha. In general, similar to project complexities, project sizes have trended upward over time, with the largest single restoration project being 73.2 ha of wetland restoration occurring at the Wolf Branch Creek site during 2001.

For the 19-year time period of 1971–1989, 37 projects totaling 10.8 ha (mean = 0.56 ha/yr) of restored/enhanced/created habitats were performed for the bay. Comparatively, the successive 13 year period of 1990–2002 was more productive with 65 projects totaling 392 ha (mean = 30.17 ha/yr). The dramatic increase in numbers of projects and acreage are attributable primarily to implementation of the SWIM Program working in partnership with other federal, state, and local agencies or governments. Forty of the 51 SWIM projects (78.4%) have been constructed by volunteers or public construction crews at 25–50% savings of private construction costs.

The success of restoration efforts for the bay is strongly predicated on and the result of the level of cooperation among the many stakeholders striving to restore and properly manage the resource. The successes in ecosystem restoration for the bay are the product of the synergism of partners working toward common goals. Aside from SWIM and the TBEP, numerous other partners include local, regional, and state governments, various local, regional, state, and federal agencies, corporate entities, environmental organizations, and the public at large. While these entities often work in partnership with SWIM, each entity typically has their own programs addressing habitat and water quality projects.

During the period 1971–2002, other than SWIM and its cooperators, other notable governmental restoration programs include those of the Florida Department of Environmental Protection and the Florida Department of Natural Resources (now the Florida Fish and Wildlife Conservation Commission). What is hoped to be indicative of a trend, since 2000 several private entities either participated in or performed several non-mitigation restoration projects. In addition, for some larger, expensive restoration projects, mitigation funds were used to help offset project expenses (e.g., Florida Department of Transportation funds used for several SWIM restoration efforts, court settlements, mitigation fines, etc.). Restoration projects also have been abetted through cooperative efforts of numerous environmental organizations (e.g., National Audubon Society, Tampa BAYWATCH, Cockroach Bay User's Group, Ruskin Community Development Foundation).

Currently, SWIM and other public restoration programs have an additional 1200 + ha of projects under some stage of development. Successful completion of these 1200 + ha of coastal ecosystem restoration will provide significant increases in various habitats for the Tampa Bay system. Progress beyond that point though will, in part, be dependent on land availability for restoration.

Land Acquisition/Protection for Restoration and Management

As was stated by this author and as was also discussed by various other speakers during the BASIS 4 conference, possibly the most important single thing that has been done for the bay or will ever be done for the bay concerns the acquisition of sufficient acreage of coastal and watershed lands to insure the balance of the bay's ecological systems and wildlife populations. Without sufficient undeveloped, unaltered acreage of coastal and watershed lands, the bay cannot properly function as envisioned by coastal ecologists and resource managers. The philosophy of "buy now, restore/manage later" is based on the premise that if the land is developed, in all probability, the acreage is essentially forever lost from providing natural functions for the ecosystem (assuming that the hurricane "Armageddon scenario" discussed in BASIS 3 is not realized). Accordingly, it was and is recommended that public land acquisition should be a top priority for Tampa Bay and its watershed. What currently is in public ownership and conservation easements and what is purchased/protected over the next 20 years could conceivably be the only portions of the "natural" watershed and coastal habitats remaining for the latter 21st century and beyond. If such lands are protected from development (i.e., urban, agricultural, mining), then proper restoration and management will be feasible as funds are available. Public and private land acquisition programs (e.g., Florida Forever Program, Hillsborough County Environmental Land Acquisition and Protection Program, The Nature Conservancy, etc.) are critical to the long term success of ecosystem restoration, preservation, and management. In addition, creative land acquisition and protective methods could play important roles insuring the future of the resource; such methods include but are not limited to less than fee acquisitions, acquisition as a form of mitigation, and conservation easements.

The Future

The trend for larger, more complex restoration projects is anticipated to continue until the availability of restoration sites becomes limiting. This is not to say that the smaller, less complex restoration projects are not important, as they are. Each restoration project of any size and complexity is contributing to the gradual, incremental improvements in habitat quality and quantity. Assuming that funding continues to be available, restoration programs appear to be dedicated for the long term for the restoration and management of the bay's ecosystem. As noted, this level of dedication, cooperation, and perseverance are important reasons for the success of efforts to date and portends an optimistic future for the bay.

Funding for efficient, cost effective habitat restoration and management will continue to be needed to meet the long range habitat goals for the bay. Restoration programs should continue to capitalize on grant funds, mitigation options, and other creative funding and/or partnership opportunities. Last, but not least, education efforts need to continue to inform the public and elected officials of the need for proper restoration and management of the bay's ecosystem.

Closing Comments

Examples of restoration projects were highlighted during the presentation: Cockroach Bay, Palmetto Estuary, Clam Bayou, Davis Tract, Mangrove Bay, Lake Thonotosassa. For additional information and perspective, the reader is encouraged to review summaries concerning habitat restoration for Tampa Bay contained within both the 1992 BASIS 2 and 1997 BASIS 3 publications. For project specifics and techniques, please contact the author.

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MANAGEMENT IMPLICATIONS OF SPATIAL AND TEMPORAL PATTERNS OF SEAGRASS CHANGE IN TAMPA BAY, 1950 TO 2002

D. Tomasko

ABSTRACT

Seagrass coverage in Tampa Bay exhibits patterns of decline (1950 to 1982), increase (1982 to 1996), decline (1996 to 1999) and then increase (1999 to 2002). In addition to temporal variation in coverage, substantial spatial variation exists both in terms of locations with historical and recent losses, and also locations with recent increases. Bay-wide, the majority of historical (1950 to 1982) losses of seagrass coverage occurred in Hillsborough Bay and Old Tampa Bay. In contrast, most of the recent (1982 to 1996) seagrass increase occurred in locations such as Boca Ciega Bay and Lower Tampa Bay. The combined phenomena of patterns of loss and gain have resulted in an increased concentration of seagrass coverage in the higher salinity portions of Tampa Bay over the past 50 years. Variation in bay-wide patterns of seagrass distribution could have consequences for faunal utilization of these meadows.

INTRODUCTION

In Tampa Bay, historical (1950 to 1982) losses of seagrass coverage have been linked to both direct and indirect impacts (i.e., Lewis et al. 1985, Lewis 1989, Haddad 1989). In contrast, recent (1982 to 1996) increases in seagrass coverage in Tampa Bay have been associated with improved water quality in the bay (i.e., Johansson 1991, Avery 1997, Johansson and Ries 1997, Johansson and Greening 1999). Improvements in the early 1980s in the treatment and disposal of wastewater discharges by the Cities of Tampa, St. Petersburg and Clearwater have been previously identified as the primary causes of improved water quality in Tampa Bay (Tampa Bay Estuary Program [TBEP] 1996).

A recent review (Kurz et al. 1999) of seagrass status and trends in Tampa Bay included estimates of coverage for individual bay segments, as opposed to bay-wide coverage estimates only. Other work has been mostly devoted to seagrass coverage in Hillsborough Bay alone (e.g., Johansson 1991, Avery 1997). In contrast, many previous reports on the status and trends of seagrass coverage in Tampa Bay have not focused on the potential for segment-specific differences in the rate of recovery of seagrass coverage. Also, the Tampa Bay Estuary Program's goal for seagrass restoration is based on bay-wide coverage totals (TBEP 1996). Thus, the potentially varying role of specific portions of Tampa Bay in contributing to bay-wide patterns of loss and gain of seagrass coverage has been perhaps under valued.

This paper updates two previous summaries of the status and trends in seagrass coverage in Tampa Bay (Kurz et al. 1999, Tomasko 2003) by including data from the latest available seagrass mapping effort (2002). Additionally, this paper will assess spatial and temporal differences in seagrass coverage in Tampa Bay on both a bay-wide basis, as well as a segment by segment basis.

MATERIALS AND METHODS

For purposes of this paper, the segmentation scheme originally outlined by Lewis and Whitman (1985) will be used. The seven segments comprising Tampa Bay are: Hillsborough Bay, Old Tampa Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ciega Bay, Terra Ceia Bay, and the Manatee River (see Figure 1).

Current estimates of the coverage of seagrass in Tampa Bay (and elsewhere in Southwest Florida) are produced through a multiple step process. First, aerial photography is obtained, usually in the late fall to early winter. This time of year is typically associated with both good water clarity (i.e., Dixon 1999, Tomasko and Hall 1999) and relatively high seagrass biomass (i.e., Tomasko et al. 1996, Dixon 1999). Flights are not flown unless Secchi disk depths meet

or exceed 2 m at sampled locations for each estuary on the day that photography is shot. In addition, wind speed on the day photography is shot must be at or below 10 knots, and wave heights must be less than 60 cm.

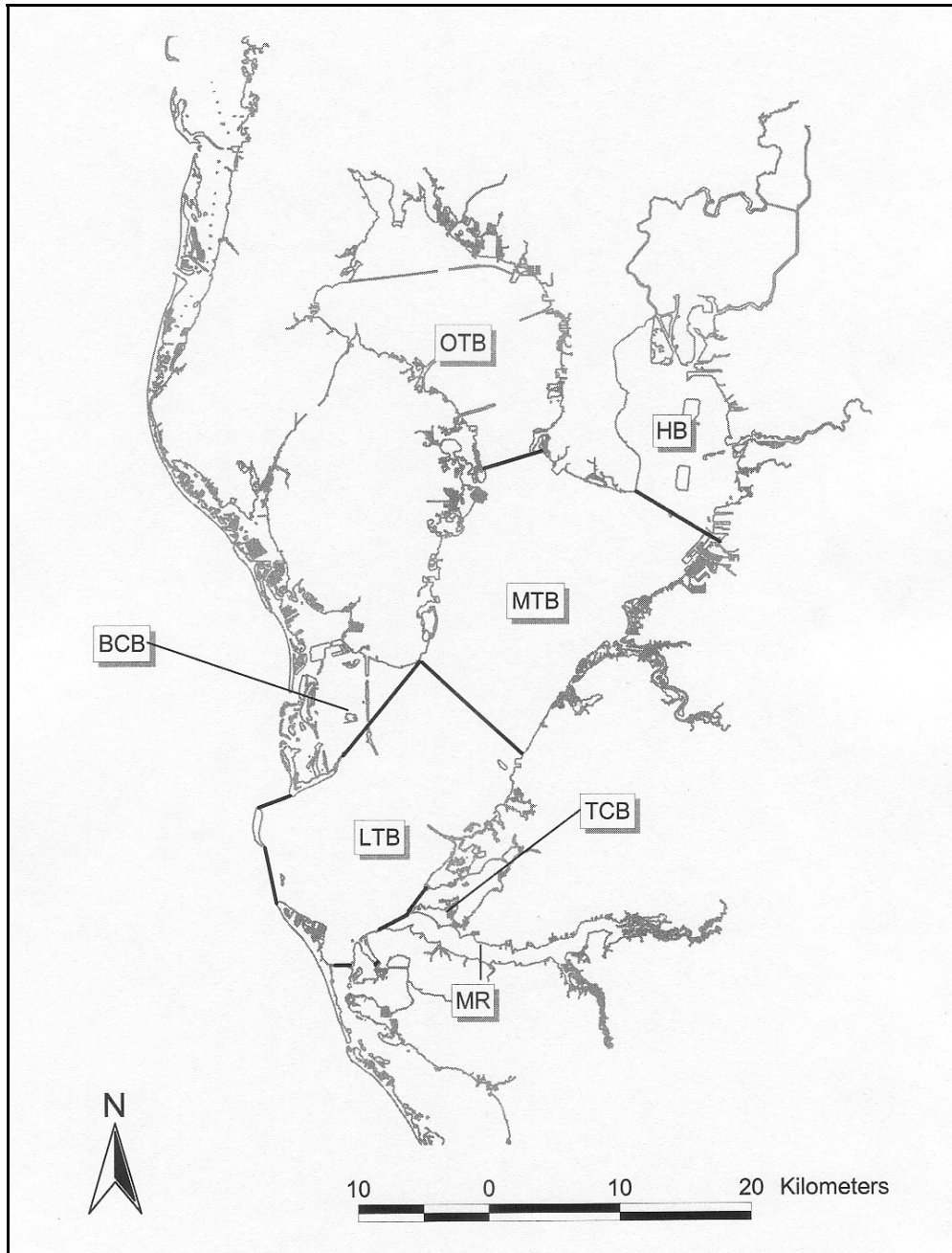


Figure 1. Tampa Bay with bay segments: HB – Hillsborough Bay, OTB – Old Tampa Bay, MTB – Middle Tampa Bay, LTB – Lower Tampa Bay, BCB – Boca Ciega Bay, TCB – Terra Ceia Bay, MR – Manatee River.

Second, photointerpretation efforts are conducted in the field, to allow for the successful evaluation of distinct photographic signatures. Seagrass signatures are divided into two classes (continuous and patchy coverage), with a minimum mapping unit of 0.2 hectares. Continuous and patchy polygons are delimited based on the interpretation of aerial photographs, with continuous polygons characterized as having less than 25 % of the delimited polygon visible as unvegetated areas. Patchy polygons have greater than 25 % of the delimited polygon visible as unvegetated areas. However, these two polygon classifications cannot be groundtruthed for accuracy by site visits (i.e., it is impossible to determine, with limited visibility, if a snorkeler is in a large patch or a continuous bed) and they must be interpreted with caution in any analysis.

Third, polygons are integrated into an ARC/Info program. For past efforts (i.e., 1988, 1990, 1992, 1994, and 1996), individual polygons were delineated on Mylar overlays, cartographically transferred using a Zoom Transfer Scope to USGS quadrangles, and then digitally transferred to an ARC/Info database for further characterization. These techniques allowed for the seagrass maps to meet USGS National Map Accuracy Standards for 1:24,000 scale maps. For 1999 and 2002 seagrass maps, a 1:12,000 National Map Accuracy Standard was met. While photography remained at a scale of 1:24,000, the higher positional accuracy standard required the use of tighter ground control and more sophisticated mapping techniques. Analytical stereo plotters were used for photointerpretation, as opposed to stereoscopes. This technique allows for the production of a georeferenced digital file of the photointerpreted images, without the need for additional photo-to-map transfer. Rather than redraw seagrass coverage polygons for each year's efforts, only the changes in seagrass coverage are mapped, using the previous effort's digital coverage as the baseline. Areas with no change between efforts are coincident with the earlier effort's coverage.

Fourth, hard copy plots are made of photointerpreted seagrass coverage, and randomly chosen points are identified for a post map-production classification accuracy assessment. A hand-held Global Positioning System is used, along with the draft seagrass map and the latitude and longitude of the randomly located stations, to develop an unbiased determination of the map's classification accuracy. A 90% classification accuracy standard is required for these efforts, and 94% accuracy was achieved for 2002 efforts (i.e., 64 of 68 stations that could be visited were accurately described).

Estimates of seagrass coverage for Tampa Bay exist for both 1950 and 1982. For 1950 estimates, the Tampa Bay Regional Planning Council (1986) utilized 1:24,000 scale true color aerial photographs. The resulting seagrass maps were digitized by the Florida Marine Research Institute, converted from raster to vector format, and horizontally georeferenced with available ground controls. This mapping effort met USGS National Map Accuracy Standards for 1:24,000 scale maps. No groundtruthing was conducted concurrent with the photography for this time period, and coverage is simply classified as polygons with seagrass coverage; the classification system used does not distinguish between patchy and continuous coverage. For 1982 coverage, estimates are from a joint project between the U.S. Fish and Wildlife Service and the Florida Department of Natural Resources. This effort digitized 1:24,000 scale true color aerial photography using the National Wetlands Inventory standard classification system. This mapping effort met USGS National Map Accuracy Standards for 1:24,000 scale maps. As with the 1950 photography, a statistically relevant groundtruthing effort was not conducted concurrent with the acquisition of photography. The classification system used also does not distinguish between patchy and continuous coverage.

RESULTS

The overall trend in seagrass coverage for Tampa Bay over the past 50 years is shown in Figure 2. In 1950, seagrass meadows covered 16,350 hectares of bay bottom. By 1982, that number had dropped to 8,763 hectares. From 1982 to 1996, coverage increased by 2,130 hectares up to 10,893 hectares. The average rate of increase between 1982 and 1996 was 152 hectares per year. From 1988 to 1996, the average rate of increase was 184 hectares per year. From 1996 to 1999, a decrease in coverage of 840 hectares was found, down to 10,053 hectares. From 1999 to 2002, an increase in coverage of 501 hectares was found, up to 10,554 hectares. Seagrass coverage in Tampa Bay in 2002 is 65 % of 1950 values.

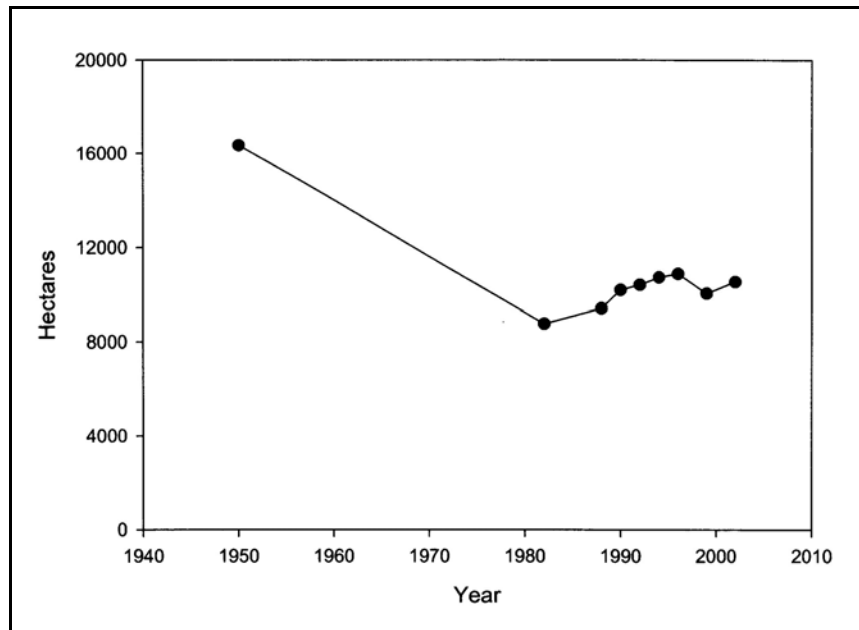


Figure 2. Seagrass coverage (hectares) in Tampa Bay, 1950–2002.

Table 1 and the text below assess changes in coverage on a segment-by-segment basis over time.

Hillsborough Bay

In Hillsborough Bay, mapped seagrass coverage dropped from 931 hectares in 1950 to a complete absence in 1982. Coverage in 2002 is 194 hectares, which gives a rate of increase of 10 hectares per year between 1982 and 2002. Seagrass coverage in Hillsborough Bay in 2002 is 21 % of 1950 values.

Old Tampa Bay

In Old Tampa Bay, seagrass coverage declined from 4,330 hectares in 1950 to 2,026 hectares in 1988. From 1988 to 1994, coverage increased at a rate of 61 hectares per year, to 2,392 hectares. From 1994 to 1996, coverage decreased to 2,332 hectares (30 hectare per year decline). From 1996 to 1999, coverage again decreased, this time to 1,779 hectares, a rate of decline of 185 hectares per year. Coverage in 2002 increased by 355 hectares, to 2,134 hectares. Seagrass coverage in Old Tampa Bay in 2002 is 49 % of 1950 values.

Table 1. Seagrass coverage in hectares (acres) by year for segments of Tampa Bay. HB – Hillsborough Bay, OTB – Old Tampa Bay, MTB – Middle Tampa Bay, LTB – Lower Tampa Bay, BCB – Boca Ciega Bay, TCB – Terra Ceia Bay, MR – Manatee River.

	1950	1982	1988	1990	1992	1994	1996	1999	2002
HB	931 (2300)	0 (0)	3 (7)	19 (47)	19 (46)	59 (147)	78 (193)	78 (192)	194 (480)
OTB	4330 (10700)	2405 (5943)	2026 (5006)	2251 (5561)	2378 (5877)	2392 (5911)	2332 (5763)	1779 (4395)	2134 (5272)
MTB	3885 (9600)	1636 (4042)	2106 (5205)	2148 (5307)	2133 (5270)	2337 (5775)	2242 (5541)	2282 (5639)	2316 (5723)
LTB	2469 (6100)	2030 (5016)	2232 (5515)	2486 (6143)	2526 (6242)	2511 (6205)	2582 (6381)	2366 (5847)	2271 (5611)
BCB	4371 (10800)	2335 (5770)	2533 (6258)	2754 (6805)	2813 (6952)	2880 (7116)	3116 (7699)	3021 (7464)	3105 (7673)
TCB	283 (700)	304 (751)	383 (947)	405 (1000)	406 (1003)	404 (999)	394 (973)	376 (929)	380 (938)
MR	81 (200)	53 (131)	140 (347)	147 (363)	147 (363)	148 (365)	148 (366)	152 (375)	154 (381)
TOTAL	16350 (40400)	8763 (21653)	9423 (23285)	10209 (25225)	10422 (25753)	10732 (26519)	10893 (26916)	10053 (24841)	10554 (26078)

Middle Tampa Bay

In Middle Tampa Bay, seagrass coverage declined from 3,885 hectares in 1950 to 1,636 hectares in 1982. From 1982 to 2002, seagrass coverage increased by 680 hectares, a 42 % increase. Seagrass coverage in Middle Tampa Bay in 2002 is 60 % of 1950 values.

Lower Tampa Bay

In Lower Tampa Bay, seagrass coverage in 1950 was 2,469 hectares. Seagrass coverage in Lower Tampa Bay in 2002 is 2,271 hectares, or 92 % of 1950 values.

Boca Ciega Bay

In Boca Ciega Bay, seagrass coverage declined from 4,371 hectares in 1950 to 2,335 hectares in 1982. From 1982 to 2002, seagrass coverage increased at a rate of 39 hectares per year. Seagrass coverage in Boca Ciega Bay in 2002 is 3,105 hectares, or 71 % of 1950 values.

Terra Ceia Bay

In Terra Ceia Bay, seagrass coverage remained similar between 1950 and 1982 (283 and 304 hectares, respectively). However, 1988 coverage was 383 hectares, a 26 % increase from 1982. In 2002, seagrass coverage in Terra Ceia Bay is 380 hectares, or 34 % higher than in 1950.

Manatee River

In the Manatee River, seagrass coverage declined between 1950 and 1982 (81 and 53 hectares, respectively). However, 1988 seagrass coverage was 140 hectares, a 165 % increase from 1982. In 2002, seagrass coverage in the Manatee River is 154 hectares, or 90 % higher than in 1950.

DISCUSSION

Historical losses of seagrass coverage in Tampa Bay (i.e., between 1950 and 1982) have been attributed to both direct and indirect impacts associated with rapid population growth

experienced in the region in the post-World War II years (TBEP 1996). Direct losses occurred due to dredge and fill activities associated with waterfront development for residential and commercial land uses. Indirect losses are thought to have been associated with increased point and non-point source nutrient loads that accompanied the population growth and urbanization of the watershed.

In contrast, the overall trend of increasing seagrass coverage in Tampa Bay over the past twenty years has been attributed to increased water clarity during that same time period (Johansson 1991, Johansson and Ries 1997, Johansson and Greening 2000). Increased water clarity, in turn, appears to be related to decreased phytoplankton populations (Johansson 1991, Johansson and Greening 2000), which are in turn related to the approximately 61 % decline in nitrogen loads into Tampa Bay between 1976 and 1992-1994 (TBEP 1996). Seagrass planting efforts have played a minor role in bringing about the sustained increases in coverage in Tampa Bay, as many of the areas where seagrass increases have occurred are in parts of the bay where no transplanting efforts have been undertaken (Tomasko, personal knowledge). Also, seagrass transplanting efforts have usually been on the level of one hectare (or less) of effort, whereas increases in seagrass coverage averaged 184 hectares per year between 1988 and 1996.

Although Tampa Bay's seagrass resources have increased in the recent past, considerable spatial and temporal variability in patterns of recovery warrant closer analysis. For example, Hillsborough Bay's present seagrass coverage, while significantly higher than estimates from the 1980s, is only about 20 % of the coverage in 1950. In Old Tampa Bay, seagrass coverage peaked in 1996, and is at present approximately half of the coverage in 1950. The restoration of seagrass coverage in Tampa Bay to nearly the levels found in 1950 will be difficult to achieve, should recovery rates in both Hillsborough Bay and Old Tampa Bay continue to lag behind other bay segments.

Differential patterns of loss and recovery of seagrass coverage in various bay segments over the past fifty years have resulted in changes in the distribution pattern of seagrass meadows bay-wide. In 1950, seagrass coverage in Hillsborough and Old Tampa Bays combined (5,621 hectares) was 32 % of bay-wide coverage (16,350 hectares). In 2002, coverage for Hillsborough and Old Tampa Bays combined (2,328 hectares) had dropped to 22 % of the bay-wide total (10,554 hectares). In contrast, combined coverage for Lower Tampa Bay and Boca Ciega Bay in 1950 (6,840 hectares) was 42 % of bay-wide coverage (16,350 hectares). In 2002, combined coverage for Lower Tampa Bay and Boca Ciega Bay (5,376 hectares) accounted for 51 % of the bay-wide total (10,554 hectares).

Over the past fifty years, seagrass meadows have not only been reduced in coverage, but they have become more concentrated into the higher salinity, lower portions of the bay. In Australia, various studies have shown that faunal utilization of seagrass meadows within a single estuary can vary as a function of distance from the mouth of the estuary (e.g., Bell et al. 1988, and references within). In some locations, faunal utilization of seagrass meadows varies more strongly as a function of the location of the meadow within an estuary than the presence or absence of seagrass itself (Connolly 1994).

If such phenomena are similarly important in Tampa Bay, then restoration of seagrass meadows to an overall coverage goal may be insufficient, by itself, for restoring populations of fauna associated with seagrass meadows to the levels found in the bay in the 1950s. Portions of the bay where both the historical reductions (1950s to 1980s) were strongly felt,

and recent increases (1980s to present) have been more meager, such as Hillsborough Bay and Old Tampa Bay, may benefit from more detailed diagnostic assessments.

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HARD BOTTOM HABITATS: AN OVERVIEW OF MAPPING AND MONITORING NEEDS ON EPIBENTHIC COMMUNITIES IN TAMPA BAY, FLORIDA

T. Ash & R. Runnels

OVERVIEW

Much of what is known about hard bottom communities in Tampa Bay has been gleaned from several relatively small, unrelated efforts to map out known areas of epibenthic communities and obtain a cursory knowledge of their biological assemblages. Efforts in the early 1980s began with the observation of dark patches of bay bottom that resembled those caused by seagrass beds but in areas thought to be too deep to support seagrasses (Derrenbacker & Lewis, 1982). In the early 1990s, somewhat more sophisticated approaches were used including aerial photo interpretation coupled with field verification of suspect sites (Savercool & Lewis, 1994). While these techniques did yield better results for finding hard bottom areas in relatively shallow water (up to 22' in depth), informal field observations indicate that published species lists do not adequately represent the diversity of these areas. Additional taxonomic work will provide species identifications as a necessary step toward a functional understanding of these systems. Characterizing the substrate, itself, should be done based on an existing classification system like that developed by the Florida Fish and Wildlife Conservation Commission (2002).

In the present environmental climate, the level of sophistication that comes with global positioning, remote sensing, geographic information systems and spatial data management is only beginning to catch up to the need to understand these often-overlooked hard bottom communities. Projects such as the Gulfstream Pipeline and various harbor and ship channel dredging operations emphasize the importance of data collection prior to making environmental management decisions with little or no knowledge of the impacted resource. The environmental community of the Tampa Bay area has a long and distinguished track record for monitoring water quality, sediment quality, seagrasses, and coastal zone habitats. Seldom does such a large, multi-jurisdictional approach to resource management get so much accomplished and have so much to be proud of. Yet, despite all of this local knowledge and expertise, there is still too little data related to these critical hard bottom habitats. More is known about the bay's artificial reefs and their locations and biological assemblages than is currently understood about the naturally occurring hardbottom habitats that they are meant to mimic.

There is a need for a comprehensive and continuing account of hardbottom communities in Tampa Bay. Past efforts, while adequate at the time, need to be revisited, updated and be far more reliable. Biological assemblages must be identified and, to the greatest extent possible, compared with those inhabiting artificial substrates distributed throughout the bay. Due to the ephemeral nature of these areas, a continuing effort should be in place to ensure that seasonal, hydrologic and geomorphological changes can be accounted for much like the current approach used for Tampa Bay's seagrass communities. The framework exists within the Comprehensive Conservation and Management Plan for Tampa Bay. The local scientific community needs only to work out the details and divide the labor among the Tampa Bay Estuary Program's member agencies.

NATURAL HARD SUBSTRATES IN TAMPA BAY

The areal extent of hardbottom habitats in Tampa Bay appears to be small (likely hundreds of acres) relative to unconsolidated substrates and seagrasses. Unlike areas like the Florida Keys (e.g., Goldberg, 1973) very little scientifically rigorous study has focused on Tampa Bay hardbottom.

The most extensive exposed rock is along the southeast margin of Tampa Bay. A trend of hardbottom roughly parallels the shoreline from the Little Manatee River southward offshore of Bishop Harbor and Rattlesnake Key. Patches of hardbottom also are found within the embayments of this area. An accurate GIS-based map of these features has not been done. While the substrate in these areas appears to be natural, geological distinctions between Arcadia limestone, beach rock, oyster reef and other natural substrates have not been made. Recently, a small reef made entirely of bryozoans was discovered a short distance off the mouth of Bishop Harbor. The dimensions of this feature are on the order of 10 m long, and the relief of the offshore edge is approximately 20cm above the adjacent sand bottom. While this bryozoan reef does not represent much habitat area, it is especially important as a growing, biogenic, hard structure. Other than oyster reefs, bio-erosion may be outpacing accretion on many of the other hard structures in the bay.

Geological characterizations are also needed for hardbottom areas in the upper part of the bay. Chiappone and Sullivan (1994) combined characterizations of geology, community structure and ecological dynamics in comparing two hardbottom areas in the Florida Keys, and a similar multidisciplinary approach would be very informative on hardbottom areas along the environmental gradient of Tampa Bay. Whether these areas are of native limestone, ship ballast stones or other origins is often not clear. Ongoing work on the formation and geological structure of Tampa Bay likely will shed some light on these questions.

Because of the small size and isolation of hardbottom sites, their associated communities probably are influenced by the availability of recruits from distant sources. Present and planned circulation modeling in Tampa Bay may give some insights into the availability of recruits of hardbottom species on a local scale. Hardbottom areas with much greater diversity are located outside Tampa Bay, and an understanding of the communities within the bay must include better knowledge of these sources of potential recruits.

DYNAMIC SYSTEMS

Compared to coral reefs and offshore hardbottom areas, disturbance may play a greater role in structuring hardbottom communities within Tampa Bay. In addition to chronic anthropogenic disturbances like ship wakes and nutrient influxes, these communities are subject to several dramatic natural fluctuations.

Because typical hardbottom areas within the bay have little to no relief from the surrounding unconsolidated sediments, migration of sandbars and shoals likely buries and exposes some of the hardbottom features. While species living in the bay are likely more resilient than species in more stable environments, the extent to which disturbance structures communities is poorly understood. A better understanding of the proximity of limestone to the sediment surface and the movement of shoals may allow community comparisons between continually exposed and periodically buried areas.

One of the most interesting natural disturbances on southeast Tampa Bay hardbottom is the annual *Sargassum* bloom. Each winter, much of the area becomes blanketed by growth of the attached brown alga. In the spring, the *Sargassum* detaches and floats away, but for several months, many other species are shaded. The effect of this temporary shading on other attached algae and on the algal symbionts of invertebrates is not known. This phenomenon, as well as seasonal temperature fluctuations, likely has profound effects on the persistence of some hardbottom species within the bay.

Rates of photosynthesis and respiration have been studied for seagrass beds in Tampa Bay (Yates & Halley, 2003). The same equipment could be used to study primary productivity, respiration, calcification and dissolution on Tampa Bay's hardbottom ecosystems.

ASSESSING THREATS

By virtue of their location in a densely urbanized watershed, Tampa Bay's hardbottom communities face a variety of anthropogenic threats. A better understanding of the location, ecological structure and function of these systems will enhance the accuracy with which these threats can be evaluated, and if necessary, prevented and/or mitigated.

A variety of fuels and other hazardous cargos are transported and loaded short distances from some of the most pristine hardbottom communities. The threat of contamination and strategies for preventing it should be part of resource inventory efforts. Preparations should be made to investigate the impact on, and recovery of, occasional boat groundings as soon as they occur in conjunction with current damage assessment efforts throughout the state.

Linear features, like fiber optic cables and pipelines are often planned for relatively unpopulated areas. Since much of Tampa Bay's hardbottom habitat is located in these areas, accurate resource inventories are essential to avoidance and minimization of impacts. In the event that impacts are unavoidable, comparisons of the structure and ecological function of the natural communities will aid analyses of whether appropriate mitigation is possible. Lindeman and Snyder (1999) found evidence that dredge-related impacts may affect fish populations associated with hardbottom off the east coast of Florida. Baseline fish censuses for Tampa Bay hardbottom habitats would provide valuable information for similar studies.

Expanding commercial shipping opportunities will likely contribute to existing concerns over introducing additional exotic species into the Tampa Bay system. The Asian green mussel, *Perna viridis* is a good example of the need to understand the ecology of these species. Questions include why the green mussel has established high densities on artificial substrates but not on natural substrates? If artificial substrates provide a greater source of recruits, then natural substrates may be colonized more by chance alone. Information related to natural ecological bottlenecks, like cold winters, in exotic populations could also be valuable in determining the long-term viability and impact of these species.

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FRESHWATER WETLANDS: STATUS AND TRENDS

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ABSTRACT

The areal extent of freshwater wetlands in the Tampa Bay watershed has been reduced by a number of human activities. In order to estimate the magnitude of these reductions, the pre-development extent of freshwater wetlands was estimated using soils as a predictor of historic land cover. A GIS coverage of land use and land cover developed by the Southwest Florida Water Management District, based on interpretation of 1999 color infrared aerial photography, was used to estimate the present-day extent of freshwater wetlands. The resulting estimates of pre-development and post-development wetland extent were 150,959 ha. (373,020 ac.) and 81,977 ha. (202,565 ac.), respectively. This suggests a total reduction of approximately 46% between the early 1900s and 1999.

A more detailed assessment of wetland loss based on the same methodology indicates that herbaceous freshwater wetlands during this period experienced a reduction from 48,189 ha. (119,085 ac.) to 20,570 ha. (50,826 acres) or approximately 57%, while forested freshwater wetlands experienced an overall reduction of 40%. Within the forested wetland category, cypress-dominated wetlands appear to have experienced the most pronounced reduction, from 41,801 ha. (103,290 ac.) to 12,011 ha. (29,677 ac.) or 71%. Hardwood-dominated systems experienced an estimated reduction from 60,965 ha. (150,645 ac.) to 49,398 ha. (122,062 ac.) or 19% overall.

The use of soils to extrapolate historic land cover appears to provide a reasonably accurate estimate of overall pre-development wetland coverage. However, the approach applied in this study is a relatively coarse tool for distinguishing between different types of wetland systems. Additional refinement of the methodology would be helpful to more accurately distinguish herbaceous from forested systems, and cypress-dominated from mixed hardwood systems.

INTRODUCTION

A great deal of attention is currently focused on the protection and restoration of emergent tidal wetlands in the Tampa Bay region (Henningsen et al. 1996, TBEP 1996). Substantial acreages of these habitats—primarily mangroves, tidal marshes and salt barrens—have been lost in the region, particularly during the years 1950 through 1990 which were characterized by rapid population growth and urbanization. In response to those losses a multi-agency habitat restoration initiative has developed, adopting a goal of “restoring the balance” of relative habitat acreages to predevelopment levels (TBEP 1996). This goal recognizes the infeasibility, both physically and financially, of restoring 100% of the acreage that has been lost. Rather than complete replacement, it seeks to protect the 18,750 acres of emergent tidal wetland acreage that were estimated to exist in the Tampa Bay watershed in a selected benchmark year (1990) and focus restoration efforts on the particular habitat types that had suffered disproportionate acreage losses prior to that year. The long-term objective of the restoration program is for each major type of emergent tidal wetland to have roughly the same proportional coverage (relative to the other types) that it exhibited under pre-development conditions (TBEP 1996).

This “restoring the balance” approach has achieved considerable success in the protection and restoration of emergent tidal wetlands, and it seems reasonable to ask if it would be helpful for managers to expand the approach to include other habitat types. The purpose of this paper is to provide two pieces of background information—estimates of pre-development and present-day acreages of freshwater wetlands—that could be used if a decision were made to expand the approach to include these habitats as well.

METHODS

The geographic boundaries of the Tampa Bay watershed considered in this paper follow those used by the Tampa Bay Estuary Program (TBEP) and the Southwest Florida Water Management District (SWFWMD). They include the hydrologic sub-basins of the

Hillsborough, Manatee, Little Manatee and Alafia rivers, and the coastal sub-basins of Old Tampa Bay, Hillsborough Bay, Tierra Ceia Bay, Boca Ciega Bay, and Upper, Middle, and Lower Tampa Bay.

The acreages of three categories of freshwater wetland habitats—herbaceous, mixed hardwood, and cypress—were estimated within each of these sub-basins under pre-development and present-day conditions using GIS. Present-day acreages were estimated using 1999 land cover maps provided by the SWFWMD. Pre-development acreages were estimated using soils data provided by the National Resource Conservation Service (NRCS), and fall into three categories based on the availability of detailed soils data and the anticipated accuracy of the resulting acreage estimates:

1. Detailed Soils Data Available

In areas where detailed digital soils mapping data are available, NRCS SSURGO (Soil Survey Geographic Data Base) data stored in ESRI® shapefile format provided the principal data source that was used to estimate the pre-development extent and general types of wetlands (herbaceous and forested). SSURGO files for six counties (Hillsborough, Manatee, Pasco, Pinellas, Polk, and Sarasota) were clipped to the Tampa Bay watershed. Very poorly drained and poorly drained hydric soils were isolated from the remaining soil types and saved to a separate shapefile. The associated wetland vegetation associated with each soil type was then identified based on each soil's natural vegetative growth as described in published soil surveys and guidance documents correlating plant communities and soil series. If the associated plants or community types were chiefly trees or forested wetland communities, we assumed that the soil historically supported a forested wetland. On the other hand, if the associated plants or community types were chiefly herbs or herbaceous communities, we assumed that the soil historically supported an herbaceous wetland. Where there appeared to be a combination of both herbaceous and forested community types, a forested community was assumed for the sake of simplicity. Overall, SSURGO or detailed soils data were available for 83 % of the watershed.

2. General Soils Data Available

Where detailed soils data were not available, due to extensive disturbance from activities such as mining, excavation, land filling or other forms of terrain modification that occurred prior to detailed soils mapping, the following procedures were used. Estimates of pre-development wetland extent were made using the NRCS general soils map file, STATSGO (State Soil Geographic Data Base). The STATSGO map file, which is statewide in extent, was first clipped to the watershed. All severely disturbed SSURGO soils, which included all soils resulting from mining and reclamation activities, excavation, and land filling, were then extracted and spatially overlaid atop the STATSGO mapping. Although a few of the STATSGO general soil types reflected severe disturbance, similar to that noted for the SSURGO soils, particularly in the phosphate mining district in the eastern portion of the watershed, most of the STATSGO soil types were comprised of natural soils. Pre-development wetland acreage estimates were computed from these latter, or “natural,” STATSGO soil types. This was accomplished by identifying which of the component specific soil types comprising each of the “natural” STATSGO soil types are wetland supporting (following the approach used on the SSURGO soils), calculating the sum of their percent composition in the STATSGO soil type, and multiplying that sum by the total acreage of each polygon belonging to that STATSGO soil type. The resulting acreage was added to the acreage derived directly from the SSURGO-based acreage estimate. This method was necessary in approximately 10% of the watershed.

3. No Soils Data Available

A third type of estimate was used for the remaining 7% of the watershed in areas located primarily in heavily-mined portions of the Alafia River basin and heavily urbanized portions of the City of Tampa and Pinellas County where no native soils data, SSURGO or STATSGO, were available. For these areas pre-development wetland acreages were estimated by extrapolation, multiplying the total area covered by each basin by the percent composition of wetlands based on the combined SSURGO-STATSGO estimate, and assuming that the same proportion of wetlands to all land areas holds true, proportionally increased the wetland and upland acreage to account for 100 percent of the basin area. In making this estimate of the final 7% of the watershed area it should be understood that the map depicting the location of freshwater wetlands in the pre-development condition makes no attempt to identify the location of these “extrapolated” wetlands.

RESULTS

The estimated pre-development extent of freshwater wetlands in the Tampa Bay watershed, generated using the soils-based approach described above, is shown in Figure 1 and Table 1. Wetland areas that could be reliably characterized as “herbaceous,” “mixed hardwood” or “cypress” based on specific or general soils data are identified as such. Upland areas and areas for which no soils data were available are identified as “no community defined.” Wetlands that may have existed within this “no community defined” zone were estimated based on a method of extrapolation.

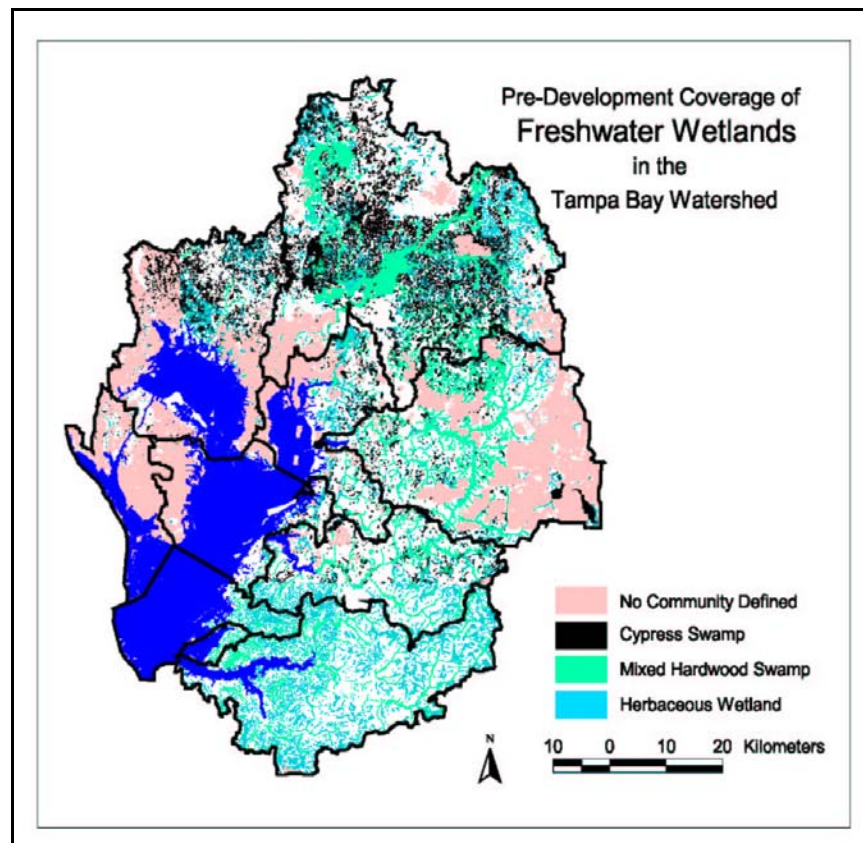


Figure 1. Pre-development coverage of freshwater wetlands in the Tampa Bay watershed.

Table 1. Estimated freshwater wetland area, pre-development and 1999.

SUB-BASIN	Pre-Development		1999		change		change %
	hectares	acres	hectares	acres	hectares	acres	
Hillsborough R.	57,329	141,660	37,756	93,295	-19,573	-48,365	-34.1 %
Alafia River	25,637	63,349	11,692	28,891	-13,945	-34,458	-54.4 %
Old Tampa Bay	21,719	53,668	8,521	21,055	-13,198	-32,612	-60.8 %
Manatee R.	17,350	42,872	11,311	27,949	-6,039	-14,922	-34.8 %
Little Manatee R.	11,666	28,827	7,671	18,955	-3,995	-9,872	-34.2 %
Hillsborough Bay	8,610	21,275	2,435	6,017	-6,175	-15,258	-71.7 %
Middle Tampa Bay	3,569	8,819	989	2,444	-2,580	-6,375	-72.3 %
Boca Ceiga Bay	3,056	7,551	212	524	-2,844	-7,028	-93.1 %
Lower Tampa Bay	1,692	4,181	1,245	3,076	-447	-1,105	-26.4 %
Tierra Ceia Bay	332	820	146	361	-186	-460	-56.0 %
TOTAL	150,960	373,022	81,978	202,568	-68,982	-170,455	-45.7 %

The largest areal coverage of the “no community defined” category occurs in the phosphate mining district of Polk and eastern Hillsborough counties and in older urban portions of the City of Tampa and Pinellas County, where extensive soil disturbance occurred during or prior to the early 1900s. Watershed areas affected by this data gap include the eastern and western portions of the Old Tampa Bay sub-basin, the lower Hillsborough River and western portions of the Coastal Hillsborough Bay sub-basin, and the majority of the Boca Ciega Bay sub-basin. The Alafia River sub-basin was significantly affected as a result of phosphate mining particularly in the upper reaches of both the north and south prongs of the river.

Estimated changes in the overall areal extent of freshwater wetlands between pre-development and present-day conditions, at the watershed and sub-basin scales, are summarized in Table 2. Estimated percent reductions in wetland extent ranged between 26 % (in the Coastal Lower Tampa Bay sub-basin) and 93 % (in the Boca Ciega Bay sub-basin), with a total estimated, watershed-wide reduction of 46 %.

Under pre-development conditions the soils data indicate that the Old Tampa Bay and Hillsborough River sub-basins contained considerable acreages of cypress stands (Figure 1) Mixed hardwood swamps were present in the inner portions of the major riverine systems including the Hillsborough River and its tributaries, the Alafia River and its distinct north and south prongs, the Little Manatee River, and to a lesser extent the Manatee River. Herbaceous wetlands were widely distributed in the Manatee River and the headwaters of the Alafia River and Hillsborough River sub-basins. Cypress stands appear to have been substantially reduced in several sub-basins, including the Hillsborough River with 13,378 ha. (33,058 ac.) lost, followed by Old Tampa Bay 7,513 ha. (18,565 ac.), Alafia River 4,678 ha. (11,559 ac.), the Little Manatee River 1610 ha. (3,977 ac.) and Hillsborough Bay with 1,868 ha. (4,617 ac.) lost.

The estimated pre-development areal extent of herbaceous freshwater wetlands was greatest in the Hillsborough River sub-basin, followed by the Manatee River, Old Tampa Bay, Little Manatee River, Hillsborough Bay and the Alafia River sub-basins, respectively. Four sub-basins appear to have experienced the greatest losses of freshwater herbaceous wetlands: Manatee River and Old Tampa Bay with greater than 7,000 ha. (17,000 ac.) each and the Little Manatee River and Hillsborough Bay with losses exceeding 3,000 ha. (7,000 ac.) each. The smallest estimated losses occurred in the Hillsborough River sub-basin which also contained the largest area of herbaceous wetlands under pre-development conditions.

Mixed hardwood wetlands represent the largest wetland type in the Tampa Bay watershed under both pre-development and current conditions. They also appear to have undergone

smaller coverage losses than herbaceous and cypress dominated wetlands at both the watershed and sub-basin scales (Figure 2). The Hillsborough River and Alafia River sub-basins contained almost 70% of the hardwood dominated wetlands under pre-development conditions and just under 60% of the hardwood wetlands in 1999 (Table 2). Our estimates suggest that substantial losses have also occurred in the Alafia River sub-basin, where nearly 50% of the predevelopment coverage has been lost. On a percentage basis, other notable losses have apparently occurred in the Boca Ceiga and Terra Ceia Bay sub-basins, but these are tempered by the fact that relatively small acreages existed in these sub-basins prior to development.

Table 2. Estimated changes in extent of wetlands within sub-basins, by dominant vegetation type.

HERBACEOUS	Pre-Development		1999		change		change
	hectares	acres	hectares	acres	hectares	acres	%
Hillsborough R.	11,520	28,468	9,686	23,933	-1,834	-4,535	-15.9%
Manatee R.	11,304	27,933	4,100	10,130	-7,204	-17,803	-63.7%
Old Tampa Bay	8,517	21,046	1,314	3,247	-7,203	-17,799	-84.6%
Little Manatee R.	5,089	12,575	1,823	4,505	-3,266	-8,070	-64.2%
Hillsborough Bay	4,107	10,150	1,096	2,707	-3,011	-7,443	-73.3%
Alafia River	3,323	8,212	2,159	5,335	-1,164	-2,877	-35.0%
Middle Tampa Bay	2,138	5,284	147	364	-1,991	-4,920	-93.1%
Lower Tampa Bay	1,115	2,757	185	456	-930	-2,301	-83.4%
Boca Ceiga Bay	983	2,430	35	87	-948	-2,343	-96.4%
Tierra Ceia Bay	93	230	25	62	-68	-168	-73.1%
TOTAL	48,189	119,085	20,570	50,826	-27,619	-68,259	-57.3%
CYPRESS-DOMINATED	Pre-Development		1999		change		change
	hectares	acres	hectares	acres	hectares	acres	%
Hillsborough R.	21,620	53,423	8,242	20,365	-13,378	-33,058	-61.9%
Old Tampa Bay	10,505	25,958	2,992	7,393	-7,513	-18,565	-71.5%
Alafia River	4,958	12,251	280	692	-4,678	-11,559	-94.4%
Little Manatee R.	1,927	4,761	317	784	-1,610	-3,977	-83.5%
Hillsborough Bay	1,910	4,720	42	103	-1,868	-4,617	-97.8%
Middle Tampa Bay	442	1,092	2	5	-440	-1,087	-99.5%
Boca Ceiga Bay	439	1,085	3	7	-436	-1,078	-99.3%
Lower Tampa Bay	0	0	2	4	2	4	increase
Manatee River	0	0	131	324	131	324	increase
Tierra Ceia Bay	0	0	0	0	0	0	increase
TOTAL	41,801	103,290	12,011	29,677	-29,790	-73,613	-71.3%
MIXED HARDWOOD DOMINATED	Pre-Development		1999		change		change
	hectares	acres	hectares	acres	hectares	acres	%
Hillsborough R.	24,189	59,770	19,828	48,996	-4,361	-10,774	-18.0%
Alafia River	17,355	42,885	9,253	22,864	-8,102	-20,021	-46.7%
Manatee River	6,045	14,938	7,080	17,495	1,035	2,557	17.1%
Little Manatee R.	4,650	11,490	5,530	13,665	880	2,175	18.9%
Old Tampa Bay	2,697	6,664	4,215	10,415	1,518	3,751	56.3%
Hillsborough Bay	2,592	6,406	1,298	3,207	-1,294	-3,199	-49.9%
Boca Ceiga	1,633	4,036	174	429	-1,459	-3,607	-89.3%
Middle Tampa Bay	989	2,443	840	2,076	-149	-367	-15.1%
Lower Tampa Bay	576	1,423	1,059	2,616	483	1,193	83.9%
Tierra Ceia Bay	239	590	121	299	-118	-291	-49.4%
TOTAL	60,965	150,645	49,398	122,062	-11,567	-28,583	-19.0%

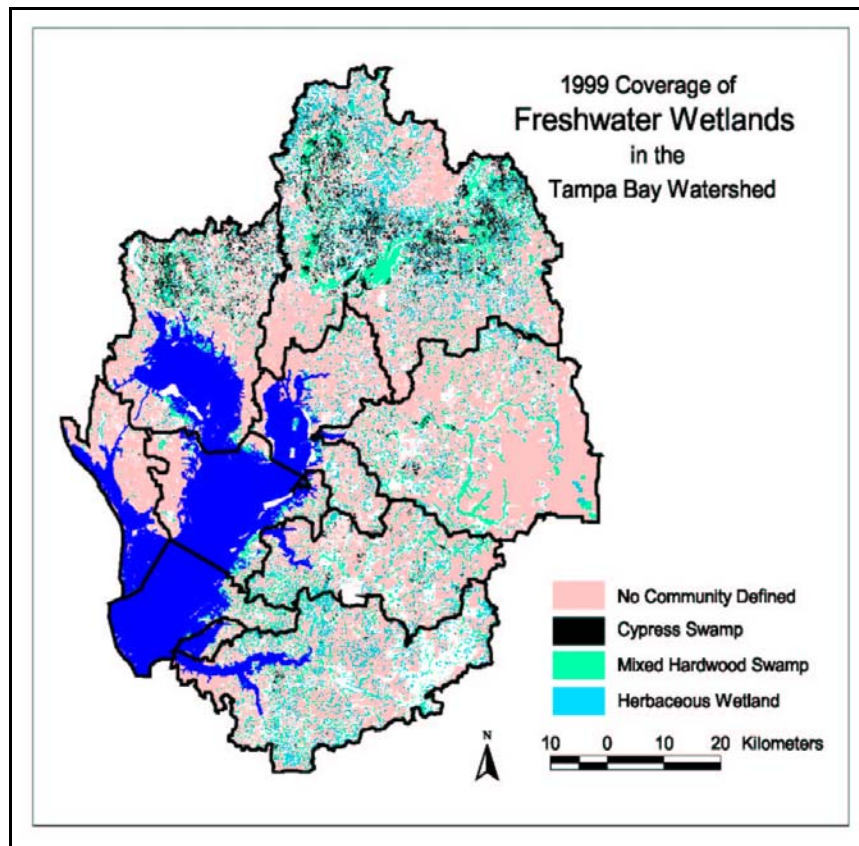


Figure 2. 1999 coverage of freshwater wetlands in the Tampa Bay watershed.

DISCUSSION

Nationally, in the 48 contiguous states, approximately 54% of the pre-development wetland acreage (or about 11 million acres) is estimated to have been lost between the mid-1950s and the mid-1970s (Frayer and Hefner, 1991). Frayer & Hefner also estimated that at a statewide level Florida has suffered similar percentage losses, which have occurred at an average rate of 72,000 acres per year during the period of the 1950s to 1970s. Much of Florida's wetland loss has been attributed to long-term impacts that have occurred in the Everglades, Lake Okeechobee and the Kissimmee River basin. In addition to these areas, however, extensive agricultural, urban and industrial developments have also caused wetland losses in other portions of the state.

The current study indicates that a substantial loss of freshwater wetland acreage has occurred over time in the Tampa Bay watershed. On a percentage basis certain sub-basins appear to have experienced disproportionately large losses, including Boca Ciega Bay (93%), coastal Middle Tampa Bay (72%), and Hillsborough Bay (72%). Estimated losses greater than 50% have also occurred in the Old Tampa Bay (61%), Terra Ceia Bay (56%), and the Alafia River (54%) sub-basins. Among the different freshwater wetland categories examined in this study, cypress-dominated systems appear to have experienced the most substantial reduction, estimated at 71% of the pre-development acreage on a watershed-wide basis. Caution is necessary, however, when interpreting our estimates of coverage changes in individual wetland types, such as cypress or mixed hardwood systems. The relatively simple methods we have used to estimate pre-development coverage have greater accuracy when applied to total wetland habitat, and less accuracy when applied to specific wetland types.

In addition to the overall magnitude of the estimated losses, the geographic distribution of freshwater wetland losses is also an issue of concern to resource managers. An example of this can be seen in the loss of freshwater marshes and prairies that once existed within the foraging areas of coastal-nesting wading birds such as the White Ibis (TBEP 1996, Paul 2003). One of the factors contributing to the state's listing of the White Ibis as a "species of special concern" is the necessity for nesting adults to have accessible freshwater wetlands as foraging sites where they can obtain prey for their nestlings (Kautz et. al. 1994). Maintenance and restoration of appropriate freshwater wetland habitats within the foraging areas of coastal-nesting wading birds could be an important factor in successful long-term management of these species.

Although the use of soils to estimate historic land cover appears to provide a reasonably accurate estimate of overall pre-development wetland coverage, a helpful next step in characterizing changes in the distribution and areal extent of wetland habitats in the Tampa Bay watershed would be the development of more accurate estimates of pre-development acreages of specific wetland types. Florida's initial public lands surveys, which laid out the townships and sections that remain in use today, left a detailed record of the environmental setting and habitat types that existed in the Tampa Bay watershed prior to intensive human alteration. These surveys were largely carried out during the 1840s and 1850s. A comprehensive reconstruction of historical wetland acreages based on those survey records would allow managers to develop more accurate estimates of the pre-development distribution of specific wetland categories, such as cypress-dominated and mixed hardwood systems. By providing more detailed information on the geographic distributions of specific wetland habitat types, the approach would provide helpful information for the selection and prioritization of future wetland conservation and restoration efforts.

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SOUTHWEST FLORIDA COASTAL CONSERVATION CORRIDOR PLAN FOR THE TAMPA BAY REGION

J. Beever & M. Bryant

ABSTRACT

The Southwest Florida Coastal Conservation Corridor Plan (CCCCP) is a detailed planning and protection initiative from Crystal River to Everglades National Park's Shark River Slough and east to the Lake Wales Ridge. The CCCC compiles, maps, and gathers biological, ecological, and hydrological data on natural lands critical for endangered species and habitat conservation. The CCCC has two phases: Scoping and Final Product. Work began in March 2000 and was completed July 2003. During Scoping, we compiled regional information from over 39 agencies and manifold published reports. The Nature Conservancy's knowledge of private land natural resource values formed a component of the analysis. The Final Product is a detailed GIS-based map series with narrative descriptions of the natural resources, and other site attributes. The CCCC encompasses all existing conservation lands, proposed conservation lands; county platted ownerships, existing public access points, existing conservation easements, and metadata of ownership information. The CCCC analysis of the map series and concomitant data layers generates a conservation corridor system along Florida's west coast including estuarine bays, lagoons, and tributaries. CCCC partners will work to implement the corridor system through various fee simple and less-than-fee conservation methods to sustain Southwest Florida's biological diversity, estuarine hydrology, watershed quality, and estuarine fisheries. Specifics of the Tampa Bay Regional Basin of the CCCC are the focus of this paper.

INTRODUCTION

The southwest coast of Florida was once a reticulate necklace of beautiful emerald, blue, and amber gems composed of an interlocked complex of bays, lagoons, inlets, sounds and harbors decorated with wetlands, submerged aquatic vegetation and coastal rivers supporting perhaps the most biologically diverse plant, fish, and wildlife populations in the continental United States. This entire system has been fragmented by habitat loss, water quality degradation, and hydrologic alterations and has lost much of its natural productivity from rapid growth and loss of habitat along the coast. State and federal agencies, local governments, conservation organizations, as well as the general public, overwhelmingly support programs and efforts that focus on the protection of the remaining coastal ecosystems.

Spanning almost 400 square miles, Tampa Bay is the largest open water estuary in the state of Florida and the second largest estuarine system along the entire Gulf Coast. The Tampa Bay ecosystem has suffered serious and widespread anthropogenic impacts over the last century, as described in the Tampa Bay National Estuary Program's Comprehensive Conservation and Management Plan. Since the turn of the century, over 80% of the natural sea grass community and 44% of the emergent wetlands along the coastal fringes of the bay have been lost due to development, shoreline and bay bottom alterations, wetland destruction and increased pollutant loading, leading to the gradual degradation of Tampa Bay. These habitats are crucial to the health of the bay and to the region's economy since they provide nursery areas for juvenile fish and shellfish of commercial and recreational importance, flood protection, stabilization of shorelines, and critical habitats for endangered wildlife.

The protection and restoration of coastal conservation corridor 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. Developed lands constitute 41.3% of the watershed (60% of all uplands). Based on soils, elevation, and hydrology, it can be 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 & 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 mapping of southwest Florida indicated that pine flatwoods have dropped to fifth in aerial 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 habitats with almost all of the coastal pine forest systems on the shores of Tampa Bay eliminated.

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-listed and state-listed species. Hayes (1991) determined that habitat destruction is a major factor which contributes to the status of threatened and endangered mammal species. The process of preserving species diversity through large scale habitat protection favors the listed species of the Tampa Bay region.

Coastal conservation corridor habitats are 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 local extinction (Dennis et. al. 1991). Coastal conservation corridor habitat planning is the process of identifying and protecting coastal conservation corridor habitat through proactive implementation methods.

MATERIALS AND METHODS

The Southwest Florida Coastal Conservation Corridor Plan (CCCCP) is a detailed conservation planning and protection initiative for a broad region of Southwest Florida including Charlotte, Citrus, Collier, DeSoto, Glades, Hardee, Hendry, Hernando, Highlands, Hillsborough, Lake, Lee, Manatee, Marion, mainland Monroe, Pasco, Pinellas, Polk, Sarasota, and Sumter Counties. The CCCC compiles, maps, and gathers biological, ecological, and hydrological data on natural lands critical for endangered species and habitat conservation.

The CCCC has two phases: Scoping and Final Product. Work began in March 2000 and was completed July 2003. During Scoping, we compiled regional information from over 39 agencies and manifold published reports. The work was undertaken by the Florida Chapter of The Nature Conservancy (FTNC), on behalf of the U.S. Fish and Wildlife Service (USFWS) through a contract administered by the State of Florida Department of Environmental Protection (FDEP). The geographic information system (GIS) compilation work was undertaken by the FTNC, on behalf of the FDEP, the Florida Fish and Wildlife Conservation Commission (FWC) and the USFWS. The primary author, with over 30 years of conservation experience in the southwest Florida region, acted as a leader of the CCCC effort, coordinated between and among regional workgroups and liaison throughout the study area and initiated multi-agency partnerships to develop restoration programs.

The work was divided into two phases, Scoping and Final Product. During Scoping, we compiled regional information from over 39 agencies and manifold published reports. Relevant information on the region included data from the Southwest Florida and South

Florida Water Management Districts, the State of Florida's Conservation and Recreation Lands program, the University of Florida's GeoPlan Center, the Coastal Zone Management program within the Department of Community Affairs, the Department of Environmental Protection's Division of Recreation and Parks and Office of Coastal and Aquatic Managed Areas, the Florida Natural Areas Inventory, the National Wetlands Inventory, the Florida Fish and Wildlife Conservation Commission, the U.S. Fish and Wildlife Service and their National Wildlife Refuge system, the National Park Service, the Florida Department of Transportation, local and regional governmental entities (i.e., counties, cities and regional planning councils) and a variety of published reports from varied sources. Wherever possible we utilized a wide variety of existing GIS mapping tools in the coastal conservation corridor habitat planning methodology including FWC Landsat habitat maps, false-color infrared aerial photographs, U.S. Soil Conservation Service maps, U.S. Geological Service maps, USFWS habitat mappings, National Wetland Inventory maps, maps produced by National Estuary Programs and Surface Water Improvement and Management (SWIM) Plan projects, FWC Strategic Habitat Conservation Area (SHCA) maps, FDEP Greenways maps, existing published and gray literature, and maps associated with development reviews including Developments of Regional Impact (DRI).

The FTNC's institutional knowledge of existing private lands and their natural resource values (including substantial data on rare species occurrences and high quality natural communities) also formed a component of the data layers brought together for the conservation analysis. Most of the data was sought and obtained in a GIS-ready format for rapid incorporation into the FTNC's GIS system.

The Florida west coast was divided into 9 Management Zones with regional coordinators to compile regionally significant information and coordinate regional involvement by agencies, organizations and the general public. The team leaders within these Management Zones assisted in the development of this plan and performed data collection in gap areas.

The identified Management Zones, with team leaders, are as follows:

- Big Cypress — Judy Haner, FDEP, Rookery Bay
- Caloosahatchee — Lynda Riley, Lee County
- Charlotte Harbor — Lisa Beever, Charlotte Harbor National Estuary Program (CHNEP)
- Estero/CREW — Heather Stafford, FDEP-Estero Bay
- Green Swamp — Marian Ryan, Sierra Club
- Myakka River/Sarasota Bay — Ed Freeman, Sarasota County and Gary Raulerson, Sarasota Bay National Estuary Program (SBNEP)
- Peace River — Brian Sodt, Central Florida Regional Planning Council (CFRPC)
- Springs Coast/Withlacoochee — Mercily Toledo, FDEP
- Tampa Bay — Suzanne Cooper, Tampa Bay Regional Planning Council (TBRPC) & Tampa Bay Agency on Bay Management

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 were identified as large preserve areas and habitat links (Figure 1). Large preserve areas and their linkages are essential to a coastal conservation corridor habitat system. Utility and abandoned easements and rights-of way were considered, where they

have appropriate habitat and location, to add width and continuity to the coastal conservation corridor habitats.

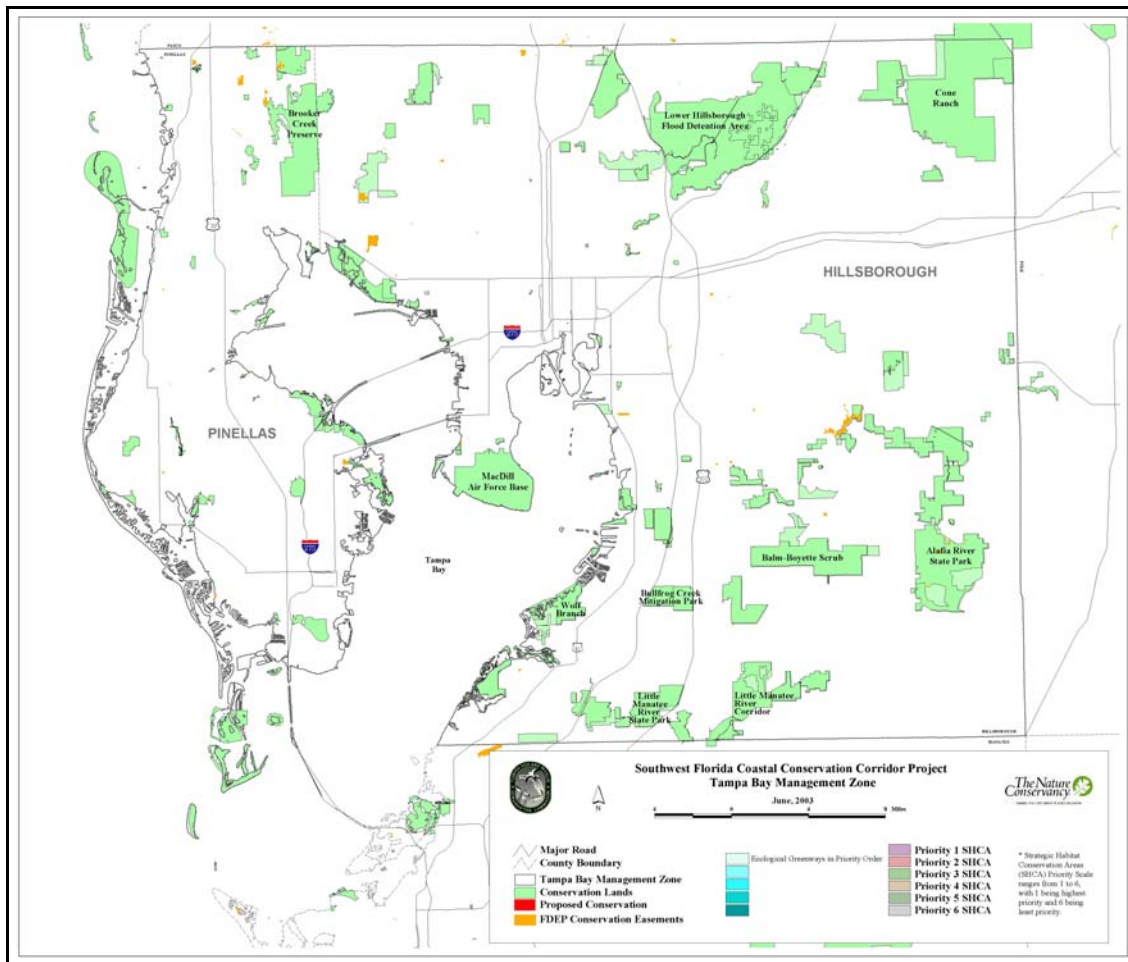


Figure 1. Existing conservation lands.

Proposed public and private lands that are designated for acquisition for conservation/preservation purposes were included when on a substantiated list such as Florida Forever, the Save Our Rivers (SOR) and SWIM programs, Preservation 2000, and county bond issues and capital improvements programs (Environmental Lands Acquisition Program, Pinellas County, etc.). Lands designated as preserves/conservation areas by the local governments in their comprehensive plans and lands designated by the Regional Planning Council in their Regional Comprehensive Plan were included. Lands under review or on candidate lists but not finalized or ranked were not included.

The 46 target animal species used to identify coastal conservation corridor habitat were derived from the FWC lists 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 were Florida black bear, Florida panther, river otter, bobcat, long-tailed weasel, Southeastern big-eared bat, Sherman's fox squirrel, Florida mouse, round-tailed muskrat, 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, peregrine falcon, southeastern American kestrel, eastern American kestrel, northern harrier, Audubon's crested caracara, burrowing owl, red-cockaded woodpecker, Florida scrub jay, Bachman's sparrow, Florida grasshopper sparrow, Atlantic green turtle, Atlantic loggerhead turtle, Suwannee cooter, gopher tortoise, eastern indigo snake, Florida pine snake, short-tailed snake, sand skink, American alligator, gopher frog, and common snook. Documented animal use areas and travel corridors were initially identified utilizing existing wildlife databases (FNAI, Florida Breeding Bird Atlas, FWC 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 by FWC biologists 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, including the FWC SHCA maps (Kautz 1989) (Figure 2) and the FDEP Greenways maps (Figure 3), these sites were field investigated and ground-truthed 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 FWC, including project review, habitat planning, and other research projects, suitable habitat was recorded and surveyed for target species. Subsequently, new data on areas of habitat and target species presence provided additional information to FWC mapping and databases that were not previously documented.

Where large tracts of suitable habitat and target species were present, expansions of existing preserves or new preserves were proposed. Where existing suitable habitat and target species were 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.

The Tampa Bay coastal conservation corridor habitat plan was coordinated with adjacent counties, municipalities, and regions to maintain inter-county/city wildlife habitat linkage and preserve connections. The CCCP has also identified or is identifying coastal conservation corridor habitat plans in all the counties of the Southwest Florida Regional Planning Council.

The coastal conservation corridor habitat plans for the counties adjacent to the north of southwest Florida are being developed. This Scoping Phase also included gathering similar information from the Florida panhandle region for incorporation into the USFWS funded North Gulf Initiative Project, as well as coordination between that project and the Southwest Florida Coastal Wetlands Conservation Plan. This coordination involved reviewing of components and issues addressed between the plans; reviewing GIS efforts for consistent appearance and layers; and review of both documents for completeness and consistency.

RESULTS

The final product is a detailed GIS-based map series with linked database, narrative descriptions of the natural resources, appropriate notes on field work and landowner contacts, rare/threatened/endangered species, and watersheds of the region of Florida's west coast extending from the Crystal River to Everglades National Park's Shark River Slough and east to the Marion Uplands and Lake Wales Ridge physiographic provinces. The final product allows analyses and multiple thematic prioritizations of the existing undeveloped/natural lands that are deemed critical for the conservation of the resources,

species and watersheds of this large region of Florida. The maps show all existing conservation lands (i.e., managed areas), proposed conservation lands (e.g. CARL, SOR, local government and grant projects), SHCA, FDEP Greenways, county platted ownerships, existing public access points, existing large scale development permits, conservation easements, and metadata of ownership information, including tract/parcel size in the study area.

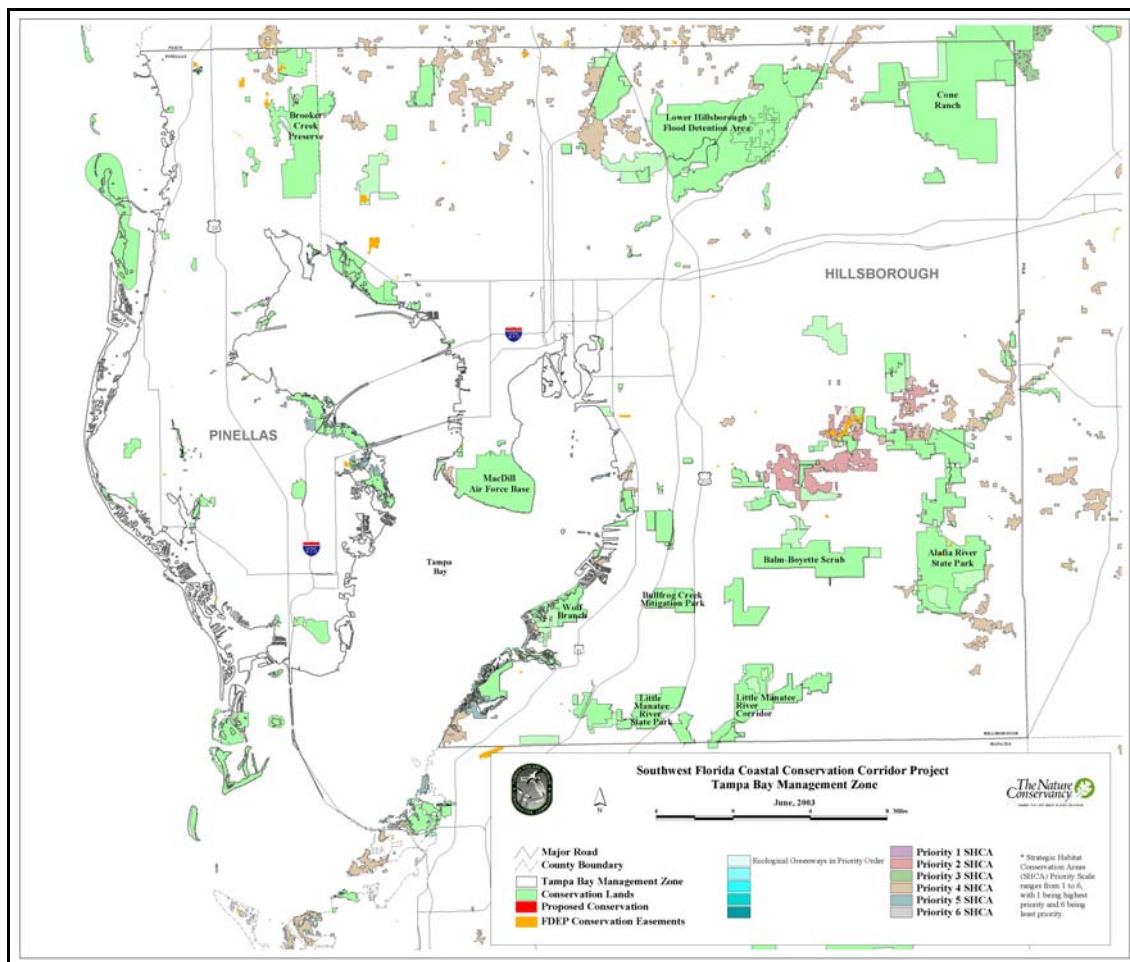


Figure 2. Existing conservation lands with strategic habitat conservation areas.

An analysis of these maps and concomitant data layers was performed to design a conservation corridor system along Florida's west coast (including inland watersheds) that form the key sites that should be protected through various fee simple and less-than-fee conservation options to sustain the region's natural resources, especially its biological diversity (including the myriad rare and endangered species and endemic taxa), hydrological and estuarine/fisheries values

The plan is dynamic. Updates and plan revisions will be completed annually, as funding permits, to show progress on implementation of the plan. This has generated a map series showing opportunities for landscape-scale connections and an interactive conservation database served via an internet map site.

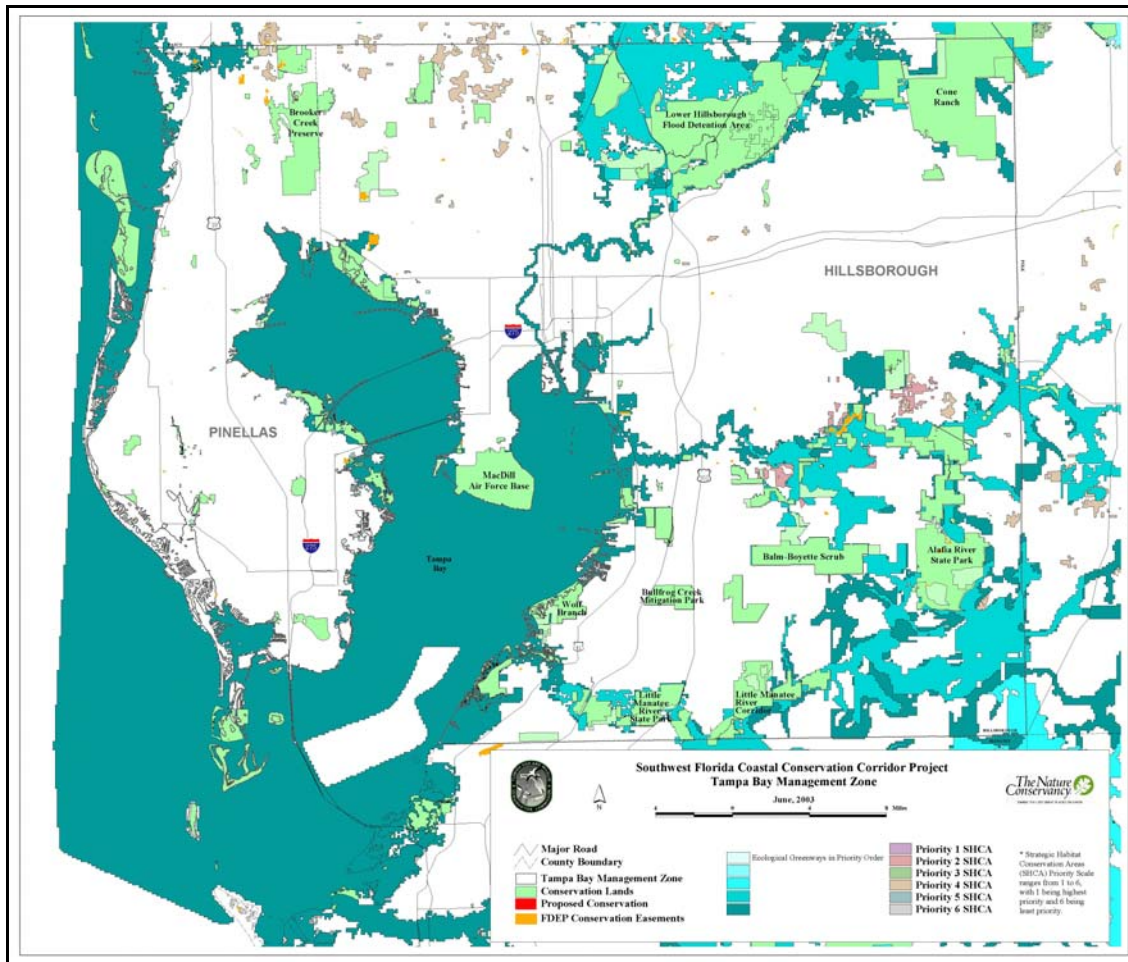


Figure 3. Existing conservation lands with strategic habitat conservation areas and the habitat greenways of the Southwest Florida Greenways Coordinating Council.

A composite map of the Tampa Bay Region Wildlife Corridor System as of August 2003 is presented in Figure 4. The Tampa Bay coastal conservation corridor 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 13 years of data collection and coastal conservation corridor habitat planning.

For the Tampa Bay Region, three general types of coastal conservation corridor habitat were identified: coastal, riverine, and large interior. The designated coastal corridors buffer and interconnect estuaries and their tributaries. This 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 forests. The Tampa Bay Region includes one of the least intact natural 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 relictual 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 Tampa Bay region's coastal scrubs. Only a small percentage of the Tampa Bay region's coastal wetlands and coastal uplands (Figure 1) are conserved by federal, state, local, and land trust ownership.

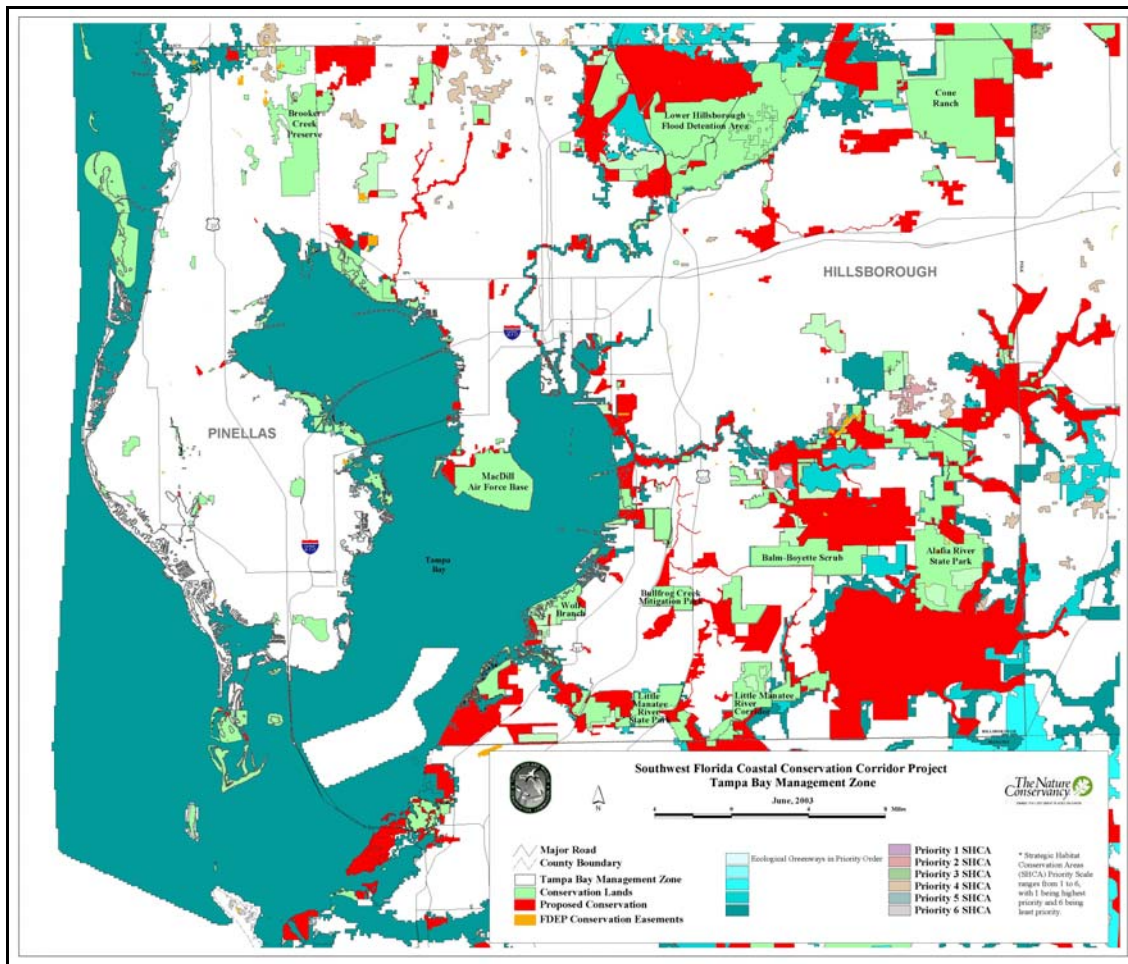


Figure 4. Targeted acquisition and protection areas indicated in red.

The designated riverine corridors are, by nature, 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 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. Hillsborough River, for example, is substantially developed at the 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 plan. Likewise, the Manatee River connects a wide variety of scrub, pine, and wetland habitats with the

coastal conservation corridor habitat of lower Tampa Bay. Other riverine systems provide similar critical links. Rivers that do not connect the coastal conservation corridor habitat to a large mammal coastal conservation corridor habitat are included if the riverine habitat system is intact and target species are present.

The designated interior corridors consist of large preserve areas and their linkages. Large interior corridors and typically an admixture of wetland and upland habitats, though smaller interior corridors are occasionally upland alone. The habitats included 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 interior corridor habitat. Both Florida panther and Florida black bear use forested systems, including cypress swamps, pine flatwoods, and hardwood associations (Belden et. al. 1988, Maeher 1984, Maeher 1986). Both species will travel along 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 new territory and/or mates (Maeher 1992). These habitats also correspond to habitats 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.

Five large preserve areas consisting of expansions and new preserves are recommended for the Tampa Bay Region. 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 counties, the Little Manatee River System linking eastward to the Peace River, the upper Manatee River system, and the Myakka River system of 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 were evident in existing databases and literature 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. The absence of information was exacerbated by entrenched paradigms that certain of these species were not present in or could not be present in portions of the Tampa Bay Region. Ongoing theoretical conflicts concerning the design of preserves (Levin 1993) has impaired practical implementation of the coastal conservation corridor habitat plan, while the listed species habitat under consideration is lost to development. In the Tampa Bay region, viable population theory, theoretical arguments about edge effects, conceptual attacks on wildlife corridors, habitat-centered versus species-centered protection methods and the single-large versus many-small preserves debate are routinely utilized by development interests and their consultants to oppose regional planning for wildlife and support fragmentation or outright loss of listed species habitats. Any disagreement among or between theoreticians is exploited to favor habitat loss or simple inaction on the premise that if the experts cannot agree there is no valid method of habitat protection.

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 values and functions sought. The Tampa Bay coastal conservation corridor habitat plan can serve as a tool to insure continuity among the various development preserves and conservation areas to avoid habitat fragmentation.

CONCLUSIONS

The Tampa Bay coastal conservation corridor 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, less-than-fee-simple 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 coastal conservation corridor habitat plan. Other portions of the plan have been nominated for P-2000, Florida Forever, and SOR acquisition projects by various entities. Several land developments, such as Fishhawk Ranch DRI, have incorporated wildlife corridors within the project design to address concerns for listed species and biodiversity. The Hillsborough River Greenways Project corresponds with portions of the Tampa Bay coastal conservation corridor habitat plan.

As the Tampa Bay coastal conservation corridor habitat plan takes physical form, recreational and tourism opportunities will be made 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 CCCP provides new opportunities for federal, state and regional governments to work together with local governments and the public sector in exploring and developing innovative programs for the protection of fish and wildlife resources. The Conservation Corridor is a realistic goal. There is a substantial amount of land already in public ownership, a substantial amount of planning has already been initiated and on the ground implementation is underway. Southwest Florida may be the only place in the state where such a project can be achieved, partly because of the proven public support and partly because of the amount of ecologically significant land still undeveloped.

In 1997, the U.S. Fish and Wildlife Service completed a strategic plan to conserve, protect, and enhance fish and wildlife and their habitats. Goal two of that plan is to establish an ecologically diverse network of land and waters of various ownerships to provide habitat for listed species. In partnerships with state and local governments, this goal can be expanded to include all fish and wildlife resources, including those resident species under state jurisdiction. The conservation of coastal resources along the Gulf Coast is unattainable without the support and unified efforts of both public and private sectors. A unified planning effort with state and federal agencies, local governments, private land owners,

non-governmental organizations and businesses will lead to improved coordination and cooperation and better implementation of all acts to protect coastal resources. The CCCP provides a partnership vehicle to synchronize comprehensive planning efforts by a host of independent partners. Numerous formal agreements currently existing between agencies and partners along the southwest coast of Florida and new formal agreements will help to consolidate the planning efforts. Furthermore, this initiative will identify current actions that are ongoing to acquire, enhance, restore, or protect coastal wetland resources and species that depend on them. This collaborative planning approach provides a multi-jurisdictional framework to involve more partners in the cooperative management of coastal habitat.

It is widely known that southwest Florida is a 'hot spot' for endangered and threatened plant and animal species. The Southwest Florida Conservation Corridor holds great promise. It will establish a multi-jurisdictionally governed partnership to manage a coastal corridor system composed of coastal wetlands, scrub habitat, maritime forests, palustrine pine flatwoods, riverine transition habitat and freshwater swamps. This partnership is based on cooperatively 'managed property' composed of refuges, aquatic preserves, estuarine research reserves, county and city owned lands, conservation easements, state managed areas, parks, etc., located from the Crystal River south through the Shark River Slough. The Southwest Florida Conservation Corridor will ensure a cooperative, balanced effort between government agencies, private groups and citizens. The resulting benefit would be several geographically and biologically defined corridor systems for hydrology, fish, wildlife and passive recreational opportunities.

As a component of the CCCP the Tampa Bay coastal conservation corridor habitat plan, with its preserve areas and linkages, will function as a fish and wildlife reservoir. With its implementation, the protection of coastal conservation corridor 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 the Tampa Bay region to continue to survive, to be enjoyed by residents, visitors, and future generations.

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SYNTHESIZING SEAGRASS MODELS: APPLICATION TO ECOLOGICAL FORECASTING

B. Robbins, M. Fonseca, E. Koch & A. Malhotra

INTRODUCTION

The literature is replete with studies detailing the importance of seagrass with nearly every published study extolling its virtue as habitat, refugia, etc. Although seagrass research has a long history beginning with an eelgrass study by Peterson published in 1891, the first mathematical model used to describe seagrass (*Zostera marina*) productivity was not published until 1980 (Short 1980), nearly a century after Peterson's seminal work. Short's modeling effort began with the creation of a conceptual model based on the Odum paradigm of energy flow diagrams followed by the development of a numerical model whose purpose was to begin synthesizing the immense body of seagrass data available in the literature. Short correctly argued, that models provide insight into the dynamic response of the ecosystem that is not apparent from instantaneous or time series measures. In addition, a model may be a reliable predictive, and thus a useful management, tool. Following is a brief discussion of a NOAA-funded research being conducted by the authors. The discussion can be divided into two parts. The first details the project's status after its first year, and the second is an introduction to a new (old) modeling tool being developed as part of this research.

RESEARCH

Our two-year project has two goals. The first is to synthesize information available on the dynamics of seagrass landscapes in response to anthropogenic stressors and natural variability. Here we define "landscape" as an integrated mosaic of habitats with seagrass as the habitat of interest. To reach our goal, we have completed an exhaustive review of the literature both electronic and paper, searching for manuscripts that outline models designed to represent seagrass dynamics across a variety of environmental conditions including those experiencing anthropogenic stress. Our product will be a synthetic critique of seagrass models that will include a comparative analysis of required input data, their spatial and temporal scales and restrictions, and the model's input and output.

Each model is being summarized in a table with the following eight criteria used for comparative purposes:

1. What seagrass species is/are being modeled?
2. What region was the model developed for?
3. Is the model a growth model? If so, what surrogate is used?
4. What physiological parameters are employed?
5. Is the model scale limited? What are these limitations?
6. Can the model be used to make an ecological forecast?
7. Is the model a unit, conceptual or statistical model?
8. Is the model a component of an integrated model or autonomous?

Also to be included in our synthesis will be a discussion of model types and their advantages and/or disadvantages. For example, often the simplest way to understand a complex system is through the use of a conceptual model, which may be as simple as a picture (Figure 1) or as complex as an Odum's energy flow diagram. Our critique will include a discussion of the benefits and drawbacks of these simplistic models as well as other model types (e.g. numerical, unit, integrated).

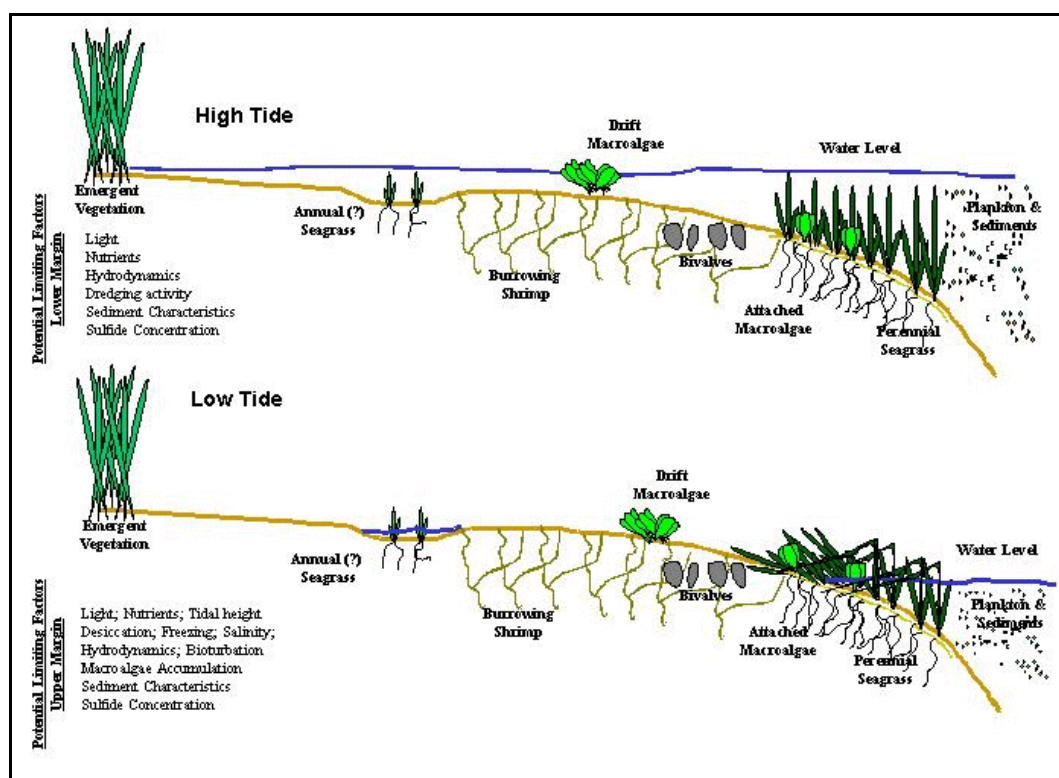


Figure 1. To better understand the dynamics of an estuarine seagrass landscape within the Yaquina Bay, OR, a conceptual model that included both intertidal (annual) and subtidal (perennial) *Zostera marina* populations along with other components of the landscape was developed (Robbins unpubl.). The model includes floral and faunal components and lists factors that are expected to “control” the system. This estuary typically experiences a 2 m tidal flux.

Our second goal is to utilize information from the published seagrass models we summarize (see above) to refine the REI (relative exposure index; see Robbins et al. 2002) algorithm, although we know that a strong relationship exists between REI, water depth, and the probability of seagrass occurrence (Figure 2). Specifically, we expect that we will be able to develop exclusion zones within an estuary based upon species-specific physiologically constraints of seagrasses. This portion of the study focuses on Chesapeake Bay and builds on our past attempts with an earlier version of this model (Chiscano 2000) to augment the current Exclusion Zone factors (Dennison et al. 1993). The Chesapeake Bay is an obvious choice for conducting this research because of its unusually long-term historical database of seagrass distribution and long fetches (*i.e.*, high wave exposure). Our approach is taken directly from our recent publications (Kelly 2001; Fonseca et al. 2002). We are utilizing georeferenced water quality data (e.g., light attenuation K_d , total suspended solids, chlorophyll *a*, DIN, DIP) available for Chesapeake Bay that link with output from the REI model, and conduct several analyses of forecasting strength. This process is ongoing.

We are also conducting an exercise to determine the appropriate scale at which to resample our historical data. To achieve this we have chosen three historical aerial photographs from each of our study estuaries (Chesapeake Bay, Core Sound, NC, and Tampa Bay, FL). Using three 2500 m² grids each with a different cell size (10 m, 25 m, and 50 m) we interpret a seagrass site within each photograph by assigning a binary value to each cell to indicate the absence (0) or presence (1) of seagrass. Following a statistical determination of “appropriate” scale, a minimum of 30 sites within each study estuary will be reinterpreted for seagrass and

these data will be compared to probability of seagrass as predicted by REI values (see Figure 2).

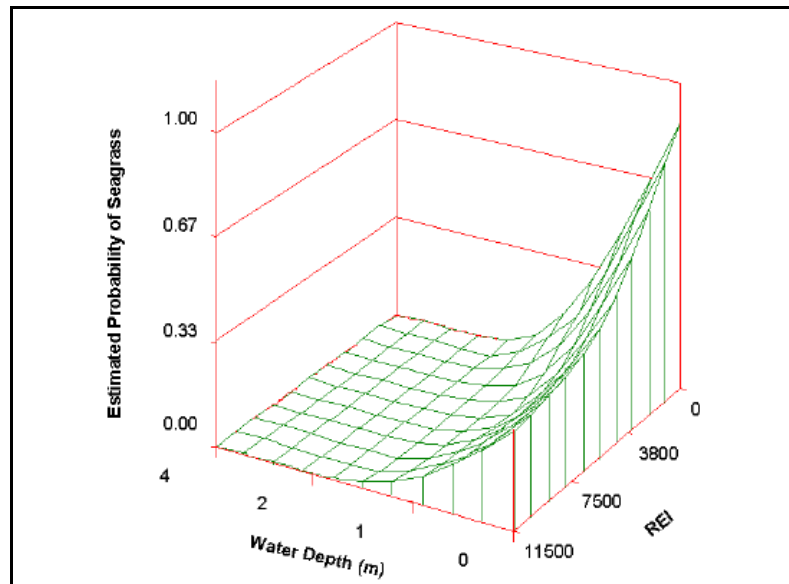


Figure 2: Splined response of probability of seagrass cover to water depth and REI values.

Following these exercises we will apply our model to our three estuaries to evaluate a suite of sites (minimum of 30 per estuary) within each as to their potential as seagrass restoration sites.

WEMo

Coupled with our desire to increase the sophistication and subsequently the predictive capability of the REI algorithm we also have an interest in simplifying the use of the model; thus the creation of the Wave Exposure Model (WEMo). The creation of WEMo from the REI model (a.k.a. NCCOS Hydrogeographic model) was not merely the result of a name change however. WEMo resulted from a collaborative effort over a number of years with several manuscripts (e.g. Fonseca and Bell 1998; Kelly et al. 2001; Fonseca et al. 2002; Robbins et al. 2002) produced along the way. Based on Keddy's 1984 research on wave exposures and freshwater macrophytes, the model originally used fetch (effective) and wind to calculate a relative exposure index (see Robbins et al. 2002 for full model description). To increase the model's predictive ability we incorporated water depth into the algorithm whereby effective fetch is weighted by water depth. For example, two sites with equal fetch distances would have different REI values if a shoal protected one while the other was adjacent to deep water. To make the model more user-friendly the algorithm was moved from ESRI's ARC/INFO aml language to Visual Basic resulting in the creation of a Windows-based GUI interface (Figure 3). Although still requiring some version of ARCView or ARCGIS, WEMo calculates REI values at specified locations as a means of predicting the amount of wave energy at each site.

Basically WEMo provides an interface that allows a researcher to develop a project that includes the dynamics of seagrass areal extent or the potential to restore seagrass to specific sites. The model requires the user to input four variables, a bathymetric grid (ARC-based), a shoreline (shapefile), wind data (duration and speed from the 8 major compass headings) and a file that defines georeferenced points or sites of interest. Model output includes a table

that lists the REI value for each point, a shapefile of the points, and a contour plot of interpolated REI values. Currently the contour plot has to be generated outside of WEMo using ARC or some other GIS software. REI values can be imported to one of the ESRI ARC products or another GIS package, where one can interpolate the REI values across the area of interest.

PROJECT STATUS

After completing our first year, we can report that our progress is proceeding albeit with an occasional bump. At this writing, WEMo is not ready yet for release and our critique is not yet completed; both should be completed by late summer 2004.

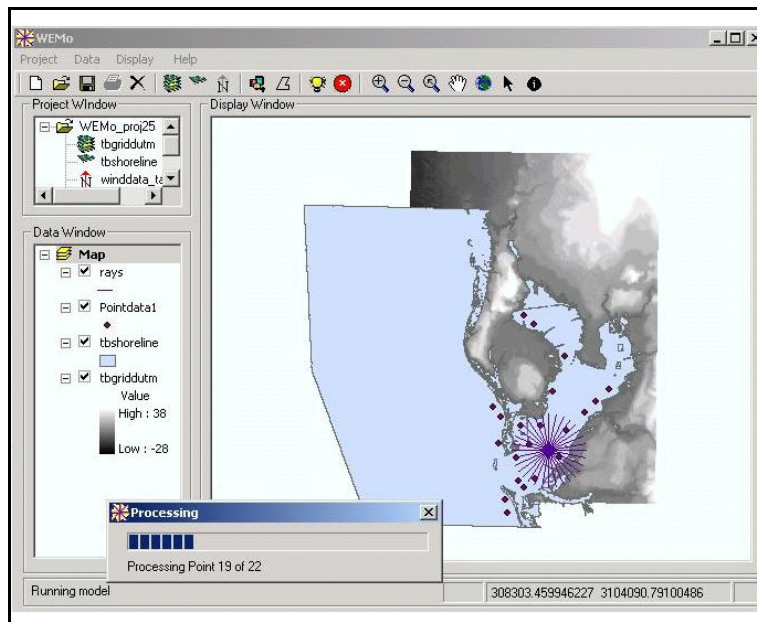


Figure 3: An illustration of WEMo's Windows-based GUI interface as the program draws a series of rays to compute effective fetch for Tampa Bay.

ACKNOWLEDGMENTS

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HABITAT SUITABILITY MODELING AND MAPPING: LINKING FISHERIES-INDEPENDENT DATA TO HABITATS IN TAMPA BAY AND CHARLOTTE HARBOR

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ABSTRACT

Habitat suitability modeling (HSM) was conducted by the Florida Marine Research Institute (FMRI), by using geographic information systems (GIS) to predict spatial distributions and relative abundance of estuarine fish species in Tampa Bay and in Charlotte Harbor, Florida. Environmental data collected by the FMRI Fisheries-Independent Monitoring (FIM) program and other sources were aggregated and interpolated to create seasonal habitat layers (surface and bottom) for salinity, temperature, and dissolved oxygen in each estuary. Depth was mapped by interpolation of NOAA bathymetry data. Bottom type was mapped using submerged-aquatic-vegetation (SAV) and bare-bottom categories. Seasonal habitat affinities were determined in each estuary by fitting splines to gear-standardized mean catch rates (CPUEs) across environmental gradients. CPUE values derived from the splines were assigned to the habitat layers by using the ArcView Spatial Analyst module within ArcGIS 8.3. The modeling was conducted across raster-based grid layers within the GIS to produce predicted seasonal HSM maps, depicting four suitability zones for each species' life stage. The output tabulated mean CPUEs (no. fish/m²) within each suitability zone and calculated the area of each zone in hectares. The models were verified by overlaying observed gear-corrected CPUEs (by latitude and longitude) onto the predicted HSM maps to determine whether observed mean CPUEs increased across the predicted suitability zones. Maps created from abundance indices within each estuary and transferred from the other estuary were used to test transferability of the models. Completed analyses for spotted seatrout (*Cynoscion nebulosus*), pinfish (*Lagodon rhomboides*), and bay anchovy (*Anchoa mitchilli*) produced from this research included mapped water-column and benthic habitats, suitability functions to explain the range of environmental conditions across which each life stage was most abundant and seasonal HSM maps predicting spatial distributions and relative abundance for each species life stage. The information can be used to manage estuarine species in relation to habitat conditions.

INTRODUCTION

Early attempts to link fish and "habitat" stem from the U.S. Fish and Wildlife Service's (FWS) Habitat Evaluation Program (FWS 1980). Suitability indices have been used as input to Habitat Suitability Index (HSI) models. Suitability curves are usually continuous functions fitted across environmental gradients. Unit-less suitability indices have generally been used in HSI models. Scaling suitability indices to the same maximum value (e.g., 1 or 10) results in each variable being given equal weight in the HSI model. When abundance-based suitability indices are used as input to the model, higher suitability values imply that areas with higher relative abundance in terms of numbers or biomass are "more suitable habitat."

In 1997, the Strategic Environmental Assessments Division within the National Ocean Service (NOS) of the National Oceanographic and Atmospheric Administration (NOAA) developed spatial HSI models for Casco Bay and Sheepscot Harbor, Maine (Brown et al. 2000) and Pensacola Bay, Florida (Clark et al. 2003). Suitability indices used as input to HSI models were developed based on expert opinion and information obtained from scientific literature.

Recent efforts at the Florida Marine Research Institute (FMRI) have focused on developing quantitative methods to link the institute's fisheries-independent monitoring (FIM) data (McMichael 1991, Nelson et al. 1997) to habitats mapped via GIS (Rubec et al. 1998, 1999, 2001, 2003). During the present study, we evaluated habitat suitability models (HSM), which is more general than HSI. Geometric means computed in the HSM, with mean CPUEs used as input (rather than scaled suitability indices), were used to create predicted seasonal maps for each species' life stage. This allowed for differential weighting of CPUEs in the model.

We recognized the potential of HSM models to predict the spatial distribution and relative abundance of a species' life stage in a nearby estuary lacking long-term fisheries monitoring. We wanted to determine whether suitability values could be transferred from one estuary to another without significant loss of precision and biological interpretability.

The present paper summarizes HSM analyses for spotted seatrout (*Cynoscion nebulosus*), pinfish (*Lagodon rhomboides*), and bay anchovy (*Anchoa mitchilli*) in Tampa Bay and Charlotte Harbor. (Tampa Bay and Charlotte Harbor were chosen for the present analyses based on the availability of comparable FIM data from both estuaries since 1989.) Our previous research found mixed results using 4- or 5-factor HSI models and 4- or 5-factor HSM models for juvenile and adult life stages of these species in the two estuaries (Rubec et al. 2001, 2003). Verification tests suggested that the models that used annual suitability functions worked well for juvenile pinfish, juvenile bay anchovy and, to some extent, early-juvenile spotted seatrout but not with adult pinfish, adult bay anchovy, and either late-juvenile or adult spotted seatrout. The present analyses used seasonal suitability functions to create predicted HSM maps.

METHODS

Study Area

Tampa Bay is the largest open-water estuary in Florida comprising 103,627 ha of open water and receiving drainage from a 569,950 ha watershed (Lewis and Estevez 1988). The estuary extends 56 km from north to south, is about 16.1 km wide near the mouth, and has a shoreline of about 393 km. The maximum water depth is 17.4 m, the mean depth is 3.4 m, and the tidal range averages 0.5 m. Tributaries to Tampa Bay include the Alafia, Little Manatee, Manatee, and Hillsborough rivers. The area analyzed in Tampa Bay and tributary rivers encompassed 101,999.5 ha. The bottom types found in Tampa Bay include seagrass, mangrove, salt marsh, bare bottom (mud/sand), hard-bottom, and oyster reef. More than 80% of the bay has mud or sand bottom.

Charlotte Harbor, situated on the west coast south of Tampa Bay, is the second largest open water estuary in Florida (Haddad and Hoffman 1988). It extends approximately 56 km from north to south, has an area of 92,000 ha, and 320 km of shoreline (excluding mangrove islands). The present study included the area sampled by the FIM program (53,113.4 ha) in northern Charlotte Harbor. Shallow water with depths less than 1.8 m predominates, and the tidal range averages 0.5 m. Bottom habitats similar to those found in Tampa Bay exist in Charlotte Harbor.

FIM Sampling

Ten principal types of sampling gear were used from 1989–2000 by the FIM sampling program (McMichael 1991; Nelson et al. 1997; Ault et al. 2002). One group of gear types had a mesh size of 3 mm (21-m seines, blocknet, dropnet, and trawl) and principally targeted smaller animals, whereas another group had mesh sizes ranging from 38 to 152 mm (183-m seines and gillnets) and targeted larger animals. For the period 1989–1995, sampling was conducted on a seasonal basis with emphasis on spring (March–May) and fall (September–November). From 1996 to 2000 sampling was done on a monthly basis at both fixed and randomly chosen station locations, using various types of gear that depended upon depth and habitat type (Nelson et al. 1997, Ault et al. 2002).

Changes in gears and FIM sampling effort within seasons over time created special problems. Because we wished to model and map species distributions and abundances across Tampa

Bay and Charlotte Harbor, it was necessary to create standardized FIM datasets and then develop methods to standardize catch-per-unit-effort (CPUE) among gear types.

Gear Standardization By Life Stages

Size ranges for species' life stages were chosen during 1999 from a review of the scientific literature or analyses of FIM length-frequency data, to determine the size attained by young-of-year (fish in their first year of life), juvenile (older than one year with < 50 % of population not sexually mature), and adult (length attained when 50 % or more of the population are sexually mature) life stages.

To use all survey data in a comprehensive analysis, sample CPUEs were standardized across gear types to create gear-correction factors (GCFs) by species' life stages by using a modification of Robson's (1966) "fishing power" estimation method (Ault and Smith 2000). Gear-corrected CPUE data sets for Tampa Bay and Charlotte Harbor were created for the following species and species life stages: early-juvenile (10–119 mm SL), late-juvenile (120–199 mm SL), and adult (≥ 200 mm SL) spotted seatrout; juvenile (10–99 mm SL) and adult (≥ 100 mm SL) pinfish; and juvenile (15–29 mm SL) and adult (≥ 30 mm SL) bay anchovy.

Sample Size

We analyzed data derived from FIM samples obtained from 1989 to mid-1997. The total number of samples obtained from Tampa Bay (7,220) was higher than from Charlotte Harbor (4,029) because Tampa Bay has a larger total area. The number of seasonal samples in both estuaries varied by species (depending on gear types combined) and was higher in spring and fall in Tampa Bay (range 1038–2522), and Charlotte Harbor (range 647–1559) than during summer and winter seasons in Tampa Bay (range 577–1408) and Charlotte Harbor (range 221–603), because fixed sampling was only conducted in spring and fall from 1989 to 1995. The sample numbers have been tabulated elsewhere (Rubec et al. 2003).

Seasonal Suitability Functions

Suitability functions were fitted to mean CPUEs across environmental gradients by species life stages within seasons in Tampa Bay and Charlotte Harbor. Gear-corrected CPUEs were computed from GCFs created by Ault and Smith (2000). Mean CPUEs were then determined within seasons across each environmental gradient. Splines (variable lambda) were fitted to unweighted mean CPUEs across gradients of salinity, temperature, dissolved oxygen, and depth. Mean CPUEs also were determined within bare/SAV bottom-type categories. The functions were presented on a CD-ROM (Rubec et al. 2003). The ranges (top 25 % of the curve estimated by eye) and the mode (where mean CPUEs were highest) for the suitability functions across each environmental gradient were tabulated. Each species' life stage was considered to show an "affinity" for the parts of each environmental gradient where CPUEs were highest.

Habitat Mapping

Habitat maps were created to depict seasonal conditions respectively within Tampa Bay and Charlotte Harbor using the ArcView Spatial Analyst extension to ArcGIS 8.3 (Rubec et al. 2003). Surface and bottom temperature, salinity, and dissolved oxygen data from the FIM database were supplemented with similar data from other agencies.

Environmental data were averaged within one nautical-mile-square FIM sampling grids (Rubec et al. 2001, 2003). Universal-linear kriging was used to interpolate monthly mean

temperatures, mean salinities, and mean dissolved oxygen values across sampling grids (subdivided into 18.5 m² cells) using a variable radius with 12 neighboring points (ESRI 1996). Surface and bottom temperature, salinity, and dissolved oxygen habitat layers were created for each estuary. Monthly layers for each estuary then were averaged using the Spatial Analyst map calculator to produce seasonal habitat layers for spring (March–May), summer (June–August), fall (September–November), and winter (December–February). The habitat layers created are presented on a CD-ROM (Rubec et al. 2003).

Areas with submerged aquatic vegetation (SAV) were determined from aerial photography conducted during 1996 in both estuaries (Rubec et al. 2001). Areas with rooted aquatic plants (e.g., seagrass) or marine macro-algae were coded as SAV, and remaining areas were coded as bare bottom prior to the creation of bottom-type layers for each estuary. Depth layers were derived by interpolation of NOAA/NOS NGDC bathymetry data using inverse distance weighting (IDW) with 8 neighboring points and a power of 2 (ESRI 1996). Larger datasets facilitated the use of IDW with bathymetry data.

HSM Models and Parameter Estimation

Suitability values (CPUEs) derived from the suitability functions were used as input to HSM. The CPUEs for environmental intervals (e.g., 1°C temperature, 1 g/L salinity, 1 m depth, 1 mg/L dissolved oxygen, bare or SAV bottom type) were assigned to habitat layers through the use of allocation tables within Spatial Analyst. Composite HSM values were computed as the geometric mean of the suitability values within each 18.5-m² cell of the habitat layers for n environmental factors. Each computed habitat suitability value (Equation 1) used abundance indices associated with five habitat layers.

$$HSM = (CPUE_i)^{1/n} \quad (1)$$

For bay anchovy, a pelagic species, we used surface-habitat layers for temperature, salinity, and dissolved oxygen along with depth and bottom type layers in the HSM. With spotted seatrout and pinfish bottom temperature, salinity, and dissolved oxygen layers were used with the layers for depth and bottom-type in the analyses. The predicted HSM grids were further classified into CPUE ranges to create four predicted HSM zones: low (0–2.49), moderate (2.50–4.99), high (5.00–7.49), and optimum (7.50–10.00).

Within Verification

We developed several measures of model performance (Rubec et al. 2001, 2003). The first evaluated the within-estuary correspondence between the predicted seasonal HSM zones and the mean observed CPUEs that fell within the predicted zones. If histograms of mean observed CPUEs increased from “low” to “optimum” HSM zones, then model performance was judged to be adequate.

Transfer Verification

A similar test of performance evaluated predictor relationships developed for one estuary in a reciprocal transfer of suitability values to the other estuary. The test evaluated whether observed CPUEs increased across predicted HSM zones when transferred from one estuary to the other (Rubec et al. 2001, 2003).

RESULTS

Seasonal Suitability Functions

Of the 280 seasonal suitability functions created for the life stages of the three species (Rubec et al. 2003) most were unimodal (dome-shaped), indicating higher habitat affinities

somewhere within the range of each environmental gradient. Some functions either decreased or increased across the gradient. There were also bimodal suitability functions. The suitability functions with narrow peaks indicated the most marked habitat affinity, whereas those with broad curves and flat peaks indicated a weaker affinity for the environmental variable in question. Generally speaking, pronounced seasonal habitat affinities (narrow peaks) were found for depth, bottom type, and dissolved oxygen (D.O.) for many species' life stages. Fitted functions across temperature and salinity gradients generally had broader peaks.

Early-Juvenile Seatrout

Early-juvenile spotted seatrout in Tampa Bay had an affinity (higher mean CPUE) for warmer water (28–34°C) during spring, summer, and fall, and for lower temperatures (6–10°C) during the winter (Rubec et al. 2003). Similarly, early-juvenile seatrout were found in warm water (27–32°C) in Charlotte Harbor during spring, summer, and fall, and moderately cool water (21–23°C) during winter. In Tampa Bay, suitability functions for salinity were different between seasons, being high in the spring, both low and moderate (bimodal) in the summer, moderately low in the fall, and both high and low (bimodal) in the winter. Peaks in the suitability functions were moderate (15–25 g/L) during spring and fall and somewhat higher in the winter (22–29 g/L). For D.O., the densities were generally high (10–14 mg/L) in spring, summer, and fall, and lower (5–9 mg/L) during the winter in Tampa Bay. In Charlotte Harbor, higher densities were in the low-end of the D.O. range (2–5 mg/L) during summer and winter in Charlotte Harbor, whereas they were high at both low and high parts of the D.O. range in the spring. Densities during the fall were highest at moderate D.O. levels (4–12 mg/L). For depth, early-juvenile seatrout were most abundant in shallow water (< 2m) during most seasons of the year in both estuaries. In Charlotte Harbor, the winter distribution was bimodal, with some fish also occurring in deeper water (2.5–3.5 m). There was a strong affinity for SAV in both estuaries during all seasons of the year, but in Charlotte Harbor, early-juvenile seatrout were found over both SAV and bare bottom during the winter.

The shapes of the seasonal suitability functions indicated that bottom type, depth, and salinity were the most important environmental variables influencing spatial distributions of early-juvenile spotted seatrout.

Late-Juvenile Seatrout

Late-juvenile spotted seatrout in Tampa Bay showed variable salinity affinities between seasons (Rubec et al. 2003). The suitability functions were bimodal during spring and winter, with late-juveniles having affinities for both low (10–16°C) and moderate (22–24°C) temperatures. During summer and fall seasons, they had affinities for higher temperatures (27–34°C). In Charlotte Harbor, the functions were flat during spring and winter, with small peaks indicating association with low temperatures (10–15°C). During summer and fall, the affinities were for moderate temperatures (22–28°C). With respect to salinity in Tampa Bay, late-juvenile seatrout were found associated with moderate salinities in spring (19–23 g/L), lower salinities (8–19 g/L) during summer and fall. The affinity during winter was flat with some indication of an affinity for higher salinities (25–30 g/L). In Charlotte Harbor, there was an affinity for low salinity (1–5 g/L) in the spring and fall, and for moderate salinities (15–30 g/L) during summer and winter. In Tampa Bay, late-juvenile seatrout showed no affinity for any range of D.O. (flat function) during the spring. The suitability affinities were bimodal with peaks shown for both low (0–1 mg/L) and high (7–14 mg/L) D.O. levels during both summer and fall. They occurred at moderate D.O. levels (5–7 mg/L) during the winter. In Charlotte Harbor, late-juvenile seatrout affinities for D.O. were high (9–13 mg/L) during the spring, moderate (5–10 mg/L) during summer and fall, and flat (no affinity) during the winter. Late-juvenile seatrout generally occurred in shallow water (< 2 m) in both Tampa Bay and

Charlotte Harbor during most seasons of the year. The suitability function was bimodal in Tampa Bay during the fall, indicating late-juvenile seatrout also occurred in deeper water (5–7 m). During winter, they occurred in deeper water (4–6 m) in Tampa Bay. There was no affinity for deeper water in Charlotte Harbor. Late-juvenile seatrout showed an affinity for bare bottom during most seasons of the year in both Tampa Bay and Charlotte Harbor. In Tampa Bay, they switched their affinity to SAV during the fall. In Charlotte Harbor, there was some affinity for SAV during the spring and an affinity for SAV during the summer.

Seasonal suitability functions indicated that salinity, depth, bottom type, and temperature were the most important environmental variables influencing spatial distributions of late-juvenile spotted seatrout in the two estuaries (Rubec et al. 2003).

Adult Spotted Seatrout

Adult spotted seatrout in Tampa Bay had an affinity for high water temperatures (30–34°C) during spring, summer, and fall (Rubec et al. 2003). The affinity was bimodal during the fall, with a secondary peak at 17–22°C. In winter, the peak was between 15 and 19°C. In Charlotte Harbor, affinities occurred at more moderate temperatures (20–30°C) during all seasons. In winter, the suitability function was bimodal, with a secondary peak occurring at 15–17°C. For salinity, adult seatrout in Tampa Bay showed an affinity for low salinity in the spring (5–10 g/L) and more moderate salinities during summer, fall, and winter (20–30 g/L). In winter, the function was bimodal, with adults also occurring at very low salinities (0–2 g/L). In Charlotte Harbor, adults had affinities for high salinity in the spring (28–33 g/L), moderate (16–20 g/L) and high (31–34 g/L) salinities in the summer, low salinity in the fall (7–13 g/L), and high salinity (32–34 g/L) during the winter. Dissolved oxygen affinities for adults were generally moderate (5–10 mg/L) for most seasons in both Tampa Bay and Charlotte Harbor. For depth, adult spotted seatrout were found in shallow water (< 1 m depth) during most seasons. In Tampa Bay, adults occurred in deeper water (mode 3 m) during the winter. Adult seatrout were most abundant over SAV during all four seasons. In Charlotte Harbor, they were most abundant over SAV during spring, fall, and winter, but in summer, adult seatrout switched their affinity to bare bottom. They also were abundant over bare bottom during the fall in Charlotte Harbor.

For the variables considered, the shape of the suitability functions indicated that bottom type, depth, and dissolved oxygen were the most important variables influencing the distributions of adult spotted seatrout in the two estuaries (Rubec et al. 2003).

Juvenile Bay Anchovy

Juvenile bay anchovy showed an affinity for warm water (26–30°C) during spring, summer, and fall, and with lower temperatures (15–20°C) in both Tampa Bay and Charlotte Harbor during the winter (Rubec et al. 2003). In Tampa Bay, juvenile anchovy were found in low-salinity (2–10 g/L) waters during all seasons. In Charlotte Harbor, the suitability functions were bimodal, indicating an affinity for both low (6–7 g/L) and moderate (15–20 g/L) salinities. Juvenile anchovy were found associated with the low-end of the D.O. range (3–4 mg/L) in spring and summer and with the mid range (6–10 mg/L) during fall and winter. They were most abundant in shallow water at depths < 2m during most seasons of the year. In Tampa Bay and Charlotte Harbor, they had an affinity for bare bottom during most seasons. They also were abundant over SAV during the fall in Tampa Bay and during the summer in Charlotte Harbor.

The shape of the suitability functions indicated that depth, bottom type, and salinity were important environmental variables influencing spatial distributions of juvenile bay anchovy in the two estuaries (Rubec et al. 2003).

Adult Bay Anchovy

Adult bay anchovy showed an affinity for warm water (28–32°C) during spring, summer, and fall and for lower temperatures (near 23°C) in the winter in both estuaries (Rubec et al. 2003). The anchovies' salinity affinity in Tampa Bay changed from being moderate in the spring (15–18 g/L) to more widespread (8–24 g/L) in summer and fall and to low (2–10 g/L) during the winter. In Tampa Bay, the affinity was for moderate salinities (15–25 g/L) in the spring and for the low salinities (5–10 g/L) in summer, fall, and winter. In Charlotte Harbor, the affinity peaked at 18 g/L in the spring and was lower (5–15 g/L) during the other seasons. With D.O., adult anchovy were found at the low end of the range (2–6 mg/L) during most seasons in Tampa Bay. The suitability function was bimodal during the fall indicating that adults were also found at mid-range D.O. (6–8 mg/L). In Charlotte Harbor, the adult anchovies' affinity was for low D.O. (3–8 mg/L) during the spring, but was indeterminate (flat) for the other seasons. Adult anchovy were most abundant in shallow water (< 2m) in both estuaries during all seasons of the year. They also occupied deeper water (3–5 m) in Tampa Bay during spring and summer. With bottom type, adults were most abundant over SAV for most seasons. In Tampa Bay, they also were abundant over bare bottom in the spring. In Charlotte Harbor, adult anchovy were abundant over both bare bottom and SAV during spring and fall and most abundant over bare bottom during the winter.

The shape of seasonal suitability functions indicated that salinity and bottom type were important environmental variables influencing spatial distributions of adult bay anchovy in the two estuaries (Rubec et al. 2003).

Juvenile Pinfish

Juvenile pinfish showed an affinity for low to moderate water temperatures (15–25°C) during spring and winter and for higher temperatures (26–36°C) in summer and fall in both estuaries (Rubec et al. 2003). Affinities of juvenile pinfish in Tampa Bay and Charlotte Harbor were in the high end of the salinity range (30–42 g/L) for all seasons, but some affinity for low salinity (bimodal distribution) was shown during the winter in Tampa Bay. Bimodal suitability functions for D.O. were found during spring, summer, and fall in Tampa Bay and during the spring in Charlotte Harbor, indicating that juvenile pinfish affinities for both the low and high ends of the D.O. gradient. Juvenile pinfish were found in shallow water (< 2 m) in both estuaries, although they tended to occupy somewhat deeper water in Charlotte Harbor (1–2 m) than in Tampa Bay (< 1 m) during the summer and fall. Juvenile pinfish were most abundant over SAV in the two estuaries during most seasons, but in Charlotte Harbor, they were more abundant over bare bottom during the fall.

The shape of seasonal suitability functions indicated that bottom type, salinity, and depth were important environmental variables influencing spatial distributions of juvenile pinfish in the two estuaries (Rubec et al. 2003).

Adult Pinfish

Adult pinfish showed affinities for lower water temperatures (15–20°C) during spring and winter and warmer water (30–36°C) during summer and fall in each estuary (Rubec et al. 2003). They were associated with high salinities (30–35 g/L) during all seasons in both estuaries. Adult pinfish in both estuaries were most abundant in the middle (6–9 mg/L) part of the D.O. gradient for most seasons, except in Tampa Bay, where they were most abundant

associated with low D.O. (1–4 mg/L) during the fall. Adult pinfish were prevalent in shallow water (< 2 m) during spring, summer, and fall and were more abundant in deeper water (2–8 m) during the winter. In Charlotte Harbor, they occupied shallow water (< 2 m) in spring and fall and deeper water (3–5 m) in summer and winter. Adult pinfish were generally most abundant over SAV for most seasons in both estuaries. In Charlotte Harbor during the summer, adults were most abundant over bare bottom; but were also abundant over SAV.

The shape of seasonal suitability functions indicated that salinity and bottom type were important environmental variables influencing spatial distributions of adult pinfish in the two estuaries (Rubec et al. 2003)

Predicted Habitat Maps

We created 52 habitat layers created to map seasonal surface and bottom patterns for temperatures, salinities, and dissolved oxygen as well as maps for bathymetry and bottom type in the two estuaries (see CD-ROM, Rubec et al. 2003).

Predicted HSM maps

We produced 112 seasonal HSM maps for the three species life stages (56 per estuary) presented on the CD-ROM (Rubec et al. 2003). Associated with each map were histograms depicting whether observed mean CPUEs increased across the predicted low to optimum zones and tables presenting observed mean CPUEs, and predicted mean CPUEs within each predicted zone. The areas for each predicted HSM zone in each estuary were presented in a third table in hectares (ha) and as percentages of the total area.

Within Verification

The within verification worked for most cases with early-juvenile, late-juvenile, and adult spotted seatrout and for adult bay anchovy, juvenile pinfish, and adult pinfish in both estuaries (Table 1). For Charlotte Harbor, mean CPUEs increased from low to optimum HSM zones for 82.1 % of the 28 predicted HSM maps produced using within-estuary habitat layers and suitability values. In Tampa Bay, increasing observed mean CPUEs across HSM zones occurred in 78.6% of 28 cases.

Table 1. Number of cases where increasing trends in observed mean CPUEs were found across HSM zones using suitability values derived from seasonal splines.

SPECIES	LIFE STAGE	Ratio (Yes) Scores Across Seasons			
		CHARLOTTE HARBOR		TAMPA BAY	
		Within	Transfer	Within	Transfer
Spotted seatrout	Early-juvenile	4/4	4/4	3/4	1/4
	Late-juvenile	3/4	0/4	3/4	2/4
	Adult	3/4	1/4	3/4	1/4
Bay anchovy	Juvenile	2/4	3/4	2/4	0/4
	Adult	3/4	4/4	4/4	3/4
Pinfish	Juvenile	4/4	3/4	3/4	4/4
	Adult	4/4	4/4	4/4	3/4
TOTALS		22/28 (82.1%)	18/28 (64.3%)	22/28 (78.6%)	14/28 (50.0%)

Within – map produced using habitat layers and suitability values from within the same estuary.

Transfer – map produced using habitat layers within the estuary and suitability values transferred from the other estuary.

Transfer Verification

The transfer verification test worked for most seasons with early-juvenile spotted seatrout and juvenile pinfish in Charlotte Harbor and for adult bay anchovy, juvenile pinfish, and adult pinfish in both estuaries (Table 1). In Charlotte Harbor, 64.3 % of 28 cases showed increasing observed mean CPUEs across suitability zones created from suitability values transferred from Tampa Bay. In Tampa Bay, increasing mean CPUEs occurred in 50.0% of 28 cases for predicted seasonal maps created from suitability values transferred from Charlotte Harbor.

DISCUSSION

The HSM analyses within each season used the same habitat layers associated with each species' life stage analyzed in either Tampa Bay or Charlotte Harbor. Hence, differences in predicted HSM maps within each season (within and transfer) result from differences in the suitability values going into the models.

Performance Criteria

Within Verification Test

Species life stages, such as late-juvenile and adult spotted seatrout, adult pinfish, and adult bay anchovy showed changes in habitat affinities between seasons (Rubec et al. 2003). For example, late-juvenile spotted seatrout were most abundant over bare bottom for most seasons but switched their affinity to SAV during the fall in Tampa Bay and to SAV during the summer in Charlotte Harbor. Although they were most abundant in shallow water (< 2 m) for most seasons, late-juvenile seatrout moved into deeper water during fall and winter in Tampa Bay. Seasonal suitability functions incorporated these changes in habitat affinities between seasons (Rubec et al. 2003).

The within-verification test (Table 1) worked for all species' life stages during spring and fall, except for juvenile anchovy in the spring. Mixed results were obtained during summer and winter. Less FIM sampling was conducted during summer and winter because fixed-station sampling was only conducted during spring and fall. In many cases, the abundance of a species' life stages declined during the winter. This can be ascertained by reference to the tables for zonal observed mean CPUEs produced associated with predicted seasonal habitat suitability maps (Rubec et al. 2003). These factors may explain why the within verification did not work for some species' life stages during summer and winter seasons.

Transfer Verification Test

In most cases, the transfer verification revealed fewer increasing CPUE relationships for species' life stages than the within verification did (Table 1). The transfer verification worked less frequently during summer and winter seasons because of the sample size and the relative abundance problems previously discussed for the within verification. Differences in the shape of the suitability functions across gradients between the two estuaries also appear to contribute to lower results with the transfer verification than with the within verification. Because of differences in recruitment between estuaries, it is unlikely that the HSM models can predict relative abundance (transfer verification) as well as models derived using data obtained from within the estuary would (within verification).

Smaller sample sizes in Charlotte Harbor may have reduced our ability to fit reliable seasonal suitability functions there. The smallest seasonal sample sizes were associated with adult spotted seatrout in Charlotte Harbor during summer and winter.

SUMMARY

We compared our results concerning habitat affinities for the species in our study with published literature (Rubec et al. 2003). Our findings were sometimes different because the literature often described the habitats where each species' life stage was usually found; but rarely quantified where species' life stages were most abundant across the entire estuarine gradient (i.e., across the salinity gradient). Our analytical methods have quantified these habitat associations.

We developed reliable methods for seasonally predicting spatial distributions and relative abundance by zones for life stages of estuarine species. The HSM output estimated mean CPUEs (no/m²) within four predicted HSM zones both in terms of observed mean CPUEs and predicted mean CPUEs. We also quantified the area in hectares for each of the suitability zones.

The present study went further than most by using HSM models with GIS to create seasonal within and transferred predicted HSM maps and by using verification analyses in the two estuaries. We used the geometric mean algorithm with the mean CPUEs associated with habitat layers in HSM models to predict long-term average spatial distributions and relative abundance of species life stages.

Habitat suitability models using the geometric mean algorithm provide insight on the potential distribution of a species (Brown et al. 2000, Clark et al. 2003, Rubec et al. 2003). The actual distribution of an animal and subsequent catch may be influenced by other factors, including anthropogenic and predator-prey interactions. The models provide a "first order" level of assessment to help determine the potential distribution of a particular species' life stages in relation to important habitats (Rubec et al. 2003). More sophisticated statistical HSM are planned, which may improve transferability between estuaries.

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ABSTRACTS
Session 4: HABITAT

PRESENTATIONS

Coastal Upland Habitats of the Tampa Bay Ecosystem: Status, Trends and Management Perspectives. R. Whitman, Jr. (Peninsula Design, Inc.). The Tampa Bay estuarine ecosystem historically provided a nexus to sustain commerce and associated coastal development. Initially, coastal development progressed through the elimination and degradation of native coastal upland habitats. As the area of upland habitat available to support development decreased, modification of wetland habitats to support coastal development progressed. Enactment of legislation during the last quarter of the past century to protect wetlands was effective in providing some level of conservation for these wetland systems. However, the lack of any contemporaneous legislation to provide meaningful conservation of upland habitats, facilitated development of these upland habitats, absent any preservation. More recently, the protection of quality upland habitats has received more attention, particularly at the state and local level. Previous regional investigations of the status and trends of uplands in the Tampa Bay area have documented increases in the areal extent of uplands, and a corresponding decrease in wetland habitats. 5644 hectares (13,946 acres) of mapped wetland habitat was converted to upland land uses between 1943 and 1982. Analyses of these data document a decrease in native upland plant assemblages and an increase in agricultural, urban, and residential land uses. Areas mapped as upland forest types decreased by 3558 hectares (8794 acres) during the period from 1972 to 1982. The continuing trend of fragmentation of remaining native habitats was also confirmed by serial analysis of habitat mapping size/frequency data. The results of these previous regional investigations are compared with additional spatial resources. Recommendations for establishing restoration target goals, and requisite restoration techniques for coastal upland resources of the Tampa Bay ecosystem are also discussed. [whit2end@gte.net]

Sea Level Variations in Tampa Bay. T. Edgar (USGS St. Petersburg), M. Crane (USGS Sioux Falls). Recent relative sea-level change along the west coast of Florida is well documented from tide gauge records at Key West, Naples, Ft. Myers, St. Petersburg, Clearwater Beach, Cedar Key, and Apalachicola. The records indicate changes ranging from 1.53–2.76 mm/yr (0.153–0.276 m/century). According to tide-gauge measurements, the annual relative sea-level change from 1947 to 1999 in Tampa Bay is about 2.4 mm/yr (0.24 m/century). Estimates of sea-level rise in Tampa Bay by the year 2115 center on about 0.65 m. Others demonstrated using archaeological and geological data that at about 1750 to 1450 BP sea level in the Naples area was about 0.75 m higher than present. Archaeological evidence in the Terra Ceia area of Tampa Bay also indicates a possible high stand of sea level (about + 0.30 m) at about the same time as at Naples. Historical and present digital-elevation models of Tampa Bay are used to demonstrate projected sea levels out to the year 2100. The various sea-level scenarios are discussed in terms of their potential impact on mangrove swamps, oyster beds, and wetlands, as well as their implications for environmental restoration of the Terra Ceia Aquatic and Buffer Preserve and management decisions pertaining to the Tampa Bay estuary. [tedgar@usgs.gov]

Tampa Bay Interactive Mapping System and Digital Library: Providing Accessible Data and Information for Management and Research. J. Johnston, K. Smith (USGS), A. Martucci, C. Cretini (Johnson Controls World Services, Inc.). Providing easy access to data and information is an essential component of both science and management. The Tampa Bay Digital Library and Interactive Mapping System (IMS) are two online resources for accessing Tampa Bay information. The Tampa Bay Digital Library is an Internet portal for data, documents, and other products. The library centralizes this information and was designed as a “one-stop-shop” for data and information on Tampa Bay. In addition, the Tampa Bay Interactive Mapping System is an Internet geographic data-viewing system. Geographic information systems (GIS) on the Internet provides GIS software to a wide audience and is a much more dynamic tool than a static map display or paper map. The IMS allows users to view, query, and analyze geographic data, such as land use, seagrass distribution, and temperature. Users can navigate around maps, overlay different layers, query databases, and print out maps - all through an interactive mapping interface. The Tampa Bay Digital Library and IMS are a combined effort to provide scientists and managers with the tools and resources to exchange data and ideas, as well as outreach tools for providing information to the public. Current efforts are to populate the digital library with USGS data and resources, find and create links to other Tampa Bay Internet resources, establish partnerships with local agencies and groups for distribution of their resources and products, and promote the digital library and IMS as tools for scientists, managers, and the public. [jimmy_johnston@usgs.gov]

Tampa Bay Historic and Current Aerial Imagery Website. T. Udouj, K. Madley (FWC Fla. Marine Research Inst.), H. Greening (Tampa Bay Estuary Program). Tampa Bay, Florida's largest open-water estuary, provides unique habitats for a variety of marine and terrestrial life. Urbanization and poor wastewater disposal practices degraded water quality for several decades. During the 1980s, federal and state legislative measures helped limit nutrient loads to the system, and the bay began to recover. The continued recovery of the bay depends on resource

managers effectively monitoring habitats and water quality. Easy access to data related to the historic and current conditions of the bay will enhance management efforts. The intent of this project is to provide resource managers, researchers, educators, and others a Web-based application to view and analyze historic and current digital files of aerial photography and maps of the Tampa Bay region.

This Web site brings the power of Geographic Information Systems (GIS) technology and image analysis tools to ordinary Internet browsers. The Tampa Bay Image Server will host an Internet Map Server (IMS) application for displaying and querying GIS data layers. The image analysis extension allows the user to overlay and compare aerial photographs of a particular site for different years. Users have the opportunity to inspect various study sites, visually evaluate benthic habitats and coastal land uses and land cover, assess spatial and temporal trends of benthic habitats, and examine coastal development throughout recent history. Users will also be able to download GIS data, aerial photography, and associated metadata. [tina.udouj@fwc.state.fl.us]

POSTERS

Using Seagrass Transect Data to Assess Aerial Photography of a Shallow Estuarine Shelf: A Preliminary Assessment. W. Avery, R. Johansson, K. Hennenfent, J. Pacowta, G. Pinson (City of Tampa Bay Study Group). The Tampa Bay Interagency Seagrass Monitoring Program has monitored submerged aquatic vegetation (SAV) distribution annually along 60 + transects since 1998. Graphics showing seagrass species distribution along several transects from the October 2001 monitoring were overlaid onto the respective 2002 vertical aerial photographs taken as part of the Southwest Florida Water Management District's Surface Water Improvement and Management section biennial assessment of Tampa Bay's seagrass coverage. Examinations from one transect in Hillsborough Bay, two transects in Middle Tampa Bay, and three transects in Old Tampa Bay suggest that a general agreement exists between SAV presence indicated by the photography and data generated through the transect monitoring. Therefore, it appears that seagrass abundance and species composition obtained from the transect monitoring program may be of use in the interpretation of aerial photographs used in seagrass management [Walt.Avery@ci.tampa.fl.us]

The Tampa Bay Mitigation Bank: A New Option for Wetland Mitigation in the Central Florida Region. B.F. Birkitt, B. Lane, A.B. Hodgson (Birkitt Environmental Services, Inc.) Wetland mitigation banking was authorized legislatively by the Federal Interagency Guidelines for Mitigation Banking (*Federal Register*, November 28, 1995) and by the state of Florida (Florida Statutes Chapter 373.4136). The Tampa Bay Mitigation Bank (TBMB) is the first mitigation bank approved in the Tampa Bay basin, and was developed in the headwaters of Cockroach Bay, Manatee County, in response to the regionally expanding need for freshwater and estuarine wetland mitigation. Recommendations established for the restoration of Tampa Bay wetland habitats in *Charting the Course for Tampa Bay: the Comprehensive Conservation and Management Plan for Tampa Bay* (1996) included the site proposed by Tampa Bay Mitigation Bank. The TBMB consists of historically agricultural ruderal land in southern Hillsborough County on the Cockroach Bay peninsula. Site development will be consistent with and expand on the Cockroach Bay Habitat Restoration Project, a SWIM (Surface Water Improvement) project undertaken by the Southwest Florida Water Management District and the Hillsborough County Environmental Lands Acquisition and Protection Program. The TBMB will restore 81.26 acres of freshwater wetlands, including approximately 3.9 acres of freshwater ponds (a declining habitat required for white ibis [*Eudocimus albus*] reproduction), 42.16 acres of tidal marsh/mangrove wetlands, and 34.01 acres of wetland hammock habitat. The TBMB plan was developed in concert with other public efforts to improve the ecological integrity of Cockroach Bay and is supported by the Cockroach Bay Restoration Alliance, Hillsborough County, and the Tampa Bay National Estuary Program. Scheduled for implementation in 2003, TBMB will restore historical habitats and provide water quality benefits to Cockroach Bay Aquatic Preserve and Tampa Bay. [ahodgson@birkitt.com]

Toward the Production of a Photographic Guide of Macroalgal Seagrass Epiphytes in Tampa Bay, Florida. T.O. Cho, S. Fredericq (Univ. of Louisiana at Lafayette, Dept. of Biology), K. Yates (USGS St. Petersburg). Blooms of macroalgae growing as epiphytes on *Thalassia testudinum* and *Syringodium filiforme* potentially have important economic and ecological consequences in Tampa Bay, one of the Gulf of Mexico's largest estuaries. To monitor the impact of environmental stress, precise characterization of epiphyte diversity is required for efficient management of affected resources. A main goal of this ongoing study is the determination of epiphytes as indicator species for both healthy and stressed seagrass bed environments, and the production of photographic guide illustrating the overall habit and diagnostic features of each seagrass epiphyte. Checklists, descriptions of species, distributional records, and illustrations of the taxa collected will be made available to marine biologists, resource managers, scientific and recreational divers, and will form the foundation for a much needed modern taxonomic database electronically accessible on the WWW. [slf9209@louisiana.edu]

Comparative DNA Sequence Analyses and Morphological Evidence Reveal a Diverse Marine Red Algal Flora in Tampa Bay, Florida. T.O. Cho, B.Y. Won, C.F. Gurgel, S. Fredericq (Univ. of Louisiana at Lafayette, Dept. of Biology), K. Yates (USGS St. Petersburg). Common macroalgal species reported from Tampa Bay include the red algae *Ceramium gracillimum* var. *buyssoideum* (as *C. flaccidum*) and *Centroceras clavulatum* (Ceramiales, Ceramiales) which grow epiphytically on *Thalassia testudinum* and *Syringodium filiforme*, and the drift alga *Gracilaria tikvahiae* (Gracilariaceae, Gracilariales). Morphological and DNA sequence analysis of these species reveal that 1) *C. gracillimum* var. *buyssoideum* belongs to a new genus separate from *Ceramium* on the basis of number of periaxial cells, cortical filament primordia and elongate unicellular rhizoids cut off from periaxial cells, that 2) *C. clavulatum* reported from Tampa Bay comprises two species distinct from the type specimen described from Peru, and that 3) three distinct species go under the name *G. tikvahiae*: *G. tikvahiae*, *G. secunda* and *G. venezuelensis*, with the latter two taxa newly recorded for Tampa Bay. The phylogenetic and biogeographic relationships of the marine flora in Tampa Bay are more diverse and complex than is generally appreciated. [slf9209@louisiana.edu]

Community Oyster Reef Restoration Programs in Tampa Bay. P.A. Clark, C. Sutton, E. Vichich (Tampa BayWatch, Inc.). Tampa BayWatch has begun a series of community-based habitat restoration and enhancement programs to create oyster bars on spoil islands, natural shorelines and urbanized seawalled areas. Oyster communities help stabilize shorelines, provide hard bottom habitats for fish and wildlife resources and promote water quality improvements through natural filtration. The Community Oyster Reef Enhancement (CORE) program uses fossilized oyster shell to construct reefs similar in structure to natural oyster communities found along shoreline areas throughout Tampa Bay. Fossilized oyster shell is purchased from an area shell mine and delivered to the closest boat ramp the day before the event. On the day of the construction, the shell is shoveled into 12 gallon buckets or 20" shell bags by community volunteers and transported by boaters to shoreline areas where it is placed intertidally to attract oyster spat.

Tampa BayWatch's Seawall Oyster Reef Program is designed to promote the growth of oysters along urbanized canals in Tampa Bay. Residential finger fill construction has left extensive shoreline areas devoid of natural communities. Canals are often too deep for mangrove or saltmarsh establishment and have unsuitable water quality for seagrass growth. Marine friendly concrete oyster domes are constructed by community and youth groups and placed at the toe of seawalls in permitted locations to facilitate oyster settlement. These newly created oyster bars and seawall reefs benefit Tampa Bay by improving water quality through biological filtering of the water, providing habitat for small organisms, preventing further erosion, and creating foraging areas and sanctuary for many species of fish and wildlife. The projects also benefit the community by promoting environmental awareness and offering hands on experience in habitat restoration. [Pclark@TampaBayWatch.org]

Effects of Thermal Effluent on the Benthos of the Big Bend Area of Hillsborough Bay. J.K. Culter, J.M. Sprinkle (Mote Marine Laboratory). The Hillsborough Bay, Big Bend area benthos was sampled to evaluate potential thermal impacts from the Tampa Electric Company facility, in October 1997 and March 1999. Macroinfauna were sampled within six areas; discharge canal, north Apollo Bay, two thermal sites and a north and south control.

Thermal effects could only be detected within the Discharge Canal, Apollo Bay, and to a much lesser extent the nearshore Thermal I area. Thermal discharge elicited opposite benthic responses for summer and winter months. For October Apollo Bay had the greatest benthic faunal abundance, the North Control the lowest abundance. For March the Discharge Canal and Apollo Bay exhibited much greater abundance than any other areas. Faunal abundance within the Discharge Canal in March was 8 times as great as the faunal abundance within the South Control. Faunal abundance for Apollo Bay in March was 6.9 times as great as faunal abundance within the South Control.

- Stress indicator species occurred in abundance within the Discharge Canal and Apollo Bay; however, desirable fish prey items were also abundant.
- Above ambient temperatures in winter enhance species richness and faunal abundance within the Discharge Canal and Apollo Bay.
- Sediment differences, elevated organic matter and silt, accounted for some of the faunal differences between the Discharge and Apollo Bay from other monitoring areas.
- Between seasons thermal areas exhibited a greater change in species compositions than non-thermal areas.

The conclusions are compatible with the thermal plume delineations, which indicated bottom thermal water occurred primarily within Apollo Bay and affects only small areas of Hillsborough Bay. [jculter@mote.org]

Seagrass Scarring in Tampa Bay: Impact Analysis and Management Options. E. Fehrmann (Pinellas Co. Dept. of Environmental Mgt.). Scarring of seagrass beds, has occurred throughout Tampa Bay and as a result, several groups have taken steps to document the impacts and regulate access within some of the remaining areas of seagrass coverage. Pinellas County has had much success with the implementation of motorboat restriction strategies. Pinellas County's initiatives began in the mid-1980s and involved a coalition of regulatory and citizen representatives. By 1992 an ordinance was adopted that delineated areas of seagrass protection as well as a plan to study the effects of the ordinance for 5 years. Protection levels included "Seagrass Caution" areas, which allowed motorized travel, but damage to seagrass could result in monetary fines, and "Motor Exclusion" areas, which prohibited internal combustion motor use entirely. Upon placement of signage in the Management Area, the rate of increase of new scars was considerably reduced in the Seagrass Caution and Exclusion zones as compared with the control area. The study, that actually spanned 7 years, determined that Seagrass Caution and Exclusion zones both exhibit high levels of protection for the resource, thus reducing the need for some Exclusion Zones. This finding has allowed the County to modify its areas of protection to allow increased use of the areas while maintaining seagrass integrity. The areas that previously had no regulation (control areas in the study) were designated as Seagrass Caution zones to protect seagrass and assist in recovery. Since 1992, the cumulative cost of seagrass protection in the Ft. DeSoto and Weedon Island Management Areas has exceeded \$2,000,000. [efehrmann@pinellas.co.fl.us]

Ten-Year Perspective on Community-Based Salt Marsh Restoration in Tampa Bay. M.B. Garcia, P.A. Clark, S. Deitche (Tampa BayWatch). After a century of intensive shoreline development, the character and ecology of Tampa Bay and its tributaries have been significantly altered. Coastal wetland losses have exacerbated shoreline erosion and reduced water quality, resulting in major declines of fisheries and wildlife dependent on these habitats. Nearly half of all the mangrove forests and saltmarshes that once existed in the Tampa Bay estuary have been destroyed.

The Tampa Bay community has acknowledged the tremendous loss of habitat and decline in estuarine conditions and responded by undertaking numerous management, permitting and restoration programs to facilitate the recovery of the bay. Over the last ten years Tampa BayWatch has supported these efforts by establishing a program to coordinate community based salt marsh planting projects currently being accomplished by many federal, state and local governments. Community planting events provide the opportunity to mobilize 350 + volunteers who can install 25,000 new plants into new coastal tidal ponds, providing hands-on environmental stewardship.

Additionally, Tampa BayWatch created a program to construct salt marsh nurseries within 15 middle and high schools. The students build each nursery, install plants, monitor health and then transplant the nursery grown grasses into restoration projects. The nursery program currently cultivates 90,000 plants, potentially providing enough grasses to create 15 new acres of salt marsh each year. Our "Bay Grasses in Classes" program teaches students the value of maintaining a healthy environment while promoting environmental education and hands-on involvement in habitat restoration activities. [mgarcia@tampabaywatch.org]

Linkage of Benthic Community Structure with Sediment Contaminants in Tampa Bay. S.A. Grabe, D.J. Karlen, J. Barron, S. Perez, C. Holden, B. Goetting, T. Dix, S. Markham (Environmental Protection Commission of Hillsborough Co.). The relationship between benthic community structure and sediment contaminant concentrations in Tampa Bay's seven primary bay segments and four tributaries was examined. A subset of variables and their association with benthic structure (using Spearman rank correlation coefficients) was developed for each bay segment and tributary using data available for the period 1993-2001. Generally, sediment contaminants were only weakly correlated with benthic community structure. [grabe@epchc.org]

Depth Distribution and Potential Light Availability of Dominant Seagrass Species along Permanent Transects in the Upper Segments of Tampa Bay, Florida. K.B. Hennenfent, J.J. Pacowta, J.O.R. Johansson, W.M. Avery, E.V. Pinson (City of Tampa Bay Study Group). Tampa Bay seagrass density and species distribution has been monitored annually since 1997 along 60 + permanent transects by a group of local agencies, directed by the Tampa Bay Estuary Program. Generally the transects start at the shoreline, traverse the shallow estuarine shelf, and end in a water depth of 2m or deeper. Several of these transects located in the upper segments of the bay were selected for detailed and accurate measurements of depth utilizing high-resolution differential GPS. The depth profiles of the transects were combined with the seagrass monitoring information to determine the depth range for meadows of the three dominant seagrass species found in the bay: *Halodule wrightii*, *Syringodium filiforme*, and *Thalassia testudinum*. Further, light attenuation measurements from long-term water quality monitoring programs and the measured seagrass depth ranges were used to calculate the potential amount of subsurface incident light available

to the seagrass meadows. Seagrass species density and depth distribution information combined with light availability information, as has been generated for several of the Tampa Bay transects, provide a powerful seagrass management tool. [Walt.Avery@ ci.tampa.fl.us]

Tampa Bay Mini-Grants: Empowering Citizens in Bay Restoration and Education. R. Hosler (Tampa Bay Estuary Program). The goal of the Bay Mini-Grant program is to empower citizens in community-based restoration and education projects focusing on the Tampa Bay estuary. Programs such as this foster an environmental ethic and community stewardship of the bay. Mini-Grant projects must address bay-related problems and priority issues such as water quality, habitat restoration, fish and wildlife conservation, bay awareness and education, dredged-material management, spill prevention, and invasive species as identified in the Comprehensive Conservation and Management Plan for Tampa Bay, "*Charting the Course*."

In 1994, the Tampa Bay Estuary Program (TBEP) awarded the first nine Mini-Grant projects intended to improve the waters of Tampa Bay and its coastal habitats. Those nine grants totaled approximately \$25,000. Since 1998, the Bay Mini-Grant program has expanded dramatically, awarding 63 grants totaling \$266,000 to almost every type of civic and community group. Recipients often partnered with a local government or other community organization to maximize the value and impact of their projects. Countless volunteer hours and in-kind match provide additional "bang for the buck" for these grassroots Tampa Bay restoration and education projects.

Since 2000, the program has been funded completely by revenues from sales of the Tampa Bay Estuary specialty license plate; also known as the "Tarpon Tag." As the sales of specialty plates have continued to climb, it is anticipated that more than \$120,000 in Mini-Grants will be awarded this December. [ron@tbep.org]

Annual Distribution and Ecology of Spionid Polychaetes in Tampa Bay: 1993–2001. D.J. Karlen, T.L. Dix; S.A. Grabe; B.A. Goetting; C.M. Holden; S.E. Markham (Environmental Protection Commission of Hillsborough Co.). The polychaete family spionidae is one of the most ubiquitous taxa in estuaries, occupying a diverse range of habitats and are considered good indicators of stressed environments. The Environmental Protection Commission of Hillsborough County, under the auspices of the Tampa Bay Estuary Program, has been collecting samples throughout Tampa Bay and its tributaries since 1993. Samples were collected annually from August to mid-October. Over 1,500 samples were collected between 1993–2001 and analyzed for benthic species composition. A total of 31 species of spionids were identified, with the five most abundant taxa accounting for 85% of the cumulative abundance for this family. These taxa included: *Carazziella hobsonae* (25.85%), *Prionospio perkinsi* (23.14%), *Paraprionospio pinnata* (14.94%), *Streblospio cf. gynobranchiata* (14.57%) and *Prionospio heterobranchia* (6.70%). Distributions of the dominant taxa and corresponding hydrographic and sediment characteristics will be presented. [karlen@epchc.org]

Community Structure and Habitat Use by Fish Assemblages in Altered Wetlands: Ecological Repercussions of Ditching Wetlands for Mosquito Control. J.M. Krebs, A.B. Brame, C.C. McIvor (USGS Ctr. for Coastal and Watershed Studies). Salt marsh and mangrove wetlands serve as critical habitat for numerous fish species of ecological and economic importance. Habitat modification through mosquito control ditching undoubtedly alters the hydrological and geomorphological characteristics of these systems. Linearly-ditched channels with their steep, spoil-lined banks create submerged habitats atypical of natural wetlands and may render portions of the marsh surface inaccessible to fishes. We will assess potential differences between natural and altered wetlands in Tampa Bay and the effects of these differences on fish communities.

In order to determine the magnitude of functional equivalency between natural wetland habitats and those altered by ditches, sample sites were chosen randomly at county preserves: Mobbly Bayou, Weedon Island and Terra Ceia. Sample sites in creeks, ditches and ponds within the preserves will be characterized by documenting: width, length, bottom profile, substrate type/depth, water depth, flow, and quality, and shoreline/bottom vegetation. Faunal community structure will be described for each habitat by identifying and enumerating fish and invertebrate species collected in replicate seine samples. Subsamples of each species will be retained for length/weight measurements and for biomass estimation. Differences in species abundance, composition, and diversity, as well as size structure and overall biomass will be used to define community structure. Finally, habitat characteristics influencing fish community structure will be delineated using multivariate statistics. In addition to enhancing our knowledge of habitat function for fish communities, study results will be applied to guide restoration within county preserves and to assist with a model of ecosystem processes in the estuary. [jkrebs@usgs.gov]

Scuba Scouts Monitoring. D. Olson. Scuba Scouts is a group of Boy Scouts and Girl Scouts who are conducting a Coral Reef Monitoring Program as part of the natural gas pipeline project recently implemented in the Bay and the Gulf. The scouts, under the tutelage of Dr. Jaap of FMRI, have been involved in this program for 2 years now. More detailed information can be provided on their website scubascouts.org. [drolson122@aol.com]

Freshwater Inflow Effects on Salinity Preference, Growth Rate and Survival of Bay Anchovy Juveniles. E.B. Peebles (Univ. of So. Fla. College of Marine Science), R.E. Bishop (Penn. State Univ. Dept. of Biology). Monthly transects along the salinity gradients of eight tidal rivers in west-central Florida were used to describe the salinity distributions of bay anchovy (*Anchoa mitchilli*) juveniles (15–30 mm standard length). The anchovy salinity distributions were primarily determined by the ambient salinity of the transects, indicating that sampling bias can have a profound effect on estimates of the salinity preferences of estuarine organisms. Even with this bias removed by regression, preferred salinities were found to vary widely (> 15 psu) among rivers and over time within rivers (El Niño vs. La Niña years). In the Manatee River estuary, growth rates decreased during droughts and increased following isolated inflow peaks. Individuals with the highest lifetime exposure to inflow had the fastest growth rates. Accordingly, large individuals (> 30 mm) comprised a larger proportion of the total catch following months with high mean inflow rates ($r = 0.63$, $n = 16$, $p = 0.009$). This relationship became stronger ($r = 0.81$, $n = 16$, $p = 0.001$) when a term representing inflow stability was added using stepwise multiple regression. A larger proportion of large individuals implies better survival, but this effect is difficult to distinguish from the effect of faster growth rates. Given the observed variability in growth rate coupled with a lack of consistency in corrected salinity preference, we suggest that inflow-related food availability is more important than salinity as a determinant of habitat suitability for bay anchovy juveniles. [epeebles@seas.marine.usf.edu]

Coastal Wetlands of Tampa Bay: Managing a Changing Coastal Habitat. E.A. Raabe, C. McIvor (USGS St. Petersburg). According to the Association of National Estuary Programs, dredging and development since the 1950s have destroyed nearly 40 percent of Tampa Bay's salt marshes and 13 percent of its mangrove forests. To accurately interpret current conditions in Tampa Bay and to improve management in the future, we must understand the natural settings under which the present coastal wetlands developed. What is the recent history of coastal wetlands in Tampa Bay? What key factors support healthy salt marsh or mangrove habitat? How are anthropogenic factors linked to past and present coastal wetland conditions?

The US Geological Survey is currently evaluating changes in coastal wetlands from historic maps, photography and satellite imagery from 1875 to the present at four locations in Tampa Bay. Preliminary evidence strongly suggests that mangrove habitat has been replacing salt marsh and low-salinity coastal wetlands in a gradual northerly migration throughout the bay since 1875. The geographic analysis is enhanced by an examination of anthropogenic influences, and an evaluation of cores extracted from the study sites. Ancillary data reveal links between shoreline vegetation and climate, freshwater flux, and hydrologic alterations in the bay. A combination of both natural and anthropogenic factors may have shaped and perpetuated the current dominance of mangroves along Tampa Bay shorelines. Complementary work on Tampa Bay history via sediment cores sheds more light on long-term sea level and climate change and the relation to coastal wetlands (see T. Edgar et al., 2003, Tampa BASIS 4). [eraabe@usgs.gov]

Linking Environmental Monitoring to Wellfield Management. C. Shea, A. Adams (Tampa Bay Water), B. Ormiston (Ecological Consultant). Tampa Bay Water, a regional water supply utility, provides potable water to its member governments. Tampa Bay Water rotates among potable water supply sources on the basis of environmental conditions. Minimum levels in wetlands (long term median water levels required to maintain wetland health), lakes and springs are related through a regression equation to "target" surficial aquifer levels in a control point well. An optimization program is used to develop source rotation schedules that optimize surficial aquifer levels (and thereby wetland water levels) while meeting demand.

Tampa Bay Water monitors water levels and ecological conditions at over 400 wetland monitoring sites. Wetland hydrology is compared with reference and control sites on a semi-annual basis (spring and fall, or dry and wet seasons). Hydroperiods (i.e. duration of flooding) and water levels (relative to "normal pool" indicators) are statistically analyzed and wetlands with significantly reduced hydrology identified. A site-specific analysis is then conducted that can result in either the adjustment of a target level or the addition of a new control point.

Over the past two years, ten wetlands with persistently and significantly reduced hydrology relative to controls have been referred for analysis in the optimization program. In response to these referrals, four new surficial aquifer wells have been added as control points in the optimization program and an existing target level raised in order to relieve environmental stress. (Other recommendations are pending.) The analytical techniques used

to identify hydrologically stressed wetlands and to link wetland and aquifer hydrology are discussed. [cshea@tampabaywater.org]

Mangrove Forests Dynamics in the Tampa Bay Area. T.J. Smith III (USGS St. Petersburg), J. Dismukes, G. Peery, G. Tiling (ETI Professionals). Intertidal wetlands were once extensive around Tampa Bay. About one-third of their historical acreage remains. They comprise important habitats for commercial and recreational fisheries, for wading birds and other wildlife. Our objectives are to: 1) establish a long-term sampling network in Tampa Bay's wetlands to assess their health (growth, production, survival, mortality) and measure future changes; 2) assess methods used for wetland restoration and provide recommendations for improving restoration efforts. We have established permanent sampling plots that are measured repeatedly over time. Plots have been established at Terra Ceia, Weedon Island, Gateway and along the Alafia River. Our sampling has revealed natural changes over short time periods. Larger mangrove trees in plots around Moses Hole, at Terra Ceia, suffered mortality during a severe storm event in January 2002. Recruitment into the plots by mangrove stems is low and growth of the trees and saplings is slow. The slow growth we have observed is probably partly attributable to the region's recent drought. During the summer of 2003 we initiated studies of the long-term influence of mosquito ditching on mangrove forest structure at Weedon Island and Mobbly Bay. Sediment Elevation Tables (SETs) and soil water wells are being established at a subset of plots. SETs measure changes in surface elevation of wetlands. These can be related to both physical parameters (groundwater hydrology) and biological aspects of the environment (plant growth). The sampling network will allow us to quickly assess wetland responses to ongoing restoration projects around Tampa Bay. [Tom_J_Smith@usgs.gov]

A Historical Perspective for Determining Changes in the Distribution of Oyster Habitats in Southwest Florida Using Archived Maps and Charts of Federal Agencies. J. Stevely, D. Fann, G.A. Antonini (Florida Sea Grant College Program). A key issue in oyster bar restoration is to establish a historical baseline showing pre-development location and extent of this hard-bottom habitat within a bay system. Our paper discusses the utility of using U.S. Army Corps of Engineers waterway surveys and U.S. Coast & Geodetic Survey H (hydrographic) and T (topographic) Smooth Sheets as source documents for delineating antecedent oyster bars. Summary maps accompany the Annual Report of the Army Engineers to Congress in the form of House and Senate Documents. These reports provide a basis for locating detailed survey maps in the National Archives. A generalized map of southwest Florida shows the distribution of Army Engineers survey maps for the period 1880–1939. H- and T-Sheets are available as 210mm negatives from the NOAA Data Control Division, Silver Spring, MD. Generalized maps have been compiled for southwest Florida showing the distribution of H- and T-sheets for the period 1855–1976. Both the Army Engineers maps and the Coast Survey smooth sheets depict oyster bars as polygons using specific symbology. Our methodology includes scanning the source maps, identifying and digitizing the oyster polygons, and creating GIS coverages. Examples of the historical source maps and GIS coverage are shown for Little Sarasota Bay. This historical information is compared with contemporary conditions, derived from interpretation of 1999 color aerial photography, to create a change analysis oyster bar map. The methodology is in the development phase, but we hope that this effort will be useful in evaluating oyster habitat restoration in other areas of southwest Florida. [jmstevely@mail.ifas.ufl.edu]

The Ft DeSoto Aquatic Habitat Management Area: Status of the Ecosystem. A.W. Weinkauff (Delta Seven, Inc.) J.A. Jacukiewicz (Univ. of So. Fla.), J.L. Lessmann (Eckerd College), K. Levy (Pinellas Co.), T.R. Cuba (Delta Seven Inc.). Forty five years ago (circa 1960) six islands in south Pinellas County were converted into one large island by filling the shallows between them. The fill was obtained by dredging the nearby flats. The result, Ft DeSoto Park, is generally trident shaped. Each of the lagoons are subjected to varying degrees of tidal restrictions which contribute to frequent but ephemeral impairments in habitat condition and function. Some of the dredge holes have become anoxic and ecologically depressed. Pinellas County, with funding from others, has committed to a partial restoration of the tidal patterns through the construction of two bridges and the opening of channels. In 2002, NOAA, Delta Seven Inc, Pinellas County, Eckerd College, USF and The Tampa Bay Estuary Program initiated a cooperative program to document the condition of the habitats within the lagoons prior to the restoration effort. A similar program is planned for after the opening has occurred. A summary overview of the data collected during 2002 and 2003 will be presented along with a discussion of the existing state of the ecosystem and expectations of the restoration effort. Data collected include physical and chemical parameters of the waters and sediments, the condition of the sea grass beds, and information on ichthyofauna, invertebrate, and algal populations. [Amanda.weinkauff@delta-seven.com]

Spatial Distribution of Wetland Edge and Common Snook (*Centropomus undecimalis*) Sampled in Tampa Bay. S.D. Whaley, J.J. Burd, Jr. (Fla. Fish & Wildlife Conservation Commission, Fla. Marine Research Inst.) Estuarine wetlands, such as mangroves and salt marshes, are often considered important habitat for the common snook (*Centropomus undecimalis*), because these areas provide structure when submerged. Applying an approach from landscape ecology, we used a Geographic Information System to characterize the spatial distribution of mangrove and salt marsh edges across Tampa Bay. We mapped these wetland habitats in conjunction with the distribution of snook caught by FMRI's Fisheries-Independent Monitoring (FIM) Program from 1989 to 2001. We used snook data collected by two different-sized seines: a 21-m long seine targeting small fish and a 183-m long seine designed to catch larger fish. FIM frequently caught larger snook along mangrove-lined shores within the estuary and smaller snook in riverine environments near salt marshes. GIS maps illustrate these spatial trends across Tampa Bay. [Shannon.Whaley@fwc.state.fl.us]

Urban Growth And Climate Change As Causes of Seagrass Variation in Tampa Bay. G. Xian (SAIC/EROS Data Center), M. Crane (USGS EROS Data Center Sioux Falls). Seagrass is a very important component of the Tampa Bay ecosystem and an excellent indicator of the overall health of the estuarine environment. An historical look at the areal extent of seagrass meadows in Tampa Bay reveals significant declines from the late 1800s. The declining trend reversed in the early 1980's and recovery continued until 1996. Since then, seagrass meadows have been in steady decline. When seagrasses are looked at in the context of the land surface dynamics characterizing the Tampa Bay watershed, urbanization stands out as one of the most profound influences. Impacts from urban development are associated with increased pollution, decreased water quality, and increased nutrient discharges into the bay. Urban land use change also strongly affects regional surface temperatures, precipitation, atmospheric circulation, and therefore leads to the local and regional climate change. The urban heat island effect in Tampa Bay shows that temperature difference between the urban center and adjacent suburbs reaches approximately 5 degrees during the daytime and 3 degrees during the night. In both Tampa and St. Petersburg, annual average temperature exhibits a significantly increase after 1970, and annual precipitation shows a moderate declining trend after 1960. These climate changes inevitably have certain impacts on seagrass growth and distribution. Further studies are needed to explore in detail the relationship between climate change and seagrass extend variations.

This study uses a combination of remote sensing, GIS and modeling techniques to integrate diverse data sets from 1940 to 2003. The results of this work illustrate the importance of an integrated science approach to better understand the impacts of human induced disturbance on the environment and natural resources. [xian@usgs.gov]

Interannual, Seasonal and Regional Variations in Epiphyte Loading on Seagrasses in Tampa Bay. L.A. Yarbro, P.R. Carlson, A. Ketron, D. Saindon, H. Arnold. (Fla. Fish & Wildlife Conservation Commission, Fla. Marine Research Inst.). Epiphytic growth on seagrasses reduces the light available for photosynthesis by seagrass blades and may add to existing light stress due to attenuated light transmission through the water column. Epiphyte loading on seagrass blades, both quantitatively and by types of organisms, is related to water quality and seagrass species. Light attenuation and epiphyte loading on seagrass blades was evaluated for *Thalassia testudinum* and *Halodule wrightii* throughout Tampa Bay in October 2000 and in July and October 2001. In 2002 and 2003 measurements continued in Old Tampa Bay every two months during the growing season (April–October). Chemical characteristics and types of epiphytes varied by seagrass substrate and location in Tampa Bay. Seasonal and interannual variations in light attenuation by epiphytes and epiphyte loading were observed and also appeared strongly related to location, even within Old Tampa Bay, and to seagrass substrate. [laura.yarbro@fwc.state.fl.us]

Developing Techniques to Enhance the Recovery Rates of Propeller Scars in Turtlegrass (*Thalassia testudinum*) Meadows: Sediment Tubes and Bird Stakes at the Lignumvitae Key State Botanical Site. M.O. Hall, D. Berns, K. Ferenc, J. Hynovia, M. Merello (FWC Fla. Marine Research Inst.), J. Kenworthy, K. Hammerstrom (NOAA/NOS), S. Bell (Univ. of So. Fla.), J. Anderson (Seagrass Recovery, Inc.)

IMPLEMENTING THE TAMPA BAY DREDGED MATERIAL MANAGEMENT STRATEGY

T. Leaser, H. Greening, R. McMichael, E. Sherwood & S. Grabe

INTRODUCTION

The U.S. Army Corps of Engineers (Corps) and Tampa Bay Estuary Program (TBEP) finalized the Tampa Bay Dredged Material Management Strategy (DMMS) in July 2000. The DMMS identifies placement needs, capacity, and beneficial uses of dredged material. It attempts to account for material removed from all sources within the Tampa Bay watershed, from the bay's three major seaports to private marinas. In implementing the DMMS, TBEP, along with a number of partners, received a grant from the United States Environmental Protection Agency (USEPA) in 2001 to study dredged holes in Tampa Bay, evaluate the ecological enhancement of the holes, and develop management plans for the holes. Options in management plan development include habitat restoration by filling holes with dredged material as a beneficial use, partially filling holes, or leaving holes as they are. This paper presents information on the development of the DMMS, including the findings and identified follow-up work, and on the dredged hole assessment grant, including grant project development, objectives, scope, results to date, and next steps.

DMMS DEVELOPMENT

The Clean Water Act, passed in 1972 and amended in 1987, promoted the formation of groups to study water quality, natural resources, and uses of estuaries, and to develop and implement plans to restore and maintain the environmental, recreational and economic integrity of these estuaries. Unlike traditional regulatory approaches to environmental protection, these groups, known as 'Estuary Programs', target a broad range of issues and engage local communities, from Federal agencies to local residents. TBEP was founded in 1991 and prepared its Comprehensive Conservation and Management Plan, 'Charting The Course'. Charting The Course consists of six 'Action Plans'; one of these action plans aims to coordinate dredged material placement baywide, true to the program's community-based spirit. This coordination encompasses material removed from all sources, from the bay's three major seaports down to private marinas. The advantage of this action plan, scoped before the days of Regional Sediment Management, is that it addresses placement on a watershed basis, unlike Federal Dredged Material Management Plans that address Federal placement on a per-Federal-project basis.

The products of this action plan are a committee, the Tampa Bay Dredging and Dredged Material Management Committee, meeting yearly, and a report, the DMMS.

DMMS FINDINGS

In all, about 42,000,000 cubic yards (cy) of material are projected to be dredged from Tampa Bay in the next 25 years, or about 1,680,000 cy per year, including maintenance dredging of existing Federal channels and dredging of new, deeper, or wider channels. These figures do not include volumes of material removed from any channel modifications that might be constructed as a result of on-going studies for the Federal Tampa Harbor and St. Petersburg Harbor shipping channels and probably underestimate the amount of material to be dredged by private interests. Over this timeframe, the placement capacity shortfall is estimated to be 15,000,000 cy if existing upland areas are not enlarged. If the existing upland placement areas are enlarged, this shortfall is reduced to 400,000 cy. Placement area shortfall numbers are most likely overestimated based on recent topographic surveys. The DMMS concludes that in order to meet future capacity needs, the following four actions should occur: place material on beaches, use dredged material beneficially for habitat restoration or commercial applications, manage aggressively existing upland areas, and share placement areas. The

DMMS recommends additional work to guide the completion of the four actions. This work is the following: additional study of dredged material volumes and placement, collection of dredged material characteristic data, development of a circulation/salinity/sediment movement model, analysis of dredging and disposal methods, investigation of beneficial uses of dredged material, inventory of the environment, examination of economic activity, summary of regulations guiding dredging and dredged material placement and discussion on implementing regional sediment management. A follow-up action compatible with the nature of estuary programs is an investigation of beneficial use of dredged material, particularly for habitat restoration. Beneficial use of dredged material for habitat restoration involves knowing the needs of the resource management community as well as the needs for placement of dredged material. Coupling the restoration and placement needs of Tampa Bay highlights previously dredged holes and borrow pits as obvious sites for habitat restoration using dredged material as fill. Submerged dredged holes are prime candidates to become shallow water habitat for seagrass. Many questions arise when considering whether or not to fill such holes, such as whether the shallow water habitat to be created is more valuable than the existing deeper water habitat and whether the holes provide critical fish habitat, particularly during cold weather.

THE DREDGED HOLE ASSESSMENT GRANT

The grant funded by the USEPA marks a major step in the implementation of the DMMS. Known as the 'Dredged Hole Assessment Project,' the grant work truly captures the 'community effort' principle fundamental to estuary programs. The work is being conducted by a wide variety of agencies and groups including TBEP; the Corps; Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute; Southwest Florida Water Management District; Hillsborough County Commission (representing the anglers); and Environmental Protection Commission of Hillsborough County. The grant provides funding and gathers resources to establish a scientific basis for dredged hole management plans. It contributes to the formation of a framework for environmental restoration decisionmaking. The primary objective of the project is to assess the current habitat values of the holes. The ultimate objective of the project is to develop specific implementation plans for each hole. The major tasks of the project are to convene an advisory group to collect and interpret data needed to support management plan development, to develop and implement a plan to collect physical, chemical and biological data for ten holes (Figure 1) and to develop management plans for the selected holes.

RESULTS TO DATE

The following is a general summary of work completed and findings through one year of the project.

Literature Review

The Corps' Dredging Operations and Technical Support program researched the restoration of dredged holes throughout the country and prepared a response entitled, "Ecology of Bathymetric Depressions in Estuarine and Coastal Waters" (USACE 2002). This paper includes descriptions of dredged holes and an extensive literature search listing.

Bathymetric Surveys

The Corps also collected hydrographic surveys at each hole location to provide information on bottom surface elevation, hole volume and sideslope configuration. From June 6 to 20, 2003, the Whiskey Stump Key holes were surveyed. The other nine holes were surveyed from July 15 to 24, 2003. Surveying methods consisted of single-beam echo soundings spaced at 100-foot intervals throughout holes. Horizontal positioning was accomplished with Differential

Global Positioning System (GPS) using the United States Coast Guard NavBeacon at MacDill Air Force Base (AFB). The charting datum was referenced to the National Oceanographic and Atmospheric Association (NOAA) Mean Lower-Low Water Tidal datum (1960-1978 epoch). For the Whiskey Stump Key holes, tidal corrections were made from NOAA benchmarks 6262 A and 6262 B, located at Big Bend Terminal; for the remainder of the holes tidal corrections were made from the NOAA Physical Oceanographic Real-Time System (PORTS) located throughout Tampa Harbor.

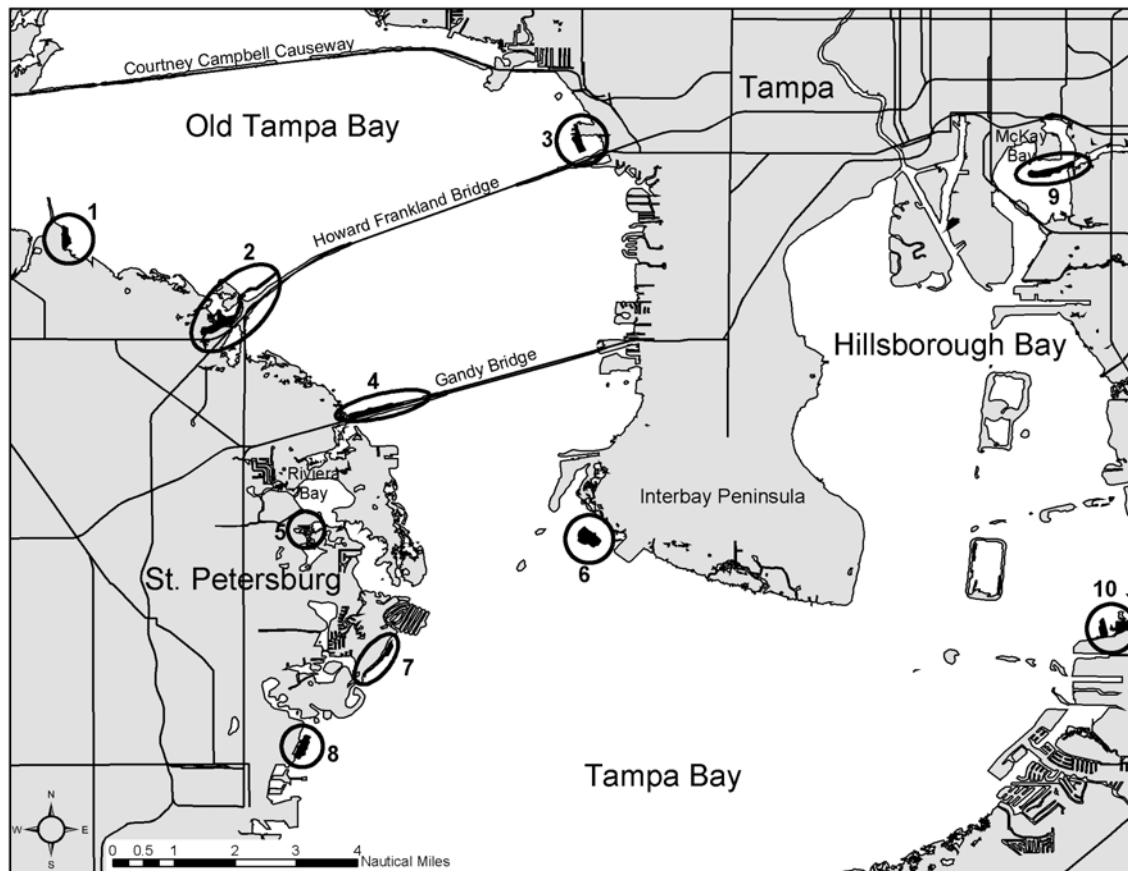


Figure 1. Selected dredge hole locations: 1—St. Pete/Clearwater Airport east; 2—Big Island cut and dredge hole; 3—Cypress Point dredge hole; 4—Gandy Channel north; 5—Northeast St. Pete pit 1; 6—MacDill AFB runway extension; 7—Shore Acres; 8—Northshore Beach; 9—McKay Bay dredge cuts; 10—Whiskey Stump Key holes 1 and 2

Fisheries

The Fisheries-Independent Monitoring (FIM) Program of the Florida Fish and Wildlife Conservation Commission's (FWCC) Florida Marine Research Institute began a study of the fish and macrocrustacean communities of the selected holes. The goal of this research is to determine the extent to which existing dredged holes provide habitat to fish and macrocrustaceans and whether these holes are utilized by commercial or recreational fishers. Data collection includes a fisheries-independent survey and a fisheries-dependent survey.

Fisheries-Independent Survey

Sampling Methods—The FIM program performed monthly monitoring within and adjacent to the dredged holes using trawls (standard, 2 panel 6.1-meter [m] otter trawl with 38-millimeter [mm] stretch mesh and a 3-mm, #35 knotless nylon Delta mesh liner) and seines

(standard 21.3 m x 1.8 m center bag seine with 3-mm, #35 knotless nylon delta mesh and fitted with float and lead lines). Two randomly selected trawls were performed inside and outside (if applicable) each dredged hole in deeper waters (1.8–7.6 m). Additionally, two randomly selected seines were performed outside the dredged holes in depths less than 1.5 m to collect ancillary data if the holes were filled.

Sampling followed standard FWCC-FIM program protocols (FMRI 2000). Trawls inside and outside the dredged holes were towed for a target five minutes (0.08 to 0.12 nautical miles [nm]). Seining with the 21.3-m seine was conducted using an offshore seine technique (FMRI 2000). All species collected were identified to the lowest practical taxon and measured. Three representative samples of each species collected during a sampling day were brought back to the lab to ensure proper field identifications. Any unidentifiable species collected were brought back to the lab for identification. Physicochemical data were recorded for each sample site, and a gross characterization of the bottom, surrounding habitats, and weather conditions was recorded, as well.

Data Analysis—Abundance estimates were calculated for 21.3-m seines and 6.1-m otter trawls as the number of animals per 100 square meters (m^2) of area sampled (catch-per-unit-effort, CPUE). Total number of animals and species captured for the entire sampling period were summarized for all the dredged holes. Multivariate analysis was used to detect community level differences for trawl catch inside versus outside the dredged holes using PRIMER (Plymouth Routines in Multivariate Ecological Research) software. An analysis of similarity (ANOSIM) was used to test the null hypothesis that there was no difference in community structure among inside versus outside trawl sites (Clarke and Warwick 2001) based on the fourth-root-transformed, Bray-Curtis rank similarity matrices of samples (Bray and Curtis 1957).

Results, All Dredged Holes—A total of 63,608 animals were collected from 641 samples during the sampling period. Of those, 32,184 animals were collected within the dredged holes ($n = 246$, 6.1-m otter trawl samples), while 5,672 and 25,752 animals were collected outside the dredged holes in either 6.1-m otter trawls ($n = 183$ samples) or 21.3-m seines ($n = 212$ samples), respectively. In total, 73 species were collected within the dredge holes, whereas 63 and 73 species were collected in either 6.1-m otter trawls or 21.3-m seines outside the dredged holes, respectively. Dominant species collected inside the dredged holes ($n = 246$ samples) included spot (*Leiostomus xanthurus*, 5.6 ± 3.5 fish/100 m^2 [mean $\pm$ 1 Standard Error]) and bay anchovy (*Anchoa mitchilli*, 5.3 ± 1.8 fish/100 m^2). Of the 73 taxa collected within the dredged holes, 15 were of economic importance and 17 were unique to inside the dredged holes when compared to trawls performed outside the dredged holes (Table 1). Dominant species collected outside the dredged holes ($n = 183$ samples) included spot (1.9 ± 0.7 fish/100 m^2) and sand seatrout (*Cynoscion arenarius*, 0.5 ± 0.2 fish/100 m^2) in trawls, and bay anchovy (20.9 ± 6.0 fish/100 m^2) and spot (19.2 ± 6.4 fish/100 m^2) in seines. Of the 63 taxa collected outside the dredged holes in trawls, 12 were of economic importance and seven were unique to outside the dredged holes when compared to trawls performed inside the dredged holes (Table 1). Of the 73 taxa collected outside the dredged holes in seines, 15 were of economic importance and 16 were unique to outside the dredged holes when compared to trawls performed inside the dredged holes (Table 1).

Results, Trawl Comparisons—Trawl samples collected inside all dredged holes were more similar to each other when compared to trawl samples collected outside all dredged holes. Significant differences in community structure from trawl samples collected inside versus outside each dredged hole were apparent for most of the dredged holes; although, the

magnitude of difference varied by dredged hole (Range of ANOSIM R-Values: 0.271 to 0.858; $p \leq 0.039$, in all cases).

Table 1. Species unique to each location (inside or outside the dredged holes) and gear type used (6.1-m otter trawl or 21.3-m seine) based on comparing inside 6.1-m otter trawl vs. outside 6.1-m otter trawl samples and inside 6.1-m otter trawls vs. outside 21.3-m seine samples. Number captured is indicated in parentheses and economically important species are indicated in bold.

INSIDE 6.1-m Otter Trawl	OUTSIDE 6.1-m Otter Trawl	OUTSIDE 21.3-m Seine
<i>Anarchopterus criniger</i> (27)	<i>Aluterus schoepfi</i> (3)	<i>Aluterus schoepfi</i> (1)
<i>Anchoa cubana</i> (25)	<i>Ancylosetta quadrocellata</i> (1)	<i>Brevoortia</i> spp. (1)
<i>Anchoa</i> spp. (1)	<i>Diplectrum formosum</i> (2)	<i>Calamus arctifrons</i> (1)
<i>Archosargus probatocephalus</i> (77)	<i>Etropus crossotus</i> (1)	<i>Cyprinodon variegatus</i> (2)
<i>Bathygobius soporator</i> (1)	<i>Gobiosoma longipala</i> (1)	<i>Dorosoma petenense</i> (2)
<i>Centropristis striata</i> (1)	<i>Menticirrhus saxatilis</i> (1)	<i>Hyporhamphus meeki</i> (27)
<i>Diapterus plumieri</i> (1)	<i>Monacanthus ciliatus</i> (10)	<i>Membras martinica</i> (29)
<i>Elops saurus</i> (1)		<i>Menidia</i> spp. (1,953)
<i>Floridichthys carpio</i> (1)		<i>Menticirrhus saxatilis</i> (7)
<i>Gobiosoma bosc</i> (3)		<i>Mugil gyrans</i> (1)
<i>Hippocampus zosterae</i> (2)		<i>Oligoplites saurus</i> (45)
<i>Hypsoblennius hentzi</i> (3)		<i>Poecilia latipinna</i> (1)
<i>Lucania parva</i> (12)		<i>Sphyrna tiburo</i> (1)
<i>Lutjanus griseus</i> (2)		<i>Strongylura marina</i> (5)
<i>Myrophis punctatus</i> (1)		<i>Strongylura notata</i> (4)
<i>Rachycentron canadum</i> (1)		<i>Strongylura</i> spp. (1)
<i>Syngnathus floridae</i> (3)		

Fisheries-Dependent Survey

Sampling Methods—During the routine, monthly fisheries-independent survey, the FIM program recorded the incidence of fishers in all the dredged holes. Fishers were identified as either recreational or commercial and were interviewed periodically. Fisher catch, time spent fishing in the dredged hole, fishing methods, and targeted species were recorded during the interviews. In addition, the FIM program and the TBEP solicited local anglers and guides through various advertisements to provide their catch information when fishing in any of the dredged holes. Because local angler data collection was lacking during the initial sampling period, the FIM program performed two hook and line fishing trips to random dredged holes starting in August 2003, continuing every other month thereafter to supplement the angler data. The FIM program also conducted various other monitoring projects in the same general vicinity of some of the dredged holes. The gears used in these projects varied, and if a sample site occurred in a dredged hole, data was recorded similarly to the fisheries-independent survey. These data were used to provide further insight on the potential species utilizing the dredged holes.

Data Analysis—The incidence of fishers and their reported catch within the dredged holes was examined by month. Further data from opportunistic sampling and directed hook and line sampling trips was examined for the entire sampling period.

Results—Overall, 32 recreational fishers and 16 commercial fishers were observed or reported fishing in the dredged holes during the sampling period. Nineteen different species were identified as inhabiting the dredged holes based on our various fisheries-dependent surveys. Of those 19 species, 12 were of economic importance. Three species were identified as inhabiting the dredged holes that were not represented in the fisheries-independent survey: snook (*Centropomus undecimalis*), striped mullet (*Mugil cephalus*), and permit (*Trachinotus falcatus*).

Summary

There was an apparent difference in fish and macrocrustacean community structure inside versus outside the dredged holes. Generally, more species were collected at a higher rate (as determined by the $\#/100\text{m}^2$) within the dredged holes than outside (considering trawl samples only). Furthermore, it was evident that the dredged holes provided some habitat value to a variety of fish and macrocrustacean species, and that local fishers were utilizing the dredged holes to target these species. There is still some degree of uncertainty regarding the habitat value of the existing holes to fish and macrocrustaceans. The seasonality of the fish and macrocrustacean community structure has not been explored, and may provide information with regards to cyclic patterns of species use in the holes. Further investigations of the seasonality, environmental, and abiotic conditions (i.e., temperature, dissolved oxygen stratification) of the holes and how these parameters affect the fish and macrocrustacean community structure are currently being evaluated.

Benthos and Sediment Chemistry

Study Design

At each dredged hole, boat transects were run along the longitudinal axes. GPS readings of latitude and longitude were made at the start and finish of each run. Location estimates were made for the center point and four other points, each approximately one-third of the way in from the start and end points of the axes. This yielded five possible sampling locations. Temperature, salinity and dissolved oxygen were measured at 1-m intervals from the surface (0.1 m below the air-water interface) to the bottom (0.2 m above bottom) and again from the bottom to the surface at each of the five sampling locations as well as a sixth location outside the dredged hole (measured in a random direction north, south, east or west of the hole). All measurements were made using a Hydrolab Surveyor. Hach kit measurements of hydrogen sulfide (H_2S) were also made at selected locations to determine whether dataloggers could be deployed for continuous (every 15 minutes) measurements of temperature, salinity and dissolved oxygen (DO). Where near-bottom DO was greater than 2 parts per million (ppm) and H_2S concentrations were less than 0.5 ppm, dataloggers were deployed at one of the sites within the dredged hole and at the reference location outside the hole. Three of the five possible sampling locations were selected at random for collection of benthic samples and sediment chemistry samples (in the summer/fall of 2002 only). Samples were collected with a 0.04-m^2 stainless steel Young grab sampler. Samples for sediment chemistry were placed in chemically cleaned glass (organics) and plastic jars (metals) and placed on ice. Benthic samples were cored for determination of the apparent redox potential discontinuity layer (RPD); the width of the apparent RPD was measured with a metric rule. This sample was then extruded into a plastic vial, stored on ice, and returned to the laboratory for sediment analysis. Benthic samples were rinsed into plastic bags, a solution of magnesium sulfate was added to relax the animals and the sample bag was placed on ice. At the end of the day the benthic samples were rinsed through a 0.5-mm mesh and fixed in 10% borax-buffered formalin with rose bengal stain. Within two weeks benthic samples were transferred to 70% ethanol and rose bengal stain for preservation. Laboratory analyses: For sediment chemistry, the metals analyses are ongoing and are not reported in this paper. The organic analyses (organochlorine pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons) were conducted after NOAA/NOS (1993) and USEPA (1993). Percent silt and clay (SC) were determined using methods outlined in EPC (1995). Benthic samples were sorted and identified to the lowest practical identifiable level using methods described in EPC (1995). Analysis of variance was used to test for differences between seasons for a suite of abiotic and biotic variables. The degree of water column stratification was based on criteria suggested by NOAA/NOS (1996) for differences between surface and bottom water density (as $\sigma\text{-t}$). Stratification was “low” where the difference was less than one and “high” when the

difference was greater than two. Sediment quality assessment guidelines were after MacDonald Environmental Sciences (1994).

Results

Dredged holes ranged in depth from approximately 1.5 m (Gandy Channel and St. Petersburg/Clearwater Airport #1 holes) to almost 5 m (McKay Bay hole during August 2002). Summer/fall and spring sample depths were not significantly different ($p = 0.45$). Mud-sized sediments (greater than 25.95% SC) generally predominated in the holes surveyed. The Shore Acres dredged hole was the only one that had %SC values indicative of sand-sized sediments during both survey periods. Dredged hole sediments were not significantly different between survey periods for %SC ($p = 0.5$). Near-bottom water temperatures were wide-ranging both between holes as well as between seasons ($p = 0.014$). Within the summer/fall 2002 period near-bottom temperature was significantly correlated with sample depth ($r = 0.46$; $p = 0.004$) whereas during spring 2003 they were not correlated ($r = 0.02$; $p = 0.9$). Near-bottom salinities were generally in the polyhaline (18-30 part per trillion [ppt]) range. Summer/fall and spring near-bottom salinities were significantly different ($p < 0.001$) with fall salinities higher than spring. Density stratification was moderately developed to well-developed only at the McKay Bay and St. Petersburg/Clearwater Airport-1 holes during both survey periods. Near-bottom DO was generally greater than 4 ppm and hypoxia was only observed at the McKay Bay hole during the October 2002 survey date. Summer/fall and spring near-bottom DO concentrations were not significantly different ($p = 0.19$), although there appeared to be differences between stations. DO concentrations were associated with density stratification during both survey periods. However, during the summer/fall period this association was primarily driven by the three McKay Bay samples; if these three data points are removed the r^2 drops from 0.47 to 0.21. Effects level guidelines have been developed for four organochlorine pesticides (OP): chlordane, dieldrin, total dichlorodiphenyltrichloroethane (DDT), and lindane; none were detected at concentrations above the Threshold Effects Level (TEL) (MacDonald Environmental Sciences 1994). Other OPs were present in the holes although concentrations were generally below or near the method detection limit (MDL). Polychlorinated biphenyl (PCB) concentrations were generally near or below the MDL at all sites. Total polycyclic aromatic (PAH) concentrations were less than the TEL (1,684 ppb) at all sites. Spring benthic assemblages were more speciose ($p = 0.001$) and more abundant ($p < 0.001$) than the summer/fall assemblages. The most depauperate holes during summer/fall 2002 included Cypress Point, McKay Bay, Northshore, St. Petersburg/Clearwater Airport #2, and both Whiskey Stump Key holes. The Gandy Channel dredged hole supported a much more abundant and rich assemblage during the summer/fall period than it did during spring (Figure 2). The Whiskey Stump Key holes showed the greatest increases in both abundance and species richness from summer/fall to spring survey periods.

NEXT STEPS

This paper presents a summary of work on the project through the spring of 2003, that is, over a period of about one-half of the project timeframe. All project tasks are scheduled to be complete in early 2005. Fisheries, water quality, sediment chemistry and benthos data collection and interpretation remain to be finalized. Management plans remain to be developed for each of the selected holes. Together, scientists, engineers, anglers and resource managers will develop the management plans. Decisions will be made for each hole independently, possibly ranging from no action to complete filling to partial filling such as creation of additional surface area by mounding material in pinnacles. The framework for this decisionmaking, decisionmaking intended to be win-win for the health of the bay considering the balance between commerce and the environment, is a direct result of the implementation of the DMMS, the Dredge Hole Assessment Project.

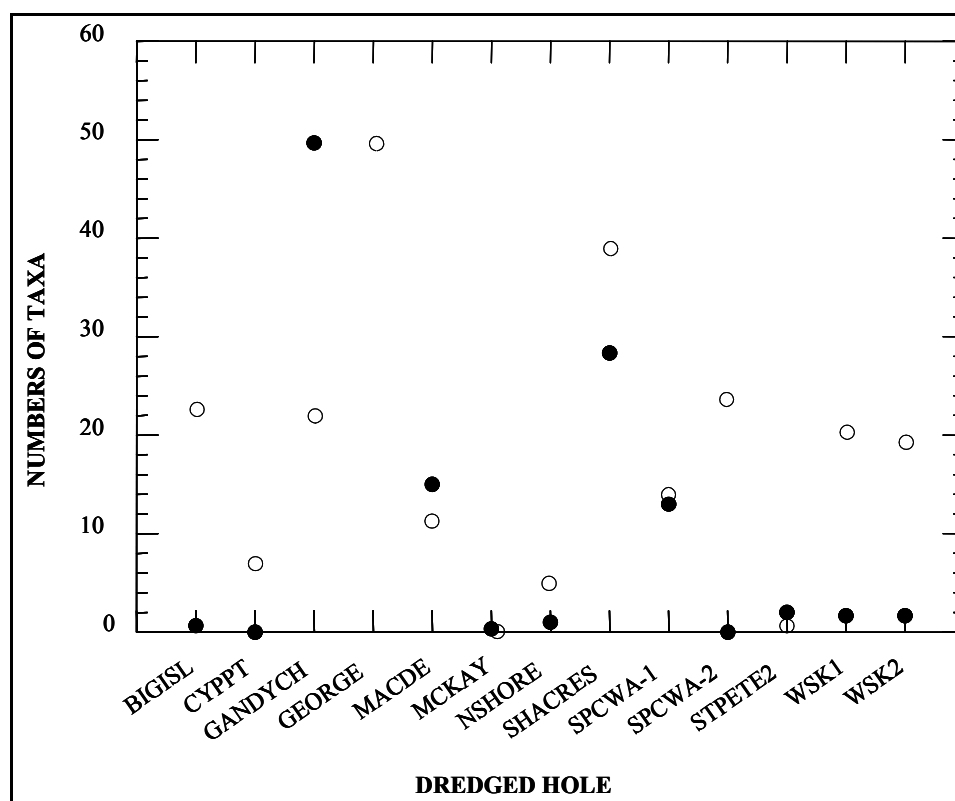


Figure 2. Species richness. Open circles—spring; filled circles—fall. SPCWA-1, SPCWA-2—St Pete/Clearwater Airport east 1 & 2; BIGIS—Big Island cut and dredge hole; CYPPT—Cypress Point dredge hole; GANDY—Gandy Channel north; STPETE2—Northeast St. Pete pit 2; MACDE—MacDill AFB runway extension; SHACRES—Shore Acres; NSHORE—Northshore Beach; MCKAY—McKay Bay dredge cuts; WSK1, WSK2—Whiskey Stump Key holes 1 & 2

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LAKE-DREDGED MATERIALS FOR BEEF CATTLE PASTURE ESTABLISHMENT IN SUBTROPICS

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ABSTRACT

The ability to reuse dredged materials for agricultural purposes is important because it reduces offshore disposal and provides an alternative to disposal of the materials in landfills that are already overtaxed. Beneficial uses of dredging or dredged materials are both economical and environmental. Economically, dredged materials can be used as soil amendments (lime and fertilizer) for early establishment of forage in beef cattle pastures. Often these materials can be obtained at little or no cost to the farmers or landowners. Productive disposal options of lake-dredged materials (DM) may provide substantial and intangible benefits that will enhance the environment, community, and society. The objective of this study was to assess lake-dredged materials from Lake Panasoffkee (LP) as soil amendment for early establishment of bahiagrass (BG, *Paspalum notatum* Flüggé) in subtropical beef cattle pasture. The treatment combinations consisted of five test plots (30.5 × 30.5 m). Each of the plots had different ratio of DM to natural soil (NS): Plot 1 (0% DM:100% NS); Plot 2 (25% DM:75% NS); Plot 3 (50% DM: 50% NS); Plot 4 (75% DM:25% NS); and Plot 5 (100% DM:0% NS). Each plot was seeded with BG and yield establishment was monitored at 16, 34, and 78 weeks. Results disclosed consistently and significantly higher BG biomass production ($P = 0.001$) from plots amended with DM than those of BG planted on plots with 0% DM at 16, 34, and 78 weeks, respectively. Addition of DM had significant effects on soil properties. Compared with the control plots, the soils in plots amended with DM exhibited: (1) an increase in soil pH, Ca, and Mg; (2) a decrease in the levels of soil Mn, Cu, Fe, Zn, and Si; and (3) no significant change in the level of Na in the soil.

INTRODUCTION

Bahiagrass, a warm season perennial, is largely grown throughout Florida, the Coastal Plain, and the Gulf Coast regions of the southern United States. The pastures are used mainly for beef cattle pastures. Bahiagrass is a good general-use pasture grass that can tolerate a wide range of soil conditions and close grazing, and withstands low fertilizer input (Burson and Watson, 1995). It has the ability to produce moderate yields on soils of very low fertility and easier to manage than other improved pasture grasses (Chambliss et al., 1999).

Establishment of an excellent, uniform stand of BG in a little time period is essential and economical. Failure to obtain an early good stand means the loss of not only the initial investment costs, but production and its cash value (Chambliss, 1999). Forage production often requires significant inputs of lime, nitrogen (N) fertilizer, and less frequently of phosphorus (P) and potassium (K) fertilizers. Dredged materials, composted urban plant debris, waste lime, and phosphogypsum are examples of materials that can be used for fertilizing and liming pastures. Often these materials can be obtained at little or no cost to the farmers or landowners (Kidder, 1999). Forage production offers an alternative to waste management since nutrients in the waste are recycled into crops that are not directly consumed by humans. Disposal or finding beneficial uses of dredged materials is quite challenging. The bottom sediment materials usually are composed of upland soil enriched with nutritive organics. These materials should be regarded as a beneficial resource to be used productively and not to be discarded as spoil materials (Patel et al., 2001; Sigua et al., 2000, Sigua et al., 2003).

The goal of this study was to explore the use of the DM from Lake Panasoffkee (LP) to improve the physicochemical properties of existing sandy soils in subtropical beef cattle pastures with calcium carbonate- and organic-enriched dredged materials. The lake-dredged materials, if found to be beneficial, could be removed from the spoil containment areas, trucked to other locations and incorporated into existing pasture fields. The objective of this study was to assess DM as a soil amendment to establish BG in a subtropical beef cattle pasture in Sumter County, Florida.

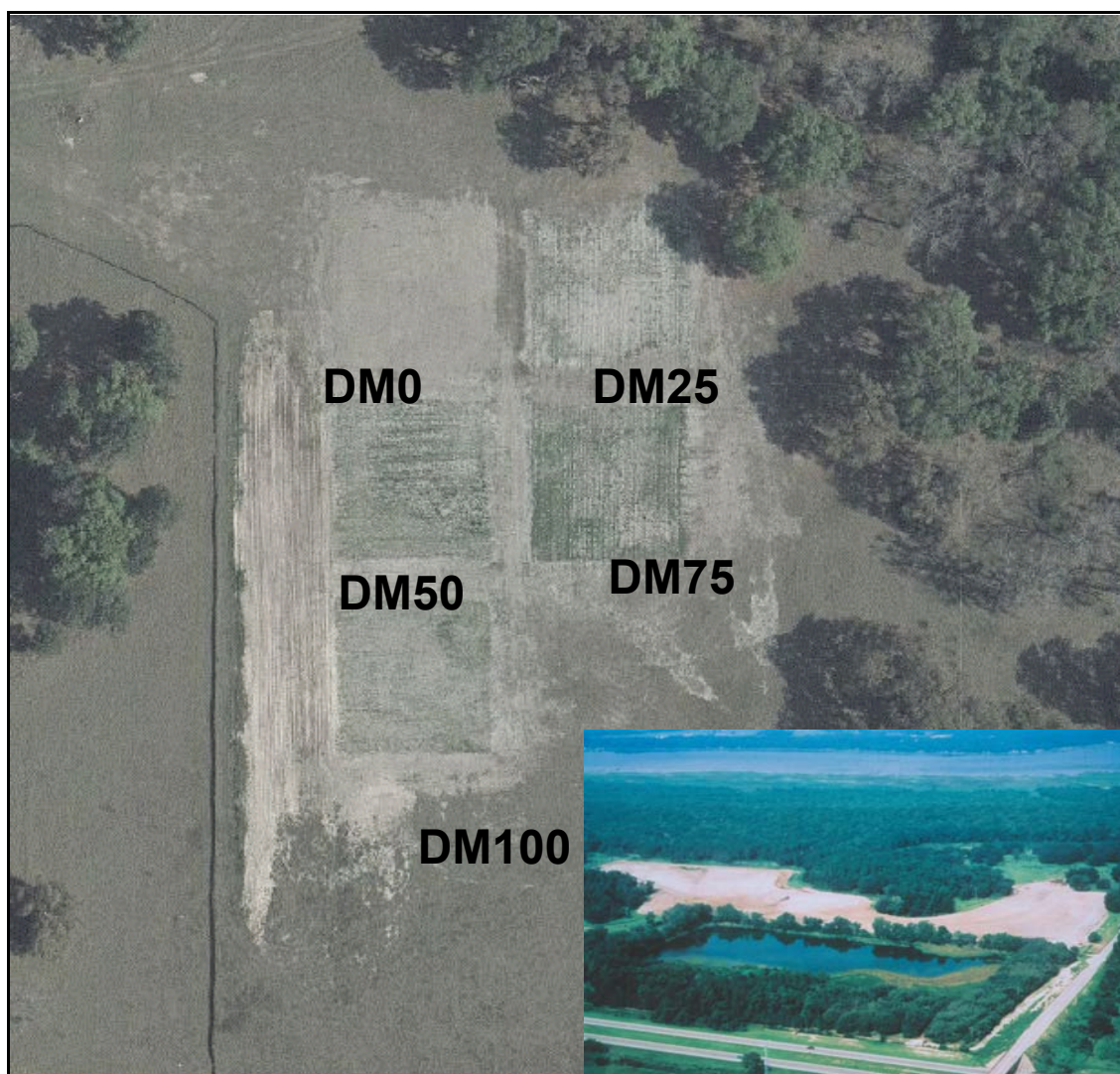


Figure 1. Aerial view of the dredging site at Lake Panasoffkee and the study site (DM0–0%, DM25–25%, DM50–50%, DM75–75%, DM100–100%) at the Coleman Landing in Sumter County, FL (28.798°N; 82.103°W).

MATERIALS AND METHODS

Study Site and Field Site Preparation

The study site is located in Coleman Landing (28.798°N; 82.103°W), Sumter County, Florida. Most of the soils at Sumter County formed in sandy marine or eolian deposits and have water table at a depth of 102 to 203 cm for more than 6 months during most years. These soils are hyperthermic, uncoated typic quartzipsammments (USDA, 1988). Aerial photograph of the study site (Lake Panasoffkee and experimental plots) that was taken on March 29, 2002, is shown in Figure 1.

This study encompassed five test plots (30.5 × 30.5 m) adjacent to the CL spoil disposal site in Sumter County, FL. Each plot was excavated to a depth of about 28 cm, and existing NS and organic materials were completely removed. Excavated NS materials were placed at the south end of the test plots. Existing vegetation from each plot was totally removed prior to backfilling each plot with different ratios of DM and NS: Plot 1 (0% DM + 100% NS); Plot 2 (25% DM + 75% NS); Plot 3 (50% DM + 50% NS); Plot 4 (75%

DM + 25% NS); and Plot 5 (100% DM + 0% NS). These ratios of DM to NS represent the treatment combinations of DM0; DM25; DM50; DM75; and DM100, respectively. Natural soils that were excavated were backfilled to each plot along with DM that were hauled from the adjacent settling pond. The total amount of DM and NS that was placed back on each test plot was in accordance with the different ratios of DM and NS that were described above. After mixing the NS and DM, each of the test plots was disked to a uniform depth of 28 cm. Plots were disked in an alternate direction until DM and NS were uniformly mixed. Each plot was seeded with BG at a rate of 6 kg per plot, followed by dragging a section of chain link fence across each test plot to ensure that BG seeds were in good contact with the NS in plot 1 and mixtures of DM and NS in plots 2, 3, 4, and 5. Each plot was seeded on January 28, 2002.

Soil Sampling and Soil Analyses

Three sub-samples of soils (0–20 cm depth) were taken from each main plot in the CL site using a steel bucket-type hand auger on January 16, 2003. Soil samples were air-dried and passed through a 2-mm mesh sieve prior to soil chemical extractions. The Mehlich 1 method (0.05 N HCl in 0.025 N H₂SO₄) was used for chemical extraction of soil (Mehlich, 1953). Soil chemical analyses were conducted at the University of Florida Institute of Food and Agricultural Sciences Soil Testing Laboratory, Gainesville. Soil P and other exchangeable cations (Ca, Mg, K, Al, and Fe) were analyzed using inductively coupled plasma (ICP) spectroscopy. Soil organic matter content was analyzed following the method of Walkley and Black (Walkley and Black, 1934). Soil pH was determined by using 1:2 soil to water ratio (Thomas, 1996).

Yield Measurements and Statistical Analysis

Yield measurements of BG were taken from four sub-plots (0.3 × 0.3 m) that were randomly selected from each main plot at 16, 34, and 78 weeks after seeding of BG. These sub-plots were permanently marked, using yellow flags placed at the four corners of a 0.3 × 0.3 m quadrant. Freshly cut aboveground growth was oven-dried at 60°C for 24 hours at the USDA-ARS Laboratory in Brooksville, Florida.

The forage yield characteristic of BG in beef cattle pasture taken at 16, 34, and 78 weeks after seeding was analyzed statistically following the analysis of variance using the SAS PROC GLM model (SAS, 2000). Where the F-test indicated a significant ($p = 0.05$) effect, means were separated, following the method of Duncan Multiple Range Test (DMRT), using appropriate error mean squares (SAS, 2000).

RESULTS

Plant Factor (Above-Ground Biomass)

The above-ground biomass productivity of BG at 16, 34, and 78 weeks after seeding is shown in Table 1. Above-ground biomass of BG varied significantly ($P = 0.001$) among plots with DM additions. The greatest biomass productivity of $673 \pm 233 \text{ kg ha}^{-1}$ in week 16 was from plots amended with 50% DM while BG in plots amended with 100% DM and 75% DM had the highest biomass productivity for 34 and 78 weeks with average yield of 3349 ± 174 and $4109 \pm 220 \text{ kg ha}^{-1}$, respectively (Table 1). The lowest biomass of 89 ± 63 , 1513 ± 166 , and $1263 \pm 116 \text{ kg ha}^{-1}$ were from the control plots for weeks 16, 34, and 78, respectively (Table 1). The average biomass increase of BG in plots amended with DM (averaged across treatments) was 512%, 82%, and 173% when compared with BG in plots with 0% DM for weeks 16, 34, and 78, respectively (Table 1). These data show the favorable influence that DM had on yield of BG during its early establishment in subtropical beef cattle pastures.

Table 1. Above-ground biomass (kg ha⁻¹) of bahiagrass during its early establishment (January 2002 to June 2003).

TREATMENT COMBINATION (% DM + %NS)	16 WEEKS	34 WEEKS	78 WEEKS
DM0 (0 + 100)	88.9 ± 63.2d*	1512.8 ± 165.9c	1262 ± 115.6d
DM25 (25 + 75)	378.4 ± 184.7c	2409.2 ± 423.2b	2780.2 ± 678.4c
DM50 (50 + 50)	673.2 ± 233.0a	2466.5 ± 320.2b	3076.8 ± 322.2bc
DM75 (75 + 25)	653.6 ± 106.1ab	2764.3 ± 320.2b	4108.9 ± 220.3a
DM100 (100 + 0)	470.3 ± 92.7bc	3348.7 ± 173.8a	3803.9 ± 1120.0ab

*Means on each column followed by same letter(s) are not significantly different from each other at $p \leq 0.05$.

Mean biomass of BG during week 16 in plots with 50% DM of 673 ± 233 kg ha⁻¹ was not significantly different from that in plots with 75% DM (654 ± 106 kg ha⁻¹), but was greater than that in plots with 25% DM (378 ± 185 kg ha⁻¹) and 0% LDM (Table 1). For weeks 34, the greatest biomass among plots amended with DM was from plots with 100% DM + 0% NS (3349 ± 174 kg ha⁻¹). The lowest biomass of 1513 ± 166 kg ha⁻¹ was from plots with 0% DM + 100% NS. Mean biomass of BG in plots with 50% DM of 2467 ± 320 kg ha⁻¹ was not significantly different from that in plots with 75% DM (2467 ± 320 kg ha⁻¹) and 25% DM (2409 ± 423 kg ha⁻¹), but was greater than that in plots with 0% DM (Table 1).

For weeks 78, mean biomass of BG in plots with 100% DM of 3804 ± 1120 kg ha⁻¹ was comparable with that of BG biomass in plots with 75% (4109 ± 220 kg ha⁻¹) and 50% DM (3077 ± 322 kg ha⁻¹). Mean biomass of BG in plots 75% DM was significantly different from the mean biomass of BG in plots with 50%, 25%, and 0% DM (Table 1).

Soil Properties

Except for sodium (Na), the levels of soil pH, K, calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn), copper (Cu), iron (Fe), aluminum (Al), and silicon (Si) varied significantly among plots amended with different rates of DM (Tables 2 and 3). Compared with the control plots, the soils in plots amended with DM exhibited: (1) a decrease in the levels of soil K, Mn, Cu, Fe, Zn, and Al; (2) an increase in soil pH, Ca, Mg, and Si; and (3) no significant change in the level of Na in the soil.

Table 2. Levels (mean ± SD) of pH, K, Ca, Mg and Zn in soils (mg kg⁻¹) with or without addition of dredged materials (Jan. 16, 2003).

TREATMENT COMBINATION (% DM + %NS)	pH	K	Ca	Mg	Zn
DM0 (0 + 100)	5.98 ± 0.10c*	3.6 ± 0.6ab	105.2 ± 5.4b	4.4 ± 2.6b	0.690 ± 0.128a
DM25 (25 + 75)	8.39 ± 0.27ab	0.9 ± 0.1c	1962.7 ± 25.8a	11.9 ± 0.7a	0.010 ± 0.005b
DM50 (50 + 50)	8.35 ± 0.14ab	2.8 ± 1.4ab	2040.3 ± 29.1a	13.6 ± 1.1a	0.006 ± 0.001b
DM75 (75 + 25)	8.17 ± 0.09b	1.8 ± 1.0bc	2008.7 ± 87.1a	14.6 ± 1.7a	0.007 ± 0.001b
DM100 (100 + 0)	8.54 ± 0.11a	2.5 ± 0.7bc	2030.0 ± 9.2a	14.7 ± 0.6a	0.005 ± 0.000b

*Means on each column followed by same letter(s) are not significantly different from each other at $p \leq 0.05$.

Addition of DM resulted in higher soil pH than those plots with 0% DM. Soil pH (averaged across plots with DM) of 8.4 ± 0.2 was higher than plots with 0% DM, which had an average soil pH of 5.9 ± 0.1 . The range of soil pH among plots with DM was from 8.17 ± 0.09 to 8.54 ± 0.11 (Table 2). The amount of soil Ca and Mg among plots with DM were significantly higher than that in the control plots. However, the amounts of soil Ca and Mg among plots with DM were statistically comparable among each other. Addition of DM had increased the levels of Ca and Mg by about 1811% and 211%, respectively when compared with the level of soil Ca and Mg among plots with no DM application (Table 2).

The levels of soil Mn, Cu, Fe, and Al were significantly lowered by the addition of DM. Levels of Mn, Cu, Fe, and Al (averaged across treatments) were reduced from 2.9 to 0.3, 0.456 to 0.002, 15.61 to 0.01, and 187.23 to 0.07 mg kg⁻¹, respectively when compared with the levels of Mn, Cu, Fe, and Al for soils with 0% DM (Table 3). The levels of Si in plots with DM were significantly higher than the level of Si in plots with 0% DM while Na level in the soil was not affected by DM additions (Table 3).

Table 3. Levels (mean $\pm$ SD) of Mn, Cu, Fe, Al, Si and Na in soils (mg kg⁻¹) with or without addition of dredged materials (Jan. 16, 2003).

TREATMENT COMBINATION (% DM + %NS)	Mn	Cu	Fe	Al	Si	Na
DM0 (0 + 100)	2.86 $\pm$ 0.39a*	0.456 $\pm$ 0.053a	15.606 $\pm$ 5.598a	187.23 $\pm$ 13.28a	20.47 $\pm$ 2.02b	20.21 $\pm$ 1.16a
DM25 (25 + 75)	0.35 $\pm$ 0.05b	0.001 $\pm$ 0.001b	0.029 $\pm$ 0.051b	0.19 $\pm$ 0.25b	30.75 $\pm$ 8.82a	23.52 $\pm$ 6.18a
DM50 (50 + 50)	0.031 $\pm$ 0.01b	0.002 $\pm$ 0.001b	0.006 $\pm$ 0.001b	0.03 $\pm$ 0.02b	37.14 $\pm$ 1.10a	21.31 $\pm$ 0.92a
DM75 (75 + 25)	0.25 $\pm$ 0.01b	0.002 $\pm$ 0.002b	0.007 $\pm$ 0.001b	0.01 $\pm$ 0.01b	37.89 $\pm$ 2.20a	22.51 $\pm$ 3.17a
DM100 (100 + 0)	0.34 $\pm$ 0.04b	0.003 $\pm$ 0.002b	0.005 $\pm$ 0.000b	0.04 $\pm$ 0.07b	36.38 $\pm$ 1.11a	22.14 $\pm$ 2.44a

*Means on each column followed by same letter(s) are not significantly different from each other at $p \leq 0.05$.

Soil K levels, unlike other nutrients that were described above, did not show any distinct trend and/or response to DM additions. The highest average soil K levels of 3.6 $\pm$ 0.6 mg kg⁻¹ was observed from plots with 0% DM while the lowest soil K value of 0.9 $\pm$ 0.1 mg kg⁻¹ was from plots with 25% DM. Levels of soil K among plots with 0%, 50%, 75%, and 100% DM were statistically comparable (Table 2).

DISCUSSION

Results have shown the favorable influence that DM had on BG during its early establishment in sandy subtropical beef cattle pasture sites. Addition of DM had significant effects on soil properties in the pasture area. Sediments dredged from Lake Panasoffkee have high CaCO₃ content (82%) and when these materials were incorporated into existing topsoil they would have the same favorable effects as liming the field. Some of the indirect benefits of liming pasture fields among others would include: enhancing P and microelement availability, nitrification, nitrogen fixation, and improving soil physical conditions (Tisdale and Nelson, 1975; Russel, 1973). A similar study on beneficial use of dredged materials in east central Florida was reported by Sigua et al. (2000). Patel et al. (2001) reported that grasses grown in muck-amended topsoil had adequate and comparable nutrient levels with grasses grown in heavily fertilized and well-maintained golf course soils. They also reported that horticultural studies showed encouraging results of several plant species, such as the holly (*Ilex cornuta*), liriopse (*Liriope muscari*), oyster plant (*Rhoeo spathacea*) and bermudagrass (*Cynodon dactylon*).

Although DM only contained relatively low nutritional values, its effect on BG in the beef pasture field was remarkable because BG during its early establishment requires low levels of nutritional needs. The levels of nitrogen, phosphorus, and the liming effects of LDM were enough to promote and sustain the early establishment stage of BG in the beef pasture field (Sigua et al., 2003).

Liming the field could have some direct and indirect effects on early establishment of BG on the chemical status of the soils. Perhaps the single direct benefit of liming is the reduction in acidity and solubility of aluminum and manganese (Peevy et al., 1972). Addition of DM resulted in higher soil pH than those plots with 0% DM. Soil pH (averaged across plots with DM) of 8.4 $\pm$ 0.2 was higher than plots with 0% DM, which had an average soil pH of 5.9 $\pm$ 0.1. The amount of soil Ca and Mg among plots with DM were

significantly higher than that in the control plots. Addition of DM had increased the levels of Ca and Mg by about 1811 % and 211 %, respectively when compared with the level of soil Ca and Mg among plots with no DM application. The levels of soil Mn, Cu, Fe, and Al were significantly lowered by the addition of DM.

CONCLUSIONS and OUTLOOK

The ability to reuse dredge materials from Lake Panasoffkee for agricultural purposes is important because it reduces offshore disposal and provides an alternative to disposal of the materials in landfills that are already overtaxed. The bottom sediments that were dredged from Lake Panasoffkee contained neither materials that would not classify them as a human health risk nor would require expensive hazardous waste handling and disposal. As such, the agricultural or livestock industry could utilize these DM to produce forages. Dredged materials should be regarded as a beneficial resource, as a part of the ecological system.

Our results have shown the favorable influence that DM had on yield of BG during its early establishment in subtropical beef cattle pastures. Bahiagrass in plots that were treated with DM had significantly higher aboveground biomass productivity when compared with those BG in the control plots. This study will continue exploring and assessing the long-term efficacy of DM on productivity and quality of BG beyond its early establishment stage in subtropical beef pastures.

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ABSTRACTS

Session 5: DREDGING AND DREDGED MATERIAL MANAGEMENT

PRESENTATIONS

Challenges of Beach Nourishment in Pinellas County, Florida. N. Elko (Pinellas Co. Public Works). The Tampa Bay Estuary comprises several of the tidal inlets in Pinellas County. Beach-quality sand has been dredged from these inlets since the early 1900s. The sediment was often disposed offshore. Pinellas County has also been engaged in the enhancement of its sandy beaches for over 30 years. One of the first beach nourishment projects in Florida was the nourishment of Treasure Island in 1969. At that time, we dredged sediment for beach nourishment projects from offshore borrow areas in the Gulf, typically about 500 m offshore.

In the early 1980s, the U.S. Army Corps of Engineers developed a 50-year plan to combine maintenance dredging of Pinellas County's tidal inlets with beach renourishment, using the adjacent beaches as "disposal sites." As a result, substantial cost savings and environmental benefits have been realized. This paper highlights dredging projects at John's Pass, Blind Pass, Pass-a-Grille Channel, and Egmont Channel. The dredged material has been used to nourish beaches along Sand Key, Treasure Island, and Long Key.

Many lessons have been learned as some projects proved successful and others challenging. Sediment was pumped from Egmont Shoal several times, but during the nourishment of Sand Key in 1998, limestone rocks were inadvertently deposited within the beach fill. The 1993 oil spill in Tampa Bay came back to haunt us in 2000 when oil was encountered in Blind Pass; however, only clean sand was recovered from John's Pass, less than 6 km away, in 1996.

Some benefits from combining inlet maintenance dredging with beach nourishment include cost savings associated with combined projects, maintenance of channel depths for boating access, storm surge protection for coastal infrastructure, economic benefits from tourism, and increased habitat for coastal wildlife, such as shorebirds and sea turtles. [nelko@co.pinellas.fl.us.]

POSTERS

Integrated Modeling of Hydrodynamics, Water Quality, Sediment Resuspension, and Submerged Aquatic Vegetation to Assist in Managing Environmental Impacts from a Dredging Operation. R.S. Copp (DHI Inc.). DHI provided environmental modeling support to the Danish government during the planning, design, and construction management for a bridge from Denmark to Sweden. The construction of the bridge required dredging of over 10,000,000 m³ of dredged material from the Øresund, a natural connection between the Baltic and North Seas. The model was developed and calibrated to measured data describing currents, tide levels, water clarity, nutrients, phytoplankton, and submerged aquatic vegetation. A forecast model was developed so that predictions of water quality could be developed based on regional weather predictions. This model was used to determine the appropriate fill design to prevent and loss of circulation between the Baltic and North Seas, and to predict the response of aquatic biota to re-suspension of dredged material caused by the bridge construction. The model was then used to design the dredging project to minimize impacts to water with transparencies exceeding 10 meters. The model was then used during the dredging project to project periods when dredging would cause permanent impacts to aquatic biota. If the modeling projected long-term impacts, the dredging operations were modified to reduce the impact. DHI also monitored water quality during dredging to enhance the accuracy of the forecasting model. The bridge construction project was completed without reducing estuarine circulation and loss of submerged aquatic vegetation and mussels. This paper will describe the tools used in the project, the success of the model for forecasting environmental impacts, and changes that were made in the modeling to improve model performance. [roc@dhigroup.com]

Tampa Ship Channel Study. T. Leeser (US Army Corps of Engineers). This poster will describe the Corps of Engineers' planning process and apply it to the ongoing feasibility study of channel modifications. In particular, the poster will provide information on how the economy, the environment and other social effects are considered in decision-making. [Tracy.T.Leeser@ saj02.usace.army.mil]

A Regional Waterway Management System. R. Swett, G. Antonini, D. Fann (Univ. of Fla. Florida Sea Grant), C. Listowski (West Coast Inland Navigation District). Managing coastal development remains a critical challenge facing Florida and the nation. Thousands of miles of channels dredged as by-products of waterfront development are used as navigable waterways by many of Florida's nearly one million recreational boaters. As marine resources are used to capacity and natural environments decline, a compelling need exists to foster compatible and sustainable community development. In response, Florida Sea Grant developed the Regional Waterway Management System: a standardized, science-based system that includes geographic information system data

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(boats, depths, moorings, facilities, signs, and habitat), analytical techniques, and policy recommendations for prioritization of waterway management options on a regional basis.

Principal elements include: (a) documentation of existing depths; (b) establishment of maintenance dredging requirements according to user vessel draft; (c) sign placement to conform with boat density and traffic patterns; (d) boat traffic management based on existing boat distributions and travel routes; (e) siting of habitat restoration to protect waterways; (f) regional scale permitting to accommodate water-dependent uses and minimize environmental impacts; and (g) public education using waterway maps and guide materials that encourage environmental stewardship and best boating practices.

Regional Waterway Management System successes include a new State of Florida administrative code, “Chapter 62-341.490 Noticed General Permits for Dredging by the West Coast Inland Navigation District (WCIND).” Benefits include: 1) greater efficiency and effectiveness in dredging and maintaining waterways, by allowing decision-makers to assign regional priorities, 2) savings in dollars and staff time, and 3) better public policy through a holistic, ecological decision-making process. [rschwett@ufl.edu]

PRE-PLANNING A COOPERATIVE DAMAGE ASSESSMENT FOLLOWING A SPILL IN TAMPA BAY

J. Jeansonne

ABSTRACT

Following an oil spill into the Tampa Bay estuary, state and federal natural resource Trustees initiate data collection as a first step in conducting a potential Natural Resource Damage Assessment under OPA, CERCLA, and/or Florida law. The clearest picture of resource exposure and injury is obtained when data collection commences within hours of the incident, to preserve ephemeral data. This rapid mobilization by Trustees requires preplanning. Industries that handle oil and chemicals routinely engage in planning and training for spill emergency response, and may include NRDA data collection in their plans as well. Unless Trustees and potential spillers engage in coordinated and cooperative NRDA pre-spill planning, the two parties will generate separate data sets, which may become difficult sticking points during NRDA liability discussions, rather than the objective scientific data that they are meant to be. If however, the NRDA data collection is planned and implemented by a cooperative Trustee-PRP team it is more likely to become the basis for fruitful discussion to achieve appropriate restoration. Such cooperative ephemeral data collection plans have been completed for one fuel terminal in Tampa Bay, and plans are in process for other facilities and operators using Tampa Bay.

INTRODUCTION

This paper describes pre spill trustee-industry coordination for collection of ephemeral data for natural resources damage assessment (NRDA) following a spill into the Tampa Bay estuary such as occurred in 1993 (Figure 1). After a spill there is only a brief time window to collect critical data to establish an accurate picture of environmental conditions and the degree of exposure to the spill. Trustee agency and responsible party reps often work independently to generate separate data sets. These often conflicting data sets may lead to technical & legal haggling, a delay in resolution of the NRDA, and postponing restoration actions.



Figure 1. Photo of the burning fuel barge Maritrans 255 during the Tampa Bay oil spill of August 10, 1993.

BASICS OF A NATURAL RESOURCE DAMAGE ASSESSMENT — NRDA 101

NOAA, DOI, States, & Tribes are Natural Resource Trustees under CERCLA, OPA & other federal Laws. Florida also has an NRDA law for coastal spills of oil, chlorine, ammonia, and pesticides. Trustees act on behalf of the public to protect and restore natural resources injured from oil spills, hazardous substance releases and vessel groundings. Following an incident, Trustees collect data regarding resource injuries, and may conduct a damage assessment to recover damages to implement resource restoration.

The first few days or weeks of the NRDA following an incident are the “Pre-assessment Phase.” Critical ephemeral data must be collected during this period to preserve the ability to go forward with an NRDA under OPA/CERCLA. At the conclusion of the Pre-assessment, federal Trustees decide if an assessment is warranted by the extent of injury and public losses, and evaluate restoration options. Florida NRDA statutes mandate an NRDA using either their compensation formula or a full assessment. Trustees encourage the spiller to engage in a fully cooperative NRDA at all phases of the process.

Advantages of Cooperative NRDA Planning

A cooperative and coordinated ephemeral data collection is a great start toward a fair and early resolution of the NRDA so that restoration can proceed. A good example of a pre-spill cooperative NRDA plan is the ChevronTexaco Ephemeral Data Collection Plan that was completed in Feb 2003. The planning process was initiated by ChevronTexaco (Mike Ammann) in 2002. It is specific for the C-T Port Tampa light fuel products terminal and focuses on the bay area near Port Tampa (Figure 2).

Important Elements Of a Cooperative Data Collection Plan

- It is the company’s plan, but developed in full coordination with the NRDA Trustees.
- Primarily a technical plan addressing the specific contacts and actions needed to immediately start data collection.
- Should be flexible and may be modified as needed and time permits.
- Should cover data collection needs for the first few days following a spill (not intended for long term studies).
- Focuses on the bay areas near each facility

Typical Plan Contents

- Company policy statement supporting cooperative data collection
- Critical team contact and coordination information
- Field sampling protocols – including chain of custody, field cleaning of sampling devices, sample storage and shipping
- Lab analysis methods (EPA and FL approved methods & detection limits agreeable to all parties)
- Sample handling & shipping instructions, with kits
- Field sampling kits—pre-assembled and available
- A list of pre-selected sampling sites with directions to access them, photos, maps and GPS coordinate.

The ChevronTexaco Sampling Kit

Figure 3 shows the ChevronTexaco sampling kit ready to use. It is composed of a pair of duplicate kits to outfit two field teams. The ChevronTexaco kit may be used for any spill in Tampa Bay by contacting the CT data collection team coordinator: Jim Jeansonne (NOAA) 727-570-5714 or jim.jeansonne@noaa.gov.

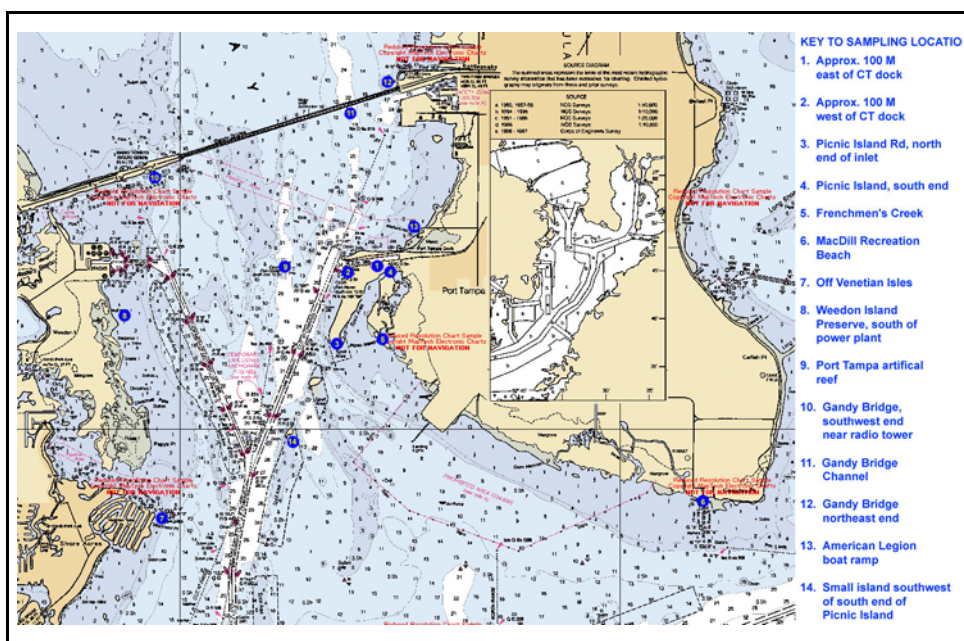


Figure 2. Map of pre selected sampling sites for the ChevronTexaco Ephemeral Data Collection Plan, February 2003.

Example of Pre-Selected Sampling Station

Figure 4 is a photo of one of the pre-selected sampling stations at the east end of Gandy Bridge, north side. GPS coordinates, driving directions, and sampling protocol are established and included in the plan.

On-Going Tampa Bay Cooperative NRDA Pre-Spill Planning Efforts

Any interested party may participate in the bay wide pre-spill NRDA coordination and planning efforts. Specific industries or groups of industries should contact Jim Jeansonne. Bay area scientific, NGOs, or user groups may also participate as appropriate by contacting the author.

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Figure 3. Photo of the ChevronTexaco spill sampling kit located at the Chevron Port Tampa fuel terminal.



Figure 4. Photo of a pre-selected sampling station located at the east end of the Gandy Bridge.

ABSTRACTS
Session 6: SPILL PREVENTION AND RESPONSE

PRESENTATIONS

The Tampa Bay Physical Oceanographic Real-Time System (TBPORTS). M. Luther (USF College of Marine Science), S. Fidler (Tampa Port Authority). The Tampa Bay Physical Oceanographic Real-Time System (TBPORTS) was built between 1990 and 1992 by the NOAA National Ocean service. It became operational in 1992 and local operations and maintenance were turned over to a local consortium of maritime interests. TBPORTS consists of 8 sites measuring wind speed and direction (5 sites), water level (4 sites), and water current speed and direction profiles (3 sites). Data from all sites are telemetered in real-time at 6-minute intervals by line-of-sight radio to data acquisition computers at the USF College of Marine Science. The data are checked for quality assurance and then immediately relayed to the maritime and environmental protection community and to the general public through dedicated terminals, through the Internet (<http://ompl.marine.usf.edu/PORTS>), and through an automated voice response system (1-866-TBPORTS). Data from the system are used to drive a nowcast-forecast model of the currents and water levels in the bay. The primary purpose of TBPORTS is to improve the safety and efficiency of maritime transportation. In the 5 years before TBPORTS became operational, there were 35 ship groundings in the bay. In the 5 years after TBPORTS became operational, there were 14 ship groundings. TBPORTS data and the USF model also are used in environmental protection and management. TBPORTS data regularly are used in oil spill drills and contingency planning, in USCG search and rescue operations, in analyses of impacts of regional water supply projects on the bay, in tracking raw sewage spills, and in analyses of the effects of the discharges of treated phosphate process water from the Piney Point facility.

The local funding for TBPORTS has come from state and county trust funds (DEP, DOT, and Hillsborough County), from the Tampa Port Authority, from the Tampa Bay Pilots, from Tampa Bay Water, from the City of St. Petersburg, and from a few shipping interests. The local funding is administered through a not-for-profit corporation, the Greater Tampa Bay Marine Advisory Council-PORTS, Inc. The corporation has formal cooperative agreements with NOS to operate the system and with USF to house the system. The corporation subcontracts to various entities for services to operate and maintain the system. NOS provides in-kind costs in the form of the continuous monitoring for QA/QC and phone support for technical issues. NOS owns the Data Acquisition and Distribution System, and thus the liability associated with the data. They provide no direct funding. [luther@marine.usf.edu]

The FMSAS, Coastal Area Contingency Plans, ArcIMS and ArcPAD Digital Integration for Spill Prevention and Response. R. Knudsen (FWC), E. Lesnett (Env. Protection Commission of Hillsborough Co.). In the years since the 1993 Tampa Bay oil spill, the Florida Marine Research Institute (FMRI) has remained active in spill prevention and response activities throughout the state. In cooperation with the Florida Department of Environmental Protection's Bureau of Emergency Response (BER), the United States Coast Guard (USCG), the National Oceanic and Atmospheric Administration (NOAA), the US Environmental Protection Agency (EPA), and other state and local entities, FMRI has been compiling an extensive library of GIS data for spill prevention and response while developing a broad range of integrated applications that use this data for contingency planning, risk assessment, interagency coordination, and effective response to spills. These efforts have long focused on protection priority for fish and wildlife habitats, as these are the resources most affected by marine spills. In recent years, though, there has been more focus in defining areas based on risk. Well-considered contingency planning and broad dissemination of contingency information have proven highly desirable for quick, coordinated spill response. Everyone is on the same page when responding to an incident. This includes the Oil Spill Response Organizations (OSROs), the Responsible Party (RP), the Coast Guard, Law Enforcement Agencies, and the various state and local agencies that become involved during the response.

This concept has proven itself in the Tampa Bay area through the Tampa Bay Digital Area Contingency Plan (ACP). FMRI designed the CD-based ACP, for the USCG and BER. The ACP was subsequently produced as an ArcIMS (Internet Map Server) Web site with associated Adobe PDF documents and maps. Since its production, the ACP has been used as an effective organizing and planning tool at numerous government and industry led spill drills in the area. The concept works. FMRI continues to evolve and improve on the digital area contingency plan by developing new field-based, mobile, Internet-connected tools for use in accurate and timely field data collection and dissemination of critical spill planning and response information. This mobile workforce holds the promise of making Web-based GIS technology affordable and available to other agencies and users who may find a need for accessing or modifying GIS data in the field. The applications developed also hold promise of an on-scene, GIS-enabled incident-reporting tool that can be used by state agencies to rapidly and consistently report on the numerous smaller spills that occur throughout the state. [richard.knudsen@fwc.state.fl.us]

A Summary of Restoration Projects for Natural Resource Injuries and Lost Human Use from the 1993 Oil Spill. J. Iliff (NOAA Restoration Center), B. Pridgeon, P. Wiczynski, D. LetoBarone, G. Henderson, S. Fluke, M. Malvern, L. Craig (FWC Fla. Marine Research Inst.). The Oil Pollution Act defines restoration as activities that restore, replace, rehabilitate or acquire the equivalent of the natural resources or natural resource services lost. After reaching a settlement for the 1993 Tampa oil spill in April of 1999, the National Oceanic and Atmospheric Administration, the Department of the Interior's Fish and Wildlife Service, and the Florida Department of Environmental Protection, acting as a Trustee Council, began selecting and implementing restoration projects which were defined by publicly reviewed restoration plans. Two broad categories of loss occurred as a result of the spill: ecological losses and recreational losses. A separate restoration plan was developed for each of these broad categories. The ecological restoration plan addressed restoring losses of mangrove, saltmarsh, oyster, and seagrass habitats, sea turtles, birds, water column, sediments, and beach sand. Mangrove and saltmarsh restoration projects were designed and implemented by the responsible parties with Trustee oversight and the remaining projects were identified and funded by the Trustees with settlement dollars. The recreational restoration plan identified restoration alternatives and projects designed to acquire or enhance public access to natural resources for recreational purposes. Recreational projects included construction of fishing piers, public trails, and walkways, enhancement of boating opportunities, and enhancement of natural resource amenities. All recreational projects were selected and funded by the Trustee Council with settlement funds and are being implemented by beach municipalities affected by the spill and Pinellas County. An overview of all the restoration projects is provided and the rationale for choosing those projects is discussed. [john.iliff@noaa.gov]

POSTERS

Fine-Scale Mutational and Breeding System Effects of Environmental Contaminants on Red Mangroves in Tampa Bay, Florida. C.E. Proffitt, S.E. Travis (USGS National Wetlands Research Ctr.) We assessed the sensitivity of *Rhizophora mangle*, to sublethal stress from mutagens across a fine spatial scale by comparing the frequency of mutations for albinism between historically contaminated and uncontaminated sites in Tampa Bay. We also examined hypotheses that increased mutation rates (MR) could have deleterious consequences on *R. mangle* reproductive output (estimated as reproducing trees km⁻¹) and that sites with greater MR might have an increased rate of self-fertilization in order to more rapidly purge the mutant alleles. Differences in MR for two different types of mangrove systems (e.g., riverine vs. non-riverine), variation in rates in stands of different distances from the Gulf of Mexico, and the effects of tree size on MR were also assessed. MR in populations with known exposure to oil or chemical spills were significantly higher than at other sites within the bay (24.62 ± 8.99 compared to 9.18 ± 1.99 mutations per haploid genome per generation [MHGG], all values are $\times 10^{-4}$). MR were lower in the upper reaches of the bay nearer urban areas, but did not differ between riverine and non-riverine forests. A significant negative correlation between MR and numbers of reproducing trees per km⁻¹ ($r = -0.46$, $P < 0.027$) suggests the possibility that increased mutational load may affect stand viability. Percent outcrossing was not different in contaminated versus non-contaminated sites, although outcrossing varied locally from 0 to 59.2%. Comparisons with Puerto Rico indicated significant regional differences in MR in addition to differences in both regions due to contamination. [Edward_proffitt@usgs.gov]

REACHING TAMPA BAY RESTORATION GOALS THROUGH WATERSHED MANAGEMENT

R. Eckenrod

Communities in the Tampa Region made substantial commitments over the past 20 years to cleaning up and restoring Tampa Bay. Most notable are improvements in wastewater treatment that reduced nitrogen loading, improved water clarity and spurred recovery of seagrass in much of the bay. And while the command and control regulatory approach proved effective in controlling point-sources, the emergence of stormwater runoff and atmospheric deposition as major sources of nitrogen and other pollutants reinforced the need to manage Tampa Bay and its watershed as a linked system.

The addition of Tampa Bay to the National Estuary Program in 1990 strengthened the movement toward watershed management initiated at least 5 years earlier with publication of the Future of Tampa Bay (Tampa Bay Management Study Commission, 1985). Centered on 42 priority issues identified by the Tampa Bay Management Committee that preceded it in 1983, the Study Commissioner developed the first comprehensive management plan for Tampa Bay. Members of the Management Committee and Study Commission recognized the dependence of bay restoration on its watershed by ranking control of nonpoint source pollution among the third highest of 42 priority issues.

Controlling runoff from the watershed was also emphasized by SWFWMD's Surface Water Improvement and Management (SWIM) program which made retrofitting stormwater collection systems one the highest priorities in the first Tampa Bay SWIM plan adopted in 1988. The theme of the second Bay Area Scientific Information Symposium (BASIS 2) three years later was understanding watershed/estuary interactions.

Management of Tampa Bay and its watershed was elevated to another level with the naming of Tampa Bay to the National Estuary Program (NEP) in 1990. Created in 1987 as part of an amendment to the Clean Water Act, the NEP was designed to assist communities in the watersheds of nationally significant estuaries to develop and implement comprehensive conservation and management plans (CCMP) to restore and protect their estuaries. Administered through the U.S. Environmental Protection Agency (EPA), the NEP prescribes a formal watershed approach patterned after two successful Great Waters programs – the Great Lakes and Chesapeake Bay programs. In exchange for \$5,000,000 in federal funding over five years, local government and agency partners in the Tampa Bay NEP committed through a Management Conference Agreement with EPA to establish a formal committee structure and follow seven prescribed steps in developing a CCMP for Tampa Bay.

Development of the CCMP was overseen by a Policy Committee consisting of elected representatives from six local governments (the cities of Tampa, St. Petersburg, and Clearwater and the counties of Hillsborough, Pinellas and Manatee) along with high ranking officials from the Florida Department of Environmental Protection (FDEP), the Southwest Florida Water Management District (SWFWMD), and EPA. A 16-member Management Committee of senior managers, a Technical Advisory Committee (TAC), and a Citizen Advisory Committee provided decision support for the Policy Board. Membership on the TAC was open to all scientists, engineers, and resource managers from public and private sectors with an interest in serving. The TAC drew more than 200 individuals from the diverse scientific community in the Tampa Bay region. The Citizen Advisory Committee (later the Community Advisory Committee) was initially appointed by members of the Policy Board, each board member appointing three CAC members. After nine years the CAC was expanded to include thirty-six members, most selected from the community at large.

In keeping with EPA guidelines, the Tampa Bay NEP followed a non-regulatory, watershed planning approach as follows.

Identification of Priority Problems: Identifying priority problems was the first task of the program's Technical Advisory Committee. Building upon earlier efforts of the Tampa Bay Management Committee, Study Commission, ABM, and SWIM, the TAC compiled a list of 44 priority problems/issues. Individual issues were grouped into six general categories in the management plan that followed: water and sediment quality; bay habitats; fish and wildlife; spill prevention and response; dredged material management; and public education and involvement. The CAC deferred to the TAC on the identification of technical issues and focused its attention on supporting the public education and outreach efforts.

A Rigorous Characterization of the Problems and Their Causes: A significant portion of the program's resources leading up to the CCMP was devoted to characterizing the status and trends of bay water quality and living resources and the factors affecting the abundance and health of those resources. Early workshops of the TAC were instrumental in identifying critical gaps in the already voluminous body of knowledge on the Tampa Bay ecosystem and establishing research priorities for characterization phase of the program. A major effort was devoted to developing the paradigm relating seagrass recovery to nitrogen loading. Drawing on the rich water quality data base compiled by the Hillsborough County Environmental Protection Commission and research on light requirements of seagrass conducted by Mote Marine Laboratory and others, the program developed various empirical relationships linking nitrogen loading to chlorophyll *a* concentrations in the water column, to light extinction, and finally to seagrass recovery. Results of the characterization phase of the program were documented in sixty-one technical reports published by the program and accessible through the program's Technical Website.

Establishing Measurable and Achievable Goals: Scientists and resource managers advising the program emphasized the importance of grounding bay restoration on a scientifically defensible set of living resources goals. The concept was carried over from the Resource-Based Water Quality Subcommittee of the Agency on Bay Management. Senior managers and administrators on the program's Management Committee placed a premium on achievability of goals, not wanting to commit the entities they represented to goals that couldn't realistically be reached because of technical or economic constraints. A set of achievable, resource-based goals emerged from the conjunction of the two trains of thought. Among the goals were restoring 13,000 acres of seagrass while protecting the existing 25,000 acres and restoring at least 100 acres of oligohaline wetland habitat every five years.

Developing 40 Specific Actions to Address Priority Issues: Technical and citizen advisors to the program pooled their energy to devise and assess various options to tackle the priority problems. Subcommittees of the TAC engaged in countless workshops to draft and refine actions. Members of the CAC used their networks in the community to organize focus groups among bay user groups which critiqued proposed actions and provided invaluable input. The Management Committee identified potential deal-breakers in early drafts of the plan and used their collective experience in problem solving to work through apparent impasses. The planning phase of the program culminated in November 1996 with approval by the Management and Policy Committees of Charting the Course, the Comprehensive Conservation and Management Plan (CCMP) for Tampa Bay consisting of 40 separate actions, each one setting forth the necessary steps, responsible parties, estimated costs, and an implementation schedule.

Adopting a Unique Interlocal Agreement Committing the Partners to Implementing the

Plan: After a year of professionally facilitated discussions among member governments on the Management Board, thirteen entities signed a landmark Interlocal Agreement pursuant to Sec. 163.01, Florida Statutes committing to implement the CCMP. The EPA and Corps of Engineers executed ancillary agreements to the primary agreement. Unique among NEPs at the time, the Tampa Bay Interlocal Agreement has since served as a model for other NEPs around the country. Central to the agreement was a commitment by the parties to develop and periodically update local action plans, describing actions the entity would take to help advance the goals of the CCMP. Program staff was given responsibility for collating and tracking the partners' action plans to ensure that the cumulative effect of the partners' actions represented adequate progress toward CCMP goals. Through the agreement, the Tampa Bay National Estuary Program was reconstituted as the Tampa Bay Estuary Program (TBEP), an independent legal entity later determined by the Florida Department of Community Affairs to be an independent special district of the state of Florida.

Implementing a Comprehensive Environmental Monitoring Program and Identifying

Research Priorities: Arguably the most studied estuary in Florida, Tampa Bay has benefited from a wealth of environmental monitoring programs and research projects conducted by local government and agency partners of TBEP. Every three to four years, TBEP partners conducting various monitoring programs collaborate to produce a Baywide Environmental Monitoring Report (BEMR) documenting status and trends of key environmental indicators and progress, or lack thereof, toward CCMP goals. Freshwater inflow and pollutant loads from the watershed are among the key elements of the BEMR.

A particularly noteworthy feature of the baywide environmental monitoring effort in the Tampa Bay region is the exceptional degree of cooperation and coordination among agencies and local governments. Coordination of the water and sediment/benthic quality elements of the baywide program, for example, is accomplished through a Regional Ambient Monitoring Program (RAMP). Initiated by the TBEP in 1992, the RAMP is now operated by its fifteen local government and agency partners that conduct monitoring programs from Pinellas County to Collier County. The principal objective of the programs is to ensure comparability of analytical methods for a core group of water quality parameters including TN, nitrate + nitrite, ammonia, TSS, TP, and chlorophyll *a*.

Educating and Engaging the Public in Bay Restoration Activities: Involvement of diverse stakeholder groups in developing and implementing the waterbody restoration plan is a hallmark of a successful watershed management program. TBEP organized its initial public education and outreach strategy around priority problems that the public could impact in meaningful ways. To address problems associated with contaminated stormwater runoff from yards and neighborhoods, for example, TBEP teamed up with its neighboring Sarasota Bay NEP to develop the Florida Yards and Neighborhoods program. Experts from county extension services, which now administer the FY&N program in counties throughout the state, teach residents ways to reduce polluted runoff and enhance their local environment by improving home and landscape management.

To promote protection of seagrasses and other vital bay habitats and wildlife, TBEP collaborated with the Florida Marine Research Institute to publish a Boater's Guide to Tampa Bay in 1992. The popular Tampa Bay Boater's Guide, published in its third edition in 2004, has served as a model for other estuaries around Florida.

TBEP has been instrumental in engaging citizens in field activities to help restore and protect the bay. In 1993, TBEP helped establish a Bay Conservation Corps under the direction of Tampa BayWatch, Inc. In its early years, the Corps enlisted thousands of citizens for dozens of bay improvement projects, including many wetland restoration projects implemented by the SWFWMD SWIM Program. To supplement volunteer activities sponsored by Tampa BayWatch, TBEP sponsors four to five volunteer workdays each year that directly involve close to 400 citizens each year. These "Give A Day For The Bay" workdays are conducted in partnership with local governments or non-profit organizations and have included such diverse projects as oyster reef construction, Brazilian pepper removal, litter cleanups and salt marsh plantings. TBEP's Bay Mini-Grants program has provided more than \$350,000 in grants to community organizations for bay restoration and education projects. Funded by sales of the Tampa Bay Estuary license plate, the Program provides grants of up to \$7,500 to school, non-profits, neighborhood associations and others. CAC members helped to develop the selection and eligibility criteria for the program, and serve as judges of grant applications.

In 2003, TBEP held its first-ever "Estuary Academy," an all-day intensive seminar to expose citizens to ongoing research in Tampa Bay. Participation was limited to 100, and the event was at capacity. All participants attended a series of engaging lectures in the morning highlighting important aspects of Tampa Bay and research related to those topics; the afternoon was devoted to several hands-on workshops that allowed attendees to be "scientists for a day" by building robotic underwater vehicles, hauling a seine net to sample fish stocks, or examine marine algae and seagrasses through microscopes. The 2004 Estuary Academy, scheduled for National Estuaries Day, is expected to be equally successful.

TBEP has been a pioneer in educating citizens on measures to prevent and control the spread of invasive species, the most recent priority problem targeted by the Program. TBEP has sponsored volunteer workdays targeting removal of invasive plants from nature preserve and has developed an entire section on its website, called "Eyes On The Bay," that provides information about invasive species. The program has helped to finance an extensive, interactive exhibit at The Florida Aquarium called "Invaders!"; and co-sponsored production of a popular Field Guide to Invasive Plants in Tampa Bay and the "Divers Alert!" Card that enlist divers to report sightings of eight known or suspected marine invaders.

Managing the bay and its watershed is a never-ending task. As long as the human population of the Tampa Bay watershed continues to grow, placing greater demands on wastewater and stormwater management facilities and competing with native fish and wildlife populations for land and water resources, government and private sector partners in the Estuary Program will be challenged to stay the course on restoring the bay. The cornerstone goal of the TBEP—holding the line on nitrogen loading to achieve the long-range seagrass recovery target—demands, for example, that additional actions to reduce or preclude nitrogen loading to the bay be taken each year to offset the potential increase in nitrogen loading associated with population growth. The drafters of the Interlocal Agreement recognized that proactive, perpetual measures to maintain recovery goals once attained will be necessary to sustain the achievements.

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WATERSHED MANAGEMENT: THE PINELLAS COUNTY EXAMPLE

A. Squires

ABSTRACT

Since the late 1980s, the concept and practice of watershed management has filtered down from the federal level to state, regional, local environmental agencies. Pinellas County is used as an example of how local government has integrated watershed planning into existing programs, and how local government activities at the watershed or landscape level may ultimately have the greatest impact upon water body protection.

Pinellas County was among the first local governments in the United States to adopt a watershed management program. In 1987, the County adopted major revisions to its Comprehensive Plan (CP) requiring County staff to: 1) prioritize the management needs of County drainage basins, 2) develop management plans for priority waters, 3) implement management plan recommendations, and 4) monitor water quality in receiving water bodies. The CP mandates that County watershed plans are holistic and must address flood protection, water quality, and habitat issues. This paper summarizes how Pinellas County has integrated watershed planning into existing programs through its local government CP, a water quality monitoring program, a Capital Improvement Program project prioritization process, careful use of available funding, and development of watershed management plans. The importance of collaboration among watershed stakeholders is also discussed.

INTRODUCTION

In many cases, the concept and practice of watershed management over the last ten to fifteen years has filtered down from the United States Environmental Protection Agency (EPA) to state, regional, and local government agencies. Beginning in 1987 when Congress established the National Estuary Program following the example of the Chesapeake Bay Program, the EPA incorporated the watershed management approach to water body protection and restoration on a national scale. Tampa Bay was accepted into the National Estuary Program in 1990. Upon promulgation of the Florida Watershed Restoration Act in 1999, the Florida Department of Environmental Protection (FDEP) created the Bureau of Watershed Management. That bureau houses both the total maximum daily load (TMDL) program as well as the National Pollutant Discharge Elimination System (NPDES) stormwater permit program. The Southwest Florida Water Management District (SWFWMD) recently implemented a Comprehensive Watershed Management (CWM) program emphasizing “Areas of Responsibility” priorities that include: water supply, flood protection, water quality, and natural resources (SWFWMD 2002).

EPA, FDEP, and SWFWMD have provided leadership, guidance, structure, and funding to manage water bodies using a holistic watershed approach. In many cases, however, watershed management-based programs and projects can best implemented by local governments. Local governments have the ability, organizational structure, revenue-generating authority, and enforcement authority to make landscape-level changes at the drainage basin level that can best support watershed initiatives. One could argue that the “hot zone” of watershed management is truly at the local government level.

The local government watershed management arsenal or toolbox includes the ability to directly control, affect, or implement: 1) land use, 2) development, 3) transportation-related services, 4) utility services, 5) drainage, 6) natural resource and habitats, 7) environmentally sensitive lands, and 8) public education initiatives. The ability to build, operate and maintain infrastructure places local governments in a strong position to impact water bodies through watershed-based activities. For example, no entity in Pinellas County other than local government is better positioned and equipped to impact the quantity, timing, and quality of urban stormwater runoff delivered to Tampa Bay.

This paper, as illustrated in Figure 1, will describe how Pinellas County has integrated watershed planning into their existing programs through strategic planning (local government CP), use of a reconnaissance network (water quality monitoring program), good “Intelligence” (project prioritization process), available resources (funding), development of battle plans (watershed management plans), and use of an allied support network (collaborators).

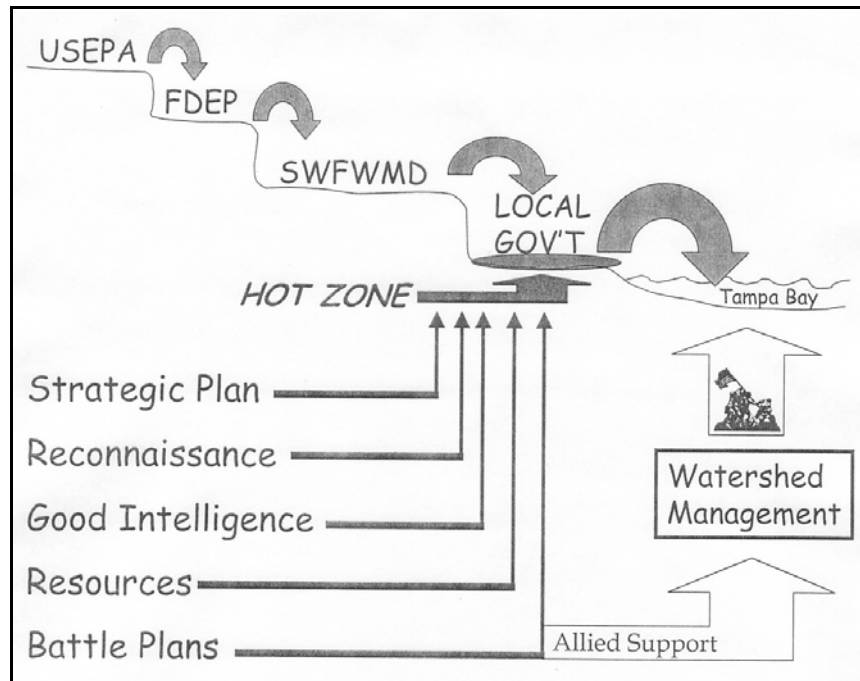


Figure 1. Watershed management from a local government perspective.

STRATEGIC PLAN (LOCAL GOVERNMENT COMPREHENSIVE PLAN)

Pinellas County was among the first local governments in the United States to adopt a watershed management program. In 1987, Pinellas County formally adopted major revisions to its local government CP that required staff to: 1) prioritize the waters and watersheds within the County in terms of their need for management on a watershed basis; 2) develop watershed management plans for priority waters; 3) proceed with implementing the recommendations of watershed management plans; and 4) monitor to detect trends or improvements in the quality of surface waters.

The first goal of the Surface Water Management Element of the comprehensive plan states “SURFACE WATERS SHALL BE MANAGED TO PROVIDE FLOOD PROTECTION FOR THE CITIZENS OF PINELLAS COUNTY, TO PRESERVE AND ENHANCE THE WATER QUALITY OF RECEIVING WATER BODIES, AND FOR THE PURPOSES OF NATURAL RESOURCE PROTECTION, ENHANCEMENT AND RESTORATION, PLANT AND WILDLIFE DIVERSITY, AND ESTUARINE PRODUCTIVITY.” The Surface Water Management Element includes numerous objectives and policies under the categories of Stormwater Control and Treatment; Water Quality and Natural Resource Protection, Enhancement, Restoration and Management; Intergovernmental Coordination; and Implementation of Surface Water Management Projects and Programs.

Water body protection through development and implementation of watershed management plans is deeply embedded into the County’s CP, the thinking of County policy-makers and

administrators, and programs affecting stormwater control and protection of natural upland, wetland, and open water resources. CP policies also include provisions to support and cooperate with FDEP, SWFWMD, and Tampa Bay Estuary Program (TBEP) Comprehensive Conservation and Management Plan (CCMP) priority activities aimed to protect, restore and enhance natural bay habitats.

RECONNAISSANCE (WATER QUALITY MONITORING)

Pinellas County CP objectives and policies emphasize the critical link between watershed management planning and water quality monitoring. The County currently utilizes a three-tiered program to monitor water quality countywide (see Hammer Levy and Squires 2004, this volume). The elements include 1) an open water status and trends sampling program, 2) a freshwater stream fixed site sampling program, and 3) a special studies program. Parameters measured under Tier 1 and Tier 2 include in situ testing (temperature, salinity, pH, dissolved oxygen) as well as laboratory analyses of nutrients and chlorophyll-a.

A network of over 100 water quality monitoring sites has been sampled each year since 1991. The original program of fixed open water monitoring sites and tidal stream sites was revised after 2002. Results of the original program (1991–2002) are reported in Squires and others (2003).

The revised program utilizes a probabilistically-based open water site selection design to assess the long-term status and trends of water quality in 18 open water strata or segments. This new open water sampling program represents Tier 1.

In January 2003, the revised countywide water quality program eliminated previously sampled tidally influenced stream sites characterized by widely varying salinities. New stream sites were established in the most downstream sampling point in each selected freshwater stream reach but upstream of marine water influence. The new program also added flow measurements at more than 40 freshwater stream sites in portions of 22 basins. This freshwater sampling program represents the Tier 2 program and will enable calculations to estimate annual constituent loadings from sampled basins.

Finally, the Tier 3 program encompasses special projects that are typically focused on more localized water quality concerns. Special projects may include a series of stormwater pollutant loading measurements from small basins to determine event mean concentrations, a series of measurements to determine stormwater pond treatment effectiveness, or a site-specific investigation to determine the cause of poor water quality detected by Tier 1 or Tier 2 monitoring program results.

GOOD “INTELLIGENCE” (DETERMINING PRIORITIES)

County staff use results obtained from the three-tiered water quality monitoring program to help develop watershed management planning priorities. A Capital Improvement Program (CIP) project ranking committee periodically meets to rank projects eligible for CIP funding. The committee includes department representatives from Public Works Engineering, Environmental Management, Highway, and Development Review Services. Projects are ranked separately by category. Categories include: flood control, erosion control, water quality/habitat, and watershed plans. A unique matrix of weighted elements is used to develop scores for each of four project categories. Consequently, a proposed watershed project is only prioritized relative to other watershed projects. For example, a watershed project that typically cost \$300,000-\$500,000 will not be ranked and prioritized against a major highway

drainage improvement project with a \$5,000,000 budget. Separate pots of CIP funds are reserved for each category.

A completed ranking sheet for watershed management plans is shown in Table 1. The committee representatives consider and debate category points before reaching a consensus score for each project. As shown in Table 1, the quality of surface waters, as determined from the County monitoring programs, may receive a large proportion of the total possible points.

Table 1. Example of a watershed management plan ranking sheet (last revised 2/4/2003).

RANKING CATEGORY	Cross Bayou	Roosevelt Creek	Curlew Creek	Joe's Creek	Brooker Hydrology	Brooker Creek	St. Joseph Sound	South Creek
Flooding (0-25 points)	10	12	22	9	20	15	0	5
Maint./Erosion (0-10 points)	8	5	7	5	6	6	0	6
Water Quality (0-35 points)	34	35	25	30	15	15	15	15
Functional Habitat (0-10 points)	10	10	6	8	8	7	8	2
Cost/Benefit (0-5 points)	4	2	3	3	4	4	5	1
Receiving Waters (0-5 points)	5	5	3	5	5	5	5	3
Previous Commitments (0-5 points)	4	2	3	2	3	3	2	1
Improvement Potential (0-5 points)	14	4	3	3	4	4	4	2
TOTAL	79	75	72	65	65	59	39	35

Political realities can often reshuffle project priorities. For example, a generous federal appropriation to restore a lake, purchase sensitive land, or restore a wetland, may instantly move a lower ranked project to the top of the list. Nevertheless, the CIP project ranking committee's role is very important since the resulting project rankings are used each year to develop a six-year CIP schedule. Furthermore, the process shows staff has used due diligence for big-ticket public spending decisions.

RESOURCES (FUNDING)

The County CIP, as summarized in Pinellas County (2003a), is a six-year work plan developed annually in conjunction with the County's annual budget. The CIP provides funding for projects with a useful life greater than five years that exceed a total cost of \$50,000. Each year the Board of County Commissioners approves CIP project funding appropriations for the first year of the six-year schedule. The remaining five years provide guidance for future development of infrastructure needs. Projects are established using input from citizens, other agencies, County staff, and Commissioners. Projects are also identified from the County's

state mandated Growth Management Plan and the Metropolitan Planning Organization's Long Range Transportation Plan.

Funding for development of watershed management plans comes from the County CIP. The County CIP also provides funding for many other projects outside the scope of the ranking committee's responsibility. Pinellas County's total CIP funding level for surface water management projects was \$14.6 million in fiscal year 2003 (October 2002 through September 2003), and is \$18.5 million for fiscal year 2004. The six-year 2004–2009 CIP schedule shows a total of \$2.56 million allocated for development of watershed management plans. In most cases 50% of County dollars spent on watershed management plan development is reimbursed by SWFWMD through cooperative funding agreements. Other municipal governments often help fund the remaining 50% of the total cost prorated based on the proportion of their land area to the total land area in the watershed.

BATTLE PLANS (WATERSHED MANAGEMENT PLANS)

Pinellas County covers 280 mi², is the second smallest county in the state, ranks fifth in state population, and is the most densely populated county in the state with 3,339 persons per mi² (Pinellas County Planning Department 2003). Given that the county is nearly entirely built out, successful redevelopment planning and watershed planning will be critical to preserve both economic and environmental viability into the foreseeable future.

The County's comprehensive surface water management program, initiated in the late 1970s with the commitment to the Master Drainage Plan, has evolved into the County's innovative watershed planning program. This program provides a strong link between land and water planning (Pinellas County 2003b). Figure 2 shows how Pinellas County has been divided into 52 drainage basins (basins 1-52), and an additional 11 marine segments (basins 53-63). The completion of the Pinellas County Master Drainage Plan in the early 1980s was a major step towards a comprehensive approach to identify and correct existing and future stormwater needs (Pinellas County 2003b).

In recent years, stormwater and surface water management efforts have emphasized improving water quality (Pinellas County 2003b) in addition to water quantity. Since 1987, Pinellas County has shifted its focus to improving water quality (Pinellas County 2003b) and has made watershed management planning a priority. County watershed management planning initiatives are uniquely developed and implemented for each watershed, yet they complement and are consistent with TBEP CCMP and SWFWMD CWM planning efforts. Many County watershed implementation projects have been folded into TBEP CCMP action plans and have become elements of SWFWMD CWM plan initiatives. Watershed planning efforts must now incorporate elements to address FDEP's TMDL program to identify and restore impaired waters to their designated uses. This is of utmost importance given that FDEP will add TMDLs of pollutants into local government NPDES Municipal Separate Stormsewer System (MS4) permits.

Pinellas County has completed four watershed plans and will be developing three new plans over the next few years (Figure 3). Existing watershed plans cover 114 km² (44 mi²) of drainage area plus an additional 13 km² (5 mi²) of open water lake area. Upon completion of the three new plans, a total of 217 km² (84 mi²) of drainage area, or 30% of total County land area, will be covered by a watershed plan. Existing plans for Allen's Creek, Alligator Creek, Lake Tarpon, and Lake Seminole were completed in 1996, 1997, 1998, and 2001, respectively. Private consultants and County staff developed each plan with considerable stakeholder collaboration throughout the planning process. Local government staff administered each

consultant contract with Pinellas County taking the lead for Allen's Creek, Lake Tarpon, and Lake Seminole. City of Clearwater staff administered the contract for Alligator Creek. Local government and SWFWMD each contributed to 50% of the total project cost. In most cases, each local government's funding share was in proportion to its drainage area of the subject watershed. As projects transitioned from the planning to implementation phase, separate contractual agreements were developed for each project or set of recommended projects. Similar stakeholder funding arrangements were developed for project implementation with 50% of costs paid by SWFWMD. The remaining costs were funded by the local government entities benefiting by the specific project and with each local government's funding contribution in proportion to its drainage area associated with the specific project.

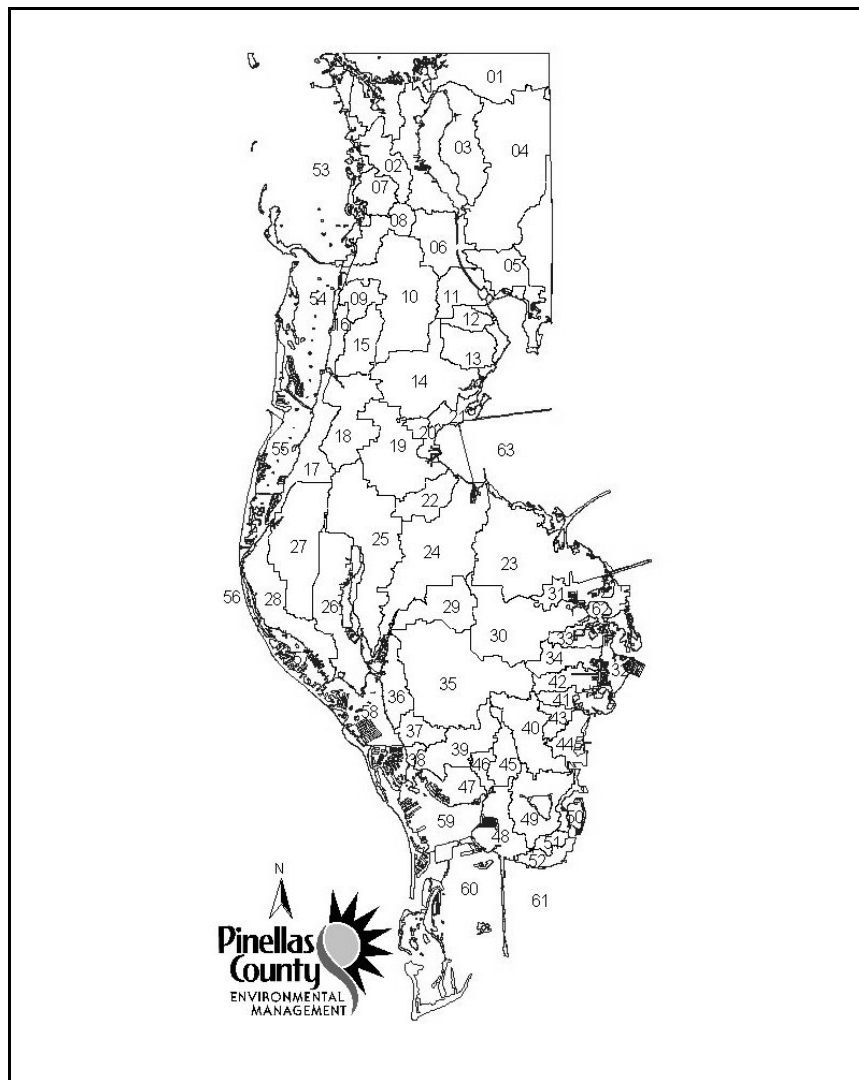


Figure 2. Pinellas County basins.

Each of the four completed watershed management plans is unique. They include two creeks and two lakes. One common component to most of these watersheds is a high proportion of privately owned urban land uses and low acreage of conservation/preservation land uses. The lack of available land has become one of the largest obstacles to effective implementation of

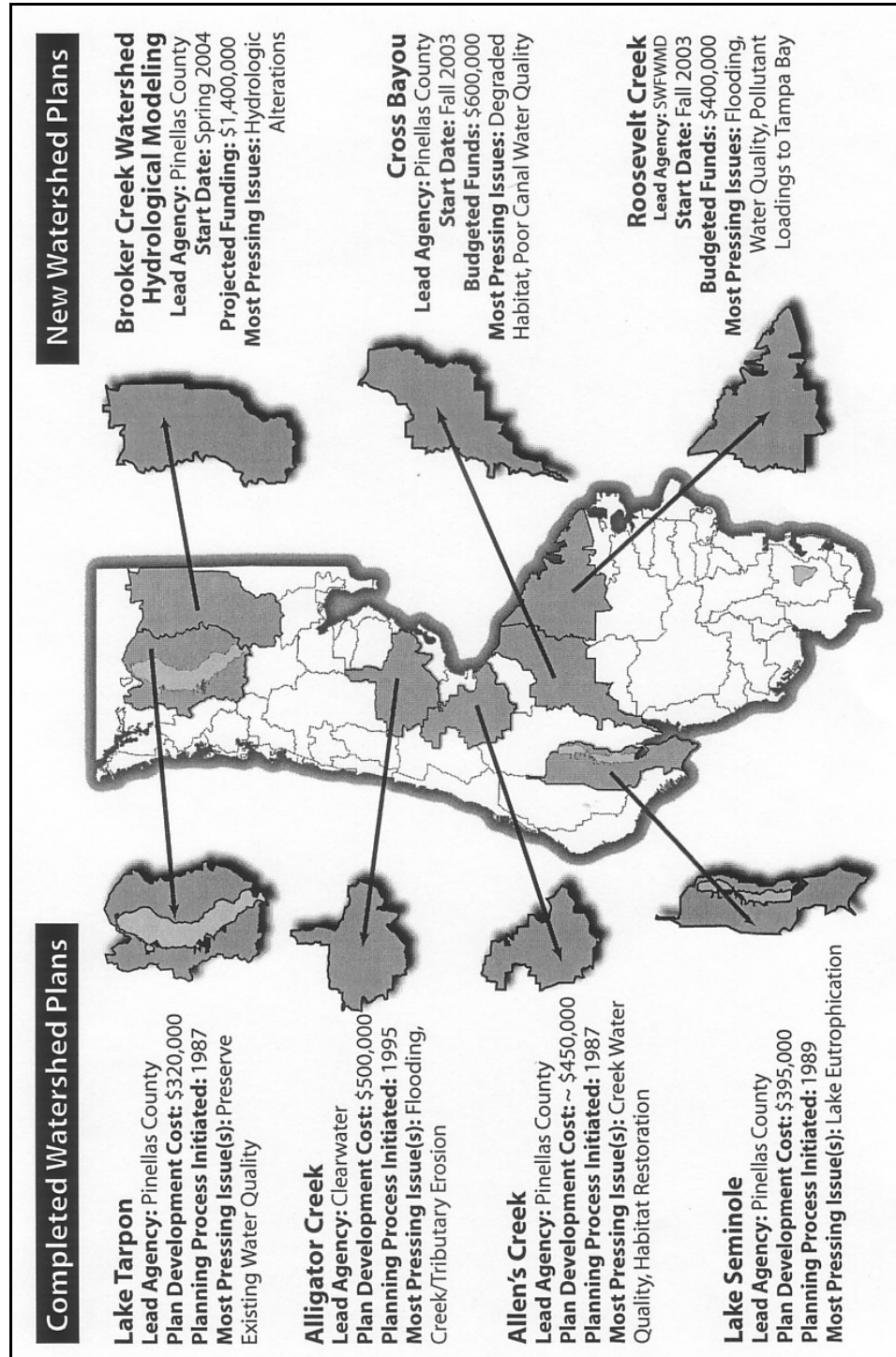


Figure 3. Completed and new watershed planning efforts in Pinellas County.

watershed plans throughout Florida, and is particularly true in densely populated Pinellas County. The new plans to be developed in the next few years (see Figure 3) generally have a greater proportion of conservation/preservation lands compared to the watersheds of the completed plans. In the case of Cross Bayou, considerable vacant land exists along the main drainage feature, the Cross Bayou Canal. These characteristics may provide better opportunities to protect and improve existing drainage and water quality conditions relative to those in the first four watershed plans developed for Pinellas County.

ALLIED SUPPORT NETWORK (CRITICAL COLLABORATORS)

Successful watershed planning must include stakeholder involvement throughout the process. Given that watersheds do not stop at jurisdictional boundaries, if stakeholders are left out of the planning process, it is unlikely a successful implementation of the watershed plan will follow. Pinellas County is no exception and watershed planning efforts would not have been possible without support from a variety of federal, state, regional, and local stakeholders. Critical Pinellas County collaborators in watershed planning initiatives have included:

- The TBEP,
- The SWFWMD,
- The FDEP,
- The Florida Fish and Wildlife Conservation Commission (FFWCC) including the Florida Marine Research Institute,
- Other local governments (Clearwater, Largo, Seminole, Pinellas Park, Safety Harbor),
- The environmental consulting community,
- Agency and university scientists, and
- County citizens.

The County's CP includes a policy (Policy 1.4.4, Pinellas County 2003b) to work with watershed stakeholders to ensure cooperation in plan development and implementation, consistent implementation of agreed-upon management strategies, and shared funding responsibilities.

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FROM PUSHING PAPER TO MOVING DIRT: LOCAL IMPLEMENTATION OF WATERSHED MANAGEMENT PLANS

H. Zarbock, A. Squires, E. Araj, J. Merriam & R. Brown

ABSTRACT

Tampa Bay and its watershed have been the subject of a vast array of studies, research projects, and data collection programs. Findings of these studies have been used by entities such as the Tampa Bay Estuary Program (TBEP), Southwest Florida Water Management District (SWFWMD), Tampa Bay Regional Planning Council (TBRPC), local governments, and others to develop resource management plans.

The implementation of management plans often becomes the responsibility of local governments. However, other agencies and private entities may also be tasked with implementation activities through volunteer efforts, or for compliance with regulatory mandates. Successes and challenges in watershed management plan implementation, with an emphasis on local government opportunities and limitations are discussed. Implementation of watershed management plans can include a wide variety of activities that address all facets of resource management.

Frequently encountered obstacles to implementation may include funding restrictions, political or citizen resistance, lack of land availability for projects in urbanized areas, inadequate coordination between participants, regulatory inconsistencies, and unrealistic or inadequate management plans (Moores, 1996). Public and private groups in the Tampa Bay area have experienced all these hurdles and have overcome them in many instances.

INTRODUCTION

The purpose of this discussion is to briefly summarize how local resource management plans have been developed, and the means by which they are most likely to be implemented. Several examples of how local governments accept and conduct management responsibilities are detailed. A wide range of studies, research projects, and data collection programs have been conducted to better understand the local ecology of Tampa Bay and its tributary watershed. A few examples of the work that has been completed over the past 35 years include:

- Hillsborough Bay Water Quality Study (Florida Water Pollution Control Agency, 1969),
- Numerous academic studies (by, among many others, Brooks, Doyle, Estevez, Lewis, Peebles, Simon, et al.),
- Research conducted by Florida Department of Environmental Protection at the Florida Marine Research Institute,
- Studies and restoration projects conducted by SWFWMD Surface Water Improvement and Management (SWIM) group,
- US Geological Survey investigations (by Goodwin, Levesque, Stoker, et al.),
- A variety of research and resource management studies sponsored by TBEP, and
- Ambient water quality and benthic monitoring programs by Hillsborough, Pinellas, and Manatee counties.

Findings of these studies have been used as a basis for developing management plans to help protect local resources. Knowledge of the requirements of local flora and fauna is essential if their populations are to be sustained. Through the implementation of sound management plans, environmental elements important to the bay's biota such as water quality, habitat size and type, seasonal freshwater flow patterns, and sediment quality can be maintained in a manner that will ensure the survival of numerous desirable species. Existing management plans that have utilized our knowledge of the bay and watershed include, among others:

- Comprehensive Conservation and Management Plan (TBEP),
- Numerous SWIM Plans for priority water bodies (SWFWMD),

- Comprehensive Watershed Management (CWM) Plans (SWFWMD),
- Tampa Bay Regional Planning Council Agency on Bay Management Plans,
- Local government Comprehensive Plans,
- Local government Watershed Management Plans,
- Management plans for special protection zones (aquatic preserves, etc.), and
- Management, mitigation, and reclamation plans for development activities (mining, etc.).

The development and adoption of management plans is often accomplished through a multi-part entity such as TBEP's Policy and Management Committees, or through a regional or state agency such as SWFWMD or the FDEP Total Maximum Daily Load (TMDL) group. However, the implementation of resource management plans often becomes the responsibility of local governments, with other agencies and private entities potentially tasked with selected implementation activities.

Although developing effective, technically defensible resource management plans is not easy, successfully implementing those plans is by far the most difficult aspect of protecting our living resources. Constraints to successful implementation can include time and staff limitations, budget shortfalls, lack of coordination between responsible parties, non-support of local decision makers, or lack of cooperation between groups that may have competing or conflicting goals. Plan implementation can be forced by federal, state, or popular mandates. Although funding is sometimes available, local governments are often required to shift priorities and limited funding sources.

SUCCESSFUL IMPLEMENTATION OF LOCAL GOVERNMENT RESOURCE MANAGEMENT PLANS

This section includes a summary of Tampa Bay's local governments' recent, current and proposed future activities relating to watershed management plan implementation. Implementation activities for watershed management may include actions to protect and improve water and sediment quality, protection of conservation and recreation lands through purchase or other mechanisms, water supply, wetland restoration and creation, flood protection, endangered species protection, and citizen education and involvement.

All of Tampa Bay's shore line, and most of its watershed, is encompassed in three counties—Pinellas, Hillsborough, and Manatee, with the major urban areas of St. Petersburg and Pinellas, Tampa, and Bradenton, respectively (Figure 1). Table 1 shows how each jurisdiction has successfully implemented portions of resource management plans for the betterment of the local ecology and the quality of life. The counties, although independent and distinct, share common priorities, and are bound by regional goals. Table 1 summarizes the three counties' participation in local and regional resource management programs. As can be seen, all jurisdictions are active in a number of groups, limited only by geographic location.

The counties work both cooperatively and independently on a number of in-house programs as well. The following summarizes current activities in watershed management related fields. Water quality and benthic monitoring includes both sites of local interest and the network for the Regional Ambient Monitoring Program (RAMP) (Figure 2). Sediment quality activities consist of both monitoring and remediation of sedimentation problem areas (all three counties). The City of Tampa has also initiated the installation of a network of sediment traps along the Hillsborough River and some residential canals. Air quality related efforts include area-wide monitoring (Pinellas, Hillsborough, and Manatee counties), and site-specific monitoring (Manatee County).

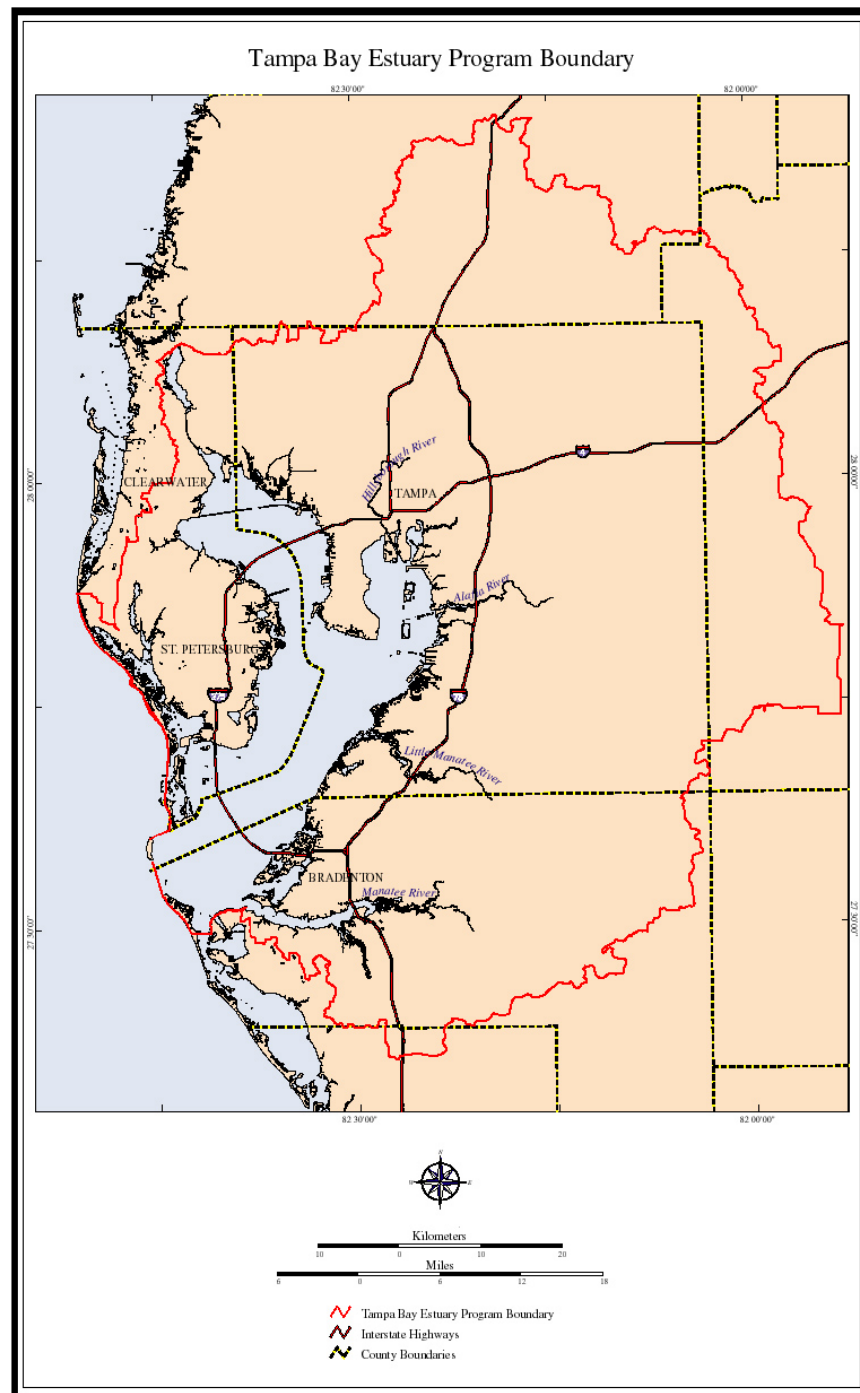


Figure 1. Tampa Bay Estuary Program boundary.



Figure 2. Crews prepare for field sampling.

Table 1. County participation in regional resource management programs.

PROGRAM	PINELLAS	HILLSBOROUGH	MANATEE
Sarasota Bay Estuary Program	NA	NA	Participant
Tampa Bay Estuary Program	Participant	Participant	Participant
Charlotte Harbor Estuary Program	NA	NA	Participant
TBRPC Agency on Bay Management	Participant	Participant	Participant
SWFWMD SWIM	Cooperator	Cooperator	Cooperator
NPDES MS4	Permittee	Permittee	Permittee

All counties have active land acquisition programs (Table 2). Pinellas and Hillsborough counties' land purchases are primarily for habitat preservation and restoration, while Manatee County focuses on land within the county's two reservoir watersheds (Lake Manatee and Braden River/Evers Reservoir) to ensure the safety of the local potable water supply. Emerson Point and the Diocese property, both on the Manatee River, are also currently part of Manatee County's land management program. All three counties have participated in the state land acquisition programs (Conservation and Recreation Lands, Save Our Rivers). Seagrass protection and endangered species protection (manatees) are both addressed on a local level through aquatic preserves in Pinellas and Hillsborough counties, and through implementation of the Florida Fish and Wildlife Commission (FWC) Manatee Protection Plan (Manatee). Manatee County also includes state aquatic preserves such as Terra Ceia Bay.

Table 2. County-sponsored watershed management activities.

PROGRAM	PINELLAS	HILLSBOROUGH	MANATEE
Water Quality	Ambient Monitoring, RAMP	EPCHC Monitoring, RAMP	Ambient Monitoring, RAMP
Sediment Quality	Project Specific	EPCHC Benthic Monitoring	Sediment Traps, Canal Dredging
Air Quality	Local and Regional Monitoring	Local and Regional Monitoring	FPL & Piney Point, Local and Regional Monitoring
Land Acquisition	Brooker Cr., Shell Key, Anclote River	Cockroach Bay, Alafia River, Blackwater and Cypress Creeks	Reservoir Watershed Districts, Emerson Point
Seagrass Protection	County-wide Aquatic Preserve, Monitoring, Ft. DeSoto and Weedon Is. Seagrass Protection Zones	Cockroach Bay Aquatic Preserve, Monitoring	FWC Manatee Protection Plan, Terra Ceia Aquatic Pres., Monitoring
Manatee Protection	Aquatic Preserve	Cockroach Bay Aquatic Preserve	FWC Manatee Protection Plan

Despite budget limitations and competing priorities, all three counties have very active watershed management programs. Although the individual programs are not identical, they do share common themes and goals. Examples of current efforts by the counties to implement watershed management plans are summarized below. Water quality issues receive significant attention in all counties, through monitoring and implementation of water quality Best Management Practices (BMPs) identified through Hillsborough and Pinellas counties' watershed management plans (WMPs). Pinellas County has adopted WMPs for several watersheds, including Lake Seminole, Lake Tarpon, Allens Creek, and Alligator Creek. A management plan is currently being developed for the Cross Bayou Watershed, and several additional watersheds will be investigated during coming years.

Hillsborough County has adopted WMPs for all seventeen major watersheds within the County. Flooding, water quality, and habitat projects are being funded through the Capital Improvement Program (CIP) in an on-going effort to implement the recommended activities. In addition, a major study of the Hillsborough River is being conducted in cooperation with the US Army Corps of Engineers.

Manatee County also has an active BMP implementation schedule, and exercises Outstanding Florida Waters compliance within the Manatee River, Braden River, and Peace River watersheds. Stringent development regulations have been developed for these potable water watersheds to protect reservoir water quality, and serve the additional purpose of protecting remaining natural areas.

Water conservation is also an important element of watershed management. All counties currently have reuse water distribution systems and are seeking to expand and optimize the use of the valuable resource of reclaimed water. Pinellas County has upgraded their South Cross Bayou Water Reclamation Facility (SCBWRF) and is expanding the reclaimed water

distribution system in coastal areas. Manatee County is expanding their Manatee Agricultural Reuse System (MARS), and is also investigating the potential for reuse ASR.

Land acquisition activities are on-going in all three counties. Pinellas County has a continuing program, as does Hillsborough County (Environmental Lands Acquisition and Protection Program, ELAPP). Manatee County's Environmental Lands Management and Acquisition Committee (ELMAC) is working towards similar goals while searching for a dedicated funding source. All three counties are also active in public education and outreach. Pinellas and Hillsborough counties have citizen participation programs (e.g. Adopt-a-Pond), and maintain environmental education centers (Weedon Island and Brooker Creek in Pinellas County, English Creek and Nature's Classroom in Hillsborough County). The three counties also have Florida Yards and Neighborhood programs through their Agricultural Extension Offices, and have public education activities pursuant to complying with their National Pollution Discharge Elimination System (NPDES) MS4 permits.

Despite the numerous activities summarized above, all three counties have encountered obstacles to implementing their plans. Funding is the most commonly cited limiting factor for plan implementation, as diverse priorities within the jurisdictions compete for available monies. For example, dollars may be spent to fund development incentives to attract growth that could otherwise go to land acquisition programs. For this reason, having dedicated funding sources is an important step in management plan implementation (Table 3).

Table 3. Current county implementation activities.

PRIORITY	PINELLAS	HILLSBOROUGH	MANATEE
Water Quality	Monitoring, Implement WMP Water Quality BMPs	Monitoring, Implement WMP BMPs	Monitoring, OFW Compliance Implement Water Quality BMPs
Water Conservation	Upgrade SCBWRF Reclaimed water to beach communities, Reuse ASR	Expanding reclaimed water systems	Expanding MARS Reuse ASR
Land Acquisition	Continuing acquisitions	ELAPP Program	ELMAC, Investigating dedicated funding source
Public Education	Adopt-a-Pond, Weedon Island, Brooker Creek, NPDES Pub. Ed., FYN	Adopt-a-Pond, Stream Water WATCH, Lake Mgmt., FYN, NPDES Pub. Ed., Environmental Ed. Centers	TMDL Stakeholders, Piney Point Focus Group, NPDES Pub Ed. FYN

Watershed management plans should address the potential for user conflicts that may arise over limited natural resources. Freshwater is a prime example, as local decision-makers strive to balance water supply needs with retaining adequate freshwater flows for local natural systems. Also, growth management is a continuing issue, with the need to balance protection of natural areas with the realities of providing urban amenities for the regions growing population. Development pressures are not the only potential source of conflicts. Competing environmental concerns may clash over proposed activities. Groups most interested in habitat

preservation may disagree with plans to convert a natural area into a regional stormwater treatment system that would improve water quality entering the bay.

Lack of good communication can also reduce the effectiveness of natural resources protection. Although many jurisdictions in the Tampa Bay areas have a history of cooperation, it is not uncommon for local governments may tend to look only inside their own jurisdiction when proceeding with a watershed management initiative, even though watersheds frequently do not respect city and county boundaries. Cooperative efforts can greatly increase the effectiveness of planning efforts in watershed management as well as other disciplines such as transportation planning.

Other obstructions to successful plan implementation include lack of regulatory support. Agencies charged with protecting environmental concerns may be hesitant to change their rules to accommodate new or changing approaches to resource management. Both the regulators and the permittees should strive to maintain flexibility when facing new situations. For example, low impact development (LID) is a relatively new approach to constructing urban land uses in a manner that attempts to, among other goals, minimize impacts to surface water and ground water quantity and quality. Although there are many specific design elements that can contribute to LID success, they are not currently recognized by local environmental permitting agencies as a viable alternative to the traditional means of water quality and quantity management. Efforts should be made to broaden the available recognized technologies that can meet the presumptions of current regulatory standards.

Uncertainties in future regulatory programs also contribute to stalling management plan implementation. The TMDL program administered by FDEP is moving forward at a pace prescribed by an administrative consent decree, focusing on meeting short term deadlines without establishing a firm approach to implementation of the entire program. As a result, future steps in the program have not been finalized (e.g., requirements for contents of Basin Management Action Plans [BMAPs]) and local governments—which stand to receive the most responsibility for TMDL program implementation—are unable to proactively prepare for upcoming requirements. Although this is unalterable to a degree because of the deadlines for setting TMDLs that have been imposed on FDEP, it does reduce the opportunity for sound planning and management.

Specific issues regarding BMP implementation also need to be addressed. Technological advances and changing approaches to urban design can alleviate current limiting factors such as the lack of available land for BMP construction in heavily urbanized areas. Also, advances in nitrogen removal BMP technology would be a significant aid to meeting local pollutant load reduction goals for Tampa Bay.

SUCCESS STORIES

Despite the many opportunities for failure, Manatee, Pinellas, and Hillsborough counties all have genuine success stories of implementing watershed management plans. However, it should be noted that many of these successes are not individual efforts. The SWFWMD has served as a funding and management cooperator for many county projects and is a valuable partner in resource management activities. FDEP has also contributed to the success of local government initiatives, as have other state, federal, or private groups.

Pinellas County has a variety of successfully completed projects, including the St. Paul's oligohaline habitat restoration, several projects on Lake Seminole that were identified in the lake's WMP, and the Joe's Creek projects. The Lake Seminole projects are especially notable, and include the removal of almost seventeen acres (31,000 cubic yards) of sediment and

muck. The dredging was finished in seven weeks at a cost of about \$13/cubic yard. In addition, stormwater ponds have been constructed adjacent to the lake to intercept and treat stormwater prior to discharge into the lake. Shoreline restoration projects have also been completed. Exotic vegetation has been cleared from several areas, and over 10,000 maidencane seedlings were planted in 2003 to supplement natural recruitment of bulrush and eelgrass (Figure 3). In addition, the old fixed weir lake outfall control structure was replaced with an adjustable height weir to facilitate lake level fluctuations that mimic more natural conditions.



Figure 3. Lake Seminole aquatic vegetation.

Manatee County has completed several projects to implement the TBEP Nitrogen Management Action Plan (as have Hillsborough and Pinellas), and conducted a lengthy effort to organize and educate stakeholders during the TMDL Impaired Waters rulemaking. Numerous sediment traps have been placed near coastal canals, and are mandated for new development to reduce sediment discharge to the estuarine system. The county has implemented non-structural measures also, such as LID requirements for new development in the reservoir watershed. Habitat enhancement efforts are being pursued as well, with the establishment of an artificial reef at Emerson Point (Figure 4). Also, the management of the Piney Point phosphate facility has proceeded successfully to date.

Hillsborough County has adopted WMPs for all seventeen of their major watersheds. Over 200 surface water management projects identified in those WMPs have been implemented and focus on nitrogen load reduction to Tampa Bay as well as flood control. In addition, major restoration projects such as Delaney Creek and Cockroach Bay have also been successful. Delaney Creek was among the first large scale restoration projects in the region to incorporate water quality treatment, flood control, habitat enhancement, and aesthetic considerations. The Cockroach Bay Project encompasses several hundred acres and includes:

- Exotic vegetation removal and replanting with beneficial plants,
- Creation of stormwater treatment ponds for agricultural runoff,
- An extensive surface water quality monitoring program to add to the body of knowledge regarding BMP efficiencies and runoff characteristics (Figure 5),
- The creation and enhancement of estuarine and freshwater habitat, and
- A public education component.

Both the Delaney Creek and Cockroach Bay projects originated from the ELAPP land purchases, and benefited from SWFWMD funding and cooperation. Also, the Cockroach Bay Restoration Project received substantial funding from USEPA and others.



Figure 4. Emerson Point artificial reef.



Figure 5. Cockroach Bay monitoring station.

FUTURE IMPLEMENTATION ACTIVITIES

Building on past successes, the three counties bounding Tampa Bay are looking forward to new challenges and opportunities. Implementation of existing watershed management plans is a long-term commitment, and is subject to adaptive management as new ideas and approaches are made available. Hillsborough County has prioritized the following efforts for coming years:

- Develop manual for LID standards,
- Complete Hillsborough River Study with USACOE,
- Expand benthic invertebrate and sediment sampling, and
- Complete stormwater BMP research project for innovative nitrogen removal methods

The stormwater BMP project is very promising as a means of enhancing nitrogen removal from stormwater. Funded by the county and FDEP, an innovative treatment system will be constructed to treat stormwater discharging from a pond in north Tampa.

Pinellas County has several future activities planned as well, including:

- Additional WMP development (Roosevelt Creek, Joe's Creek),
- Brooker Creek modeling and WMP development,
- Mobbley Bay restoration,
- Additional water quality treatment facilities (alum) at Lake Seminole, and
- Water quality treatment BMPs for Lake Tarpon.

Manatee County's future also includes an aggressive agenda for plan implementation:

- Implement existing Lake Manatee WMP recommendations,
- Develop County-wide stormwater design criteria,
- Remain proactive in TMDL program,
- Continue MARS expansion, potentially incorporating Piney Point, and
- Identify a dedicated funding source for land acquisition.

CONCLUSIONS

Based on the above discussion, the following conclusions can be made regarding the implementation of watershed management plans in the Tampa Bay area:

- Long term commitments are needed for successful resource protection.
- Successful plan implementation is not likely unless the plan is well thought out, technically defensible, and supported by local decision makers.
- Local governments will likely continue to be the primary responsible parties for the implementation of state, federal, and local resource management initiatives.
- Funding will remain a critical issue.
- Using dedicated funding sources increases the probability that management plan implementation will succeed.
- Regulators should attempt to incorporate innovative approaches to meeting permitting criteria.
- Water quality permitting criteria should incorporate pollutant loads as well as, or instead of, concentrations to as to be consistent with other load reduction based programs.
- All stakeholders should be included in WMP development process.
- Local governments have common goals for resource management, although priorities may vary.
- Tampa Bay's local jurisdictions are very active in addressing their priority issues.
- Formal or informal forums should be maintained as a means of providing feedback and assessing the progress of watershed management plan implementation.

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PROGRESS TOWARDS GOALS FOR TAMPA BAY RESTORATION AND PROTECTION

H. Greening, R. Eckenrod & N. Holland

In 1996, the local, state and federal partners of the Tampa Bay National Estuary Program (now the Tampa Bay Estuary Program) adopted the Tampa Bay Master Plan for the protection and restoration of the natural resources of Tampa Bay (TBNEP 1996). Recognizing that the establishment of clearly defined and measurable goals is crucial for a successful resource management effort, an Interlocal Agreement was signed by the TBEP partners in 1998, which included specific goals and targets to address priority issues (TBNEP 1998).

Evaluation of goals and targets for water and sediment quality, bay habitats, fish and wildlife, dredged material management, spill prevention and response, and a new action plan addressing invasive species generally shows progress in most cases. However, reaching goals will require the continuation of a strong scientific base, cooperation among scientists and bay managers, and dedication and commitment from all stakeholders. Progress towards specific goals and challenges for each priority issue are summarized here, for the time period through 2003.

WATER AND SEDIMENT QUALITY

Goals for this issue are:

- Maintain water quality and nitrogen reduction targets needed to meet seagrass goals.
- Gain a better understanding of atmospheric deposition, and identify sources of air pollution.
- Reduce toxic chemicals in contaminated sediments and protect clean areas.
- Reduce bacterial contamination to levels safe for swimming and shellfish harvesting.

Seagrass, Water Quality, and Nitrogen Reduction Targets: 2003 Update

In 1996, the TBNEP Management Conference adopted a minimum goal of increasing the current Tampa Bay seagrass cover to 95% of that present in 1950, to a total of 38,000 acres baywide (TBNEP 1996).

Between 1988 and 1996, seagrass acreage increased at a rate of 200–300 acres per year. El Niño rains and associated decreased water clarity and salinity in 1998 resulted in seagrass losses of about 2,000 acres baywide between 1996 and 1999. In January 2002, seagrass acreage increased by 1,237 acres baywide, a 5% increase from 1999 (Tomasko 2004). The 2003 seagrass goal includes the protection of the existing 26,080 acres (2002 estimate) and restoration of an additional 11,920 acres (Figure 1).

The TBEP and its partners have also adopted chlorophyll *a* targets for Tampa Bay based on the light requirement of the seagrass species *Thalassia testudinum* (turtlegrass) (Janicki and Wade 1996; Greening 2001). The average annual chlorophyll *a* targets for each major bay segment are:

Old Tampa Bay	8.5 µg/L
Hillsborough Bay	13.2 µg/L
Middle Tampa Bay	7.4 µg/L
Lower Tampa Bay	4.6 µg/L

Light attenuation goals are to maintain a minimum of 20.5 % light to depths where seagrass occurred in 1950 for seagrass recovery in each bay segment (Janicki et al. 2000).

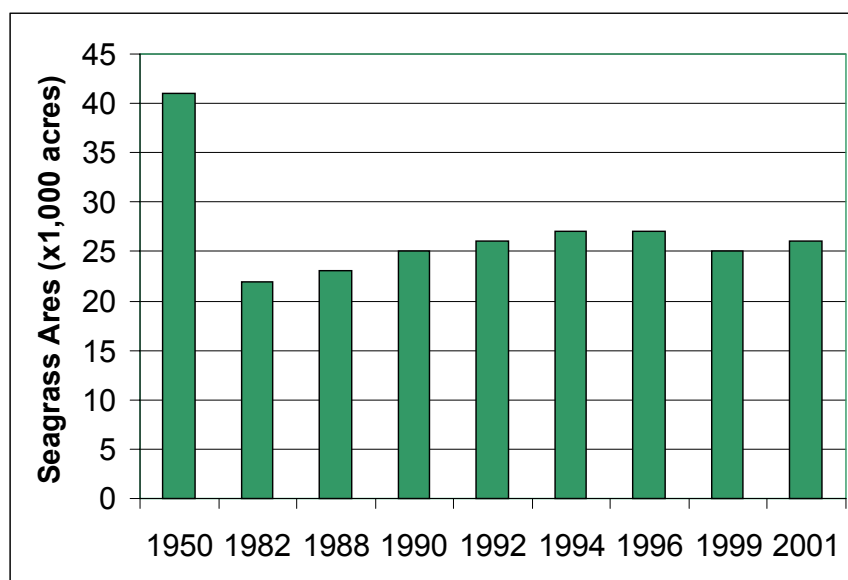


Figure 1. Seagrass cover (acres) in Tampa Bay, 1950 through 2002. (Data source: Southwest Florida Water Management District SWIM Department).

Average annual chlorophyll *a* concentrations for each bay segment show that all four major bay segments continue to show long-term improvements, and met targets in most years since 1986 (Figure 2). As expected, targets were not met in any of the segments during the heavy rainfall El Niño years in 1995 and 1998. Old Tampa Bay was the only segment which did not meet chlorophyll *a* targets in 2003, prompting initiation of a special study investigation in this segment in 2004.

Although light attenuation targets show the same general declining trend since the early 1980s, the target level has not been met for many of those years in three of the four major bay segments (Figure 3). Studies underway by USGS (Ron Miller, pers. comm.) will investigate the contribution of non-chlorophyll factors (such as resuspended sediments, color or turbidity) to light attenuation in Tampa Bay.

Based on modeling results, it appears that light and chlorophyll levels can be maintained at necessary levels by “holding the line” at average annual nitrogen loadings estimated for 1992–1994 (Janicki and Wade 1996). However, given the 20% increase in the watershed’s human population and associated increases in nitrogen loading that are projected to occur over the next 10–20 years, an average annual reduction of 17 tons, starting in 1995, is needed to offset expected increases and maintain loadings at 1992–1994 levels (Janicki and Wade 1996; Greening 2001). The Year 2000 annual goal is 84 tons reduced from 1995 levels (TBNMC 1998). This 5-year goal has now been extended through 2004.

To address the long-term management of nitrogen sources, a Nitrogen Management Consortium of local electric utilities, industries and agricultural interests, as well as local governments and regulatory agency representatives, has developed a Consortium Action Plan to address the target load reduction needed to “hold the line” at 1992–1994 levels. Implemented and planned projects collated in the 1995–1999 Consortium Action Plan met and exceeded the agreed-upon annual nitrogen loading reduction goal in 2000 of 84 tons,

with an estimated annual reduction of 134 tons in 2000 (TBNMC 1998; Greening and DeGrove 2001). The 2000–2004 Consortium Action Plan is currently under development.

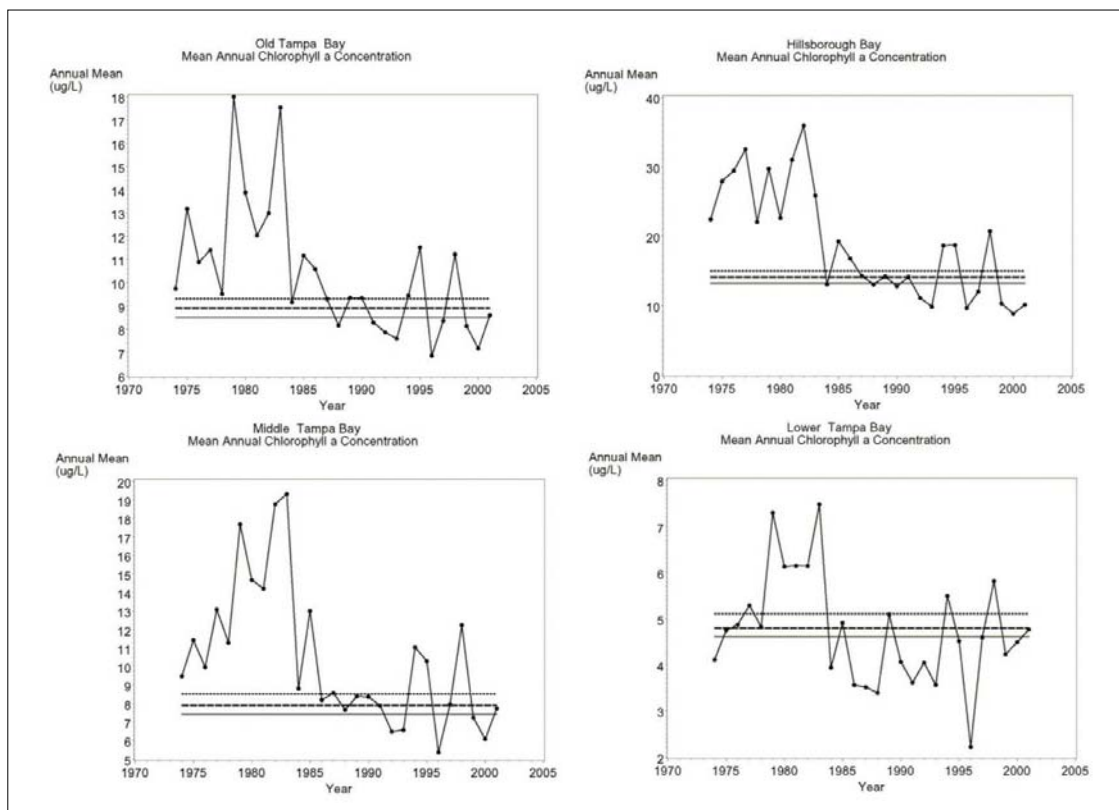


Figure 2. Average annual chlorophyll *a* concentrations (ug/l) for major bay segments. Solid line indicates target concentration, and dashed line indicates ± 2 S.D. (Data source: Environmental Protection Commission of Hillsborough County).

Atmospheric Deposition: 2003 Update

Current estimates indicate that 25–30% of the total nitrogen load to Tampa Bay is contributed by atmospheric deposition (rainfall and dryfall) directly to the bay's surface (Pribble et al. 2001; Poor and Pribble 2003; Pribble and Poor 2004). Another 10–20% is contributed from atmospheric deposition falling in the watershed, and washed to the bay in stormwater (Pollman et al. 2004).

Sources of nitrogen in atmospheric deposition contributing to nutrient loading to Tampa Bay are split between those generated within the watershed (65%) and those outside the Tampa Bay region (Pribble and Poor 2004). Preliminary results from NOAA's Regional Atmospheric Deposition Model (Dennis 2003) indicate that the nitrogen airshed for Tampa Bay includes all of Florida and north almost to Atlanta (Figure 4).

Preliminary modeling results and data also suggests that, although mobile sources (such as automobiles, trucks, and buses) contribute approximately 35% of the nitrogen emissions in the Bay area, they contribute more than 50% of the atmospheric nitrogen deposited on the bay and watershed (N. Poor, pers. comm; Poor and Pribble 2003; Pribble and Poor 2004).



Figure 3. Average annual light attenuation values (K_d) for major bay segments. Solid line indicates target concentration, and dashed line indicates ± 2 S.D. (Data source: Environmental Protection Commission of Hillsborough County).

Benthic Quality: 2003 Update

The Tampa Bay Sediment Quality Assessment Group (SQAG) has been meeting for a number of years to develop numerical targets for measuring the condition of Tampa Bay benthic habitats. A Tampa Bay Benthic Index, using metrics of the benthic organism community, was developed, revised and tested, and approved by the SQAG participants in late 2003 (Malloy et al. 2004). The SQAG and TAC also endorse the development of assessment and management strategies for priority areas containing sediment contaminants in Tampa Bay.

The Tampa Bay Benthic Index scores indicate that most of Tampa Bay remains “healthy,” with the exception of areas around the Port of Tampa, mouth of the Hillsborough River, near the St. Petersburg/Clearwater Airport, Bayboro Harbor/Port of St. Petersburg, and Apollo Beach/Big Bend (Figure 5). The SQAG and Tampa Bay Estuary Program Technical Advisory Committee participants identified those sites as priority areas for development of action plans (approved by TBEP TAC, June 2004).

Bay sediment samples taken from 1995 to 2002 show no significant changes in contamination since 1993 when intensive sediment sampling began, although additional hot spots were identified (Karlen 2003). Most of these hot spots are in the lower Hillsborough and Palm rivers, where targeted sampling didn’t commence until 1997 (Grabe 2003). Benthic monitoring is coordinated by the Environmental Protection Commission of

Hillsborough County with participation from Manatee and Hillsborough Counties. About 120 samples are analyzed each year (since modifications to the study design in 2000) for the presence of contaminants and to determine the abundance and health of organisms living in the sediments.

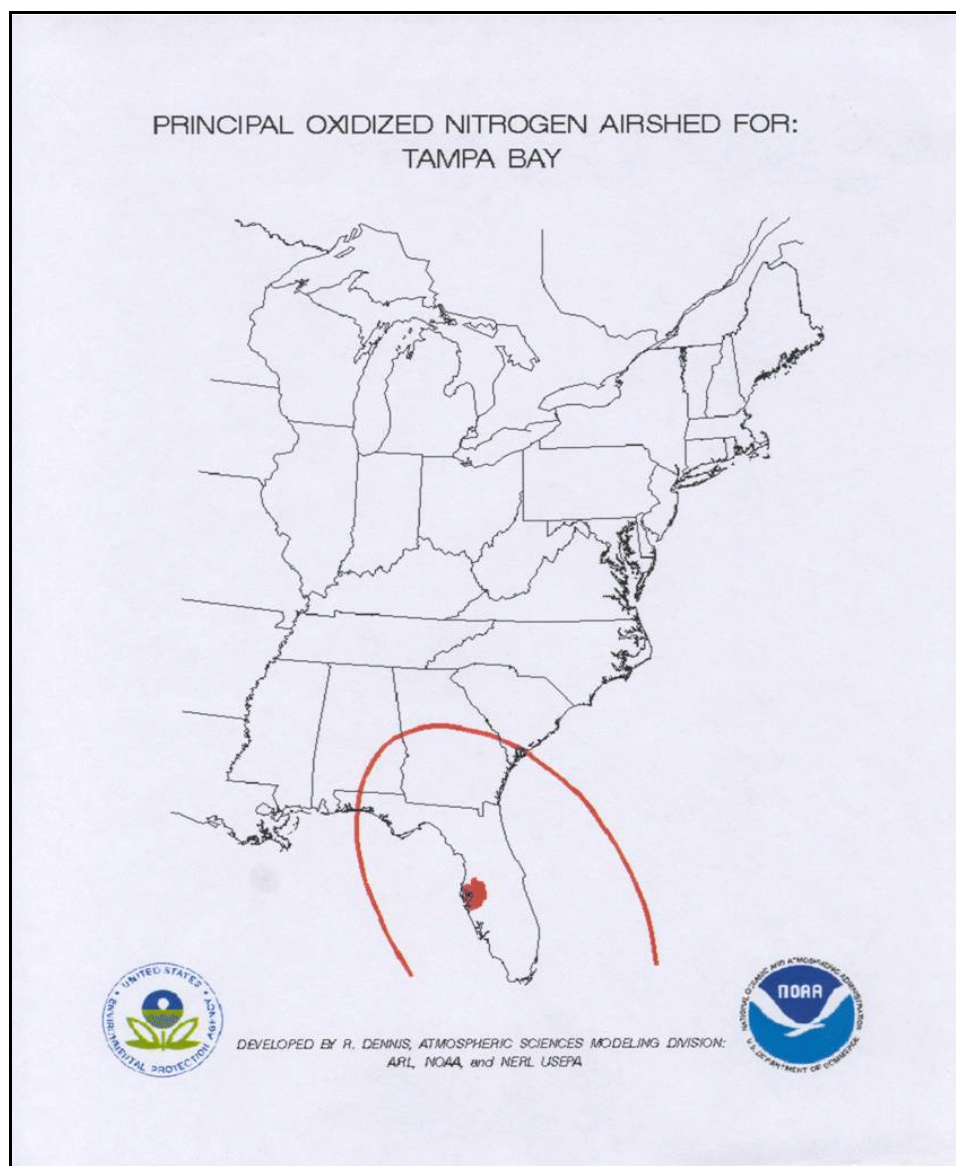


Figure 4. Oxidized nitrogen airshed for Tampa Bay. (Source: R. Dennis, Atmospheric Sciences Modeling Division, Air Resources Laboratory, NOAA and NERL USEPA)

Bacterial Contamination: 2003 Update

Pinellas County established the first Healthy Beaches program in 1998 after a growing body of evidence suggested that reliance on traditional water quality standards, such as total and fecal coliform, may not be appropriate for sub-tropical waters. This raised the concern that beaches may be closed unnecessarily, while overlooking other potential health concerns. The St. Petersburg/Clearwater Convention & Visitors Bureau recognized the implications, and together with the Pinellas County Department of Health, brought the issue to the attention of the Tampa Bay Estuary Program. TBEP, along with Pinellas County and the Southwest Florida Water Management District, helped finance the first phase of the study

through the University of South Florida College of Marine Science. Phase 1 was to recommend the best indicators for use in evaluating water quality at recreational beaches in Florida.

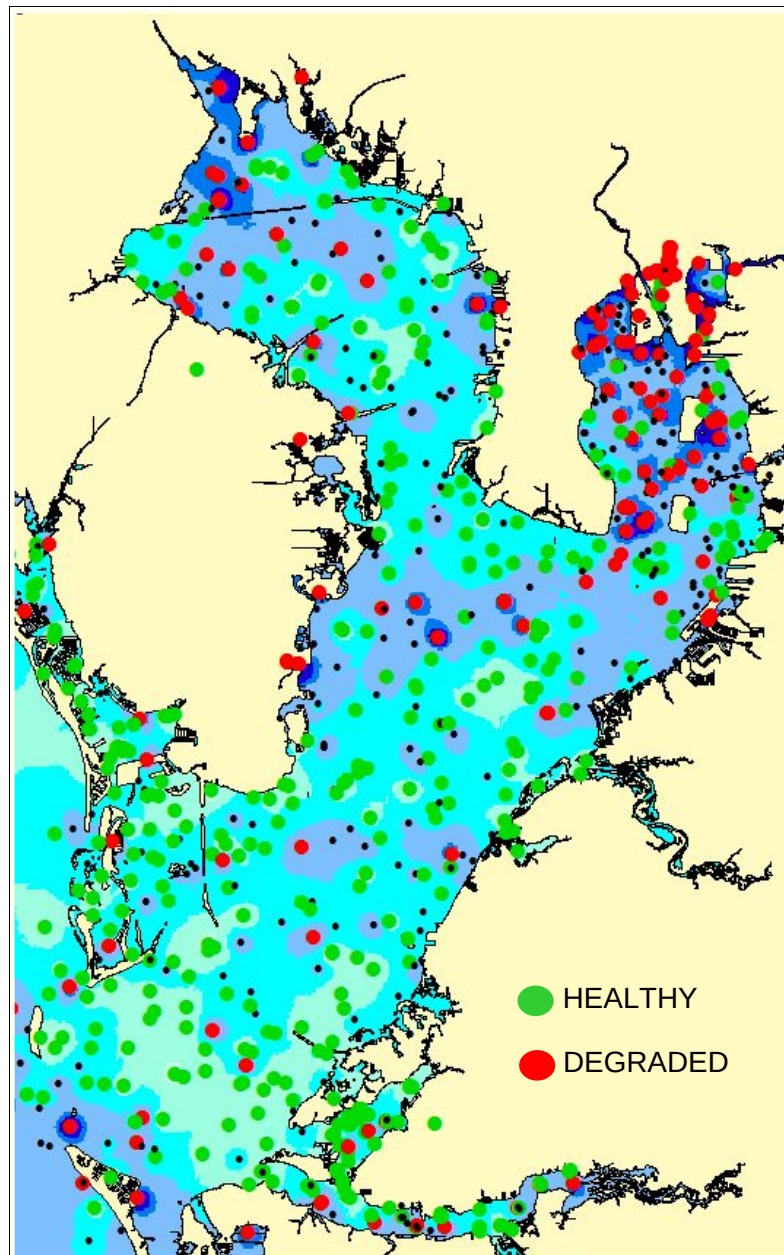


Figure 5. Tampa Bay Benthic Index scores from samples collected 1993–2000. (Data sources: EPCHC, Manatee County, Pinellas County DEM).

Phase 1, completed in 2001, found enterococci (*Enterococcus* species) to be the preferred test for marine waters because they tend to live longer than fecal coliforms and are more closely correlated with cases of gastroenteritis in recreational waters. However, enterococci share the same major disadvantage of the fecal coliform group in that they are shed in feces of all warm-blooded animals providing no clues as to their source. Phase 1 ultimately recommended the use of enterococci, along with fecal coliform bacteria, while

proposing source tracking of the fecal coliform to fingerprint the types of bacteria found (Rose et al. 2001).

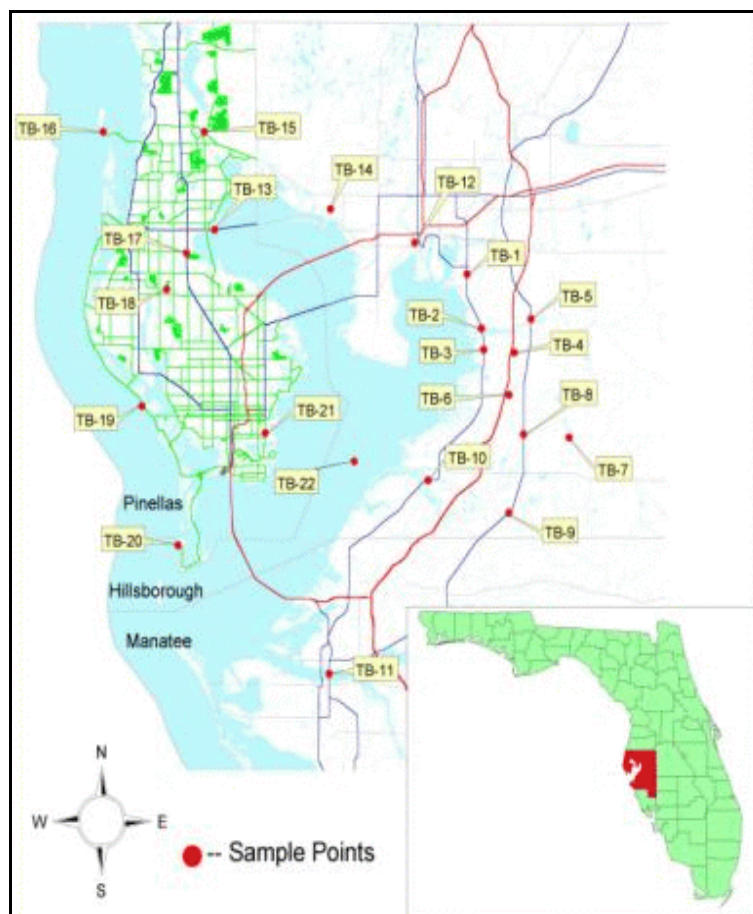


Figure 6. Healthy Beaches program sampling locations, 2000–2001.
Source: Rose et al. 2001.

Results of the Healthy Beaches Phase 1 study (Rose et al. 2001) assessed bacterial contamination at more than 20 stations baywide (Figure 6). Using a number of measurement techniques, the researchers found consistently high levels of bacterial contamination indicative of human sources in Bullfrog Creek and Sweetwater Creek in Hillsborough County, and Allens Creek in Pinellas County. The majority of sample sites, however, did not appear to be consistently affected by human sources of bacterial contaminants.

BAY HABITATS

Goals for emergent habitat restoration and protection in Tampa Bay are to:

- Restore the historic balance of coastal wetland habitats by restoring at least 100 acres of low-salinity habitat every five years.
- Preserve the bay's 18,800 acres of marsh and mangrove habitat, including 28 priority sites.
- Establish and maintain adequate freshwater flows to the bay and its tributaries.

Habitat Restoration and Protection: 2003 Update

Significant progress has been made in restoring the historic balance of coastal habitats in Tampa Bay, a key goal of the estuary program's bay management blueprint. This strategy reflects efforts to provide a mosaic of habitats to support wildlife that rely on different habitats at various stages in their life cycles (Henningsen 2004; Lewis and Robison 1995). The concept of restoring an optimum balance of habitats continues to have important implications for Tampa Bay and other areas. Historically, habitat restoration and land acquisition have been largely opportunistic ventures, with agencies and communities purchasing and restoring what was most readily available or visibly connected to the bay. That approach helped build awareness of the environmental plight and needs of the bay at a time when that was most critically needed.

In recent years, the focus shifted to providing a mosaic of habitat types within a given project to maximize the benefits to fish and wildlife. The TBEP partners took this concept a step further by developing restoration and protection goals based on the needs of key wildlife guilds or groups that share common habitat and feeding preferences. These efforts have helped drive important gains in critical habitats that might otherwise have been overlooked.

Restoration of low-salinity habitats was given highest priority in the estuary program's Master Plan for Habitat Restoration and Protection because these habitats have declined faster than others, imperiling the species that depend on them (Lewis and Robison 1995; TBNEP 1996).

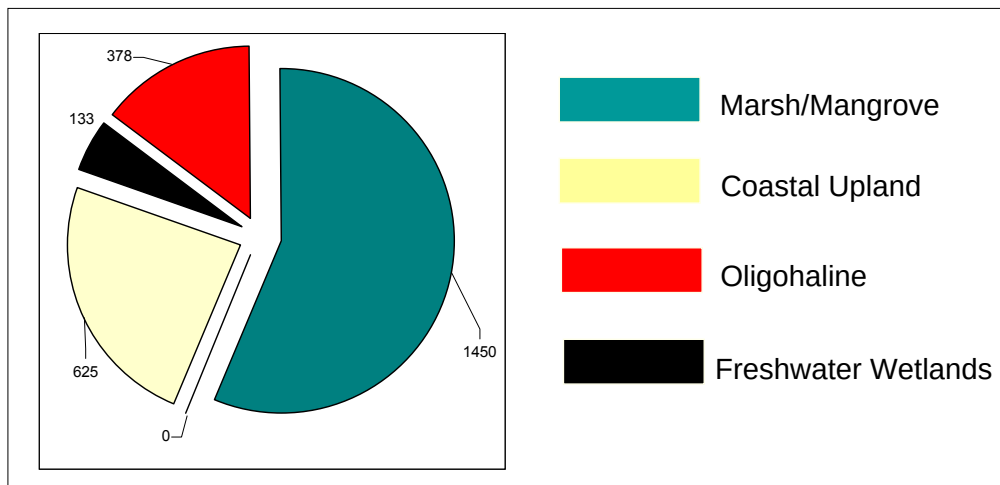


Figure 7. Estuarine habitat restoration (acres) in Tampa Bay and its watershed by type, 1995–2003. Information sources: SWFWMD, FDEP, EPCHC, counties of Hillsborough, Manatee and Pinellas, cities of St. Petersburg, Clearwater and Tampa.

As reported by TBEP partners, nearly 380 acres of oligohaline habitat was restored from 1995 to 2001, far exceeding the initial goal which was to restore 100 acres every five years. That's roughly one-fifth of the long-term restoration goal of 1,800 acres of low-salinity tidal marsh, areas that are vital to the survival of juvenile snook and mullet and numerous wading birds. TBEP partners have documented a total of 2,357 acres of estuarine habitat restoration between 1996 and 2003 (Figure 7). More than 60% (1,450 acres) of the total restored acres were marsh/mangrove, and 27% (625 acres) were coastal uplands.

The upland element of the Master Plan is incorporated in the multi-agency Coastal Conservation Corridor Plan. It emphasizes the restoration of small freshwater ponds in the vicinity of white ibis and other wading bird rookeries, acquisition of lands with existing freshwater ponds in areas where the birds forage and along wildlife corridors, and exotic plant removal from low-salinity portions of creeks and streams that serve as juvenile fish nurseries and foraging stations for wading birds. While some progress has been made, it has not yet been fully documented.

The Master Plan also identified 28 priority sites for protection to be managed or restored as necessary, either through direct purchase or other means such as conservation easements on private property. These sites were earmarked 'high priority' by the Southwest Florida Water Management District in the state's Save our Rivers and Florida Forever land acquisition programs. A total of 11,494 acres of estuarine habitat, including 2,261 acres of marsh/mangrove was preserved through acquisition by the TBEP partners between 1996 and 2003 (Figure 8). More than 75% of the total acres acquired for environmental protection, conservation or restoration in the watershed were freshwater riparian habitats.

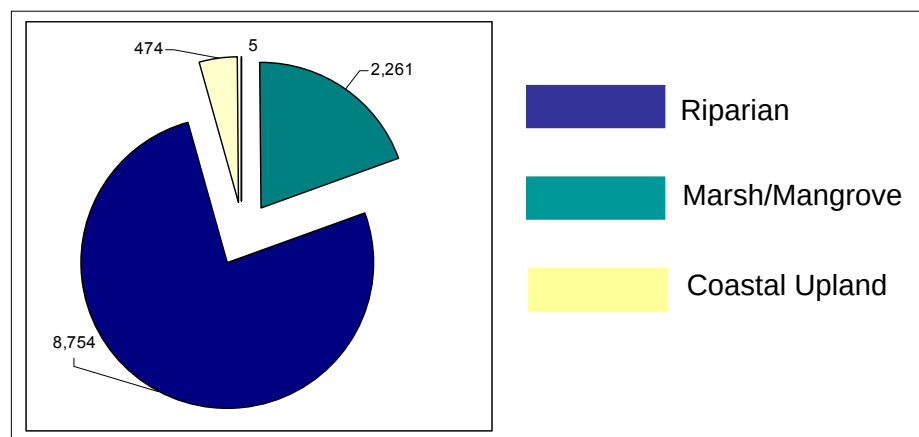


Figure 8. Estuarine habitat acquisition (acres) in Tampa Bay and its watershed by type, 1995–2003. Information sources: SWFWMD, FDEP, EPCHC, counties of Hillsborough, Manatee and Pinellas, cities of St. Petersburg, Clearwater and Tampa.

Critical habitats not included in the 1995 Bay Habitat Master Plan are hard bottom habitats, both submerged and oyster bars. These important habitat types will be included in the Master Plan update. In addition, recent research results have indicated that water quality and restoration goals and targets for tidal rivers, streams and creeks may be different than those for open waters of the Bay. A new initiative to address tidal rivers and streams is scheduled for 2004–2005.

Both Hillsborough and Pinellas counties have well established and funded land acquisition and preservation programs. A ½-cent sales tax referendum to create a similar program in Manatee County in 2003 failed to win voter approval. However, commissioners there supported a .25 millage tax increase that raised about \$3.5 million to provide the local grant match needed to purchase the 443-acre Robinson Preserve along lower Tampa Bay and the Manatee River. The County Administrator plans to request keeping additional millage on the tax roll in the future to enable the purchase of other environmentally sensitive lands.

Freshwater Inflow: 2003 Update

State legislation enacted in 1996 directs Water Management Districts to set “minimum flows” for rivers that define the limits at which further withdrawals would be “significantly harmful to the water resources or ecology of the area.” A minimum flow for the lower Hillsborough River set in 2001 stipulates that flows below the dam shall not drop below 10 cubic feet per second or about 6.5 million gallons a day. About half of the time over the past 10 years there has been no water flowing over the dam, a problem compounded by two years of severe drought. USGS and SWFWMD scientists are collecting data that will be used to reevaluate the minimum flow in 2005.

SWFWMD expects to finalize recommendations on minimum flows for Sulfur Springs in 2004 and the Alafia River in 2005. Minimum flows are scheduled for the Tampa Bypass Canal and upper Hillsborough River in 2005, to be followed by the Anclote and Little Manatee rivers in 2006. No specific schedule has been set for the Manatee River, although a preliminary minimum flow in effect since 1991 stipulates that approximately 275,000 gallons per day—roughly the equivalent of leakage from the dam—shall be released.

TBEP action plans call for an evaluation of the potential effects that MFLs may have on meeting protection and restoration goals for oligohaline areas in rivers, with an initial focus on those waterbodies which are scheduled for MFL adoption within the next year. Other potential indicators for changes in freshwater inflow, such as oyster bars, will also be examined. The action also calls for close evaluation of the results of ongoing monitoring initiatives to assess cumulative impacts, including reclaimed water projects, while continuing to move forward with the establishment of minimum flows for major tributaries to Tampa Bay.

FISH AND WILDLIFE

Goals for protecting fish and wildlife are to:

- Improve on-water enforcement of fishing and environmental regulation.
- Develop recommendations for local manatee protection zones.

The goal to improve on-water enforcement was predicated upon increasing the percentage of revenues from the Saltwater Fishing License allocated to marine law enforcement—an objective which has not yet been achieved, and for which prospects appear dim in the near future.

Despite this, some progress has been made in improving on-water enforcement of environmental laws in the Tampa Bay region. For example, the merger of fresh and saltwater law enforcement agencies within the relatively new Florida Fish and Wildlife Conservation Commission has greatly expanded the pool of officers trained to enforce both salt and freshwater regulations, and provided officials the flexibility to shift officers around to target “hot spots” or priority problems, such as illegal gill-netting. And the revamping of the Wildlife Alert program to offer rewards to citizens who report marine—as well as inland—fishing violations also has helped to boost compliance with on-water laws.

Additionally, local governments have generally expanded their on-water enforcement presence, as well as assuming a larger role in resource protection and regulation in general. In fact, two substantial manatee/seagrass protection zones have been created by local ordinance in the last three years—one expanding the Weedon Island Preserve in Pinellas County, and another creating a 6-mile-long slow speed buffer in southeastern Hillsborough County. Additional manatee protection zones were established by the state in Terra Ceia Bay and the Alafia River in 2002, and can be enforced by both state and local marine

enforcement personnel. But, as with the state, local communities also have limited resources to devote to on-water law enforcement, and the recent shift in focus to Homeland Security has further strained existing capabilities.

One potential substitute may be the increasing number of community-driven boater education initiatives, such as the Tampa Bay Manatee Watch and the Cockroach Bay Users Group programs. These efforts help to foster good environmental stewardship among boaters and anglers, while also serving as additional eyes on the water to report violations.

Adequate marine enforcement in a water body as large as Tampa Bay remains a problem. Currently, there are only 28 full-time state marine patrol officers in the Tampa Bay region, or about one officer for every 3,867 registered boats. That is triple the statewide average of one officer for every 1,200 boats—and the Tampa Bay area remains one of the state's fastest growing.

Manatee Protection Zones: 2003 Update

TBEP's Manatee Awareness Coalition, an alliance of scientists, conservationists, industry representatives and others concerned about protection of Tampa Bay's population of endangered manatees, was instrumental in FY 03 in the formation of a Local Rule Review Committee, required by state law, to evaluate proposed state manatee protection zones in Tampa Bay. The MAC was designated by TBEP's three counties as the LRRC for Tampa Bay, with TBEP's Public Outreach Coordinator serving as its chair and facilitator.

The LRRC met six times over a period of six weeks, and conducted one public forum in Manatee County that attracted more than 600 people. In general, the LRRC recommended few new state regulatory speed zones for Tampa Bay, opting instead to defer to existing local or federal zones where they existed, or were planned, and to support existing organized boater education or seagrass protection programs in areas with no regulation. Speed zones were recommended in the Little Manatee River and Apollo Beach areas of Hillsborough County, and in the Braden and Manatee rivers of Manatee County. In Manatee County, a majority of the committee supported deferring state rulemaking until the county has completed a revision of its existing slow speed ordinance, and adoption of that ordinance as the formal state rule for manatee protection in the county. No new speed zones were recommended for Pinellas County (Holland 2003).

Although committee members reached unanimous or near-unanimous agreement on several areas proposed for regulation by the state, in other areas they were sharply divided, with manatee advocates on the committee supporting at least some speed restrictions in most areas, and boating and angling representatives on the committee preferring no regulation or favoring boater education initiatives instead of regulation. In two areas proposed for regulation by the FWC—the western side of Old Tampa Bay from the Howard Frankland Bridge to the Gandy Bridge, and the eastern side of Tampa Bay from the Courtney Campbell Causeway to the Gandy Bridge—the committee failed to achieve a consensus after extensive discussion and exploration of alternatives, and ultimately was unable to make a recommendation to the state. Rulemaking on new manatee speed zones in Tampa Bay is expected in 2004.

DREDGING AND DREDGED MATERIAL MANAGEMENT: 2003 Update

The U.S. Army Corps of Engineers completed the long-term dredged material management strategy (DMMS) for Tampa Bay in July 2000 (U.S. Army Corps of Engineers 2000), thus fulfilling the original CCMP goal to develop a long-range dredged material management plan for the bay that will minimize the environmental impacts and maximize the beneficial

uses of the dredged material. The report outlined dredging projections, spoil placement options, and capacity shortfalls, noting that existing dredge disposal sites may be full to capacity within five to ten years unless steps are taken soon to expand storage areas or find beneficial uses for the material. The long-term plan will be updated to incorporate new projections for capacity, shortfall and timing based on reassessments and recent surveys of islands 2D and 3D, along with updates on beneficial use projects.

Dredging to maintain the bay's navigation channels—up to 43 feet deep in places—generates about a million cubic yards of material each year. Sediment dredged from the upper portions of the bay, where most dredging occurs, has traditionally been piped onto two manmade islands in Hillsborough Bay but they are rapidly reaching capacity. An offshore dredged material site with unknown capacity receives sediment material from the lower bay.

Plans are being finalized now to double the height of the dikes to 40 feet using dredged material already stored inside the dikes. That will increase total capacity to about 30 million cubic yards each, extending the life of the dikes until at least 2030. Another option calls for raising the dikes again, this time to 50 feet, when additional capacity is needed.

Since 1999, the Corps has found beneficial uses for all material from federal dredging projects in the bay, reflecting its strong commitment to alternative options. Beneficial use projects—ranging from stabilizing the shoreline at Egmont Key to filling dredge holes in Harbor Isles—helped redirect almost 2 million cubic yards of sediment. Another 200,000 cubic yards of sediment from maintenance dredging in the Alafia River is being used to create a series of habitats at abandoned shell pits near Cockroach Bay. One of the challenges in identifying beneficial uses is that the Corps must find “the least-cost environmentally acceptable” option, which limits alternatives. Another is that most dredged material from Tampa Bay is not suitable grade for beach renourishment, and even when it is, the cost of transporting the material is too high.

Implementing the DMMS will be an ongoing effort. In addition to the identified maintenance dredging projects in Tampa Bay, the US Army Corps of Engineers is currently evaluating options for improving navigational safety in both Tampa and St. Petersburg Harbors. Dredged material management options, including potential beneficial use placement, will be included in the Harbor Re-evaluation studies.

SPILL PREVENTION AND RESPONSE: 2003 Update

A significant portion of the goal to “Install a state-of-the-art vessel traffic and information system (VTIS) to improve coordination of ship movements along the bay's navigational channels” has been met, with the establishment of a coordinated VTIS for the bay financed by a consortium of maritime interests, including the Tampa Port Authority. And, although a permanent funding source for the Physical Oceanographic Real-Time System (PORTS) has not yet been found, current contributions from all three bay counties will secure PORTS funding for the next six years.

VTIS has equipped all harbor pilots with shipboard laptop computers linked to a differential GPS system using Automated Identification System (AIS) technology that provides real-time information on shipping traffic in Tampa Bay. The pilots can see precisely where they and all other ships nearby are located at any given time, and coordinate that information with weather and current data to guard against collisions or groundings. Since installation of AIS/VTIS, there have been no serious ship-to-ship collisions in the bay.

Up-to-the-minute information about tides, winds and currents in Tampa Bay is available to all mariners (recreational boaters included) through the Physical Oceanographic Real-Time System (PORTS), a network of data collection equipment located at key positions around the bay. PORTS was created by NOAA and is maintained by the University of South Florida Department of Marine Science (Luther 2004). The system can be accessed online or by telephone. Hillsborough County has committed to partially fund PORTS for six years from its share of phosphate severance tax revenue, and the City of St. Petersburg and Manatee County have provided funds to support PORTS. Long-term funding is still required to fully support the PORTS program.

INVASIVE SPECIES: 2003 Update

A literature review and field survey of invasives in Tampa Bay in 2002 documented 55 known, suspected or potential marine invaders in the bay ecosystem (Baker et al. 2004). Among the recommendations were that TBEP consider conducting a full-scale Rapid Field Assessment to more specifically assess the extent and impacts of invasives in the bay. Field observations have documented that the Asian green mussel, *Perna veridis*, has now displaced the Eastern oyster in subtidal areas throughout Tampa Bay (P. Baker, pers. comm.).

Another key area of focus was the continued implementation of the “Eyes on the Bay” invasive species outreach program. Projects included: continued expansion of the “Eyes on the Bay” website area; production, with Florida Sea Grant, of a laminated card for sport divers highlighting known and potential marine invaders; sponsorship of a field guide to common invasive plants in Tampa Bay; and preparation of a slide show focused on how citizens can help prevent invasions.

PROGRESS TOWARDS TBEP GOALS: TBEP STAFF EVALUATION

TBEP staff assessment of progress towards goals for 1996 through 2003 indicates that progress has been mixed. Good progress is shown in meeting chlorophyll concentration, nitrogen reduction, and oligohaline habitat restoration targets, developing manatee protection zones, and the completion of a dredged material management plan (Figure 9). Challenges with little progress to date include attaining adequate light attenuation for seagrass growth, toxic chemical sediment contamination management, and on-water enforcement. Maintaining progress made to date, and moving forward on all priority issues and actions will require dedication and continued cooperation of all the scientists and managers working in Tampa Bay in new and ongoing scientific and monitoring programs, and the strong link to goals supported by the citizens living in the Tampa Bay area.

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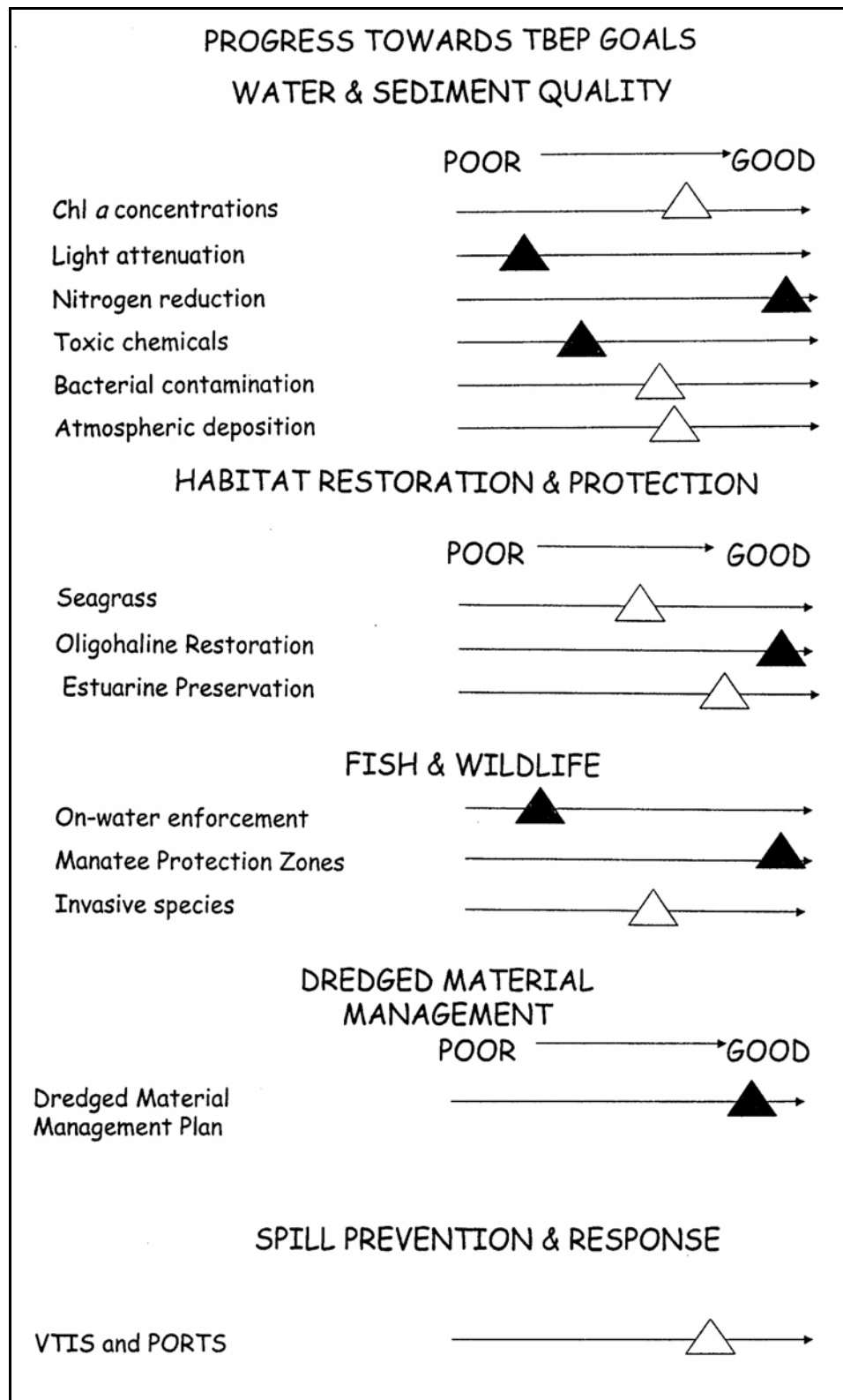


Figure 9. TBEP staff assessment of progress towards CCMP goals: 1995–2003.

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ABSTRACTS
Session 7: WATERSHED MANAGEMENT

PRESENTATIONS

Florida's TMDL/Watershed Management Program: A Status Report. D. Joynor (Florida Dept. of Environmental Protection). A variety of programs have been implemented in Florida to reduce the impacts of point and nonpoint sources of pollution on our surface and ground waters. While these programs have been very successful in reducing the effects of growth and human impacts, we unfortunately have water bodies that do not meet their designated beneficial uses, such as swimming, fishing, or potable water supply. These unhealthy or "impaired" waters are the subject of Section 303 (d) of the Federal Clean Water Act which requires the establishment of a total maximum daily load to restore these waters.

To address the restoration of impaired waters in Florida, the 1999 Legislature adopted the Florida Watershed Restoration Act, Section 43.067, F.S. In early 2000, the Bureau of Watershed Management was created at DEP from existing staff resources to lead the new TMDL/watershed restoration program. This presentation will focus on the activities, legal challenges, and watershed restoration activities that have occurred over the past three years. Linkages to ongoing regional and local watershed management efforts will be stressed. [eric.livingston@dep.state.fl.us]

Comprehensive Watershed Management at the Southwest Florida Water Management District-Tampa Bay. B. Wirth (Southwest Florida Water Mgt. District). The SWFWMD (District) Comprehensive Watershed Management (CWM) Program is a watershed approach to water management. This approach is the most effective and efficient way to integrate a variety of resource activities. The District is charged by statute with the responsibility of flood protection, water supply, water quality and natural systems. As the ability to manage an increasingly complex system of users and the impacts they have on the environment, the District has shifted its regulatory and non-regulatory programs to a watershed wide perspective.

Thirteen watersheds have been identified within the District. Internal and external teams of scientists, planners, local government coordinators and policy makers have input into the direction the District will take in carrying out its responsibility. Understanding the resource and economic challenges facing local governments and those of other agencies is vital in resource management decision-making. The private sector benefits from CWM in knowing what the environmental conditions and program boundaries are from which to conduct business.

A key component of CWM is the development of a Decision Support System (DSS) that provides easy access to all internal and external data. The DSS will provide Internet access by the fall of 2004 and seeks to be compatible with other Water Management Districts, USGS, State and local government data sources. It is envisioned that complete access to District data will allow for greater and more effective planning by government and private sector entities.

A CWM approach supported by the availability of data through the DSS will greatly improve the decision making process of not only the District, but also all of those involved in or affected by water. [Bruce.wirth@swfwmd.state.fl.us]

A Water Utility's Role in Watershed Protection. R. McConnell, D. Jones (Tampa Bay Water). The Tampa Bay region has historically relied on groundwater for drinking water supply, but an increasing population and concerns about environmental impacts have led to the development of diverse new sources including surface water withdrawals and seawater desalination. For groundwater sources, typical watershed management activities include coordination of new projects with other resource management activities, monitoring of potential impacts to environmental resources, planning to meet new water supply needs, and wellhead protection. For the new surface water sources included in Tampa Bay Water's Master Water Plan, additional required watershed management activities include the development and implementation of Hydrobiological Monitoring Programs to monitor potential water quality and ecological impacts, and the evaluation of source water protection measures for the contributing watersheds.

Although water supply projects may be opposed by the local public due to environmental concerns, these projects can provide opportunities to protect and improve river and Bay water quality through development of source protection measures and load reductions for existing environmental pollutants (e.g., nutrients). Additional benefits can include an increased understanding of environmental conditions and processes through comprehensive data collection programs and modeling activities. The Alafia River component of Tampa Bay Water's Enhanced Surface Water System affords a unique opportunity to monitor and evaluate water quality concerns and source water protection measures related to public health and environmental resources. This presentation includes examples

of management actions for water quality improvement and source water protection in the Alafia River watershed, along with examples of potential benefits. [mcconnell@tampabaywater.org]

POSTERS

Integration of Seagrass Monitoring into Tampa Bay's Resource Management Plan. W. Avery, R. Johansson (City of Tampa, Bay Study Group). In 1996, the Tampa Bay Estuary Program (TBEP) set a seagrass coverage goal of 15, 375 ha as part of the resource based management plan for Tampa Bay. The protection of 10,400 ha of existing seagrass beds and the restoration of seagrass in areas of historical coverage was linked to the management of nitrogen loading to the estuary. Further, seagrass target depths were established for each major Tampa Bay subsection based on aerial photographs from 1950. In 1997, the TBEP coordinated the development of the Tampa Bay Interagency Seagrass Monitoring Program (TBISP) to assess existing and potential areas of seagrass coverage within Tampa Bay. The major objectives of TBISP were to determine spatial and temporal changes in seagrass species composition, abundance, and zonation over a depth contour. These data may be used to augment seagrass coverage assessments developed by the Southwest Florida Water Management District, Surface Water Improvement and Management Division from biennial vertical aerial photography. Annual monitoring along 60 fixed transects began in 1998. The first five years of data indicate that seagrass coverage and species depth distribution along most transects has been generally stable. In addition, seagrass colonization along transects that had little or no seagrass present at the beginning of the program has been minimal to date. [Walt.Avery@ci.tampa.fl.us]

An Investigation of Relationships Between Freshwater Inflows and Benthic Macroinvertebrates in the Alafia River Estuary. J.K. Culter, J. M. Sprinkle, E.D. Estevez (Mote Marine Laboratory). A quantitative investigation of tidal Alafia River benthos was conducted for dry, May 1999, and wet season, September 2001 conditions. Core and sweep net samples were collected at one kilometer intervals from the mouth of the river at Hillsborough Bay to a location 15 kilometers upriver from the mouth. In addition to these two surveys, data from eighteen additional surveys from two other benthic sampling programs were incorporated into the analysis for a total of 20 sampling events. Other features of the river were also investigated including; sediment structure, riverbed morphometry, benthic habitat types and spatial distribution of macro mollusks. River surface area and volume were calculated for each 1-kilometer interval. The cumulative area of this tidally influenced portion of the river was calculated as 240.5 hectares and the cumulative volume 720.4 hectare-meters. Approximately 60% of both the area and volume are located in the first 5 kilometers of the river.

A comparison of methodologies used for the different data collection programs was also conducted. River flow, rainfall and salinity were evaluated with respect to species numbers and abundance. Cumulative rainfall for a 60-day period prior to each sampling event illustrated the best correlation to faunal abundance. However, the correlation was only significant for HBMP zones AR-2, AR-3 and AR-4, which represent river kilometers 2.33 to 7.0. Dramatic changes occur in the benthos from dry to wet season related to river flows. The mechanism and relevance of the faunal shift is discussed. The Southwest Florida Water Management District in support of minimum flow studies sponsored this project. [jculter@mote.org]

New Approaches to Lingering Problems: Updating the Bay Restoration Plan. R. Eckenrod, H. Greening, N. Holland (Tampa Bay Estuary Program). *Charting the Course*, the Comprehensive Conservation and Management Plan (CCMP) for Tampa Bay, has been guiding bay cleanup and restoration efforts of the Tampa Bay Estuary Program (TBEP) since its adoption in 1997. The CCMP was developed through EPA's watershed protection approach and is organized into five major action plans including: Water and Sediment Quality; Bay Habitats; Fish and Wildlife; Dredging and Dredged Material Management; and Spill Prevention and Response. TBEP is currently updating the CCMP with input from Program's local government and agency partners and other stakeholders. Substantial progress has been made toward achieving the seagrass restoration and the companion nitrogen management goals and many other priority actions. Less progress has been made toward some goals including, for example: establishing and implementing sediment quality targets; increasing on-water enforcement of environmental regulations; and engaging agriculture in the nitrogen management strategy. Each of the 41 separate actions in the CCMP is being re-evaluated to determine the degree of completion, appropriate course corrections, and whether any should be jettisoned from the plan. TBEP Management and Policy Board and its Technical Advisory Committee and Community Advisory Committee and other community stakeholders are actively participating in the process. The poster will include a summary of the methodology of updating the CCMP but emphasize progress toward CCMP goals and new actions recommended to spark progress toward unattained goals. [reckenrod@tbep.org]

Nitrogen Management Consortium Action Plan Database: Providing Reasonable Assurance to Meet Impaired Waters Rule (IWR). S. Janicki (Janicki Environmental, Inc.), M. Cladas (Tampa Bay Estuary Program). In 1996, the Nitrogen Management Consortium, an innovative alliance between local governments, agencies, industry and agriculture, was created to help implement the Tampa Bay Estuary Program's nitrogen management strategy. Acting under a formal resolution, partners in the Consortium implement a wide variety of projects aimed at reducing long-term nutrient loading to Tampa Bay and help to achieve the Estuary Program's seagrass recovery goal. Nitrogen in excessive amounts stimulates algae growth that clouds the water and prevents light from reaching vital submerged seagrasses.

In 2002, the Florida Department of Environmental Protection (FDEP) determined that the Nitrogen Management Consortium and other elements of the nitrogen management strategy for Tampa Bay provided Reasonable Assurance that the nutrient criterion in FDEP's Impaired Waters Rule would continue to be met.

Providing the Consortium's nutrient-reduction information accurately to FDEP as part of the Reasonable Assurance package became crucial. Initially, Consortium members submitted specific project-related information to the Estuary Program in word processing documents. That approach proved too limiting and a decision was made to create a system that could not only track project implementation, but calculate nutrient reductions based on land use factors specific to each project. A Microsoft Access database was created to act as a clearinghouse for those nutrient reduction projects implemented by partners in the Consortium. In addition to housing both point-source and non-point source nitrogen reduction projects, the database includes habitat restoration and other projects that help meet other goals of the Estuary Program. [JanickiEnv@aol.com]

Linking Innovation and Technology with Watershed Management. J. Mickel, M. Nourani (SW Fla. Water Mgt. District). The Southwest Florida Water Management District (District) has developed the Comprehensive Watershed Management (CWM) program to conduct water resource assessments and planning strategies on a watershed basis. The program was designed to allow for careful evaluation of the regional status of water resources by a multi-disciplinary and multi-agency team, with emphasis on water supply, flood protection, water quality, and natural systems. This interactive session will focus on the Tampa Bay/Anclote River (TB/A) watershed, which encompasses all of Pinellas County and parts of Hillsborough and Pasco Counties.

The two objectives of this session are to first, discuss several of the District's watershed management objectives, which include establishing conservation priorities for the remaining natural areas, implementing protective management strategies in key resource areas, outlining the existing watershed conditions, and providing adequate data and reference material to establish a baseline for future decisions related to water resources. The second objective is to display the innovative technologies such as GIS, database tools, and fly-through software, as well as traditional strategies such as inter-governmental coordination and land acquisition programs that the District is using to improve watershed management.

As the population continues to grow throughout the watershed, the ensuing development pressures (i.e., urban sprawl, loss of wetlands, storm water run-off, etc) will become increasingly difficult to manage. Fortunately, with the assistance of local governments and other agencies, the District will continue to implement innovative strategies and the latest technology to address the current and future challenges of watershed management. [jason.mickel@swfwmd.state.fl.us]

Watershed Management in Pinellas County. A.P. Squires (Pinellas Co. Dept. of Environmental Mgt). Pinellas County was among the first local governments in the United States to adopt a watershed management program. In 1987, the County adopted major revisions to its Comprehensive Plan (CP) requiring County staff to: 1) prioritize the management needs of County drainage basins, 2) develop management plans for priority waters, 3) implement management plan recommendations, and 4) monitor water quality in receiving water bodies. The CP mandates that County watershed plans are holistic and must address flood protection, water quality, and habitat issues. The County's Capital Improvement Program budget, stakeholder municipalities, as well as the Southwest Florida Water Management District have provided funding for watershed planning. Initial planning efforts for the first two watershed plans, Allen's Creek and Lake Tarpon, began in 1987. To date, comprehensive watershed plans have been completed for Allen's Creek, Alligator Creek, Lake Tarpon, and Lake Seminole. Work on new watershed plans for the Cross Bayou Canal, Roosevelt Creek, and Brooker Creek basins will begin in 2003. Although many lessons have been learned after 15 + years of watershed planning experience, several issues remain that must be overcome to improve the overall watershed planning process. Finally, in order to attain stated goals, watershed plans must be effectively implemented and the target outcomes must be measured. Lessons learned, issues to overcome, and the implementation status of existing plans will be discussed with reference to specific projects either completed, under design, or planned. [asquires@co.pinellas.fl.us]

